Wolfgang Neubauer, Immo Trinks, Roderick B. Salisbury, Christina Einwögerer
(Editors)

Archaeological Prospection

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Cover: Motorized magnetic prospection in the archaeological landscape of Uppåkra, Sweden.
Back: Airborne laser scanning with a specially fitted Tecnam aircraft from Airborne Technologies.
Photographs by LBI ArchPro and Airborne Technologies.

Welcome to the 10th International Conference on Archaeological Prospection

It is the second time that the International Conference on Archaeological Prospection is hosted by the Austrian Academy of Sciences in Vienna. The Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology and the Austrian Academy of Sciences decided to co-organize this conference on behalf of the International Society for Archaeological Prospection. It is my honor to cordially welcome all researchers globally involved in the development and application of the latest technology for the non-invasive detection and documentation of our archaeological heritage as representative of the organizing committee.

It was in the last volume of Archaeological Prospection, published 2001 by the Austrian Academy of Sciences, in which Herwig Friesinger expressed the hope for more systematic application of prospection methodology for the safeguarding of the unique remains of our ancestors. Since that time a variety of novel technologies have been added to the toolbox of the prospectors, thoroughly documented by the biannual volumes of the conference proceedings and the journal Archaeological Prospection. In 2003 the International Society for Archaeological Prospection was founded based on individual initiatives starting during the social events framing the Archaeological Conference for Archaeological Prospection in Munich and Vienna. This international association currently exceeds the number of 500 members.

It was in the mid-sixties of the last century when fundamental research into Archaeological Prospection for the first time became institutionalized. Pioneers like Martin Aitken at Oxford, John Belshé at Cambridge and Irwin Scollar at Bonn, among others, formed the basic foundations for our field of research, which cumulated in the research activities of the Fondazioni Lerici directed by Richard Linington. It lasted until 2010 when another private research foundation, the Ludwig Boltzmann Gesellschaft decided to fund a dedicated research institute focusing on Archaeological Prospection. The Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) is based on an European consortium of partner institutions covering academic institutes, national archaeological and geophysical research departments, governmental cultural heritage agencies as well as commercial archaeological prospection service providers. In particular these are the Ludwig Boltzmann Gesellschaft (LBG), the Norwegian Institute for Cultural Heritage Research (NIKU), the Province of Lower Austria (NoeL), the Central Swedish Heritage Board (RAÄ UV), the Roman-Germanic Central Museum in Mainz – Germany (RGZM), the Technological University of Vienna (TU-Wien) with the Institute for Computer Graphics and Algorithms and the Department of Geodesy and Geoinformation at the Vienna University of Technology, the University of Vienna (UNI Wien) with the Vienna Institute for Archaeological Science (VIAS) and the Department for Prehistoric and Medieval Archaeology (UFG), the IBM Visual and Spatial Technology Centre (VISTA) at the University of Birmingham, the Department of Geophysics at the Central Institute for Meteorology and Geodynamics (ZAMG) and Airborne Technologies (ABT), all supporting the 10th International Archaeological Prospection Conference in Vienna. We acknowledge also the support of Archeo Prospections®, MALÅ Geoscience, Foerster Group, Pico Envirotec Inc., Eastern Atlas, Riegl LMS GmbH, wikitude, the Archaeological Parc Carnuntum, Allsat, beta analytic Ltd. and Interspot Film GmbH.

The objective of the LBI ArchPro, currently employing 30 researchers and technicians, is the advancement of the state-of-the-art in Archaeological Prospection. This will be achieved by focusing on the development of remote sensing, geophysical prospection and virtual and augmented reality applications. Main focus is set on novel integrated interpretation approaches combining cutting-edge remote sensing and near-surface geophysical prospection methods with advanced computer science. Within the institute's research programme different areas for distinct case studies in Austria, Germany, Norway, Sweden and the UK have been selected as basis for the development and testing of new concepts for efficient and universally applicable tools for spatial, non-invasive archaeology. The collective resources and expertise available amongst the new research institute and associated partners permit innovative approaches to the archaeological exploration, documentation and investigation of the cultural heritage contained in entire archaeological landscapes. The LBI ArchPro Initiative was extended by a structured PhD college installed at the University of Vienna currently involving 17 young researchers in the LBI ArchPro research programme.

The conference aims to provide a forum for the presentation and discussion of the latest developments and cutting-edge research in the field of archaeological prospection. It is covering the entire spectrum of methodology and technology applied to the detection, localization and investigation of buried cultural heritage, i.e. aerial photography, airborne laser scanning, hyper-spectral imaging, near-surface geophysics, data processing, visualization and archaeological interpretation. The focus is set on integrative approaches exploiting the diversity of all data and information necessary for the visualization and interpretation of archaeological and historical monuments, structures and entire archaeological landscapes. This scientific and social venue is intended to provide a meeting place for young researchers and experienced professionals in the field of archaeological prospection. The respective publication combines extended abstracts from all over the globe and provides an overview of the current state of research. I like to thank all colleagues of the Scientific Committee who have helped with the reviewing, the co-editors and all individuals contributing to the in-time materialization of this volume of Archaeological Prospection and the organization of the 10th international Conference on Archaeological Prospection.

We wish you and us an interesting and fruitful conference and a pleasant stay to all our guests in Austria.

Wolfgang Neubauer
Director LBI ArchPro

About the Ludwig Boltzmann Gesellschaft

The Ludwig Boltzmann Gesellschaft (LBG), which was founded in 1960, is a non-university research organisation based in Vienna, Austria. The LBG operates research institutes and clusters, which carry out international high-level research in the areas of medicine and life sciences as well as the humanities, social sciences and cultural sciences. The LBG is named after the great Austrian physicist, mathematician and philosopher Ludwig Boltzmann, whose broad scientific interests still remain the basis for the interdisciplinarity of the LBG today. Currently the LBG operates 17 LBI and 5 Clusters and employs around 380 people.

Unique features of the LBG are its strong inter- and transdisciplinarity, its bottom-up generation and occupation of important and current research topics plus a modern partnership model, which allows the involvement of academic and research-applying partner organisations in joint research programmes - thus initiating translational research; the interface between basic and applied research. The creation of such research-networks plays a central role for the LBG in that it acts as a mediator between disciplines, between different countries, between research, industry and the public sector.

Ludwig Boltzmann Institutes (LBI) are solely set-up on the basis of tendering processes (call for proposals and international evaluation procedures) for a limited period of time. These calls are characterised by the above mentioned features of the LBG and as a result, Ludwig Boltzmann Institutes conduct research according to clearly defined questions, develop interdisciplinary fields of research and thus offer an attractive environment both for established scientists and for up-and-coming researchers.

To remain flexible in reacting to and taking on new research topics, Ludwig Boltzmann Institutes are established for the limited period of seven years with the option of prolonging its run-time for a maximum of another seven years. The requirement for such a prolongation is the development of a concept, which either guaranties the integration of the research activities of a LBI in one or more of its partner organisations within the second seven-years-period or which leads to the development of the LBI into a separate and independent institution.

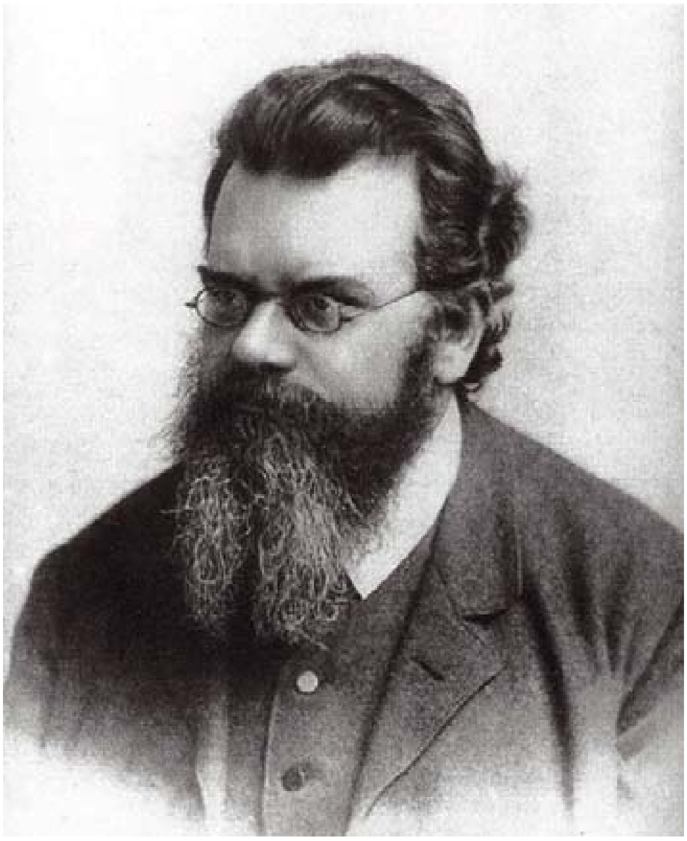
Ultimately the LBG promotes modern management, competitive structures and an open-minded approach towards translational research, which allow it to fulfil its tasks optimally, namely achieving lasting benefits for people through partnership-based research.

Ludwig Boltzmann

Ludwig Boltzmann was born in 1844 in Vienna and was the son of a tax official. His extraordinary enthusiasm for learning and his scientific talents were already evident during his school days in Linz. After his "Matura" [A-level equivalents], he studied physics and mathematics at the University of Vienna. After his graduation in 1866, Boltzmann became an assistant to his teacher, Josef Stefan, who was Head of the Physics Institute of Vienna.

By the age of 25, Boltzmann had already achieved his full professorship for mathematical physics in Graz. In 1873 he returned to Vienna for three years and then remained in Graz for 14 years as a professor of experimental physics. During this time, Boltzmann had already become part of the world's elite physicists.

From 1895 until his death in 1906, he was a Professor at the University of Vienna. Today, Boltzmann is regarded as a forerunner for quantum physics and the theory of evolution. He is also one of the fathers of biophysics and bioenergy. Boltzmann dealt extensively with physics-based research into evolution questions. As a passionate Darwin supporter and progressive thinker, Boltzmann developed ideas which partially anticipated the teaching of evolution as we know it today. He extended the biological evolution to include physical aspects and advocated the theory of existence even before the time of creation of life forms. Boltzmann was a staunch promoter of atomicity. Besides his great scientific persuasive power, Boltzmann fascinated his contemporaries with his unwavering search for true, positive findings in scientific research.



List of Sessions

Wednesday May 29th 2013

Thursday May 30th 2013

Integrated Prospection Approaches – Part 1 — *Chairman: Neil Linford*

156 How to construct a fortification system in the borderland of a swampy lowland during the 16th/17th century – a comprehensive prospection study of the Dieler Schanzen, Eastern Frisia, NW Germany
A. Hüser, C. Schweitzer

160 Multi Depth Electromagnetic Surveys in Ireland: Increasing our chances of detecting archaeological features
J. Bonsall, C. Gaffney, T. Sparrow, I. Armit

163 Nieszawa: a forgotten medieval city in Poland discovered with the use of remote sensing techniques
M. Jaworski, M. Pisz, S. Rzeźnik, W. Stępień, P. Wroniecki

165 Elements of the Bronze Age Landscape of "Cikola water system" Preliminary results
L. Reményi

168 Non-invasive surveys of the Roman fort Apsaros (Gonio) in Georgia
K. Misiewicz, W. Małkowski, M. Bogacki

171 High-resolution multi-channel GPR survey of the Roman town Flavia Solva in Austria
W. Neubauer, S. Floery, I. Trinks, A. Hinterleitner, K. Löcker, S. Seren

Processing and Visualization — *Chairman:Chris Gaffney*

173 Damping Correction for GPR Signals by using Belief Propagation
F. Chishima, H. Kamei, T. Hashimoto, T. Ako

176 Rapid processing of GPR time slices for data visualisation during field acquisition
N. Linford

179 Improvements in the identification of archaeological buried features in QuickBird imagery and in ground magnetic data
M. Ciminale, M. Noviello, L. Amoruso, V. De Pasquale

182 Understanding hyperspectral detection dynamics: Analysis and characterisation of archaeological vegetation marks using continuum removed reflectance spectroscopy
D. Stott, A.R. Beck, D. Boyd, A.G. Cohn

185 Edge Mappers Applied to Resistance and Magnetic Mapping Data
A. Stampolidis, G.N. Tsokas

187 Update on the simulation of astronomical aspects of Middle Neolithic circular ditch systems
G. Zotti, W. Neubauer

Friday May 31st 2013

GIS and Prospection — *Chairman: Eamonn Baldwin*

190 Aerial Imagery and Interpretation of Roman Viminacium
N. Mrđić, M. Korać, S. Golubović

191 Wadi Abu Dom Itinerary (W.A.D.I.) – An Archaeological Road Survey Project in Sudan
T. Karberg

193 Walk the line. Implementation of regional-scale GIS-based field survey method for agricultural areas in Hungary
M. Stibrányi, G. Mesterházy

195 Using barcode, tablet PC and smartphone technology for archaeological field surveys
J. Coolen, M. Fera, M. Doneus, E. Grillmayer

197 From point to polygon – investigating a Roman rural landscape
N. Doneus

200 Object versus Pixel -– Classification Techniques for high resolution airborne remote sensing data
M. Pregesbauer

Poster and Multimedia Session – Processing and Visualization

Poster and Multimedia Session – Technical Aspects

Saturday June 1st 2013

Interpretation and Presentation – Part 1 — *Chairman: Mahmut G. Drahor*

Interpretation and Presentation – Part 2 — *Chairman: Jörg Fassbinder*

Integrated Prospection Approaches – Part 4 — *Chairman: Jörg Fassbinder*

PREHISTORIC RING MONUMENTS IN THE NORTHERN CAUCASUS (RUSSIA): REMOTE SENSING, LARGE-SCALE MAGNETIC PROSPECTING AND FIRST TEST EXCAVATIONS

J.W.E. Fassbinder, A. Belinskiy, R. Linck, S. Reinhold

ABSTRACT

In the lowlands between Stavropol and Pyatigorsk (North-Western Caucasus, Russia), previously unknown ring-shaped structures were recently discovered by the routine analysis of CORONA satellite images and aerial photos from the 1970s and 1980s. At first glance, these structures were mistaken as the eroded remains of large kurgans or burial sites. The characteristic of the sites is an outer wall that encloses a more or less circular ditch with a central platform. In most cases, the wall and ditch revealed not any sign of an entrance or a bridge. Nevertheless, these structures resemble very much in size and shape those of the well-known Neolithic ring-monuments in Slovakia, Austria, Southern Bavaria and England. Of the more than 20 sites that were uncovered by the air photo and satellite image analysis, we surveyed eight sites with high-resolution magnetic prospecting.

1. INTRODUCTION

Neolithic ring monuments form the oldest monumental buildings of Europe. They have been widely documented and dated in Western and Central Europe, being found in England, Portugal, Southern Bavaria, Austria, Slovakia and Hungary. Among archaeologist it was commonly accepted that these monuments served a calendrical function, and that they are only concentrated in these regions. Here we report on the discovery, by satellite image analysis, of similar sites in the Stavropol region of Northern Caucasus. From 2010 – 2012 we conducted three campaigns of magnetometer prospection combined with a high-resolution topographic survey to get detailed information on the internal structure of these outstanding monuments. The magnetometer results revealed clearly that the layout and size of these sites closely resemble those from Western and Central Europe. Therefore, the areal expansion of these monumental constructions has to be enlarged to encompass the eastern part of Europe. Here we present geophysical surveys and excavation results of a selection of these newly discovered monuments.

2. REMOTE SENSING AERIAL ARCHAEOLOGY AND MAGNETOMETER PROSPECTING

Several years ago, ring-like structures were discovered on vertical aerial photos during the preparation of archaeological surveys in the framework of rescue excavations. In an essential survey of the vertical aerial photos and CORONA images, we found that 13 are now likewise visible on GeoEye-1 satellite images released by Google Earth. During a take-off with a scheduled flight from Mineralnyje Wody to Moscow by a Tupolew 154, a further site was discovered and photographed by the author.

Meanwhile we performed test measurements by a Caesium Smartmag SM4G magnetometer at eight selected sites. The resulting magnetograms revealed a typical layout and construction

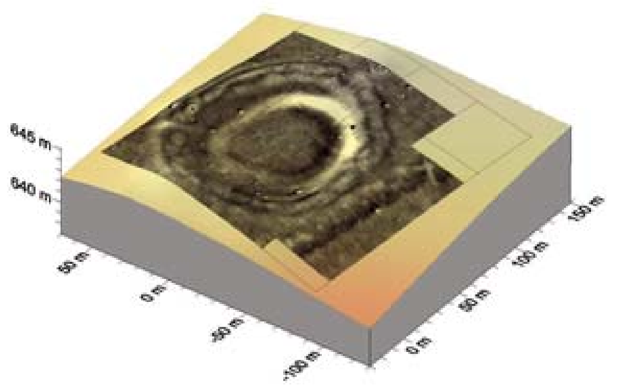


Figure 1: *Vorovskopesskar. Magnetogram of the ring-ditch discovered in 2011. Smartmag SM4G special in duo-sensor configuration, total Earth's magnetic field ca. 49,800 nT, dynamics ±10 nT in 256 grey values from black to white, grid size 40 × 40 meter, sampling density interpolated to 25 × 25 cm. Overlay with the fine levelling of the topography.*

that seems characteristic for all of these monuments. All sites consist of a more or less circular ditch (ca. 3 – 5 m depth) with diameters of ca. 60 – 140 m. Nearly parallel, but outside the ditch, we traced the constructions and remains of a wall, roughly 80 – 220 m in diameter. In 2010, the sites of Tambukan and Marins'kaja 1 were surveyed (Belinskij et al., 2011; Fassbinder *et al.*, 2011). The last one is party destroyed by erosion and by a prehistoric landslide. The remaining part, however, shows quite well the layout of the monument.

Encouraged by the promising results of 2010, we performed further prospecting at four monuments in late autumn 2011 and spring 2012. One of them, the ring near Vorovskopesskar is presented here (Figure 1). This site depicts a true revelation: for the first time it is possible to trace three entrances in the rampart of a Caucasian circular enclosure. Furthermore, the rampart reveals a very detailed and complex internal construction. The outer wall was constructed of limestone and exhibits no perfect circle but instead has several notches corresponding probably to some calendar use. The ring structures in Russia are still fairly visible on the ground, due to a comparatively late start of deep-ploughing in this part of the Soviet Union; pdeep ploughing did not begin here until the 1960s. Thus, depressions of more than one meter depth are visible at the location of the magnetic anomalies, as well as ramparts outside which form in most cases slight topographical elevations. Unlike the magnetometer results in similar sites of Bavaria and Austria, the Caucasian monuments revealed no further structures beneath the central place of the site. Beside the actual ring monument, the magnetogram of Vorovskopesskar

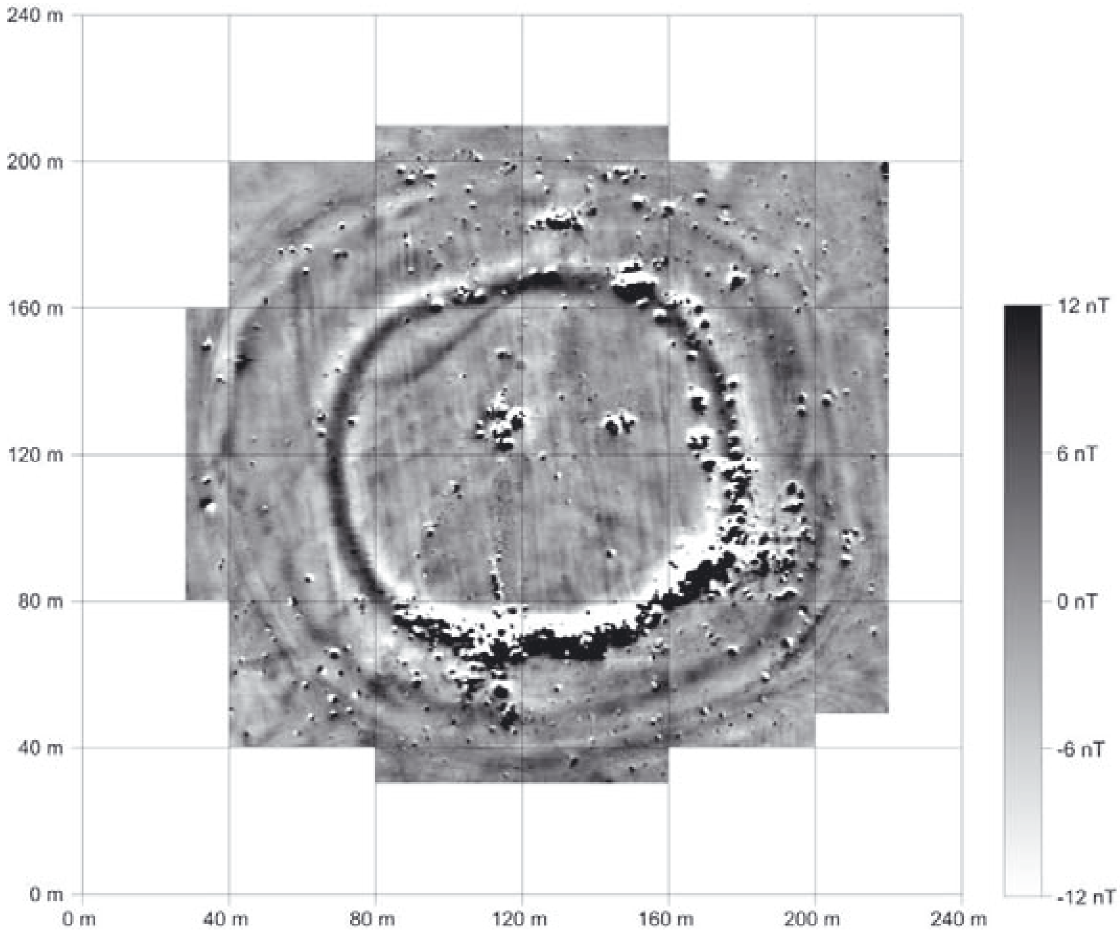


Figure 2: *Tamlyk. Magnetogram of the largest prehistoric ring monument in the Caucasus. The high magnetic anomalies in the southern part of the ditch are caused by metal waste. Smartmag SM4G special in duo-sensor configuration, total Earth's magnetic field ca. 49,800 nT, dynamics ±12 nT in 256 grey values from black to white, grid size 40 × 40 m, sampling density interpolated to 25 × 25 cm.*

reveals another linear structure that resembles the famous "Cursus" at Stonehenge in England.

In spring 2012, two more ring enclosures were investigated near Pjatigorsk. The circle Tamlyk near Suvorovskaja is the largest enclosure so far discovered, covering more than 200 × 200 m (Figure 2). The wall surrounding the rondel is still preserved to a height of 2 – 3 m. Together with an interior ditch, differences in terrains sum up to more than 5 m. Thus, Tamlyk, is the best preserved site that we investigated so far. Unfortunately, its ditch has been used as a waste dump in modern times. Hence, the resulting magnetogram it is very much disturbed by high magnetic anomalies, especially in the southern part. In its layout, the Tamlyk monument closely resembles the famous monument of Avebury in England.

A further ring shaped structure, less well preserved, but still impressive in the terrain, was discovered near the village of Orbeljanovskaja. Here a circle with a diameter of 120 – 130 m is situated at the top of a slight slope directed towards the main Caucasian mountain chain and several local volcanic hills (Figure 3). The preserved wall is still visible and about 1 m high. Orbelkanovskaja, however, like the Mar'inskaja ring 1, is partly destroyed by erosion and by a prehistoric landslide into the neighbouring valley. Thus, for both of them we assume a considerable age.

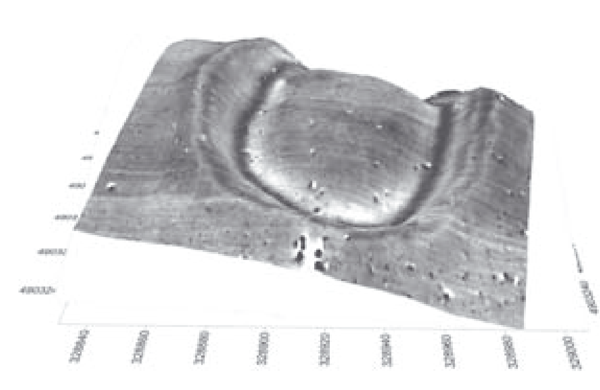


Figure 3: *Orbeljanovskaja. Magnetogram of the ring-ditch surveyed in 2012. The northern part has been destroyed by erosion. Smartmag SM4G special in duo-sensor configuration, total Earth's magnetic field ca. 49,800 nT, dynamics ±10 nT in 256 grey values from black to white, grid size 40 × 40 m, sampling density interpolated to 25 × 25 cm. Overlay with the fine levelling of the topography.*

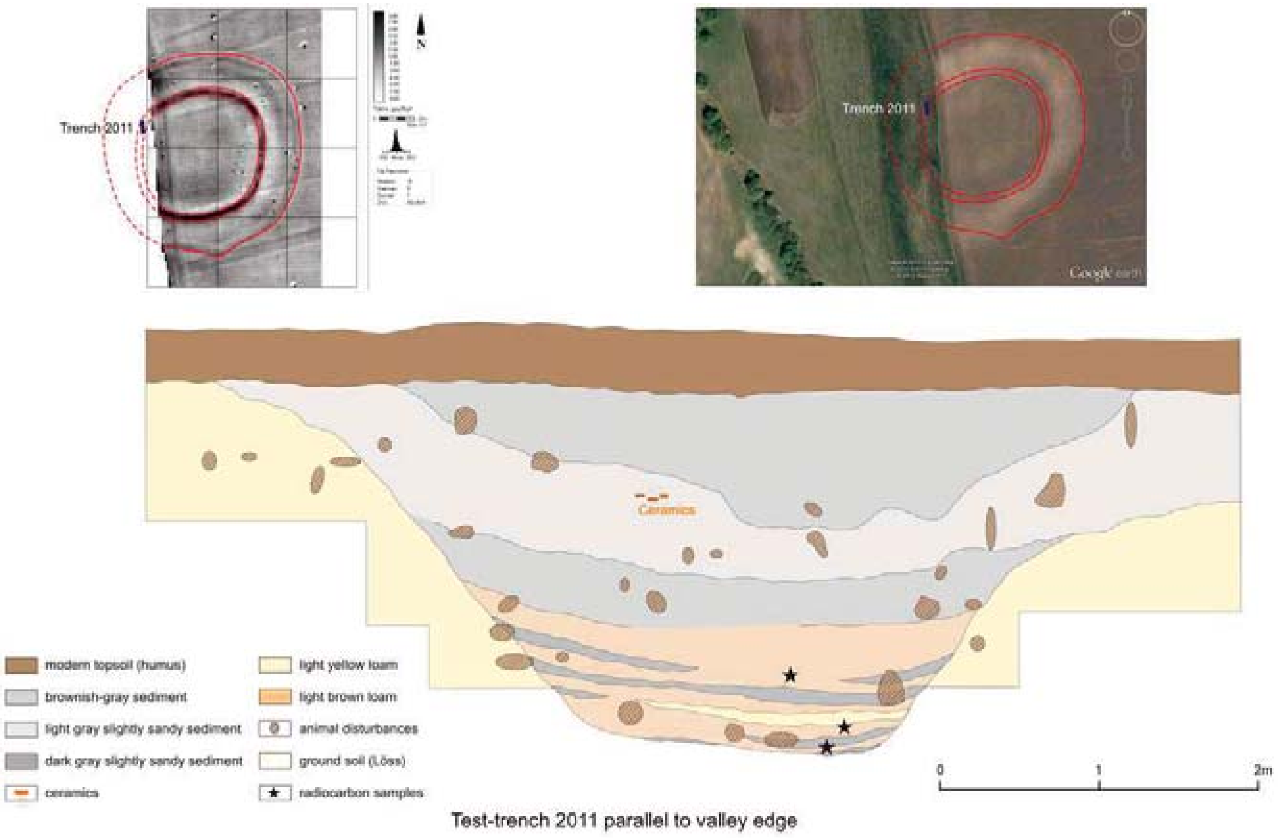


Figure 4: *Marins'kaja. Result of the magnetometer prospection with a first interpretation, optical satellite image of GeoEye-1 by GoogleEarth and results of the test excavation trench in 2011.*

3. ARCHAEOLOGICAL TEST EXCAVATION

In the Marins'kaja monument, a first test excavation trench was opened in 2011, bisecting the ditch (Figure 4). It revealed mixed layers in a typical V-shaped ditch. Among the shards, fragments of various periods were found, starting with Early Bronze Age Majkop (4^{th} millennium BC) pottery and ending in Sarmatian vessels (2^{nd} – 4^{th} century AD). Radiocarbon dates likewise revealed a mixed soil substrate. Thus, in the future, further trenches cutting wall and ditch systems have to be carried out for a better understanding of the phenomenon's chronological position.

4. CONCLUSION

Although there are some archaeological findings on the surface of these sites, it is difficult to make a reliable dating of these structures. The only hint for the construction time can be gained at the moment by the test excavation in Marins'kaja in 2011. However, the shape and layout of these structures, which were mapped by the means of magnetic prospecting, resembles very much to those ring-ditches or rondels of the Central European Late and End-Neolithic (Becker and Fassbinder, 2005; Neubauer, 2005; Schier and Trnka, 2005). So far, the easternmost rings dated to the fourth millennium BC and were found in Slovakia and Hungary (Pásztor *et al*., 2008). There are indicators for more ring-ditches also in Bulgaria. Yet, as the dating of these sites in the Northern Caucasus confirmed by an archaeological test excavation, they represent the easternmost province of a phenomenon so far related only with Central and West European Neolithic cultures. Contemporary cultures of the late 5^{th} and 4^{th} millennium BC with close links towards the West exist in the Northern Caucasus and the immediate vicinity of the newly discovered ring ditches. The enlargement of the cultural zone using rondels in the 5^{th} and 4^{th} millennium BC towards Caucasia would arise many new aspects about transfer of knowledge and ritual praxis.

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NEOLITHIC SETTLEMENT AT TĚŠETICE-KYJOVICE (CZECH REPUBLIC): MAGNETIC SURVEY AND ARCHAEOLOGICAL EXCAVATIONS

P. Milo

1. INTRODUCTION

Many remarkable findings and valuable evidence of prehistoric habitation have been amassed during decades of archaeological investigation on the Sutny tract at Těšetice-Kyjovice. Despite these important findings, questions remain regarding the extent of settlement area, the density of features in different parts of the site, and settlement structure during individual periods of development. This paper offers an outline of the development of habitation at Těšetice-Kyjovice, based on a combination of geomagnetic survey data and archaeological excavations.

2. ARCHAEOLOGICAL PAST AND THE STATE OF RESEARCH AT TĚŠETICE-KYJOVICE

Archaeological excavations at Těšetice-Kyjovice – Sutny tract have been conducted continuously since 1964. The excavated area currently covers 4.1 ha. In total, more than 700 settlement pits, over 1,400 postholes, more than 100 various trenches and 27 graves were examined. Most of the examined features belong to two large cultures of Central European prehistory – the Linear Pottery culture (LBK) and the Lengyel culture. The Linear Pottery culture can be associated with more than 70 settlement pits, almost 20 house plans, and 10 graves. Within the Lengyel culture fall multiple settlement pits of varied nature, mainly clay-extraction pits and storage pits, and above all the largest feature at the locality – a roundel enclosure. A smaller number of features belong to the Stroke-ornamented Pottery culture (STK), Baden culture, to the Bronze Age and the Iron Age (Kazdová, 2007; Podborský, 1988).

Despite the extent of excavation, however, the actual size of the area occupied by prehistoric habitation was, until recently, unknown. In 2007-2011, the entire accessible area, of 17.2 ha, was surveyed using the Cs-magnetometer SM-5 Navmag by Scintrex Ltd. (Milo and Kazdová, 2008) and the fluxgate magnetometer Foerster Ferex 4.032 DLG by Foerster Instruments, Inc.

3. ARCHAEOLOGICAL FEATURES IN GEOPHYSICAL DATA

The first goal of geophysical survey was to measure the previously excavated roundel enclosure and compare the results of geophysical survey with the results of archaeological excavations. As far as the roundel enclosure at Těšetice is concerned, it is a slightly flattened circular structure covering 63.7 × 58.6 m. Even though the entire surveyed area had already been examined archaeologically, whereby the archaeological contexts were disturbed and the fill of individual features moved onto surrounding soil, we found that the ditch of the enclosure as well as most of the settlement pits are distinguishable in the geophysical data. This can be explained by the way these structures were excavated. Feature fill was removed following natural stratigraphic

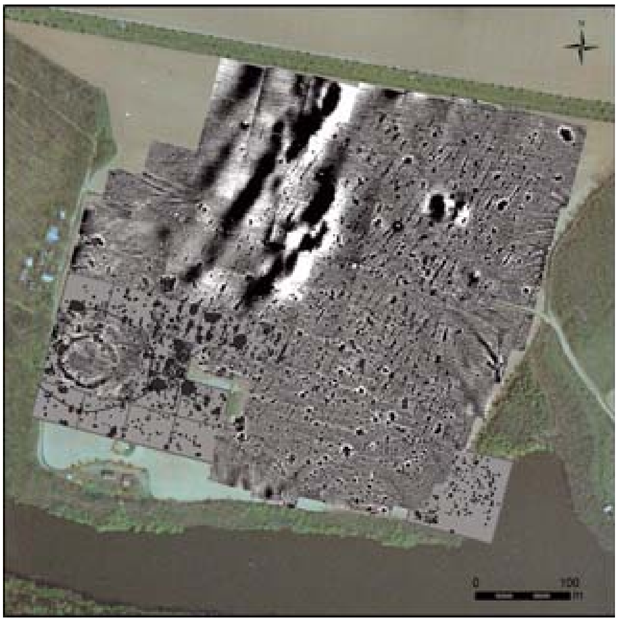

Figure 1: *General plan of geophysical measurements and archaeological excavations. About 1500 magnetic anomalies can be interpreted as archaeological features.*

layers, so that the walls of the features were not destroyed, and areas without any anthropogenic disturbance remained untouched. When the excavated area was backfilled, the empty settlement pits and ditch of the roundel enclosure were refilled with earth from their original fills, plus some topsoil, which exhibit higher magnetic values than the surrounding loess. The ditched enclosure as well as the other cuts thus again became more magnetic than adjacent intact soils, which enabled us to record them by geophysical survey.

The primary focus of the magnetic survey was on areas to the east and north of the archaeologically examined parts. In the geophysical data, we can observe many magnetic anomalies, which can be interpreted as archaeological features (Figure 1). Aside from these, there are also some interfering elements – above all anomalies caused by the geological composition of the locality. The bedrock is represented by granites of the Dyje Massif containing diorite intrusions, which are several times more magnetic than the surrounding granites, and on a magnetic map they show themselves as distinct anomalies with levels between 5 and 20 nT, which are four to twenty times higher than the values of archaeologically relevant structures (Šešulka and Milo, 2009). The anomalies, caused by geological subsoil, make it possible to define the course of rock bodies below the overlying Quaternary sediments. In places where these rock bodies are relatively close to the present-day ground surface, or in places with

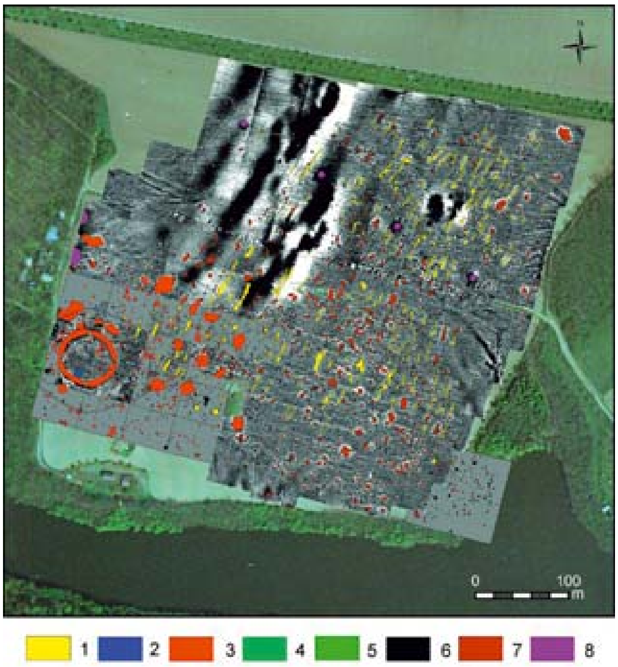

Figure 2: *Chronological classification of archaeological features and an attempted chronological classification of selected structures in the area of magnetic survey. 1. Linear Pottery culture; 2. Stroke-ornamented ware culture; 3. Lengyel culture; 4. Eneolithic; 5. Bronze Age; 6. Iron Age; 7. undated; 8. recent.*

the thinnest layer of Quaternary sediments, in our case loess, they disturb the homogeneous background of the magnetogram to such an extent that all the archaeological features become invisible due to their lower magnetic susceptibility.

The most abundant group of anomalies is represented by narrow linear structures 15 m wide and 10-50 m long. All of these are characterised by the same orientation towards NNE – SSW. In total, we can locate more than 100 such features on the magnetogram. We interpret them as extraction pits lining the ground plans of aboveground longhouses of the Linear Pottery culture. Several pits of this type at the locality have already been excavated.

Within the largest features at the site, count anomalies of varied shape sized 50 – 255 m^2. Approximately ten of them were documented, in total, mostly concentrated in the western part of the surveyed area. We interpret these features as extraction pits belonging to the Lengyel occupation, and assigned all archaeological features of this shape and size within the locality to the Lengyel culture.

Other settlement features are represented by various pits of smaller dimensions, which are distributed over the whole of the surveyed area. Magnetic survey has located approximately 1,400 such features in total. In the geophysical data, they show themselves as round, oval or irregularly shaped anomalies. Their individual specific characteristics and chronological position cannot be determined. We can assign them virtually to all cultures that have inhabited the locality.

Three narrow and long lines can be interpreted as trenches. Their specific characteristics and dating are not known. Small punctiform mono-anomalies probably represent postholes. They form multiple clusters in the surveyed area, but in none of them can we see a regular ground plan of a post-built structure.

The final type of feature is represented by the structure from the central part of the locality, which is composed of a narrow ring of about 10 m in diameter, and of a strong magnetic anomaly of square shape in its centre. Archaeological research has demonstrated that it is a perimeter trench and a burial chamber sized 3×2.5 m from the Bell Beaker period (Kuča *et al.*, in press). Other features of this type are not visible in the map of geophysical measurements. Based on this evidence, we can therefore assume that it was a solitary burial mound.

4. DEVELOPMENT OF HABITATION ON THE SITE

Combining the plans from archaeological excavations with those from geophysical survey enables partial reconstruction of the development of habitation on the site. As far as the chronological classification of individual magnetic anomalies is concerned, we can rely on their accordance, in shape and size, with archaeologically examined and dated features (Figure 2). In the geophysical data, we can distinguish, without any major problems, the extraction pits from the Linear Pottery Culture period. Their typical elongated shape and orientation to the same direction can be observed in both excavated features of this type and numerous magnetic anomalies. The overall extent of settlement area at the time of the Linear Pottery culture was 13.5 ha. The archaeologically examined segment of the settlement from this period represents approximately 17.8%. Even though Neolithic house plans were not identified in the magnetograms, they can be assumed in between the individual extraction pits (Figure 3). These pits concentrate in several rows running NNW – SSE.

Extraction pits of the Lengyel culture concentrate above all in immediate neighbourhood of the roundel enclosure. Features of this type gradually fade out farther to the north and north-east. What remains unknown is the extent of the settlement in western direction; that is in an area examined neither archaeologically nor geophysically. The overall documented area of the settlement of the Moravian Painted Ware culture is 7.7 ha, of which as much as 42.9% has been examined archaeologically. We cannot draw any conclusions regarding the number of houses from this period of habitation on the site. Only two buildings of light post construction and two small pit dwellings were identified during the archaeological excavations. Therefore, it is not surprising that houses do not appear in the geophysical data.

The results of geophysical survey alone do not allow us to draw any unequivocal conclusions on the development of habitation in later periods. The multi-cultural character of the locality does not allow us to attempt more precise dating of smaller magnetic anomalies. Some of them probably belonged to the Stroke-Ornamented Pottery culture, others to the Baden culture. Immediately to the south-east of the geophysical survey area, an archaeological rescue excavation has uncovered numerous settlement features, which date mainly to the Bronze Age and the Hallstatt Period (Podborský, *et al.* 2005, 171-218, Fig. 159), and in their shape and size resemble the above magnetic anomalies. We can assume from this that most of the anomalies identified in the south-eastern part of the magnetogram probably belonged to the Bronze Age and Early Iron Age.

5. CONCLUSIONS

Geophysical survey of prehistoric settlement areas has a relatively long tradition in Central Europe. The results of measurements taken at Těšetice-Kyjovice can therefore be incorporated into the wider archaeological knowledge base. Detection of archaeological relics has helped us to get an idea of the extent and

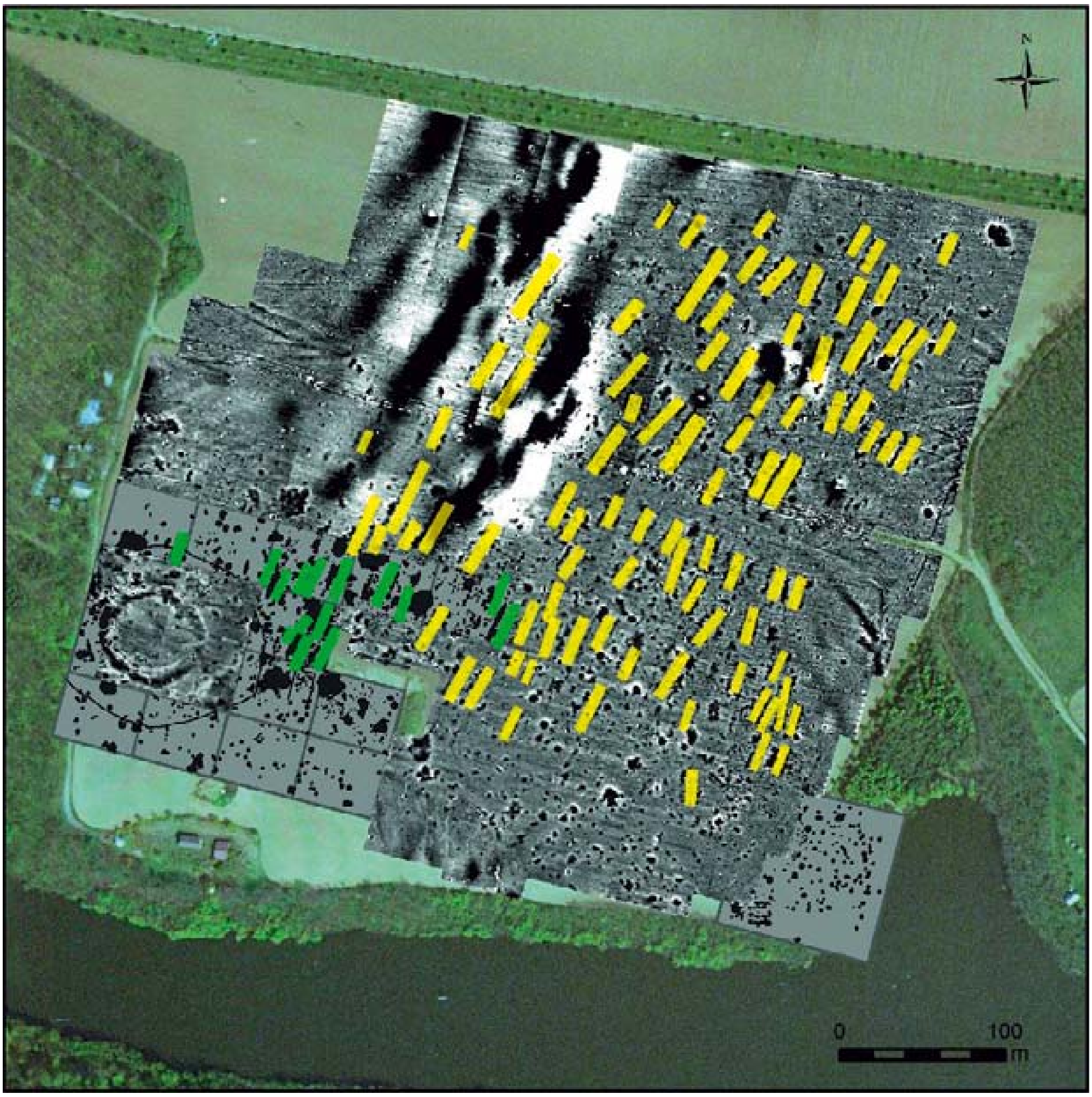

Figure 3: *An attempted reconstruction of the plan of built-up area in a settlement of the Linear Pottery Culture: green - excavated houses; yellow - assumed houses.*

intensity of habitation in individual segments of the site, and the changes in structure of identified features through various periods allowed us to draw conclusions on the settlement structure for the Neolithic and Early Eneolithic periods. The geophysical survey results from the Sutny tract at Těšetice-Kyjovice thus provide a framework for future archaeological field activities, which can target individual features without needing to expose large settlement areas.

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CHASING AEROPLANES: DEVELOPING A VEHICLE TOWED CAESIUM MAGNETOMETER ARRAY TO COMPLEMENT AERIAL PHOTOGRAPHY OVER THREE RECENTLY SURVEYED SITES IN THE U.K.

N. Linford, P. Linford, A. Payne, E. Carpenter, D. Grady, H. Winton, P. Horne

Whilst the English Heritage Geophysics and Aerial Investigation and Mapping teams have always worked closely together, recent restructuring of the organisation has combined the two into a Remote Sensing group which also includes expertise in Geospatial Imaging using lidar, laser scanning, photogrammetry and other emerging technologies. The main aim of this group is to deliver appropriate aspects of the National Heritage Protection Plan (NHPP), a newly adopted framework to prioritise available resources towards the protection of the historic environment. Two recently developed NHPP projects have combined the use of aerial photography and ground based geophysics. Together, these illustrate the benefit of such a multi-disciplinary approach and highlight the challenge of providing sufficient terrestrial coverage to complement discoveries made from the air.

The hand-operated caesium magnetometer array used by the Geophysics Team has, over the last decade, produced high quality magnetic data over a range of sites (Linford *et al.*, 2007). However, the benefits of more recently developed technology combining grid-less surveys through the integration of GPS data and vehicle towed platforms to increase the speed of acquisition has become increasingly evident (e.g. Hill and Linford, 2004; Gaffney *et al*., 2012). The course of this fieldwork saw the initial integration of a centrally mounted GPS antenna on the hand-operated cart array and the development of a combined data logging system to provide grid-less, positional tracking and display of the signal output from the sensors. Further, mechanical refinement has led to the deployment of a vehicle-towed system providing data logging and power supply from an all terrain vehicle (ATV) via a 5 m umbilical towrope (Figure 1).

Data processing requires the use of an adaptive, high-pass filter to suppress the magnetic response to the ATV and heading error across the four sensor channels. The GPS data is then interpolated to each data point, taking account of the relative offset between the GPS antenna and the sensor mounts, and gridded using a bidirectional interpolation algorithm.

Figure 1: *The vehicle-towed magnetometer array in use at Wilsford henge, Wiltshire. Four caesium magnetometer sensors are mounted on a platform together with a centrally mounted GPS receiver, towed by a light-weight ATV vehicle with low impact tyres. Power supply and data logging are provided through the umbilical link between the platform and vehicle.*

1. HAM HILL, SOMERSET

Ham Hill is an unusually large Iron Age hillfort, extending over 80 hectares and rich in the remains of later prehistoric and Roman activity. Parts of the site have been quarried for Ham Hill Stone since the Roman period, and two active quarries continue in operation, with the remainder utilized as a country park managed by South Somerset District Council. Caesium magnetometer survey was undertaken over two large fields of 10 ha each in the unthreatened north-eastern area of the hillfort to complete the geophysical coverage of the monument and augment excavation taking place in advance of renewed quarry expansion (Payne *et al.*, 2012). Aerial photography for the site has been of more limited use, perhaps due to the relatively thin soil cover over the Upper Lias Shelly Limestone and the predominance of permanent pasture. However, magnetic surveys have provided detailed evidence for activity within the hillfort interior from the Bronze Age to Roman periods, together with later quarrying sites that have obscured traces of earlier occupation in some areas. The caesium magnetometer survey of the first of the two fields was conducted using the standard hand-operated cart array and the second with a mounted GPS receiver to simultaneously record positional information together with the signal from the sensors. Collecting data using the grid-less system allowed for a much improved rate of data acquisition at an identical 0.125 m $\times$ 0.5 m sample density with no degradation in data quality. The total survey area of 20 ha took 10 days in the field to complete (Figure 2). Multi-period settlement evidence highlighted by the geophysical surveys includes:

- An early phase of probable Bronze Age field-systems and linear boundaries
- Iron Age activity represented by a major arterial roadway running between the main entrances to the hillfort and numerous ditched enclosures with associated pit clusters and roundhouses.
- Subsequent Roman activity in the form of a small corridor villa with further associated enclosures and quarries.
- Several early phases of quarrying activity, possibly dating back as far as the Roman period. These appear to have disturbed earlier traces of occupation where they occur, though fortunately their extent is limited.

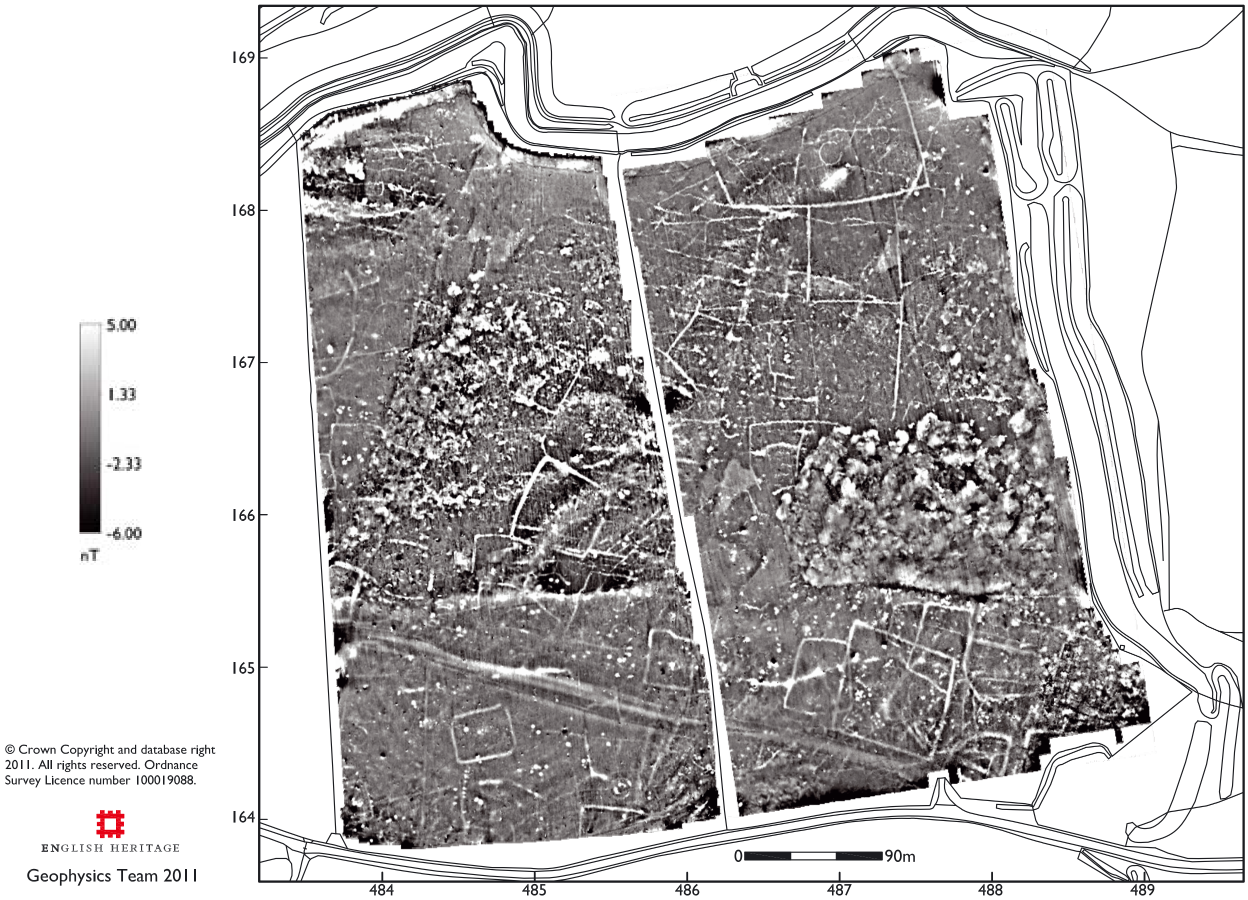

Figure 2: *Results from the caesium magnetometer survey conducted at Ham Hill, Somerset, showing the wealth of anomalies related to the multi-period settlement of the site.*

Combined with the earlier geophysical surveys (Geophysical Surveys of Bradford 1992, 1993, 1994; GSB Prospection, 2001), a near complete archaeological map of the internal character of the hillfort is now available. This will be used to inform future management of the monument and balance the protection of an important archaeological resource against the need to allow some limited quarrying of Ham Hill Stone for the repair of significant historic buildings nearby.

2. MARDEN HENGE ENVIRONS

This project builds on earlier work using non-invasive techniques including aerial photographic analysis, earthwork and geophysical survey (Field *et al.*, 2009) and a small-scale excavation focused on the Neolithic henge at Marden, Wiltshire. The aerial photographic analysis extended beyond the main henge and investigated the distribution of associated monuments throughout the Vale of Pewsey, identifying a number of relatively extensive sites where follow-up work was recommended to contribute to the enhanced understanding of the monuments.

Two sites were initially chosen for geophysical survey: the barrow cemetery and Roman villa known at Charlton St. Peter (Corney *et al.*, 1994) and a site immediately south of the Marden henge containing a further barrow cemetery and the smaller scale Wilsford henge monument recognised from the aerial photographic record. Whilst magnetic survey over the Marden henge produced relatively poor results, due to the generally less favourable Greensand geology, these candidate sites are all found to the south of the river where the sand gives way to chalk over which more pronounced contrasts might be expected. The newly developed vehicle-towed magnetometer array was deployed at both sites, over the permanent pasture site at Charlton St. Peter first and then over the arable sites at Wilsford to test the suitability of the system on more rugged terrain.

Surveys at these sites proved highly successful, although the transitional geology produced an extremely subtle response to certain features that show clearly on the aerial photography. For example, some of the weaker barrow ditches at Charlton St. Peter recorded <0.5 nT magnitude anomalies, demonstrating the importance of ensuring that the full sensitivity of the caesium sensors was not significantly compromised when deployed in a vehicle towed system. Results from the 16 ha survey at Wilsford demonstrated a slightly greater magnitude of response over the barrows ($\sim$ 1.0 nT) and also revealed a previously unrecognised Roman settlement abutting the Neolithic henge (Figures 3 and 4). The findings of the project will be used to inform decisions on the designation of these sites to ensure their protection for the future.

Figure 3: *Aerial photograph showing general view of Wilsford Henge NMR SU0957/16 (4653/39) 17-JUL-1990 ©Crown copyright. NMR*

3. CONCLUSION

The development of vehicle-towed magnetometer arrays provides the ability to place more extensive sites identified from aerial photography into a wider archaeological context, maximising the information that can be recovered in a relatively short period of fieldwork. In this case, the enhancement of the aerial photographic record has varied greatly between the sites, but even where geophysical survey appears to produce few additional anomalies, some enhanced detail and possible insight regarding the survival of the monuments has been provided. Despite partially unfavourable field conditions at the Wilsford site, the vehicle-towed array allowed for data acquisition rates approaching 1.0 ha per hour using a four sensor array with a 0.5 m cross line spacing.

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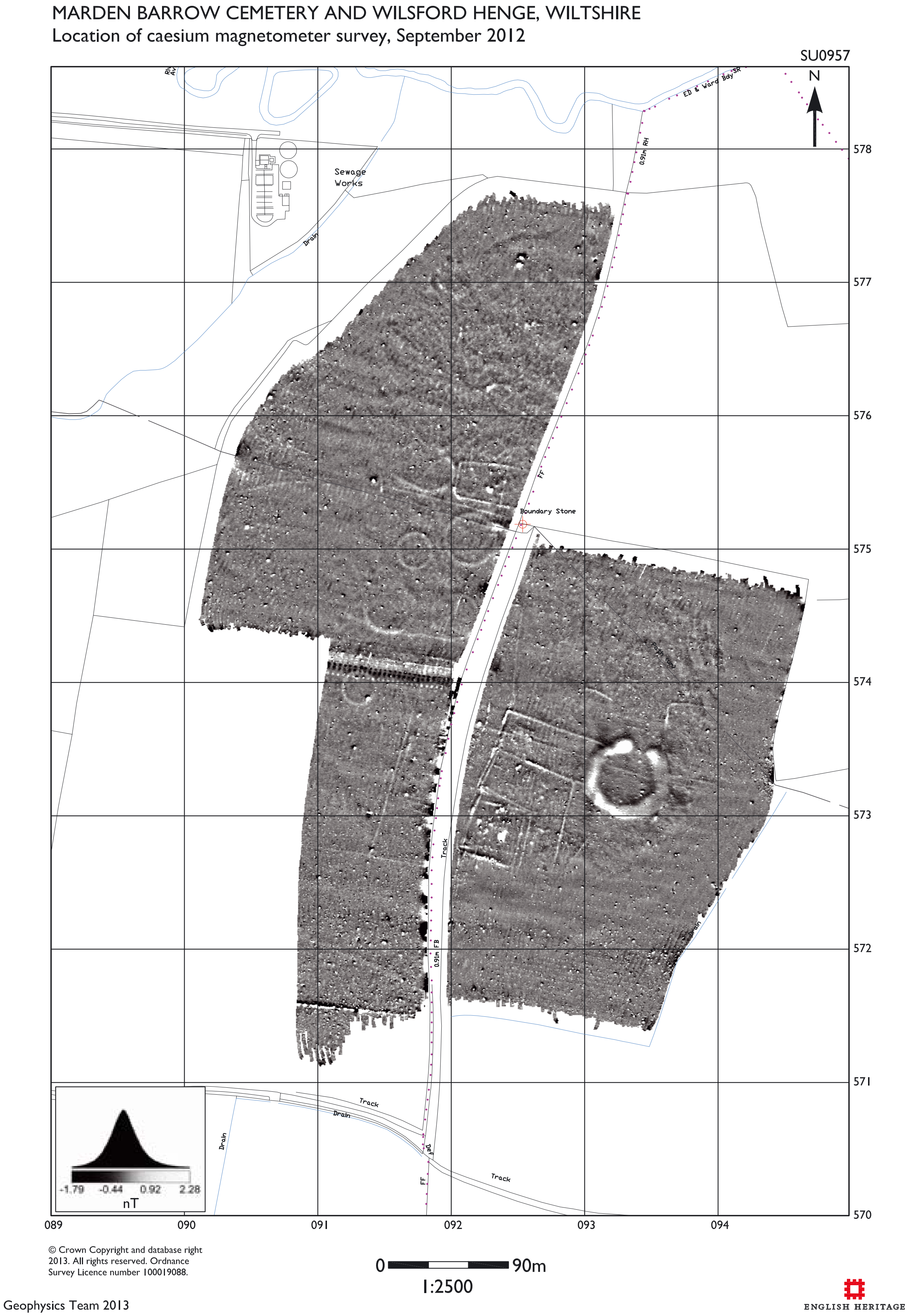

Figure 4: *Vehicle-towed caesium magnetometer array results from the Marden barrow cemetery and Wilsford henge sites. A previously unrecognised Roman settlement has been revealed by the geophysical survey data.*

IDENTIFYING AND DOCUMENTING LANDSCAPE CHANGES BY THE USE OF MULTI-TEMPORAL HISTORICAL AERIAL PHOTOS AND ALS-GENERATED DEMS – AN AUTOMATED AND RETROSPECTIVE APPROACH

O. Risbøl, C. Briese, M. Doneus, A. Nesbakken

1. INTRODUCTION

Landscapes change continuously due to a combination of natural and man-made factors. Even highly valued and protected cultural landscapes and environments are subject to changes. Most landscapes contain traces of long-term natural incidents and human actions that have contributed to their appearance today. Knowledge about the character of landscape changes is important in order to understand how present landscapes have been created within a historical/pre-historical context (Fairclough, 2003).

Identifying and documenting landscape changes are also important within a cultural heritage management context. Landscapes might be protected or given a preferred status, like World Heritage Sites, due to their cultural and historical qualities. It is obvious that in order to gain better control over important cultural landscapes or environments, cultural heritage management authorities need suitable methods to be able to follow the development as a precondition for taking the actions needed to improve and uphold protection. In order to monitor how landscapes develop, cultural heritage management needs methods to identify and document changes on various scales. Here, remote sensing is a suitable approach to identify changes on all scales from single monuments to entire landscapes in an efficient way (Mets and Skar, 2003). The fact that aerial photography has been used for more than a hundred years, resulting in repeated coverages of entire regions, provides an ideal basis for investigations on landscape change. However, a consistent workflow is still missing. Therefore, we want to explore how historical aerial photos from archives and airborne laser scanning (ALS) data sets can be used to identify and document landscape changes within a retrospective context. The basic workflow in this study will be:

i create multi-temporal 3D-models based on photogrammetry using historical aerial photos from the last five decades.

ii georeference all 3D-models together with actual data from ALS using multi-temporal control and tie features.

iii identify and document landscape changes from all multi-temporal 3D data sets using automated change detection based on a point cloud data set, a digital surface model (DSM) and a digital terrain model (DTM), and compare the outcome.

2. STUDY AREA

In order to pursue the explicit objectives we have chosen a site called Mølen in Vestfold County, Norway as a case study area. Mølen is a pebble-stone beach where more than 200 cairns were erected in the period from the Roman Iron age to the late Iron Age, a period of approximately 1,000 years. The site consists of 16 large round cairns with a diameter of up to 30 m and a height between 1 and 3 m, a boat-shaped cairn with a length of 20 m, and 192 smaller round cairns measuring from 0.5 to 2 m in diameter (Figure 1).

Figure 1: *A boat shaped cairn. To the left in the picture a row of small cairns are seen and in the background one of the largest grave cairns at Mølen. Photo: Anneli Nesbakken, NIKU.*

All are built of stone, mainly pebble stones, a fact that makes this an extremely vulnerable site since stones easily can be moved around. Like all Norwegian cultural monuments and remains older than the Reformation, which took place in 1537, Mølen is protected by law since the early 20th century. Despite this, we know that the site has been exposed to many changes and alterations, mainly due to human activity that has been ongoing for at least the last 100 years, and probably for a longer period of time (Risbøl and Nesbakken 2009). Thus, the site is well-suited for a study aiming to test different remote sensing methods and their usability in identifying and documenting changes occurred in a given period of time.

3. METHODS

Historical aerial photos are a valuable but geometrically less exploited source of information that potentially offers radiometric and geometric knowledge about the appearance and change of past landscapes throughout the period of time where aerial photos have been possible, which in practice is at least for the last century (Cowley and Stichelbaut, 2012; Risbøl and Kaun, 2012). Mølen has been covered by vertical aerial reconnaissance with different intervals from 1947 onwards. A selection of these will be used to derive digital terrain models (DTM) using mainly automated photogrammetric methods (c.f. Verhoeven, 2011; Verhoeven *et al.*, 2012). The next step will be to georeference the derived terrain models and to explore the possibilities of automated change detection based on a digital comparison of these DTMs. Some first preliminary tests using ALS gener-

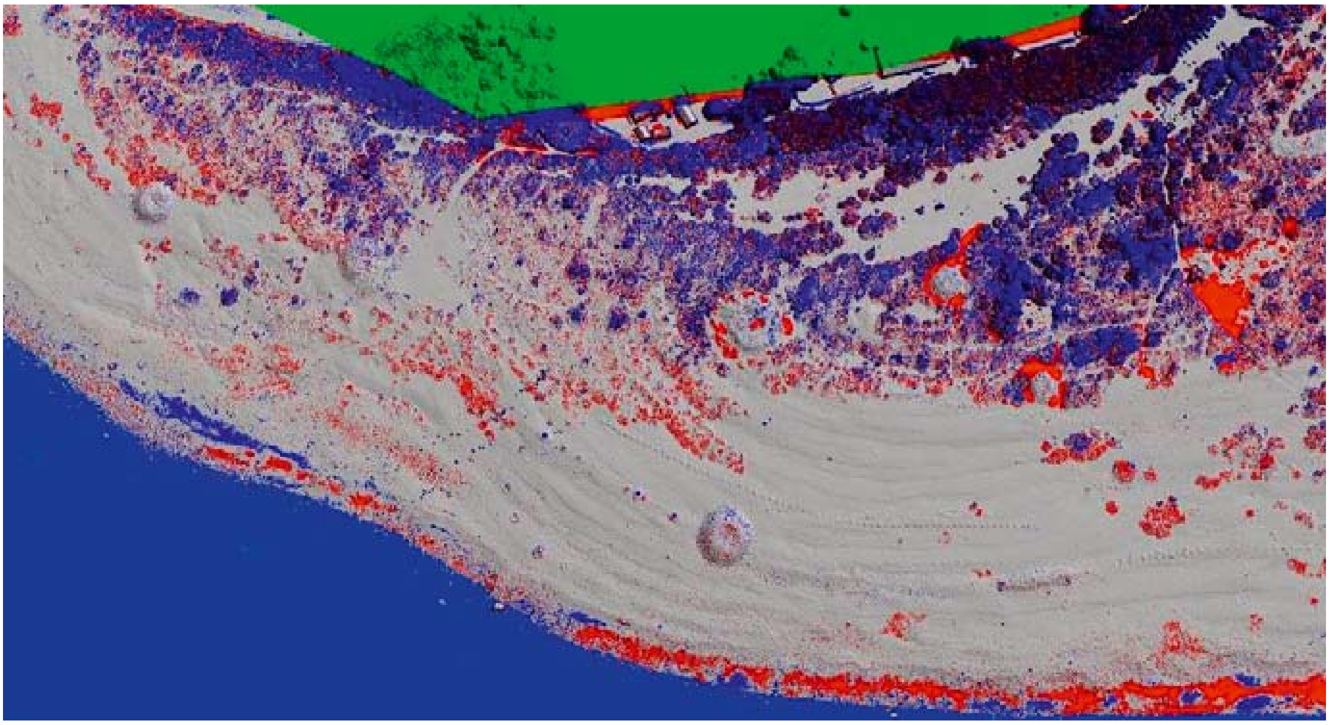

Figure 2: *This colour coded difference model shows the result of an automated change detection based on a comparison of ALS datasets from 2008 and 2010. Green colour shows an area with no overlap between the two datasets, grey colour indicates areas where the height difference between the two data sets is below 0.1 m, blue colour which parts that were elevated by more than 0.1 m and finally red colour shows areas lowered more than 0.1 m in the period.*

ated DEMs from Mølen as basis for automated change detection have already been carried out (Figure 2) and show promising results. However further research is needed to better understand the detected changes. At the moment, it is difficult to distinguish whether the detected differences in the compared datasets are all due to actual changes to the topography and/or vegetation in the studied area, or if they can be explained by differences introduced by the different sensing campaigns (different measurement accuracy and resolution, different sensing geometry), or by the processing work flow (different georeferencing workflow or DTM interpolation process). The study will also comprise a comparison of the outcome of change detection based on point cloud data sets, digital surface models (DSMs) and DTMs.

4. EXPECTED RESULTS

Using photogrammetry based on historical aerial photos in combination with ALS generated DEMs, we expect to develop a method for identifying and documenting multi-temporal landscape changes for the last 50 years in the case study area Mølen. It is our intention that the results of the study will have transfer value to other cultural environments and landscapes where multi-temporal knowledge is needed in order to document landscape changes in the point of intersection between past and future as a basis for improved understanding, protection and management.

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NEW APPROACHES FOR ARCHAEOLOGICAL FEATURE EXTRACTION OF AIRBORNE IMAGING SPECTROSCOPY DATA

G. Verhoeven, M. Doneus, C. Atzberger, M. Wess, M. Rus, M. Pregesbauer, C. Briese

1. ARCHAEOLOGICAL AIRBORNE IMAGING SPECTROSCOPY

Airborne hyperspectral scanning involves the mapping of a scene's wavelength intensity, accomplished by measuring upwelling electromagnetic radiation (reflected and/or emitted) in a multitude of contiguous narrow spectral bands. The end product consists of spatially co-registered two-dimensional images, each of them representing a spectral band that is typically just about ten nanometres wide. In this sense, imaging spectroscopy yields a three-dimensional data cube (x, y, λ) in which the first two are the spatial dimensions, whereas the third axis contains a spectral dimension: a digital number (DN) that represents the sampled and quantized at-sensor radiance L for that particular waveband. In post-processing, reflectance (or emissive characteristics) can be calculated from these DNs. Through a combination of all spectral data acquired from a particular spatial location, every individual pixel of the final image holds the complete reflectance or emission spectrum (known as spectral signature) of the material that was sampled at that specific location. Since this spectral signature can be obtained for every pixel in the image, the technique is also called airborne imaging spectroscopy (AIS).

AIS data sets offer new possibilities for archaeological research, because traditional multi-spectral sensors spectrally undersample the true signature. Despite this, archaeological AIS has occupied only a small niche in the field of remote sensing during recent decades. Even now, its application in archaeological research is limited and most results are not entirely convincing for practical applications. Aside from the common, archaeologically insufficient ground-sampling distance of 2-3 m, the technical processing of these data typically does not go beyond the calculation of band ratios and a principal component analysis.

This means that at least two broad problems need to be solved (assuming that the image geometry can be correctly handled) before AIS data can become of real archaeological interest. The first problem relates to the huge amount of available information that is not directly accessible to the human eye, making data mining approaches necessary. The second problem relates to data quality. Indeed, as the upwelling electromagnetic radiation is recorded in small bands that are only about ten nanometres wide, the signal received by the sensor is quite low compared to sensor noise and possible atmospheric perturbations. The high spatial resolution of the AIS data sets, which is of the utmost importance when flown for archaeological purposes, requires a small IFOV (instantaneous field-of-view) further limiting the useful signal stemming from the ground. For these reasons, noise reduction techniques are necessary.

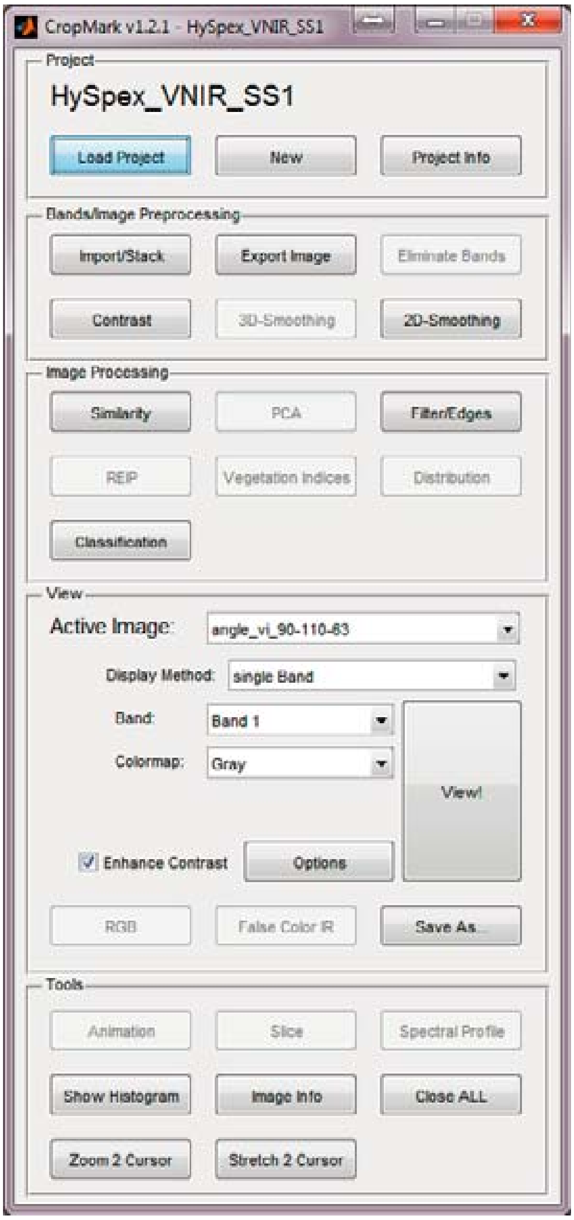

Figure 1: *The GUI for the Matlab CropMark toolbox.*

2. MATLAB TOOLBOX

To deal with these issues, a Matlab toolbox called "CropMark" and an accompanying user-friendly graphical user interface (GUI) were developed (Figure 1) to help the image analyst (not necessarily a specialist in remote sensing nor in imag-

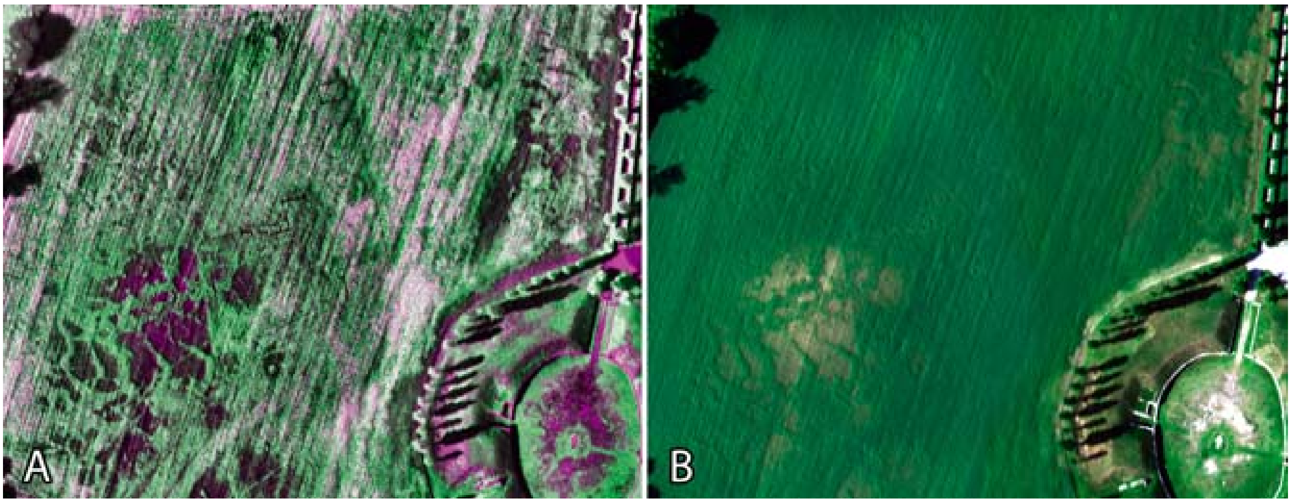

Figure 2: *(A) False colour composite (R= band 3, G = band 2, B = band 3) created by means of the REIP algorithm; (B) shows the same area in a conventional RGB image. Both images are histogram-stretched.*

ing spectroscopy) in getting the most information out of the recorded 3D data cube. As the main focus for the toolbox is archaeological AIS prospection, the aim was to visualize the data and to highlight possible crop or soil marks. Powerful, not commercially available filters based on the Whittaker smoother (Atzberger and Eilers, 2011) were implemented to deal with the noise in the hyperspectral bands. The user can visualize any sequence of individual bands in an animated way, or look at the first few principle components. Additionally, various standard and optimized hyperspectral vegetation indices were realised. Areas with a similar spectral signature can be highlighted and compared to a user-selected pixel or region of interest. The user can further test the usefulness of a large set of edge detection algorithms.

3. AIS PROCESSING

To extract archaeologically-relevant information from several hyperspectral datasets acquired in different seasons above the Roman town of Carnuntum (Austria), several new and not-commonly applied algorithms were tested.

The first technique is called the Red Edge Inflection Point (REIP) derived from spectrally smoothed and oversampled signatures. Previous research has already proven the archaeological usefulness of the red edge spectral band when used in a simple vegetation index (Verhoeven and Doneus, 2011). The REIP algorithm, however, will not use the complete red edge spectrum, but looks for the location of the highest gradient in the red edge spectral profile curve. Using the very powerful Whittaker smoother, the input AIS data are not only smoothed but also interpolated to a user-defined number of fictional "bands" between the original spectral bands. Afterwards, the REIP is calculated on a pixel-by-pixel basis and generates three image layers:

- Layer 1: band or wavelength of REIP location;
- Layer 2: value of the slope of the reflectance curve at the REIP position;
- Layer 3: Reflectance value at REIP.

Figure 2 shows the revealing power of a REIP false-colour composite (Red= band 3, Green = band 2, Blue = band 3) and a histogram-stretched conventional aerial image (2B) of the same scene: i.e. the Roman gladiator school (ludus) located next to the civil amphitheatre in Carnuntum (Austria). Obviously, the overall contrast of the archaeological marks is much higher in image 2A (which is also histogram-stretched), while certain features only become visible in the REIP product.

A second technique is called distribution fitting. It is known that different distributions exist (e.g. normal/Gaussian, Poisson, gamma, beta). All of these are characterised by one or more parameters. The well-known normal curve, for instance, is completely described using the mean and the standard deviation. In the distribution fitting approach, the histogram of the complete spectral signature is calculated on a pixel-basis. Afterwards, a user-defined curve is fitted to this histogram, while the values of the parameters describing this curve form the pixel values of the newly generated image bands. Using a gamma curve (described by its shape parameter k and scale parameter θ), zones with a higher biomass (indicated in black in Figure 3A) could be delineated much better compared to a conventional, histogram-stretched RGB aerial image.

4. CONCLUSION

By programming a specific AIS Matlab toolbox, a tool was created to test currently available AIS processing techniques as well as validate the value of completely new information extraction techniques. The examples given here prove that more specifically curve fitting and the visualisation of the red edge inflection point can yield new insights into crop vigour and crop stress.

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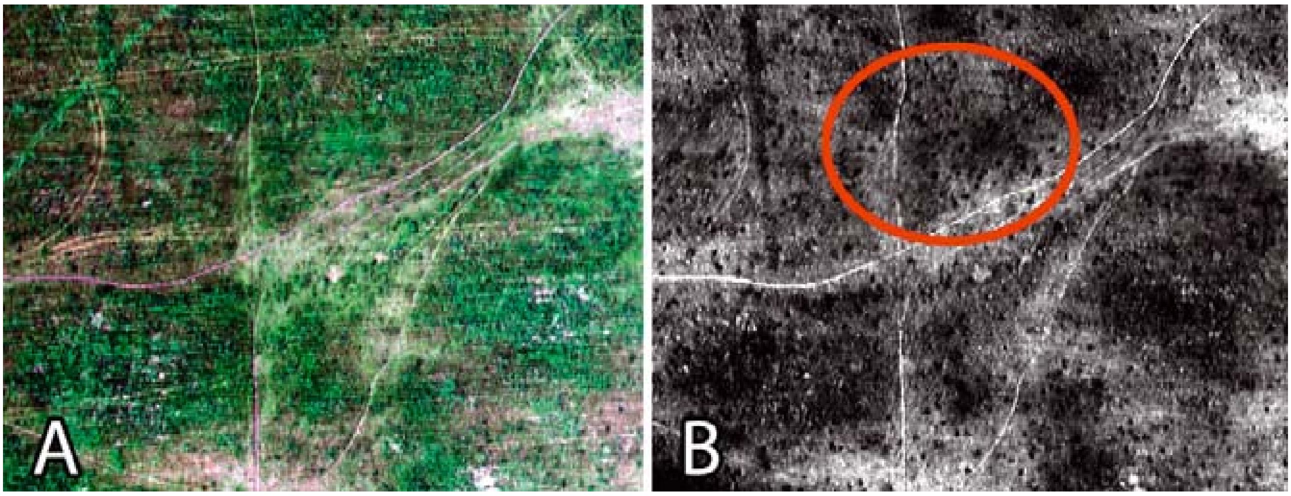

Figure 3: *(A) Normal RGB image; (B) the same area visualised by the value of the shape parameter resulting from a gamma distribution fitting. Notice the darker vegetation spots not visible in version (A). Both images are histogram-stretched.*

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MEASURING THE TOPOGRAPHY OF SUBMERGED ARCHAEOLOGICAL SITES FROM THE AIR

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G. Verhoeven, I. Miholjek, F. Daim

1. INTRODUCTION

Detailed knowledge of underwater topography is essential for many research fields, including hydraulics, hydro-morphology, and hydro-biology. In archaeology, this is a foundation for understanding the organization and distribution of archaeological sites along and within water bodies. Here, special attention has to be paid to intertidal and inshore zones where, due to sea-level rise (Lambeck *et al.*, 2004), coastlines have changed and many former coastal sites are now submerged in shallow water (depth < 10 m). Mapping the relief within these areas is therefore important to be able to reconstruct former coastlines, identify sunken archaeological structures and recognize navigable areas, which can help to locate potential former harbour sites.

Until now, archaeology has lacked suitable methods to provide detailed maps of the topography of inshore underwater bodies. Due to practical constraints and depending on the pulse length (DeJong, 2002, 322), waterborne echo sounding has its limitations at shallow water depths. Terrestrial surveys are extremely time-consuming, small-scale, and do not feature the necessary details. Currently existing hydrographic airborne laser scanning systems are designed for maximum water penetration and the moderate pulse repetition rate results in a rather rough ground sampling distance of several meters (Cunningham *et al.*, 1998; McNair, 2010, 24ff.).

Using the latest airborne laser bathymetry (ALB) system, it is now possible to measure underwater surfaces over large areas in high detail (ground sampling distance < 50 cm). Airborne laser scanning (ALS) systems for the acquisition of the topography operate in the near or short-wave infrared wavelength (typically 1064 nm or 1550 nm), which is significantly absorbed by water bodies (Curcio *et al.*, 1951). To allow water penetration, ALB instruments utilize a laser wavelength in the visible domain (typically green with 532 nm) with a very short pulse length (approximately 1 ns) for good range discrimination and low beam divergence (1 mrad). The effective measurement rate of current systems is approximately 200 kHz. Due to eye-safety reasons, the penetration depth is a compromise between a small footprint (narrow laser beam allowing a high sensing detail) and high laser energy (allowing deeper penetration). Depending on the water quality, water penetration up to one Secchi depth can be achieved with current systems (RIEGL 2012).

2. MATERIALS AND METHODS

Currently existing ALB systems are designed for maximum penetration of water bodies using high-energy laser pulses with a typical repetition rate of 1 kHz. For eye safety reasons, the green laser beam has to be spread to a diameter of several meters. This results in ground sampling distances of 4 – 5 m at typical flying heights between 200 and 500 m (Guenther *et al.*, 2000).

For the archaeological research presented here, a higher resolution was desirable. Therefore, a different system had to be used. The hydrographic laser scanner (VQ®-820-G), manufactured by the company RIEGL Laser Measurement Systems GmbH in cooperation with the University of Innsbruck, Unit of Hydraulic Engineering, is designed to yield ground sampling distances less than 1 m. This is achieved using very short laser pulses (1 ns) in the green wavelength domain (532 nm) with small footprints (in our case 0.45 m at a flying height of 450 m) and a high effective measurement rate (200 kHz). A test flight operated by the company Airborne Technologies GmbH on the 29th of March around 12:30 local time with calm water conditions (Figure 1) resulted in a point cloud with 6 points (all echoes) per square meter.

Figure 1: *Simultaneously acquired orthophoto-mosaic of Kolone, Croatia.*

To guarantee eye safety, the energy has to be adjusted to a low energy mode with a special instrument setting provided by RIEGL. This results in a reduced water penetration capability of 1 Secchi depth (i.e. the maximum depth at which a 20 cm diameter black and white colour disk can be can be seen by the human eye). The above-mentioned test over Adriatic coastal areas and fresh-water lakes demonstrated that depending on the clarity of the scanned water body, this distance can be between 0 m and 10 m.

Deriving the range between scanner and sub-water surface and assigning coordinates to the reflecting objects is difficult. To calculate the range and refraction correction due to signal propagation in air and water requires a good model of the contemporaneous conditions and shape of the water surface as the speed of light differs for atmosphere and water. While the system already gave good results, remaining systematic errors between the strips could be minimized using least square adjustment of the individual ALB strips (Kraus *et al.*, 2008; see also Figure 2).

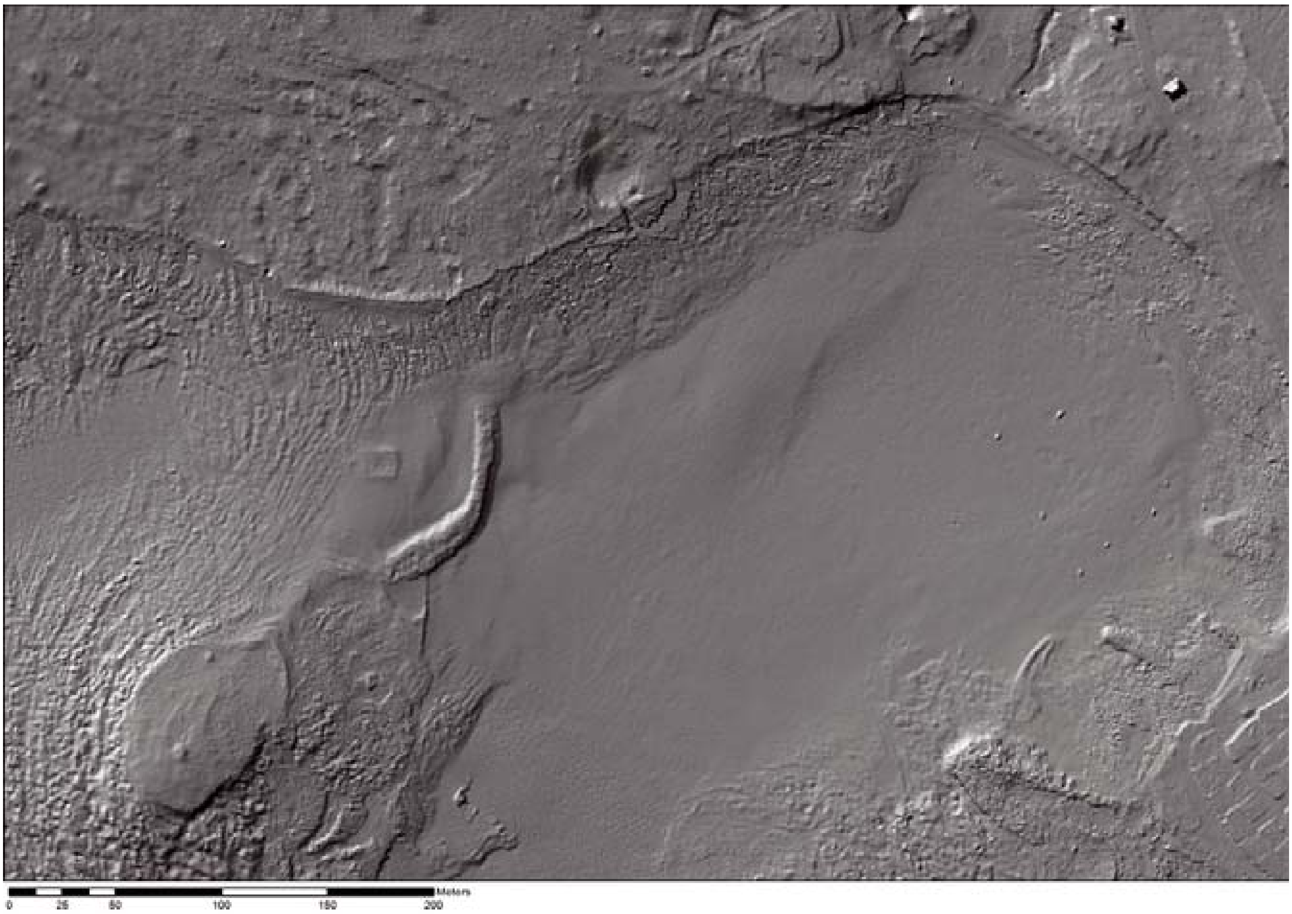

Figure 2: *Shaded digital surface model generated from the filtered and strip-adjusted ALB-point cloud over the Roman harbour site of Kolone, Croatia.*

3. THE CASE-STUDY OF KOLONE, CROATIA

In a pilot study, a RIEGL VQ-820-G ALB system was operated over the coastal area in Kolone, a Roman harbour site in the southwest of Croatian Istria. The measurements resulted in a digital model of the underwater topography with a planimetric resolution of 50 cm in waters at depths of up to 10 m. The GIS-based analysis of the data reveals a Roman embankment and breakwater walls in their topographical context (Figure 3).

The results clearly demonstrate that by using this active remote sensing technique, it becomes possible to shift the measurement border from the water-land boundary into the water. This allows including shallow-water zones, which can otherwise hardly be mapped in detail, into topographic documentation. We anticipate this technique also as a major break-through for scientific fields that are in need of detailed topographic maps of intertidal zones and shallow-water bodies. Furthermore, multitemporal ALB missions could reveal environmental change regarding underwater sedimentation and erosion rates, as well as changes in underwater vegetation. In the field of archaeology, the results will have an important impact because, with the exception of sunken ships, underwater archaeology often deals with submarine archaeological structures that are located in shallow-water zones.

ACKNOWLEDGEMENTS

The flight was funded by RGZM Mainz in preparation of the project "Harbors and landing places on the Balkan coasts of Byzantine empire (4.-12. Century). Technology and monuments, economic and communication." Special thanks also to Davor Milošević for help and advice during the underwater survey in October 2012.

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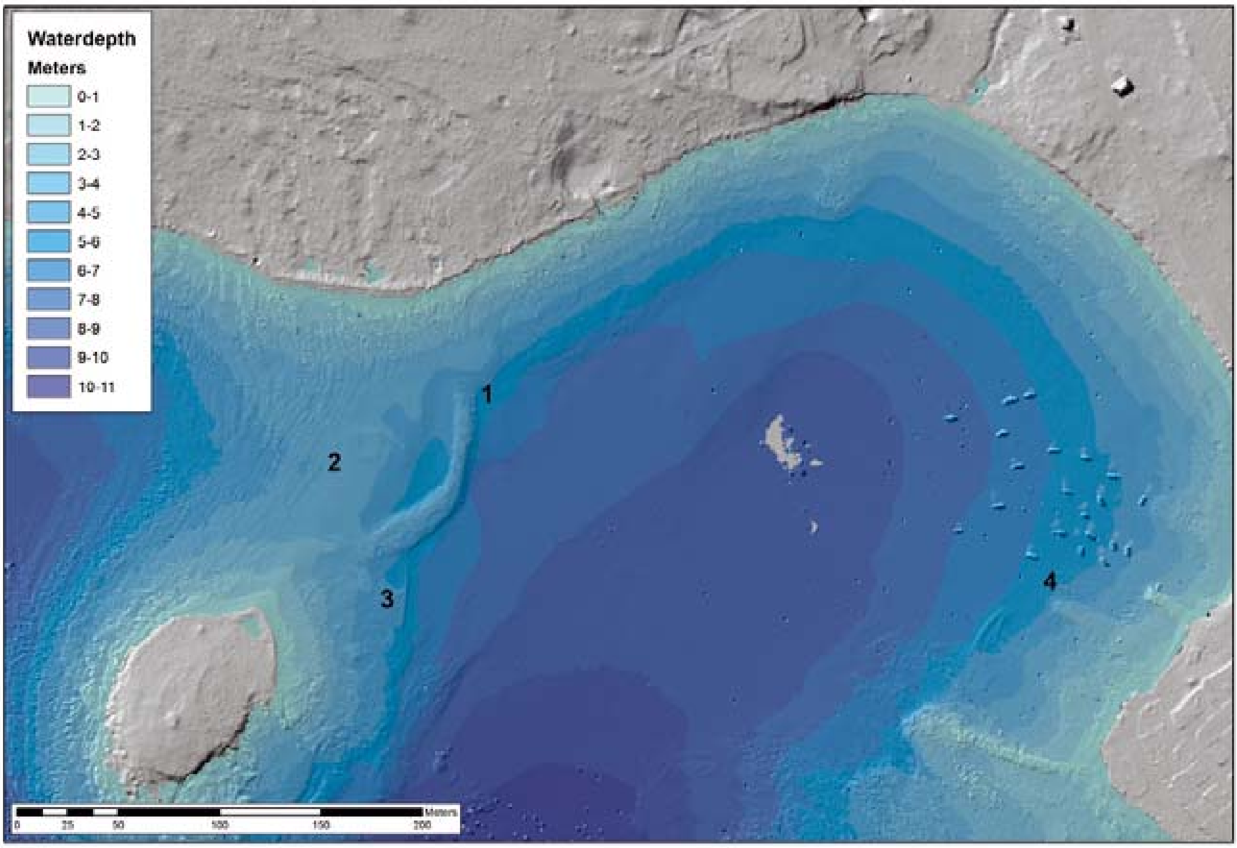

Figure 3: *Shaded filtered DTM generated from an ALB data acquisition campaign over the Roman harbour site of Kolone, Croatia. The shaded DTM combines land surface and underwater topography. Furthermore, a color-coded map of the water depth is superimposed. The following archaeological features can be recognized: (1) presumably Roman embankment connecting the small island with the main land (2) previously unknown, undated square structure, 15 m by 15 m with 0.5 m high walls, (3) wall with unknown function, and (4) Roman mole.*

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STONEHENGE HIDDEN LANDSCAPES PROJECT; GEOPHYSICAL INVESTIGATION AND LANDSCAPE MAPPING OF THE STONEHENGE WORLD HERITAGE SITE

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1. RESEARCH SUMMARY AND CONTEXT

Stonehenge occupies one of the richest archaeological landscapes in the world, recorded in the course of intensive archaeological and antiquarian research over several hundred years, yet much of this landscape effectively remains terra incognita. The Stonehenge Hidden Landscapes Project aims to address current limitations and gaps in our knowledge and understanding of the Stonehenge landscape by conducting a cutting-edge geophysical and remote sensing survey at an unprecedented scale – to encompass a large portion of the World Heritage Site – with a projected total survey area of about 10 km^2. This is possible only because of the unique expertise and combined resources of the project partners, the Visual and Spatial Technology Centre (VISTA) at the Institute of Archaeology and Antiquity, University of Birmingham, and the Ludwig Boltzmann Institute for Archaeological Prospection & Virtual Archaeology (LBI ArchPro) in Vienna.

The results of the project are used to create a highly detailed archaeological map of the 'invisible' landscape, providing the basis for a full interpretative synthesis of all existing remote sensing and geophysical data from the study area, as well as comparative evaluation of the results of archaeological excavation data in relation to geophysical results. For the first time it is thus possible to create total digital models of the Stonehenge landscape at a true 'landscape scale' that not only transcend the immediate surrounds of individual monuments within the study area, but also tie them together within a seamless map of subsurface and surface archaeological features and structures.

Although recent studies have provided an unusually detailed archaeological and digital database for Stonehenge and its immediate environs (notably: RCHME 1979; Richards 1990; Cleal *et al*. 1995; Exon *et al*. 2000; Larrson and Parker Pearson (eds) 2008), the historic research emphasis on the monuments has rarely permitted a rigorous analysis of wider landscape structures in relation to the emerging complexity of the archaeological evidence. This is perhaps surprising given the explicit landscape-scale and context of analysis and interpretation embodied in much of this work, including special prominence given to structured 'symbolic landscapes', cosmography and architectural order (e.g. Darvill, 1997; Parker Pearson and Ramilisonina, 1998; cf. Darvill, 2006, Lawson, 2007). Hitherto, despite the impressive scale and outstanding results of recent fieldwork programmes, especially those undertaken by the Stonehenge Environs and Stonehenge Riverside projects, these have reproduced a fairly traditional monument/site-focused approach to field investigation. The nature, spatial locations and extent of previous geophysical prospection work within the study area are broadly consistent with this wider pattern, being driven either by reactive evaluation strategies determined by the planning process and mitigation of proposed development, or by monument-focused research agenda, resulting in discontinuous, fragmentary, relatively small-scale and often linear rather than spatially-extensive survey areas (Payne, 1995; David and Payne, 1997; David, 2005; Darvill, 2005, Maps B, Q). The guiding philosophy of the project presented here is entirely different: the intention is to explore landscape as undivided three-dimensional space and to understand ancient built environments and associated practices at extensive scales within that spatial framework.

Figure 1: *Stonehenge within the UK.*

Whilst this approach certainly underpinned previous work in the Stonehenge landscape by members of the current team (see Exon *et al.*, 2000), the Stonehenge Hidden Landscapes Project aims to pursue a range of new research objectives (not limited to known monuments) at a much greater scale and a far higher level of both data resolution and complexity. In recent years, teams from VISTA have also been engaged in constructing a virtual environment for the immediate area around Stonehenge and have undertaken geophysical survey work within the wider landscape. There is now the opportunity to realize the full potential of this outstanding technological, methodological and research expertise and the exceptional scale of resourcing available to the project. This consortium has been created as part of the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology, which has provided funding for international participation and access to the exceptional technical resources that

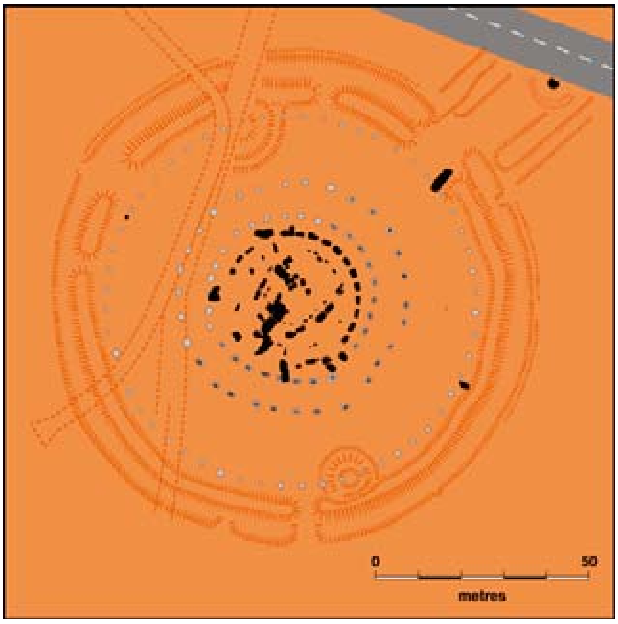

Figure 2: *Stonehenge plan.*

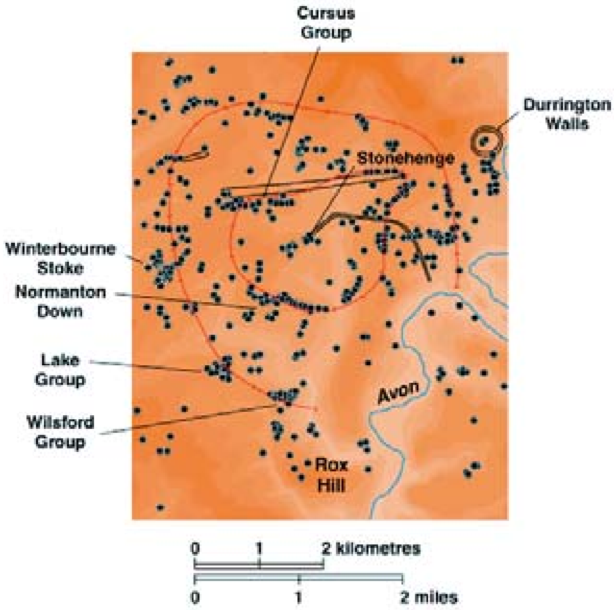

Figure 3: *Stonehenge and major monument groups.*

are used during survey. The University of Birmingham IBM Visual and Spatial Technology Centre is the UK partner within the consortium and leads the fieldwork, supports project management and provides regional expertise.

2. PROJECT OBJECTIVE

Our knowledge of the Stonehenge archaeological landscape will be revolutionized by integrating remote sensing and geophysical prospection with context aware visualization, which combines the existing landscape with prospection and other archaeological data in a seamless fashion. It has been proposed that the VISTA/LBI consortium should survey the majority of available land within the area of the 'Stonehenge Envelope' (defined by Cleal and Allen, 1995) over a period of four years using the unique equipment resource available to the group. In doing so, the partners are developing the research results to create an unparalleled remote-sensed database, integrating the data in a novel manner in order to inform archaeological research and heritage management for regional and national curators. See Figure 5 for the initial outline of the total study area.

The extent of previous geophysical prospection of all kinds within the Stonehenge World Heritage Site up to 2001 has been estimated at 3.1602 km^2 (David, 2005, 14). Since that time, additional geophysical survey in the area, primarily connected with the Stonehenge Riverside Project, probably amounts to less than 800 ha (this is a rough estimate as only a small part of this work has been published; Payne, 2006). Overall, therefore, less than 4.0 km^2 of the landscape have been subject to geophysical survey of diverse types, variable data resolution and uneven and fragmented spatial coverage. In contrast, the project outlined here consists of a single high-intensity geophysical survey encompassing an estimated 14 km^2 of the World Heritage Site, providing high-resolution, contiguous extensive mapping of geophysical data in its own right, while also providing a means to tie together and re-evaluate all previous geophysical surveys with reference to a single seamless 'control' data set.
As part of this process, it is intended to undertake more detailed surveys of selected areas combining both magnetometry and ground-penetrating radar surveys, especially of major round barrow groups close to Stonehenge (such as the Cursus, Winterbourne Stoke Crossroads and Normanton Down groups). These have been subject to very little recent investigation, despite their exceptional research significance for the British Early Bronze Age at a national scale, their relevance to European Bronze Age studies (i.e. in relation to the Wessex rich graves and continental interactions), and specific mention in all research agenda and strategy documents produced for the World Heritage Site (see below), the Wessex region (Woodward and Gardiner, 1998) and the South-West England region (Webster, 2007).

More generally, the project addresses many of the research, conservation and management priorities identified in the Stonehenge World Heritage Site Archaeological Research Framework (Darvill, 2005, 107-20) and in the Stonehenge World Heritage Site Management Plan (English Heritage, 2009). Indeed, by virtue of its scale and spatiality integrative qualities there are few research issues specified in these documents that are not addressed in some way by the project. Of these, the following stand out as exceptionally significant in terms of project design implications and their interpretative potential in relation to the already existing data sets arising from the survey work:

Stonehenge World Heritage Site Archaeological Research Framework (Darvill, 2005)

Strategic objectives

1. Investigate the essential importance and distinctiveness of Stonehenge past and present.
3. Modelling environment and landscape change.
4. Understanding occupation.
6. The Avenue – ground checking geophysical anomalies and mapping.
8. Investigate the palisade ditch northwest of Stonehenge.
10. Barrow cemetery surveys.

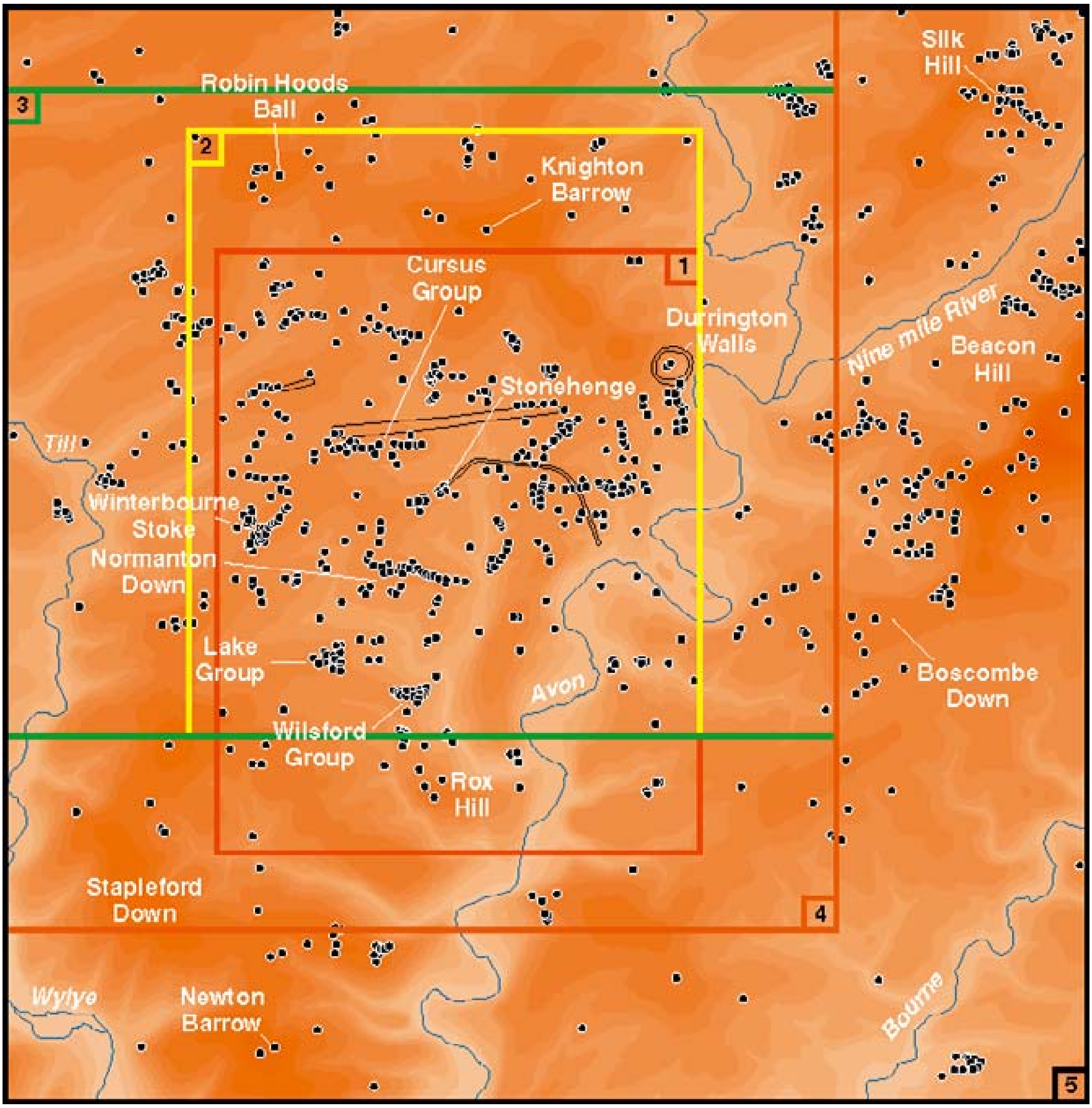

Figure 4: *Previous research areas: 1) Stonehenge and its Environs (RCHM(E), 1979). 2) The Stonehenge Environs Project (Richards, 1990). 3) Stonehenge in its Landscape (Cleal et al., 1995). 4) Birmingham Stonehenge Landscapes inner study area (Exon et al., 2001). 5) Birmingham Stonehenge Landscapes enlarged study area (Exon et al., 2001).*

12. Characterise and investigate the main fieldsystems within the Stonehenge landscape.
14. Compiling a geophysical map of the Stonehenge area.
15. Filling data gaps.
16. Validating and dating features revealed by aerial photography.
17. Understanding recent land-use change and Historic Landscape Characterization.
24. Develop enhanced mapping and visualization programmes for archaeological data sets.

Research agenda issues

7. The linear structures in the Stonehenge landscape.
9. Barrow cemetery evolution, structure and meaning.
10. Monumentality, materiality, memory, identity, and the changing landscape.
12. The social use of space.
15. Astronomy, attitudes, the idea of sacred spaces, and cosmology.
16. Field systems and the early agricultural landscape.

17. Landscape evolution and design.
18. Relationship between physical access, experience and people's sense of place.
19. The robustness of assumed knowledge based on earlier investigations.
21. Meaning and utility of traditional monument classifications.
22. Contemporaneity and relationships between monuments at landscape, regional & world scales.
23. Filling the gaps and understanding distributions.
24. Populating the record for post-Roman studies.
25. Environment and change to the physical landscape.
26. The hidden landscapes.
27. The missing slices of time.
31. Shaping popular perceptions
33. Linking research and site management.
34. Restoration and access.
35. Importance and vulnerability.

The results of survey to date have been dramatic. Without doubt this has resulted in a degree of variation to the original proposals figure 6. There will also be the need to elaborate on some aspects of the project. The serendipitous location of new monuments frequently results in the re-direction of resource during fieldwork and there will, for instance, be an increasing complementary emphasis on the survey of upstanding monuments and particularly the barrow groups surrounding the Stonehenge Envelope to provide an insight into monuments which may not have been excavated or which have only previously attracted the attention of antiquarians. The results however, will certainly be unique in terms of the holistic landscape generated and the quality and extent of the data generated.

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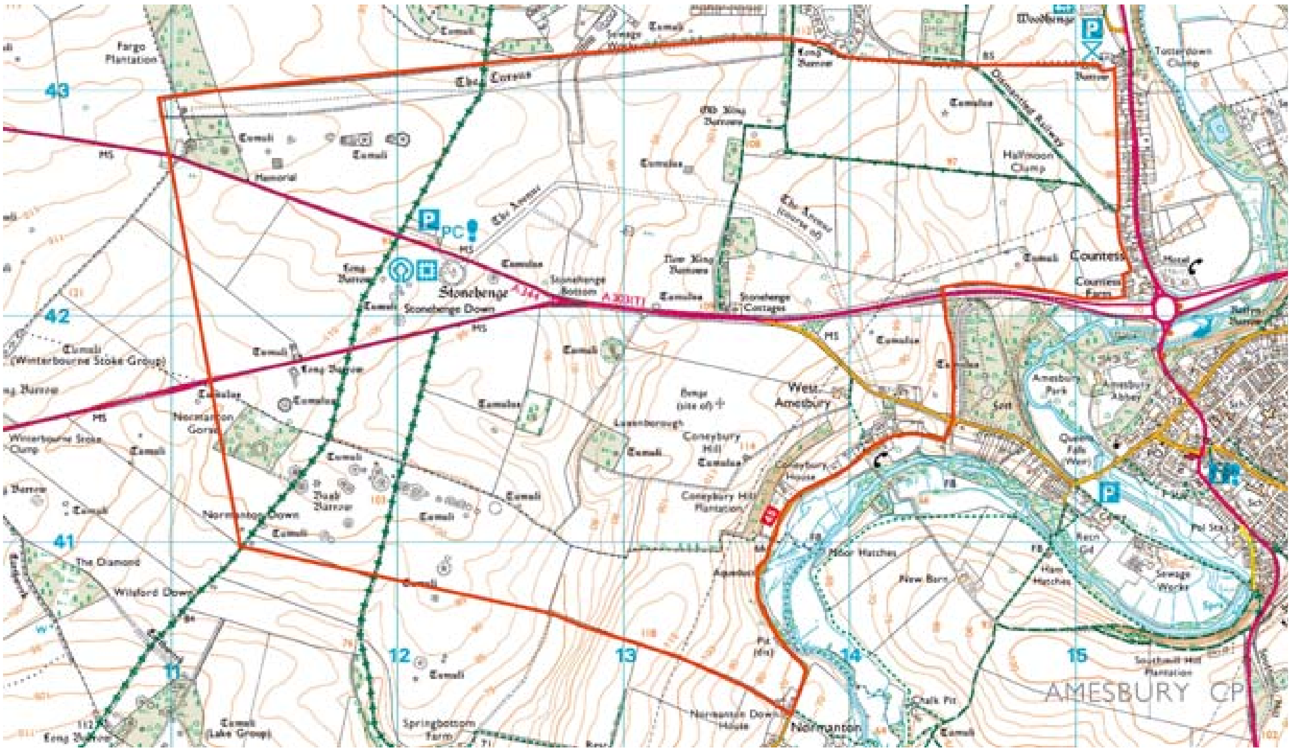

Figure 5: *Original survey area.*

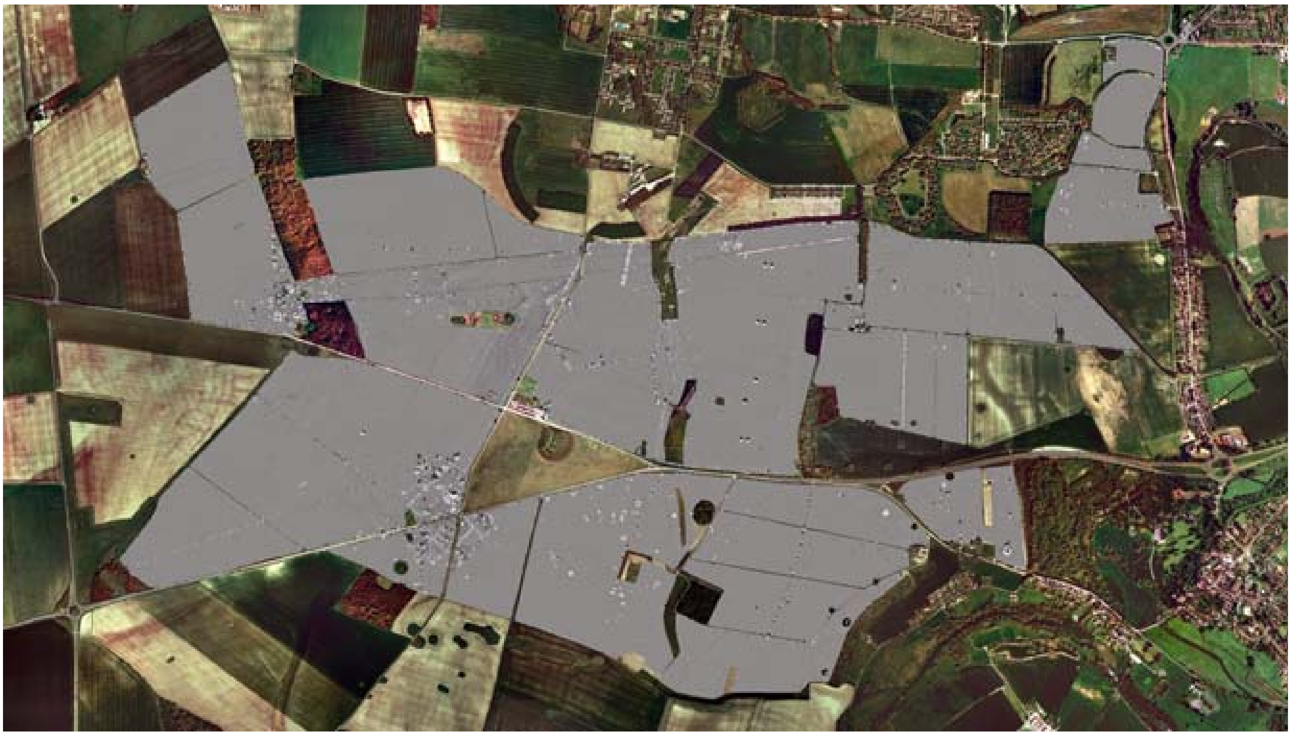

Figure 6: *Surveyed area in October 2012.*

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THE ROMAN HEIDENTOR AS STUDY OBJECT TO COMPARE MOBILE LASER SCANNING DATA AND MULTI-VIEW IMAGE RECONSTRUCTION

N. Studnicka, C. Briese, G. Verhoeven, M. Kucera, G. Zach, C. Ressl

1. INTRODUCTION

Laser scanning (LS), which can be utilized in both a static mode (terrestrial LS or TLS) or kinematic mode (airborne LS (ALS) or mobile LS (MLS), has established itself in the last decade as an appropriate approach to densely sample a whole variety of objects and scenes in 3D (Vosselman and Maas, 2010). Besides differences in their applications (ALS and MLS being more suited for large area mapping), the georeferencing of different LS approaches differs. TLS data are typically georeferenced by indirect techniques using control and tie points, while ALS and MLS require the direct georeferencing of the moving sensor coordinate system based on a global navigation satellite system (GNSS) receiver and an inertial navigation unit (INS). Obviously, these position and orientation (POS) data of the platform must be perfectly synchronised with the simultaneous LS observations and possible image data. Besides LS-based methods, research in computer vision and photogrammetry lead to advanced automated procedures in image orientation and image matching. An important impact for 3D reconstruction computer vision algorithms was gained by so-called structure-from-motion (SfM) algorithms, as they allow reconstructing 3D scene geometry and camera motion from a sequence of 2D imagery captured by a camera moving around the scene (Szeliski, 2010). To do this, the SfM algorithms use image matching to detect image feature points and subsequently monitor their movement throughout whole image collection. Using this information as input, the locations of those feature points can be estimated and rendered as a sparse 3D point cloud. As the SfM heavily depends on accurate knowledge of camera positions, estimating the latter is one of the core components in SfM (Hartley and Zisserman, 2001; Szeliski, 2010). Using the output of these SfM algorithms (i.e. the sparse point cloud and the camera positions, orientation, and calibration parameters) as input, multi-view stereo (MVS) reconstruction algorithms can generate very dense 3D geometry that present the majority of geometric scene details (Scharstein, 2002).

This paper focuses on the analysis of 3D geometry acquired by LS data and simultaneously acquired imagery from the same moving MLS platform. The Roman monument Heidentor, part of the archaeological site of Carnuntum (Austria), was selected as test object. This monument measures approximately 15 by 15 m and has a height of circa 14 m (Jobst, 2001).

2. THE MLS SYSTEM

For this comparison, the Heidentor was scanned with the RIEGL MLS system VMX-450 (see Figure 1). The hardware of the VMX-450 consists of two synchronously operated RIEGL VQ-450 laser scanners, a portable control unit box and a GNSS/INS-unit that comprises the electronics for real-time kinematic (RTK) measurements and three sensors. The modular VMX-450-CS6 camera system complements the acquisition of LS data with the

Figure 1: *Figure 1 . RIEGL MLS system VMX-450 at the Heidentor, Roman city of Carnutum.*

recording of high-resolution (5 MP) colour images. Up to six individually selectable, fully calibrated industrial digital colour cameras with electronic shutters and 5 mm optics can be integrated. In conjunction with the known mounting parameters, precisely time-stamped position and orientation of the cameras are defined on an image-by-image basis. These still images can be used to colour the scan data, but are also the basis for the photogrammetric processing presented here (further key data of the complete MLS system can be found in Briese *et al*., 2012). Data acquisition and processing

The MLS and optical still imagery of the Heidentor were acquired on the 29th of March 2012. The complete monument surface was sampled by the MLS with approximately 1 point/cm^2 (see Figure 2), while four cameras were triggered to acquire an image every 3 m. Overall, approximately 64.5 million laser points were recorded and subsequently processed with the RIEGL software RiProcess. The 1,156 images acquired images were available in the raw *.pgm (portable graymap) format. After a necessary debayering step (executed with RiProcess) the jpg-compressed imagery were subjected to additional post-processing (shadow brightening and sharpening), necessary to tackle the unfavourable illumination conditions during the data acquisition (cloudy sky with locally penetrating sunlight).

For the subsequent image orientation and surface model generation 165 images were selected and processed with PhotoScan (Agisoft). Using PhotoScan's SfM algorithm (cf. Doneus *et al.*, 2011; Verhoeven, 2011; Verhoeven *et al.*, 2012), the camera positions, orientation and calibration parameters were computed. Since highly accurate D-GNSS positional data were embedded as image metadata, the same coordinate frame could be defined for the SfM result as for the original MLS data. In the end, only 144 photographs were used for the next processing steps, since some images could not be matched while others had overly large positional errors.

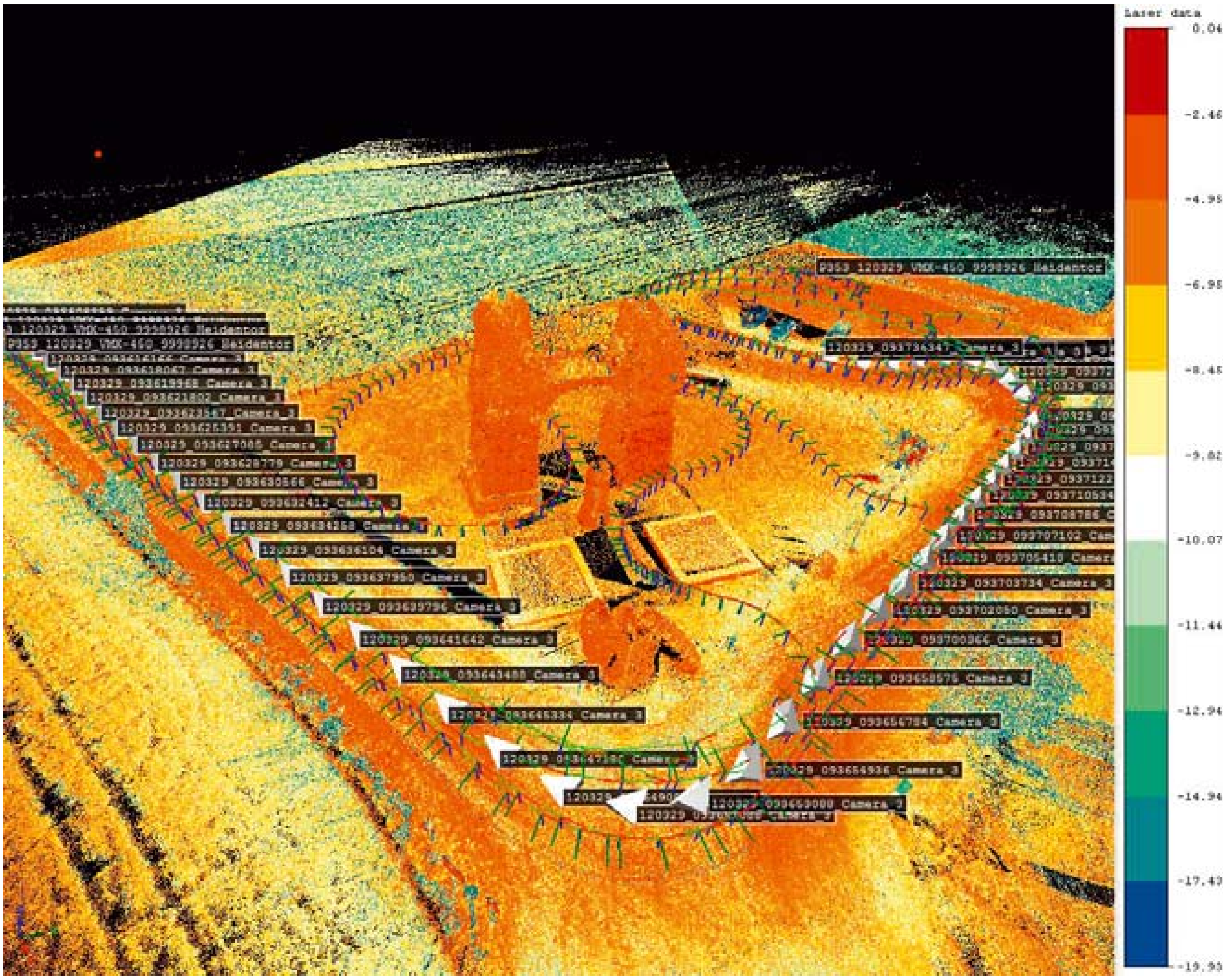

Figure 2: *MLS-sampled point cloud of the complete monument surface.*

Afterwards, PhotoScan complemented the SfM approach with a dense MVS algorithm to compute the surface geometry of the observed scene. Although the image stations are accurately known in the MLS coordinate reference system, the output of the 3D PhotoScan mesh in the MLS reference frames failed. Hence, the final 3D model needed to be re-georeferenced in a local reference fame using four ground control points extracted from the MLS point cloud. After deleting some noise, the vertices extracted from the mesh represented the final point cloud resulting from the image matching step.

3. EVALUATION

On the one hand the images were georeferenced using the GNSS/ INS system on board the RIEGL MLS system. On the other hand 144 images were successfully oriented and georeferenced using an SfM approach in PhotoScan. However, further analysis revealed that two images had significantly big positional and orientation errors compared to the direct georeferencing result. For the subsequent steps these two images were removed and the analysis is just based on the remaining 142 images.

Figure 3 presents histogram visualisations of the differences between direct and indirect georeferencing of the images. While the positional differences do not show significant systematic errors and the standard deviations of the differences (approx. 0.01 m) correspond well to the accuracies from the bundle block adjustment, the differences for the orientation angles show a small systematic error for roll and nick, but a significant median difference for the yaw component of more than 1°. The corresponding standard deviations are all higher than 1°. Analysis of the histograms showed that these high values for the standard deviation are introduced by a few gross errors. By calculating a robust measure for the standard deviation (sigma mad (median absolute deviation)) these values could be significantly reduced (more specifically from 1.467°, 1.002°, and 1.132° to 0.271°, 0.175°, and 0.203° respectively).

For the evaluation of the two surface models, one of the main facades of the Roman monument was selected for the evaluation. All LS scan data of this facade were transformed into a 2.5D facade coordinate system, yielding 6.9 million points. From those points, a 2.5D surface model was generated by a moving planes interpolation with the software OPALS. The result of the dense surface matching of the selected facade resulted in 6.4 million points. Although this result is quite similar to the LS data set, the density on the left part of the facade is significantly less than on the right part and some structural details seem to be a little bit more smoothed when compared to the LS model.

In order to compare both results analytically a difference

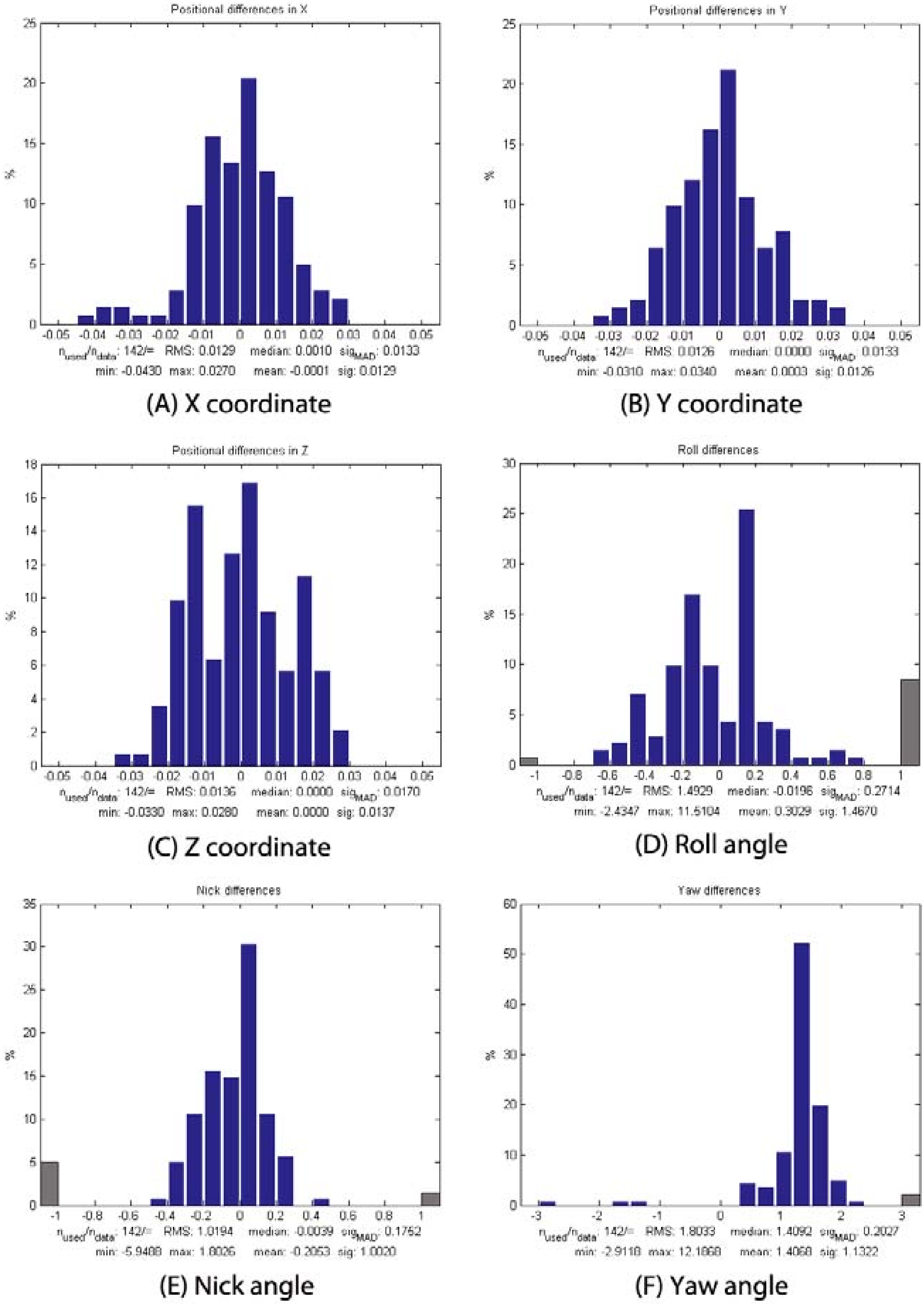

Figure 3: *Histogram visualisations of the differences between direct and indirect georeferencing of LS images.*

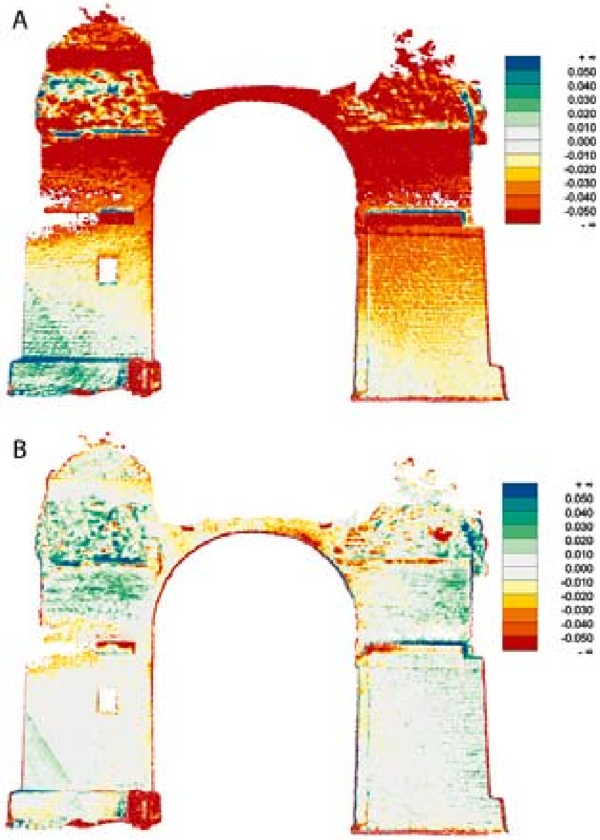

Figure 4: *Facade of the Heidentor created from LS data.*

model was calculated with OPALS. The sigma mad of the differences is about 0.04 m. In general, the differences are significantly lower for the lower part of the facade (Figure 4A). The bigger differences in the upper part seem to be mainly caused by a vertical tilt between the two models, which might be introduced by the necessary realignment step in PhotoScan. After a least squares adjustment (LSM) of the two models, the resulting difference model (displayed in Figure 4B) indicated an improved value for sigma mad (from 0.04m to 0.01m) and most of the systematic differences in the upper part of the monument could be reduced significantly. The remaining differences are mainly caused by the different surface smoothing (stronger in the image-based model), by the different view geometry and on sharp edges.

4. CONCLUSION

This paper presents a study on the comparison of simultaneously acquired LS data and image data from an MLS platform. The results indicate individual strength and weaknesses. While the indirect georeferencing worked quite well for most of the images that represented sufficient image content, some imagery definitely needs external POS data to achieve an accurate georeferencing (especially for images with homogeneous background with similar features). However, in the case of POS errors or the absence of sufficient GNSS signals, automated image orientation based on SfM algorithms might allow the determination of the position and orientation of the moving platform. However, image arrangement is of the utmost importance to fulfil this aim. While the image orientation and surface matching works typically quite well for images that are specifically acquired for a good geometric reconstruction, the surface matching based on constantly triggered cameras delivered sub-optimal results. They do not consider nor adapt to the actual shape of the observed object of interest, hence causing much more problems and reducing the degree of automatisation.

ACKNOWLEDGEMENTS

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AN ELECTROMAGNETIC INDUCTION SURVEY OF THE STONEHENGE LANDSCAPE

P. De Smedt, T. Saey, M. Van Meirvenne

ABSTRACT

Within the framework of the Stonehenge Hidden Landscapes project, different high resolution geophysical surveys are being conducted to map the archaeological landscape. Mainly magnetometry and ground penetrating radar are used to collect a spatially-extensive survey dataset that should provide insight into the "surface and sub-surface archaeological features and structures" (Gaffney *et al.*, 2011). Although field campaigns are still in progress, survey results have already allowed for new insights into the archaeological diversity of the area (Gaffney *et al.*, 2012). However, until now only little effort has been put in creating a detailed map of the natural landscape at Stonehenge. Although detailed topographical data already adds to a comprehensive landscape analysis, detailed soil mapping is needed to fully appreciate the possible palaeotopographical variations. In September 2012, a detailed multi-receiver electromagnetic induction survey was conducted on 21 ha at Stonehenge. Based on the gathered electrical conductivity data, detailed maps of the subsoil variability were composed, while the different magnetic susceptibility data layers were used to discriminate between anomalies caused by recent refuse and the underlying archaeology.

1. INTRODUCTION

To understand prehistoric human-landscape interactions, information about geological, geomorphological and pedological variations is pivotal, as these, together with climatological and biological influence, are the driving mechanisms behind settlement patterns, subsistence strategies and the general land-use of these societies. This is no different for the study of past ritual landscapes where the archaeological reality cannot be considered separate from its natural environment.

Geophysical survey techniques now offer the means to collect high-resolution information about subsurface variations at a landscape level (Keay *et al.*, 2009; Neubauer *et al.*, 2002). However, the integration of detailed information about palaeotopographical variations in geophysical survey campaigns remains rare. For this, researchers often rely on remote sensing data (e.g. LIDAR-based digital elevation models and satellite or aerial imagery), but detailed palaeolandscape analyses based on these sources can be affected by cultural (e.g. terrain levelling) or natural (e.g. erosion) topographical changes in more recent periods.

The Stonehenge Hidden Landscapes project (SHLP) has primarily been aimed at reconstructing the archaeological landscape of an area of approximately 14 km^2 at Stonehenge. The main applied geophysical survey types are magnetometry and ground-penetrating radar (GPR), which are being used at high resolutions to form the basis of a high-resolution archaeological map of the site (Gaffney *et al.*, 2012). However, until now, no emphasis has been put on reconstructing the Stonehenge soilscape or its geomorphology based on non-invasive surveying. Here, geophysical survey types mapping the electrical variations of the subsurface can offer an outcome, as these can be directly related to soil texture variability and organic matter content (Sudduth *et al.*, 2005). Although electrical imaging, earth resistance and electromagnetic induction (EMI) surveys have been included, no extensive mapping of the area's pedology has been done. We conducted the first large-scale survey with a multi-receiver EMI sensor at Stonehenge to obtain a detailed image about the lateral and vertical soil variations at the site. Furthermore, the added potential of a large-scale and high-resolution multi-receiver EMI survey within the SHLP was evaluated.

2. MULTI-RECEIVER EMI SURVEY

A Dualem-21S EMI sensor was used, which combines for different coil configurations to measure both the apparent electrical conductivity (ECa) and magnetic susceptibility (MSa) of four different soil volumes (Simpson *et al.*, 2009). While for the MSa data layers the maximum measurement depth is approximately 1.5 m below the surface, the deepest ECa measurements are representative for depth down to 3 m. This allows for accurate palaeotopographical reconstructions based on ECa depth variations, and an estimate can be made about the depth protrusion of the detected archaeological features. An added advantage of these multiple coil configurations is the possibility to differentiate between topsoil anomalies and underlying features. This way, outlying measurements caused by recent rubble (e.g. bottle caps, brick scatter) can be identified and removed from the final data plots.

An area of 21 ha was surveyed near the western end of the Cursus at Stonehenge (Figure 2). This area was selected to gain further insight into the pedological characteristics within the Cursus, and because of the known disturbance from rubble left behind from the Stonehenge festival in this part of the site. Measurements were taken by driving across parallel lines, 1.2 m apart, with an in-line resolution of 0.25 cm. In this way, we targeted the main archaeological features while gathering high-resolution information about the soil variations. To evaluate the added value from finer survey resolutions, a 2 ha area was mapped with an between line resolution of 0.8 m while a 1 ha area over one of the known monuments was measured at a 0.5 m resolution. All EMI surveys were conducted between September 17–21, 2012. The results and interpretation of these data will be presented in this paper.

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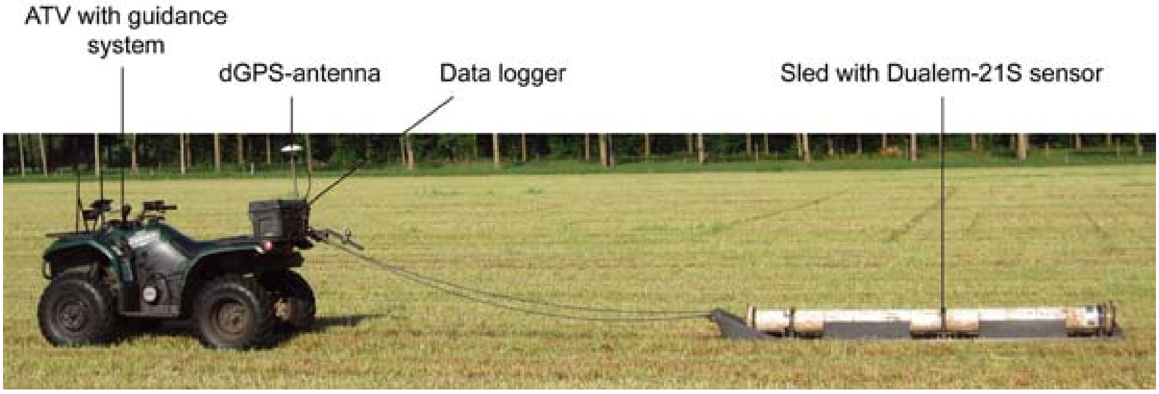

Figure 1: *Dualem 21S sensor in polyethylene sled (1) towed behind an ATV with guidance system (2), dGPS antenna for georeferencing survey data (3) and a datalogger (4).*

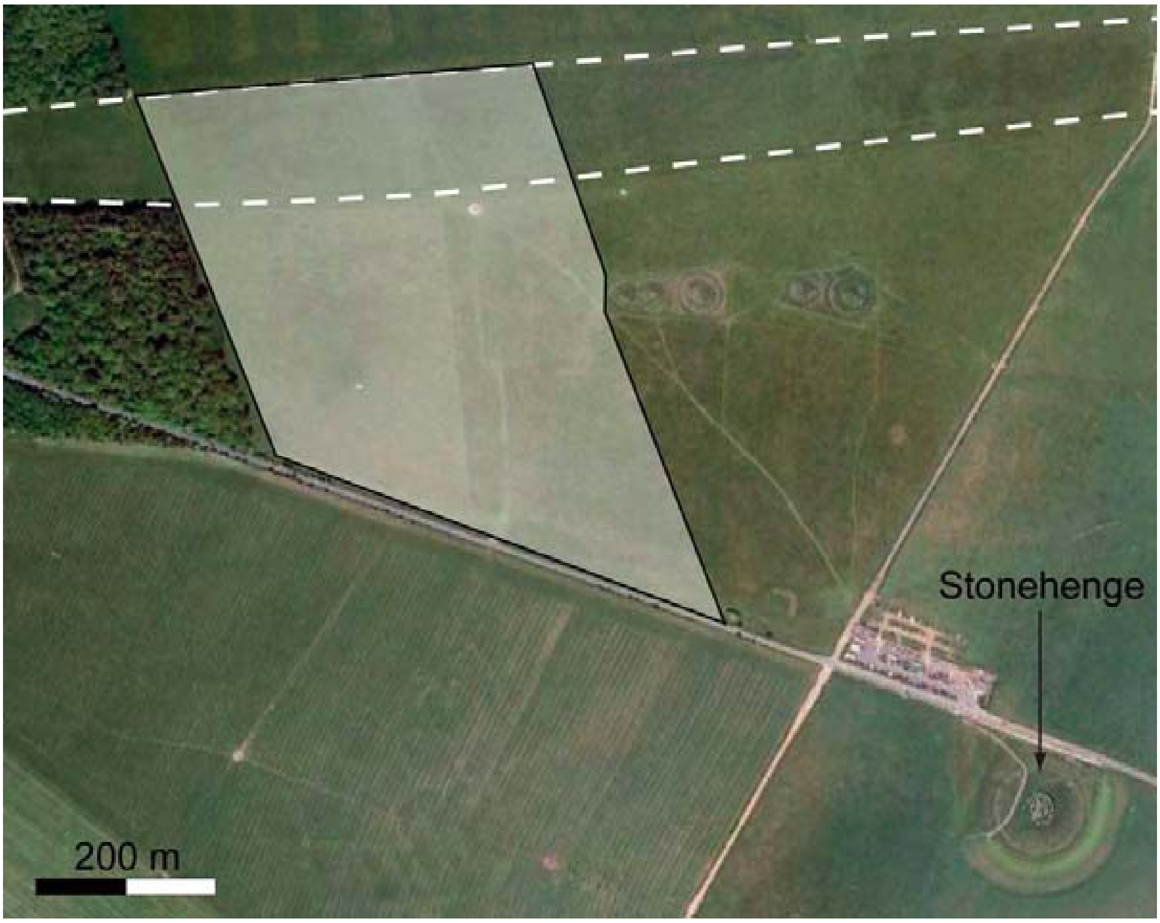

Figure 2: *Satellite image of a part of the Stonehenge world heritage site (source: Google Earth) with the surveyed zone (white area).*

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LARGE-SCALE ARCHAEOLOGICAL PROSPECTION OF THE IRON AGE SETTLEMENT SITE UPPÅKRA – SWEDEN

I. Trinks, L. Larsson, M. Gabler, E. Nau, W. Neubauer, A. Klimcyk, B. Söderberg, H. Thorén

Non-invasive archaeological prospection based on geophysical measurements is enjoying increasing popularity throughout Europe as well as Scandinavia (Viberg *et al*., 2011). While both geological and archaeological preconditions for prospection are in general more challenging in Sweden compared to applications for example in Austria or Great Britain, considerable areas as well as numerous prehistoric Swedish sites are very well suited for the use of modern archaeological prospection approaches. However, the often weakly expressed archaeological structures encountered on Scandinavian Iron Age sites require very dense measurement spacing in order to permit useful prospection results. Common glacial sediments, shallow depth of igneous and metamorphic bedrock and forestation of sites can as well impede the success of the methods.

The Iron Age archaeological site of Uppåkra in southwestern Sweden is one of Sweden's most prominent proto-urban settlements. Uppåkra is situated in the wide-open, agriculturally used Scanian landscape about five kilometres south of Lund. In 1996, members of different research institutes started the scientific project "The Social Structures of Southern Sweden during the Iron Age" led by Prof. Lars Larsson from Lund University, focusing on the settlement site Uppåkra (Larsson, 2003). Since then, several archaeological excavations have revealed the presence of thick occupational layers, rich archaeological finds, the presence of large hall buildings, as well as of an exceptional ceremonial house. Extensive metal detector surveys have outlined a continuous settlement dating from the 1st century BC until the 11th century AD (Larsson, 2003). The results of these investigations have been published in the series Uppåkrastudier 1-11 edited by Lund University.

First geophysical test measurements initiated by Larsson in 1997 demonstrated good contrasts between the archaeological structures and the background, for the magnetic prospection method, and sufficient signal penetration depth for ground penetrating radar (GPR) measurements (Lorra *et al*., 2001).

The archaeological site of Uppåkra, due to its great archaeological potential and landscape setting, offers perfect conditions for the application of motorized geophysical prospection methods. Therefore, the site of Uppåkra was considered an ideal candidate to test large-scale archaeological prospection methods developed by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro). Together with the other prominent Swedish Iron Age settlement at Birka–Hovgården, it was selected as case study area in order to demonstrate the potential of modern archaeological prospection methods, both in regard to archaeological research and contract archaeology.

Since 2010, the LBI ArchPro has been conducting large-scale archaeological prospection surveys at the Iron Age settlement Uppåkra. One of the purposes of the LBI ArchPro case studies is the development of novel motorized magnetometer and GPR systems (Figures 1, 2). The first results obtained from Uppåkra demonstrate a dramatic increase in survey speed and quality of the measurements.

In addition to the ground-based near-surface geophysical prospection methods, large-scale remote sensing data was acquired in 2012 through full-waveform airborne laser scanning (ALS) and airborne hyperspectral scanning. With financial support of the Torsten Söderberg Foundation it was possible to generate a detailed digital terrain model of Uppåkra and its surrounding landscape.

The goal of the large-scale archaeological prospection surveys conducted at Uppåkra so far is the integrated spatio-temporal analysis and archaeological interpretation of the data using all available sources of information in order to develop a new approach from site-focused archaeology towards landscape archaeology.

Figure 1: *Motorized magnetic prospection in Uppåkra 2010. The non-magnetic cart carries five Foerster FEREX CON 650 probes. The data is digitized with an Eastern Atlas EAL digitizer and recorded on the ruggedized laptop in front of the operator using the custom developed data logging software LoggerVis. Data positioning is implemented via RTK-GPS.*

Figure 2: *Measurements with the 16 channel 400 MHz MALÅ Imaging Radar Array (MIRA) with 8 cm GPR trace spacing at Uppåkra.*

In September 2012, a total interconnected area of 197 ha, centred on Uppåkra church, had been covered with high-resolution Foerster fluxgate gradiometer measurements (Figure 3). In the central settlement area, additionally 22 ha had been surveyed with high-definition GPR measurements using a MALÅ Imaging Radar Array (Figure 2) at a resolution of 8×8 cm (Trinks *et al*., 2010).

In the central settlement area, a large number of geophysical anomalies in both magnetic and GPR data indicate the remains of numerous subsurface buildings. Data from the 2010 fieldwork campaign has been interpreted in the framework of a Diploma thesis (Gabler, 2011) prepared at the University of Vienna in collaboration with the Swedish National Heritage Board and supported by Lund University and Stiftelsen Uppåkra Arkeologiska Center. The archaeological interpretation shows the traces of a dense settlement in the fields south of Uppåkra church and east of Gamla Trelleborgsvägen, consisting of approximately 60 Iron Age buildings.

On top of a ridge to the west of Gamla Trelleborgsvägen, additional traces of the settlement can be seen in the prospection data, including a possible ditch that delimits the built area to the north and north-west. Whether this ditch was part of a fortification may be clarified by additional investigations.

The western and south-western limits of the Uppåkra settlement can clearly be identified in the magnetic prospection data. In the gentle slope south of Uppåkra settlement towards the lowland, which today is still crossed by a southeast-northwest running drainage trench separating Uppåkra from Lilla Uppåkra, a former wetland has been located. This can be derived from the general pattern of the magnetic signal, drainage pipes clearly visible in magnetic prospection data, and by the traces of a prehistoric settlement or workshop area that is located in the slope and clearly delimited towards the lowland. Earlier metal detector surveys had not indicated the presence of any relevant archaeological remains, suggesting that it may not be contemporary with the Iron Age settlement, possibly dating back to the Bronze Age or even the Neolithic. In the eastern part of this field, some 950 m SSE of Uppåkra church, a pit alignment, circa 120 m long, oriented in NW-SE direction and an over-ploughed burial mound can be seen in the magnetic prospection data. The burial mound is likely to include a circular foot trench. A possible pit can be seen inside this circle.

In the above-mentioned slope, a magnetometer test measurement conducted in 1997 by a team from the University of Kiel (Lorra *et al*., 2001) revealed several large positive magnetic anomalies, suggesting prehistoric pits. Search trenches excavated in 2000 across two of these structures did not result in any finds that would explain the magnetic anomalies. However, the magnetic prospection measurements conducted in 2010 did show exactly the same magnetic anomalies. In September 2012, systematic augering of one of these anomalies confirmed the excavation results from 2000: underneath the plough layer a slightly coarser layer was found followed by the apparently undisturbed sandy soil. The drilling showed that the extent of this layer coincided with the magnetic anomaly. Soil samples were taken for magnetic susceptibility measurements but so far did not yield a clear results, indicating that the cause of the anomalies possibly has to be sought at greater depth.

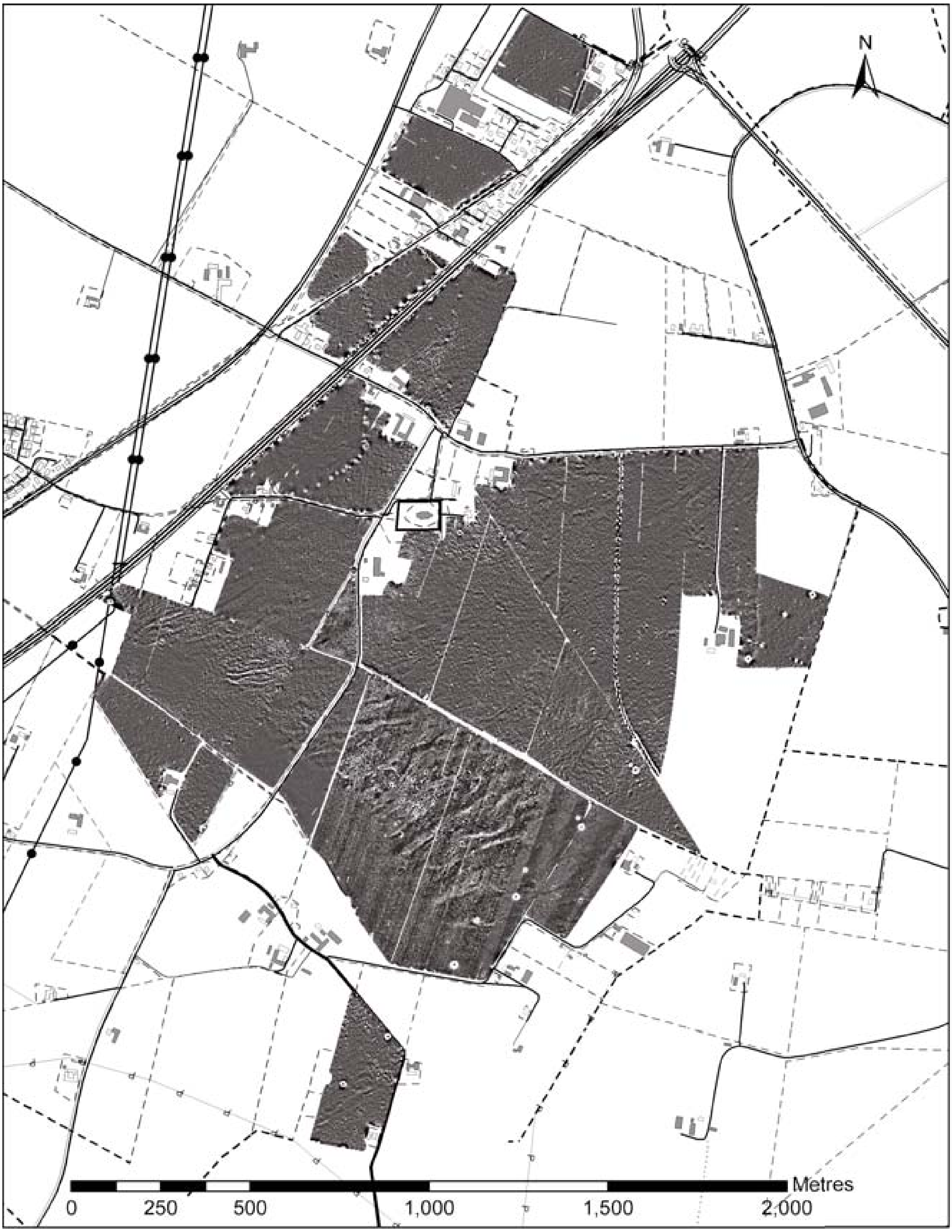

Figure 3: *197 ha of total coverage with magnetic measurements around the central Uppåkra settlement.*

On the ridge to the east and south-east of Uppåkra church numerous anomalies associated with pits or postholes can be seen in the magnetic prospection data. It is currently unclear whether these underlying structures are contemporary with the Iron Age settlement or whether they possibly have been caused in connection with a Swedish army camp of 11,000 men that reportedly had been located at the village of Uppåkra awaiting battle during Torstenson's or Horn's war in 1644 (af Lundblad, Schubert, 1826, p. 91).

Interestingly, the magnetic prospection data shows two quadratic anomalies of 28 m side length with openings in the north-eastern sides on the top of the ridge (Figure 4). These structures could well have been small redoubts or strategically placed fortifications on the highest points with views to the south from where the enemy was approaching. It is thinkable that such fortifications could have served for the protection of important items, such as the war chest or the tent of field marshal Gustav Horn himself. However, should these structures prove to be contemporary with the Iron Age settlement of Uppåkra they would be truly remarkable. During a first archaeological investigation conducted in 1986 in relation to the laying of a large pipe in the vicinity of these quadratic structures, 13 archaeological features consisting of pits, hearths, and postholes were found, preliminarily dated to the older Iron Age (RAÄ Uppåkra, 22 :1). During the subsequent archaeological excavation a skeleton burial, three urn burials, pits and hearths, a flint dagger, bronze fibulas, glass and amber beads had been recovered (dated to the Late Neolithic, Bronze Age and Roman Iron Age). The south-western side of the north-western quadratic structure was cut by an excavation trench in 2000 in search of Uppåkra's grave fields, and the enclosure was marked as archaeological structure.

A two and a half sided construction consisting of pits or large postholes with a length of 19 m on the long sides can as well be seen in the data some 470 m east of the Uppåkra church.

In the fields north of Uppåkra village, towards Lund, east of the E22 motorway, traces of the old road to Lund as well as trenches indicating historical farmsteads can be seen in the magnetic data. An 18$^{\text{th}}$ century map shows the road, farmsteads, and ponds in this area.

A Late Neolithic burial surrounded by a circular trench with a diameter of circa 8 m was discovered immediately west of the Uppåkra churchyard, along with traces of further burials and a road. Members of Lund University and the Swedish National Heritage Board excavated the circular structure in 2011, and found very good agreement between the prospected and excavated structures.

In the southwest of the settlement site, close to the border to the wetland, a distinct pit enclosed by a rectangular ditch has been detected, indicating a funeral monument with central burial.

The digital terrain model generated from the 40 km^2 of ALS data around Uppåkra permits not only the three-dimensional representation of the site of Uppåkra in the landscape but also shows very small changes in the micro-topography that have been caused by old field boundaries, field systems, roads and track ways, as well as ploughed-over burial mounds. Comparison of the ALS data with the registered monument database and historical maps permits the identification of former communication paths as well as the discovery of previously unknown buried cultural heritage sites. The location of Uppåkra at a topographically prominent position with a wetland to the south and east (Bronze Age sacrificial bog) and the Höje River to the north may at least partly explain the place's attraction throughout time. The ALS data will also be valuable in the search for communication ways to the assumed harbour place in Lomma Bay and for mapping relations between Uppåkra and other known prehistoric sites and settlements (e.g. Gullåkra mosse).

The LBI ArchPro case study Uppåkra is exemplary for the use of efficient, large-scale, state-of-the-art archaeological prospection for the investigation, mapping and non-invasive documentation of archaeological sites located in agriculturally used fields in southern and central Sweden. Irrespective of whether a site is the subject of archaeological research or a rescue archaeological project, the integrated use of the prospection methods demonstrated here provides the archaeologist with a powerful tool for the generation of valuable archaeological information about the site and its surroundings. The proposed approach permits targeted excavations as well as a sustainable cultural heritage management and site protection, while providing information about the site's structure, extent and its state of preservation.

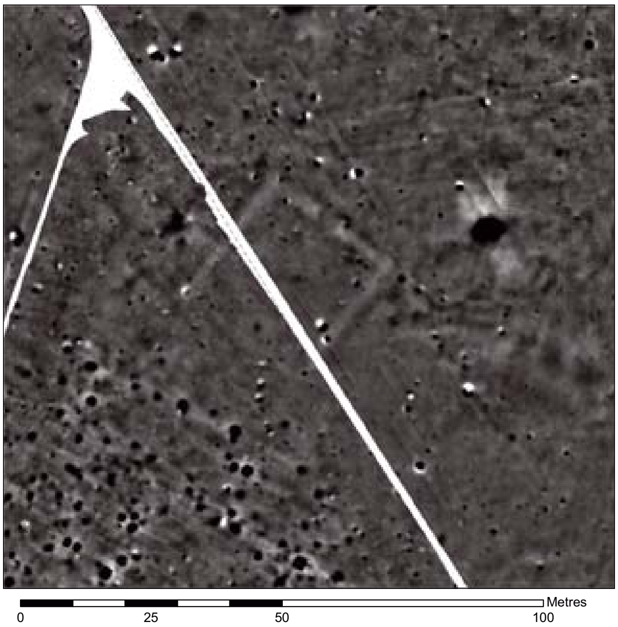

Figure 4: *Possible redoubt and pits and postholes in the magnetic prospection data.*

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THE VIKING-AGE ROYAL BURIAL SITE OF BORRE (NORWAY): LIDAR-BASED LANDSCAPE RECONSTRUCTION AND HARBOUR LOCATION AT AN UPLIFTING COASTAL AREA

M. Doneus, E. Draganits, T. Gansum

1. INTRODUCTION

Airborne Laser Scanning has found wide application in archaeological research (Crutchley, 2010). It is especially of great value to detect and document archaeological and palaeoenvironmental features in vegetated areas (Doneus and Briese, 2011), but can give important context by measuring the detailed topography in open areas (Challis *et al.*, 2006). Here, using sophisticated visualisation techniques (Hesse, 2010), insights into the microtopography of a region have become possible, which can provide a new understanding of the layout and function of archaeological remains. As Earth's topography is a combination of human and geomorphological processes, the interpretation of these high-resolution DEM data demand a combination of archaeological and geoarchaeological interpretation. This study demonstrates the impact of the analysis of an derived DTM combined with geoarchaeological insights on the interpretation of a Viking-age burial site in Borre, Norway.

2. THE VIKING-AGE ROYAL BURIAL SITE OF BORRE

Borre is an exceptional burial site in Scandinavia, located on the western shore of the outer Oslo Fjord close to a narrow part between Horten and Moss, where the fjord is just some 5 km wide (Myhre, 1992). The site is close to rich agricultural lowlands, and the small island of Bastøy is just 2 km distance from the shore. Today, seven large burial mounds, two large cairns, three chamber graves and more than 30 smaller mounds are preserved, and at least two large mounds and one large cairn been destroyed in modern times (Myhre, 1992). Some of the mounds are more than 40 m in diameter and are still up to 6 m high. At the moment the site is protected by law and the Vestfold County is responsible for the protection and maintenance of the site.

Borre is mentioned in Nordic Sagas, especially in the skaldic poem *Ynglingatal*, as the burial place of one or two kings of the *Ynglinga* dynasty (Krag, 1991; Myhre 1992). In 2007, two hall buildings were detected using georadar (Trinks, 2007). There was also a question concerning harbour facilities that was puzzling to archaeologists (Keller, 1994; Gansum, 1995): A site that had provided a ship grave, was situated on the shore and has been connected to the Viking kings of Vestfold should have a harbour. However, it has not been found with traditional archaeological surveys and the exact location is still a matter of debate. Glacial rebound and local sea-level considerations virtually exclude areas higher than 5 m above shoreline. LIDAR can contribute to the reconstruction of the former landscape of Borre and indicate areas with artificial modifications.

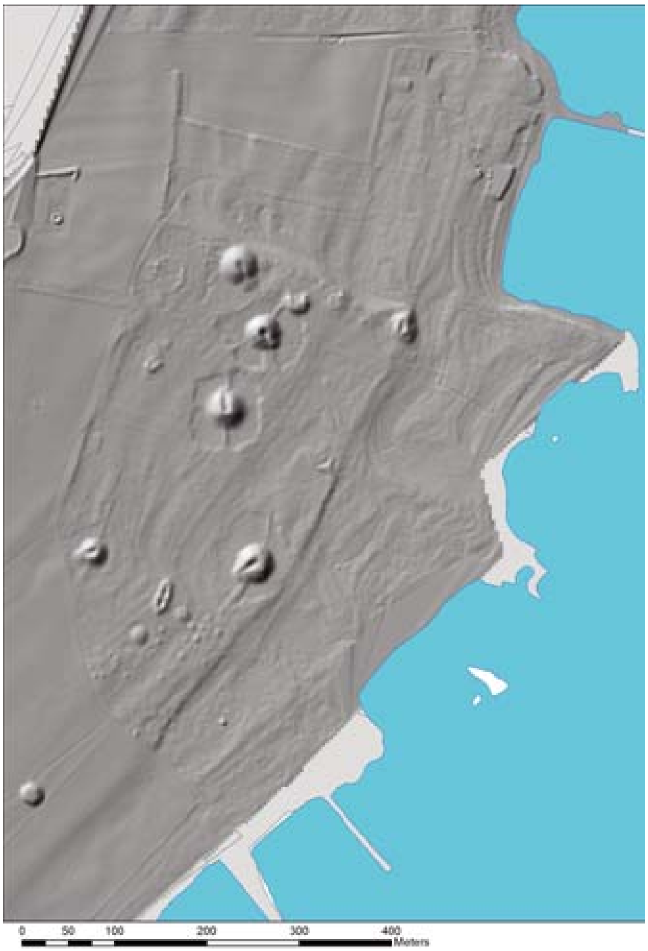

Figure 1: *Shaded relief model of the Borre site using 1 m resolution LiDAR data.*

3. POST-GLACIAL SEA-LEVEL RISE IN SOUTHERN SCANDINAVIA

Unless it was placed in rather deep water, any former harbour site is expected to be exposed to the land surface today, since the area of Borre is affected by a continuous land rise. During and after melting of the ice, glacial rebound caused surface uplift to such an extent that sea retreat was an important issue in Scandinavia already during the Middle Ages (Ekman, 2009). In the Oslo area, marine sediments can be found more than 222 m above present sea-level (Vorren *et al.*, 2008; Mangerud, 2011). Vertical crustal uplift due to glacial rebound can be reconstructed by levelling, tide-gauges and continuous GPS measurements and

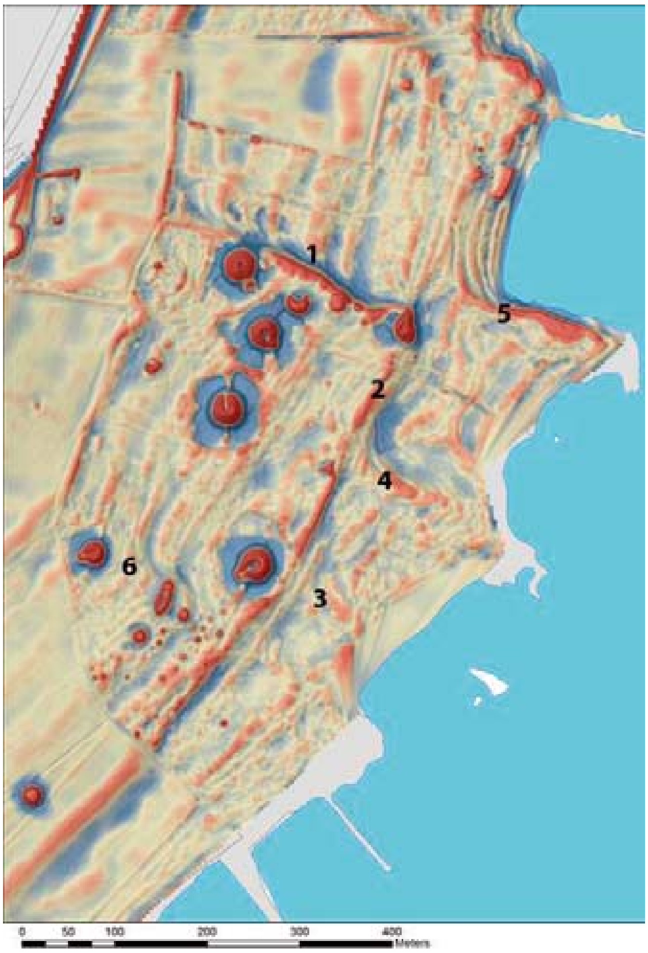

Figure 2: *Local relief model calculated from the DTM, with a kernel size of 25 m.*

is still around 8 mm/yr in the area of the Gulf of Bothnia and around 2.5 mm/yr in the southern Oslo Fjord in the area of Borre (Ekman, 1996; Dehls *et al*., 2000; Vestøl, 2006).

4. LIDAR SCAN AND DATA

The Borre area was LiDAR scanned in 2009 by the Norwegian Institute for Cultural Heritage Research (NIKU) on demand from Vestfold County Council, which both have the copyright on the data. Laser scanning of the three areas was conducted on 21 April 2009 with a TerraTec aeroplane. The flight was carried out 550 m above the ground with a scanning repetition frequency of 142 kHz and a scan angle of 20 degrees with a ground resolution of 10 points/m^2 (Risbøl, 2009). The resulting terrain model has a resolution of 1 m (Figure 1). To enhance the microtopographic features of the beach-ridges, a local relief model was calculated with a Kernel size of 25 m (Figure 2).

5. INTERPRETATION OF DERIVED DTM

The northern boundary with its steep slope seems to have been formed by the deposition of material and not by excavation in the now forested area to the North. The deposition of material there might have made use of an already naturally existing natural elevation – as indicated by the deflecting beach ridges between 6-15 m asl north of the burial site boundary (Figure 2/1). The preservation of beach ridges north of the burial ground excludes large-scale excavation of material there (Figure 2/1). The area to the North is also at too high an elevation to have had access to the sea during the Viking age.

The lower prominent beach ridge at 5-6 m asl is much larger and straighter than its surrounding ridges (Figure 2/2). Especially its seaward slope is much steeper than of any other beach ridge. Therefore, it is very likely that this ridge has been artificially modified to improve its shape as seaward boundary of the burial site.

5.1. Harbour location at the royal burial site of Borre

Below 4 m asl there are three WNE-ESE oriented, very prominent ridges that cause considerable deflection of the beach ridges in this area. They are found east of burial mound 7 (Figure 2/3), east of the triangular cairn (Figure 2/4) and east of the NE corner of the burial ground (Figure 2/5). The first one is ca. 70 m long, the middle ca. 150 m long, the northern one some 200 m. The exact width of the ridges is difficult to reconstruct due to sedimentation, but they are some <15 m wide. Strikingly, these ridges are built by polymict, sub-rounded to rounded boulders up to almost 1 m in diameter (Figure 3). These boulders can be found neither in the nearby beach areas nor in the beach ridges in the whole Borre area. Therefore, they most probably were brought here by people, and the most likely source is the prominent Ra Moraine that passes less than 0.5 km to the west of the burial site (Klakegg and Sørensen, 1991). Additionally, no beach ridges are preserved directly to the north of the middle ridge, and the surface has an appearance suggesting that some material has been dug out – possibly to increase the water depth for ship landing.

The whole coast of the western Oslo Fjord in the vicinity of Borre, between Åsgårdstrand and Horten, shows quite a straight shore line with hardly any natural harbours. Therefore, many artificial jetties exist to provide protected landing areas and harbours. These jetties are about 100-220 m long, some 10 m wide and usually built with coarse boulders. Therefore, the ridges seen in the LiDAR are exactly in the size range of the modern day jetties in this area and we believe that they have been made for the same purpose. These ridges do not continue higher than 4 m asl and deflect beach ridges below 4 m asl to the present shore line. If we use 2.5 or 3 mm/yr uplift rate, they have been built broadly 1,660 or 1,333 years ago, respectively. Possible analogue jetties from the Viking age have been indicated from Hedeby (Denmark), Birka (Sweden) and Kaupang (Norway) (Ambrosiani, 2008; Clarke and Ambrosiani, 1991). In Birka these jetties are found about 5.5 m above present sea-level (Ekman, 2009). Two WNE-ESE striking, less preserved features, at the northern limit of the burial ground and between mounds 7 and 8 (Myhre 1992, fig. 58), which deflect beach ridges between 6-16 m asl may even indicate older jetties in this area, but without detailed geophysical investigation this remains speculation (Figure 2/1 and 2/6).

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Figure 3: *Polymict, sub-rounded to rounded boulders found in an area west of the ridges.*

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ARCHAEOLOGICAL PROSPECTION OF THE UNESCO WORLD CULTURAL HERTITAGE SITE BIRKA-HOVGÅRDEN

I. Trinks, W. Neubauer, E. Nau, M. Gabler, M. Wallner, A. Hinterleitner,
A. Biwall, M. Doneus, M. Pregesbauer

The UNESCO World Cultural Heritage Site Birka-Hovgården has been selected by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) and its Swedish partner organisation, the Contract Archaeology Unit of the Central Swedish National Heritage Board, as one of several case study sites for the development and testing of novel large-scale archaeological prospection methods. Earlier successful prospection tests conducted at Birka using manually operated GPR and magnetometer systems (Trinks *et al.*, 2007), as well as a pilot study (Trinks *et al.*, 2010) involving a motorized MALÅ Imaging Radar Array (MIRA), have demonstrated a great potential for the use of modern non-invasive prospection methods at this outstanding archaeological site.

The extensive Viking Age site of Birka-Hovgården has been located on the two neighbouring islands of Björkö (Birka) and Adelsö (Hovgården) in Lake Mälaren some 30 km west of the Swedish capital Stockholm. While the so called Black Earth of Birka is considered to have been an important trading place from around AD 750 onwards, and the site where the Christian monk and missionary Ansgar erected one of the first churches in the territory of modern Sweden in around AD 829, Hovgården is assumed to have been the place where the rulers of Birka reigned and were buried (Magnus and Gustin, 2012). Since Birka had been abandoned in approximately AD 960 for reasons thus far unknown, the Black Earth of Birka has remained largely undisturbed apart of low intensity farming and some more or less scientifically conducted archaeological excavations. So far, the largest archaeological research project conducted on the island of Björkö was the "Birka Project" conducted between 1990 and 1995 under the leadership of Björn Ambrosiani, unearthing some 500 square metres using the latest stratigraphical methods and digital documentation technology. This excavation has revealed remains of buildings, such as a bronze casters workshop, building plots, alleyways, harbour constructions and numerous finds.

Figure 1: *Large-scale high-definition GPR survey in Birka's Black Earth area using the MALÅ Imaging Radar Array.*

Figure 2: *Motorized magnetic prospection of Birka.*

Over the course of three weeks in May/June 2011 and two weeks in September 2011, almost the entire accessible area on the island of Björkö has been mapped using latest GPR (Figure 1) and magnetometer (Figure 2) prospection technologies (Figure 3). In total, an area covering 38.3 ha was surveyed with very high-resolution (8 cm profile spacing, 4 cm inline sample spacing) MIRA measurements and 21.5 ha with motorized Foerster gradiometer measurements (25 cm probe spacing, 10 cm inline sample spacing). Two fields that were covered with crops close to Björkö village, as well as areas with rough topography, had to be omitted.

The survey resulted in numerous discoveries of archaeological interest, such as the exact determination of the previously unknown location of excavation trenches dug around 1874 by archaeologist Hjalmar Stolpe in the Black Earth area (Figure 4), the mapping of alleyways, buildings and fortifications of the Viking Age settlement, and the mapping of numerous ploughed-over grave mounds and burials including several assumed chamber graves. The surveys indicate a continuation of the Hemlanden cemetery towards the hillfort. A strong linear magnetic anomaly crossing the northern part of Björkö Island, including Birka's Black Earth area, could be identified, with the help of the Swedish Geological Survey, as being caused by the magnetic Kärsö diabase.

In December 2011, a full-waveform high-density airborne laser scanner survey was flown by LBI ArchPro partner Airborne Technologies GmbH, covering the entire island of Björkö and the southern part of the island of Adelsö. From the point-cloud data, a digital terrain model was derived by filtering the vegetation, resulting in a fascinating visualization of Sweden's largest accumulation of some 2,000 burial mounds.

The integration of the remote sensing results and the geophysical prospection data, as well as the archaeological interpretation of the complex geophysical data sets, are work in progress. The goal is to use this entirely non-invasive, large-scale prospection approach to generate an overview map of the buried archaeology of the UNESCO World Cultural Heritage

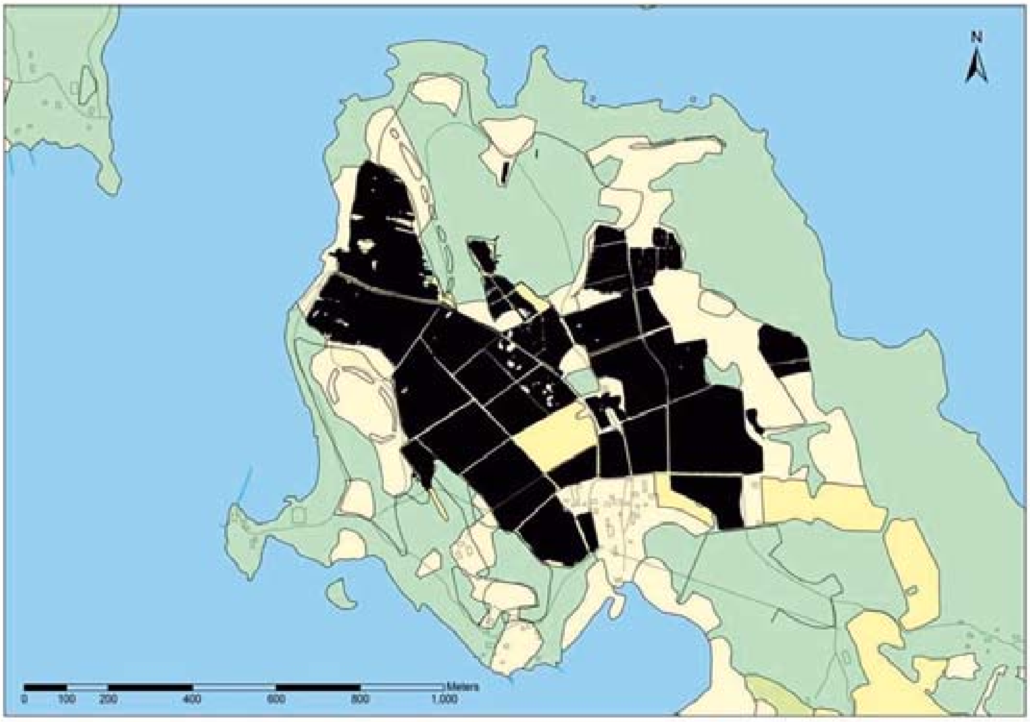

Figure 3: *Total coverage map of geophysical archaeological prospection measurements conducted on the northern part of the island of Björkö.*

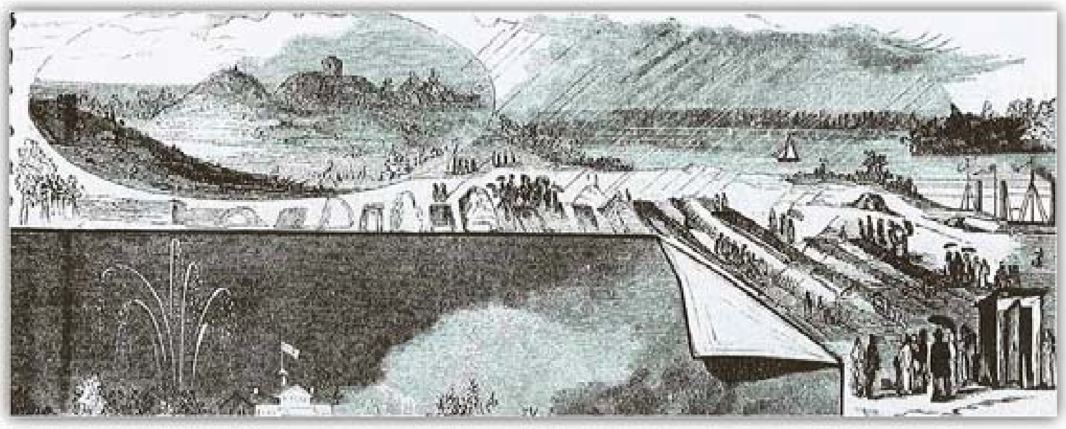

Figure 4: *Parallel archaeological excavation trenches dug by Hjalmar Stolpe in 1874 shown in a contemporary newspaper illustration. The previously unknown exact location of these excavations was relocated by magnetic and GPR prospection.*

Birka-Hovgården, suited for archaeological research and cultural heritage management alike. Using virtual reality representations of the data, scientists and the public will be given access to the new findings, documenting and illustrating "Sweden's first town".

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DETERMINATION OF THE APPLICABILITY OF HIGH-RESOLUTION X-BAND SATELLITE RADAR FOR THE ARCHAEOLOGICAL PROSPECTION BY A COMPARISON WITH A GROUND-BASED SURVEY

R. Linck, S. Buckreuss, S. Seren

ABSTRACT

It was not until the launch of TerraSAR-X in 2007 that satellite radar became high-resolution enough for archaeological prospection. All former sensors had a resolution of several metres, which is far too low to resolve faint archaeological features. TerraSAR-X now provides images of around 1 m resolution. Unfortunately, the frequency of the satellite is X-band and therefore very high. Until now, common opinion in the remote sensing community has been that these radar waves have no depth penetration into the soil. However, the comparison of a TerraSAR-X image over a Roman fortress in Syria with the corresponding depth slices of ground-penetrating radar show that there should be a penetration depth of a few decimetres in desert soil.

1. INTRODUCTION

The Roman fortress of Qreiye is situated around 12 km north of the Syrian provincial capital Deir ez-Zor near the modern village ^{c}Ayyāš at the Euphrates (Figure 1). The fortress was built in the early 3rd century AD during the formation of the two new Roman provinces of Osrhoene and Mesopotamia, but was already abandoned around 50 years later in the Parthian wars (Gschwind & Hasan, 2008) and was never rebuilt during Byzantine and Arab times. Together with the fact that Qreiye is one of the rare examples of a Roman fortress that has not been integrated into an existing city, like e.g. Raphanea (Syria), Zeugma (Turkey), Dura Europos (Syria) or Palmyra (Syria), it depicts a unique opportunity for the archaeological study of the Roman military architecture of the eastern provinces. The fortress of Qreiye was rediscovered in the 1920s by the French aerial photography pioneer Père Antoine Poidebard (Poidebard, 1934). It has a size of approximately 220 × 220 m and is orientated ca. 22° north-northeast. While the neighbourhood of the fortress remained undeveloped in the 1920s, today the modern village ^{c}Ayyāš extends to the fortification system. Between 2002 and 2006, Qreiye was surveyed archaeologically by a cooperation of the German Archaeological Institute and the Direction Générale des Antiquités et des Musées de la Syrie. Because of its size of around 5 ha, the fortress could not be completely excavated. Therefore, geophysical surveys by ground-penetrating radar (GPR) were carried out between 2002 and 2005 by Sirri Seren of the Central Institute for Meteorology and Geodynamics in Vienna. Other geophysical methods failed because of the geological conditions in the area.

Figure 1: *Topographical map of Syria showing the location of Qreiye near Deir ez-Zor at the Euphrates River.*

In 2012, another research project was set up for the fortress of Qreiye. Now it served as a test site for evaluating the penetration depth of the TerraSAR-X radar waves. This German SAR satellite operates in the X-band with a frequency of 9.65 GHz and a corresponding wavelength of around 3 cm. In the high-resolution spotlight mode and a 300 MHz bandwidth, it is possible to obtain a resolution of 1 m. Because of the special reflection characteristics of the microwave spectrum, it is possible to resolve even structures that are a little bit smaller than the actual resolution (Albertz, 2009). The main goal of the new project is to determine the penetration depth of the X-band waves in the desert soil by a comparison with the GPR depth slices. Therefore, a time series of nine SAR images taken between February and May 2012 were stacked into one image to improve the signal to noise ratio without intentionally lowering the resolution, as is done by the more frequently used multilook-processing. The effect of the improvement of the signal to noise ratio by a step by step stacking of the images can be seen in Figure 2.

2. RESULTS

2.1. Ground-penetrating radar

The GPR survey was accomplished in several campaigns with the following equipment: Sensors & Software PulseEKKO 1000 with 900 MHz antenna, GSSI SIR-3000 with 400 MHz antenna and Sensors & Software Noggin with 500 MHz antenna. The profiles have an orientation of 45° respective to the archaeological remains to be able to map each wall in the same signal strength (Seren *et al.*, 2009).

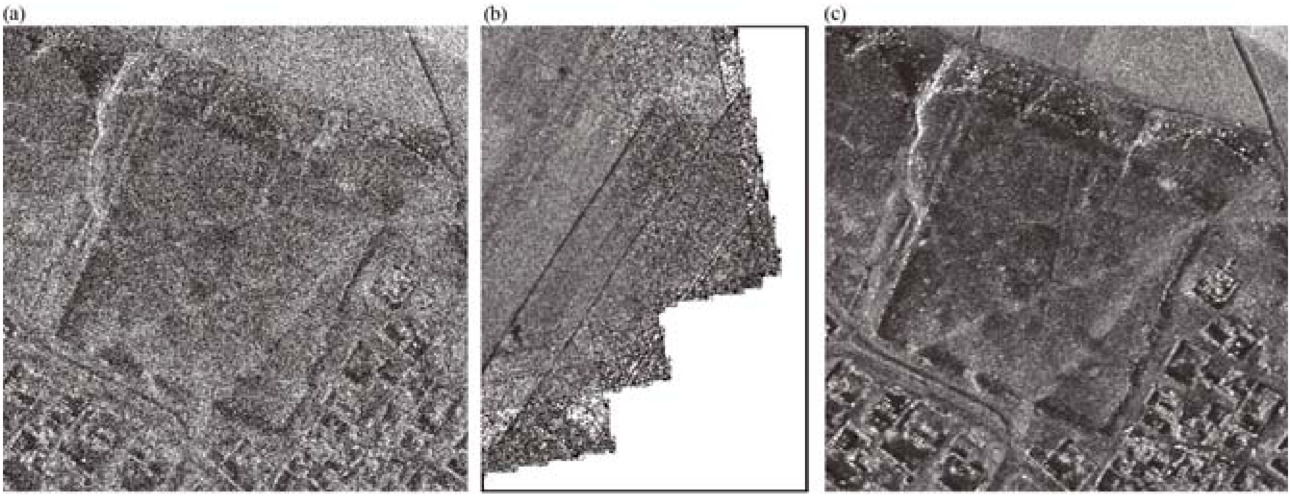

Figure 2: *Improvement of the signal/noise-ratio by successive stacking of all nine data takes of the TSX time series between February and May 2012. (a) Image of one single data take, (b) stepwise stacking of all nine images, illustrated at one edge of the scene, (c) result after stacking of all nine data takes (©DLR, 2012).*

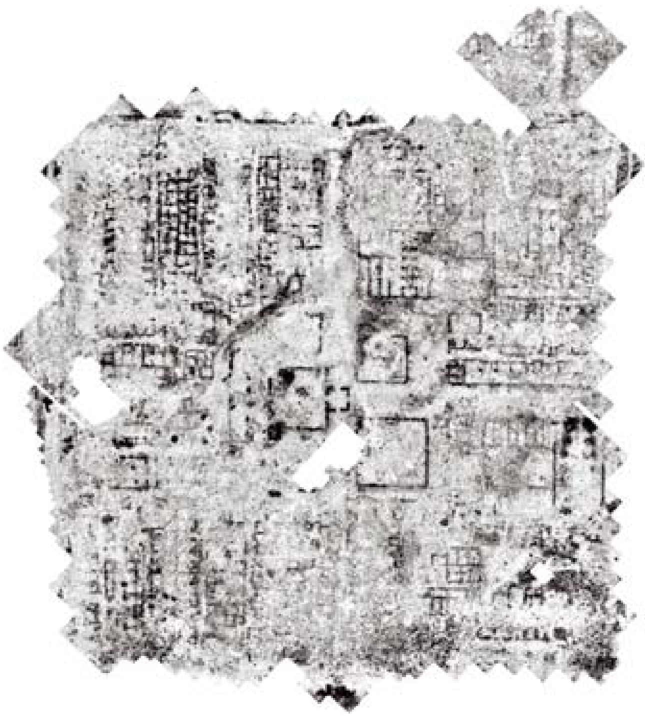

Figure 3: *GPR depth slice between 20 and 30 cm depth. GSSI SIR-3000 with 400 MHz antenna; Sensor & Software Noggin with 500 MHz antenna; Sensor & Software PulseEKKO 1000 with 900 MHz antenna.*

The Roman fortress can be detected in a depth between 0 and 100 cm (Figure 3). The visible structures in the topmost depth slices are mainly due to modern tracks and the remains of the adobe brick walls. In the eastern provinces, the Romans often constructed their military camps of bricks instead of limestone because these are more effective against the attack tactics of the Parthians. In the deeper regions of the radargrams the dark anomalies are the stone foundations of the walls. In total, it is possible to draw a quite exact plan of the fortress; it follows the standard layout of the Roman military architecture with two orthogonal roads that divide the castle into four quarters. In Qreiye, the western quarters are characterized by the principia, the praetorium, several functional buildings and some soldier barracks. The eastern part contains more barracks as well as some functional buildings. Because of the differing size of the barracks, Qreiye should have had a mixed garrison of infantry and cavalry (Gschwind and Hasan, 2008; Gschwind, 2009).

2.2. Satellite radar

Of course, the remaining aboveground structures in the surrounding of the Roman fortress are more pronounced in the TerraSAR-X image than the buried ones (Figure 4a). The reason is that the modern houses of ^{c}Ayyāš act as corner reflectors because of their sharp edges, and therefore the main part of the radar signal is reflected back to the sensor. The village therefore appears in a very bright colour. Furthermore, the geological structures are highly visible, so the water table of the Euphrates River acts like a mirror and reflects the whole signal away from the satellite, and it shows up in a very dark band in the radargram. The distinct agricultural fields in the Euphrates plain can be distinguished by the reflection difference between planted and fallow, and the height of the vegetation.

The Roman fortress has few remaining standing parts. Only the fortification system of a rampart and two ditches is preserved in the western part. Furthermore, the old enclosure wall can be seen topographically as a slight hill. Of course these structures can be resolved in the TerraSAR-X image very well; the wall itself can even be identified as a sharp reflection not only as the preserved hill (Figure 4). The rampart and the ditches at the other three sides have already been destroyed by modern roads in the south and east, and were not even built in the north because of the natural fortification by the steep slope towards the Euphrates. However, the other walls inside the fortress, belonging to the functional buildings and the barracks, can party be detected. Like in the GPR survey, the amount of visible anomalies is lower in the south-western part of the fortress, because they

Figure 4: *(a) Composite TerraSAR-X image of the Roman fortress of Qreiye. Image parameters: High-resolution Spotlight mode; 300 MHz experimental mode; spatial resolution: 1 m; inclination angle:* 34.87°*; horizontal polarization. Black = no reflection back to the sensor; white = huge reflection back to the sensor. (b) Overlay with the digital interpretation of the results. Colour coding: green = GPR anomalies in 10 – 20 cm depth; red = GPR anomalies in 20 – 30 cm depth; blue = anomalies not found in GPR; brown = preserved parts of the rampart.*

are mostly destroyed there. A detailed comparison of the GPR depth slices with the TerraSAR-X radargram shows that the resolved walls in the satellite radar image all correspond to those structures appearing for the first time in the uppermost 30 cm depth. Structures lying deeper cannot be detected. Therefore, the penetration depth of the X-Band waves into the desert soil is approximately 20 – 25 cm.

The analysis of the SAR image shows that often the reflections of the stone foundations cannot be distinguished from those of the adobe bricks, as is the case with the GPR. Both show up mainly as dark anomalies. The reason for this probably is that in each case the signal does not reach the sensor again. The stone walls reflect the signal away; the clay bricks absorb the energy. Nevertheless, bright reflections sometimes appear as well, due to the backscattering of the stone walls towards the satellite.

Astonishingly the excavation trenches do not appear as single anomalies, as might be expected, because of the lesser compaction of the refilled trenches. The reason therefore is that the contrast between the infill and the surrounding soil is often not strong enough for the electromagnetic wave to be reflected in a different way. This effect has been detected in several GPR surveys by the main author as well.

3. CONCLUSION

The results presented here show quite impressively that, contrary to the common opinion in the remote sensing community, the high-frequency X-band waves of TerraSAR-X penetrate very well into the subsurface and the satellite is hence suitable for the space-based archaeological prospection. Unfortunately, the penetration depth even in desert soils is limited to 20 or 25 cm, so it is most appropriate to very dry soils and shallow archaeological remains. As even small leafs and grass have approximately the size of one wavelength of the sensor, a totally vegetation-free survey area is required so that the signal is not scattered by the vegetation. Nonetheless, SAR is a highly recommended new alternative in the archaeological prospection for in arid regions, as it is fast and can be executed even in remote areas or countries with difficult political situations, which are not accessible for ground-based surveys. After a SAR prospection, it is possible to do a high-resolution geophysical survey by GPR or magnetometry in selected areas of a site. The satellite data then can help to embed the site into its historical landscape.

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MIRAN AND THE SILK ROAD. INTEGRATED PROSPECTION AT THE ANCIENT OASIS-CITY IN XINJIANG, CHINA

E. Smagur, K.J. Hanus, A. Buszek

Miran is an archaeological site located on the southern branch of the Silk Road, which led along the margin of Taklamakan Desert in modern Xinjiang, China. It was a town in the small oasis kingdom called The Kingdom of Kroraina or Shan Shan, which stretched all the way from the site of Niya to the salt lake Lop Nor. It flourished from about AD 200 to 400. By the 3rd century, there were Buddhist monasteries throughout the Kroraina Kingdom, and Miran may have been the administrative centre of Buddhism in this region.

The ruins of Miran consist of big, rectangular Tibetan fort, a monastery (The Vihara), several stupas and many sun-dried brick constructions. The earliest Buddhist temples in Miran could be dated around 2nd and 3rd century, and they are one of the earliest examples of the Buddhist architecture in China.

Miran is well known because its frescoes. Paintings and other artefacts found in Miran show the diverse and intricate trade relations this city must have had with the Mediterranean basin. It is also the place where the earliest examples of the Gandhara Art in Xinjiang have been found. Buddhist sculptures and frescos are in a style that closely resembles the artistic traditions of Central Asia and northern India. Iranian and Hellenistic iconographies are also present.

The first archaeologist to systematically explored the ruins of Miran was Aurel Stein, who visited Miran during 1906, 1907 and 1914, and conducted excavations in the fort as well as at the other sites in this area. There have been no major excavations of the site since Stein's third expedition. During the autumn 2013, with the collaboration with The Department of Archaeology of The National Museum of China in Beijing, we will conduct a surface survey in Miran.

The goal of our project is to create a GIS database for the Miran site, in which we will combine the data from previous research with the results of our survey. One of the tasks is reconnaissance using satellite images, which will help to answer questions such as: how does the Miran site look today? Which of the monuments discovered by Stein are still visible on the surface? Are they destroyed or not? Are there other ancient structures not marked on Stein's plan?

During the project, we will also use geophysical methods such as geomagnetic research using a FM 256 fluxgate gradiometer (Geoscan Research) and resistivity survey. Our objective is to verify which methods are suitable to local conditions, i.e. Chinese desert, and to supplement the base GIS data in conjunction with other methods used in the project.

The poster will illustrate the research methods and outcomes.

NON-INVASIVE ARCHAEOLOGICAL RESEARCH CARRIED OUT RECENTLY IN NORTHERN MUNTENIA, ROMANIA

A. Frinculeasa, M.N. Frinculeasa, C. David

Prahova County is one of the main administrative divisions of Muntenia, not only in economic terms, but also concerning archaeological research. These interrelated aspects are the foundation for using new methods and tools in archaeology. Non-invasive research in Romania is in a starting point, the financial aspect, along with a certain traditionalist opposition to change, are the main elements influencing access to this type of approach.

Morphologically, the territory of Prahova County comprises various geographic units from north to south: mountains, hills, and plains (Figure 1). Their distribution is relatively uniform, but the archaeological sites appear mainly in the piedmont plain and the hilly areas, most frequently at the boundary between these two units. The area has a temperate continental climate, directly related to the particularities imposed by the vertical variation of relief forms. The hydrographical network is largely dependent on the Prahova River and its main tributaries, the Doftana, Teleajen, Cricov and Varbilau. In the hilly region, the river valleys show well-developed terraces favourable for habitation. Geophysical investigations performed during 2010-2012 applied two geophysical methods – magnetic and electrical – with different variants of the latter. Measurements were made using the following equipment: Overhauser GSM19W magnetometers equipped with GPS of precision, a '4-point light 10W' resistivity metre, a Scintrex IPR 10 receiver and a low power transmitter. Geophysical investigations are complementary methods of prospecting, enabling researchers to obtain additional information in order to build a strategy involving adaptations of the methodology and the budget planning of research. In Prahova County, the premises behind non-invasive geophysical investigations on archaeological sites had as a starting point a series of specific traits such as age, geological context of sites, construction characteristics, traditions and customs. We approached a diversity of archaeological sites, ranging from Bronze Age cemeteries to Roman forts and medieval buildings. We mention here:

1. The Bronze Age Cemetery – Câmpina. Positioned on the Prahova terrace, the Câmpina terrace is made up of gravel and talus intercalated with lenses of resedimented clays and marls. The graves found between 0.3 and 1 m deep had the maximum dimension of 0.7/1 m. Since the cemetery lies under a high-voltage power line, we performed electrical measurements using a 0.8 m 'twin' device. Through maximums of the electrical resistance, measurements highlighted the existence of somewhat regular grave alignments (Figure 2).
2. The Late Medieval cemetery – Câmpina. Positioned on the same terrace of the Prahova river, its stratigraphy is similar to that of the Bronze Age cemetery. The graves follow the Christian-Orthodox ritual and can be found at a depth of 0.5-1 m. Geophysical investigations implied using the magnetic method on the total magnetic field in reference base system and the electrical method using a 0.8 m 'twin' device. Magnetic measurements were performed with a continuous registration, at a sampling intervals of 0.2 s, on profiles spaced at 0.5 m intervals. Primary data, both magnetic and electrical, were processed through high-pass and low-pass filtering, analytical continuations, and calculation of derivatives, using a SURFER9. Thus, electrical resistance isolines highlighted the rectangular outlines of the old graves, aligned on two directions, east-west and north-south. The magnetic anomalies, numerous but local, were interpreted as the effects of small iron objects like nails, buttons, buckles or other small objects placed near/on the people buried. The outlines of graves were only partially highlighted.
3. Tumuli/tells in the area Buda – Aricesti and Ciorani. The structures investigated are located on terrace deposits (the Prahova terrace, in the plain, and the Cricovului terrace) and are made up mainly of clay and sandy clay. We performed magnetic measurements of the total magnetic field. In the Prahova area, within the Buda-Ariceti perimeter, the results achieved were not spectacular, given the fact that the funerary structures are simple, relatively homogeneous and the skeletons buried a few metres deep are crouched, accompanied by austere inventories.

   At Ciorani, numerous magnetic anomalies, several metres in size and showing a certain circular symmetry, were registered within the area of the two investigated tumuli (Figure 3). In this case, for one of them we used as a complementary method the vertical electrical survey in Schlumberger variant, obtaining a vertical, transversal resistivity section. A maximum anomaly was highlighted at a depth of about 3.5 m, which was interpreted as the effect of empty space underground, suggesting the existence of a grave characteristic to this structure type.
4. The Roman fort and baths from Sfarleanca, found on the Teleajen terrace near the confluence with the Vrbilu. Geophysical investigations performed within the fort were limited due to several factors. One is a lack of lithological homogeneity, indicated by the existence of coarse detritic material deposits alternating with deposits of fine and argillaceous material, looking like strips oriented NW-SE. Other factors include the destruction caused while planting an orchard in the early 1980s, differences in land use within the fort and the surrounding area at the time of measurements (for example, rough ploughing, rolled ploughing, unexploited land, maize crops), and a high-voltage power line crossing the central area of the site. Geophysical investigations covered an area of about 4 ha and consisted of magnetic measurements of the total magnetic field, along with complementary measurements of the electrical resistance performed with a 1.5m 'twin' device and ERT profiles on the sides of the fort. The electrical measurements were performed un-

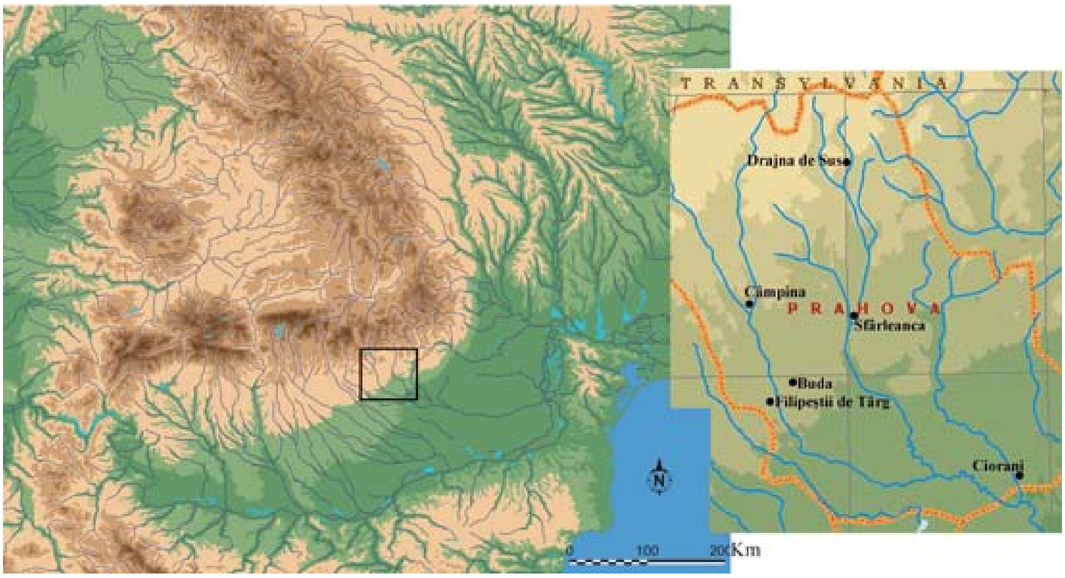

Figure 1: *The position of the Prahova County in Romania. Geophysical investigation areas.*

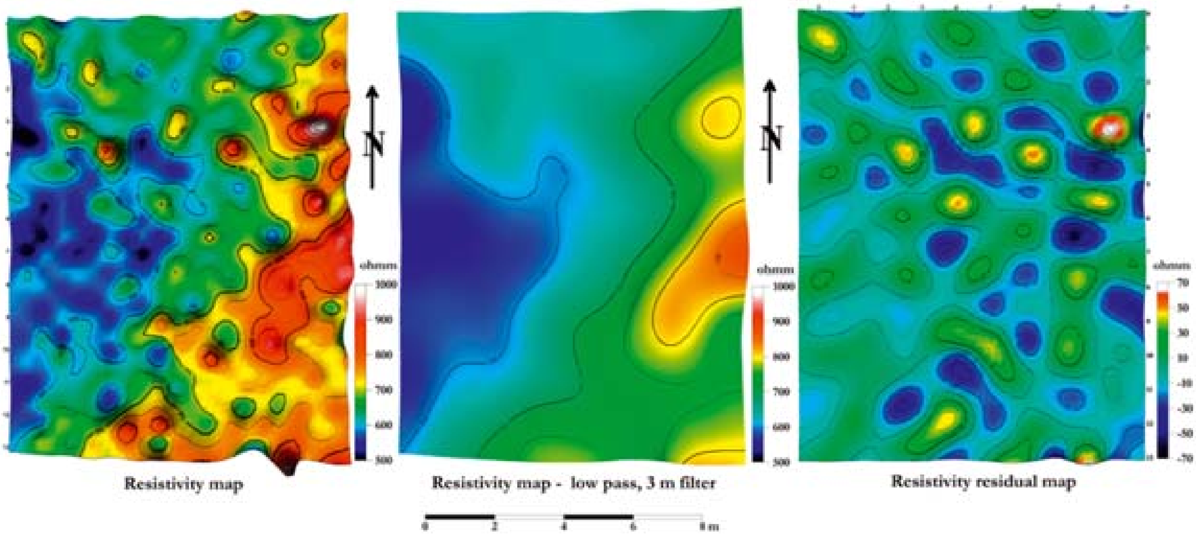

Figure 2: *The Bronze Age Cemetery – Câmpina. Processed electric data.*

der identical weather conditions and were visualized in an electrical resistance map. Maximums clearly highlighted the north-western side, with lower values for the eastern side and several interior structures without precise geometric contours. The magnetic measurements (continuous recording with sampling intervals of 0.5 s and profile spacing of 0.6 m) clearly outlined the south-eastern corner and the northern side of the fort, and highlighted numerous low-intensity local anomalies (20-50 nT) produced by ceramic materials such as tiles and bricks. The exact location of the old clay buildings was difficult to establish on the basis of magnetic data due to a serious deterioration of the site during recent activities. Electrical resistivity tomography (ERT) was performed on transects that crossed the fort sides with the distance between the active electrodes of 1 or 2 m. They show a certain inconsistency of the response obtained in the northern and eastern zones (where they are in accordance with the results of the archaeological excavations) as compared to the western and southern areas. Resistivity sections indicate a greater development of the argillaceous substrate in the central and north-eastern parts of the site as well as the existence of a strip of coarse detritic material, such as gravel and talus, in the western and south-western areas. The nature of the material excavated initially was different from that expected according to the stratigraphy of the area. The electric answer of the present conformation may be exactly the opposite in the two cases, which involves systematic reinterpretation of the data after the first excavations on the southern side. The baths are placed at about 150 m westward of the north-western corner of the fort, near the railway track and within some properties bounded by fences with metal insertions. They were investigated using the magnetic method (the total magnetic field, continuous recording at sampling intervals of 0.2 s and profile spacing of 0.5 m), and the electrical method of 0.8 m 'twin' device and ERT (1 m between the active electrodes). The magnetic measurements were strongly disrupted by local conditions. The only viable result was an anomaly with a quasi-isometric source and moderate intensity that was interpreted as the effect of a brick structure. The archaeological research conducted in 2011 and 2012 confirmed this hypothesis. The electrical measurements resulted in a map of the electrical resistance, which highlighted a rectangular, compartmentalised construction and provided information regarding its continuation towards the north-east and south-west. The bathroom foundation is made of limestone and the diving walls are partially made of brick. Two maximum anomalies of the electrical resistance were recorded, which are the effect of this deposit consisting of a mixture of boulders, brick and limestone blocks. ERT sections subsequently performed on the north-eastern and south-eastern sides of the building, initially identified on the basis of the electrical resistance, indicated its continuation beyond the fences bounding the properties.

5. The Roman fort of Drajna de Sus, investigated over an area of about 4 ha, is located on the left slope of the Drajna Valley. The stratigraphy is represented by Oligo-Miocene sedimentary deposits belonging to the external flysch of the East Carpathians – the northern flank of the Drajna synclinal, consisting of alternating gritstones, marls and calcareous marls, with levels of evaporites and volcanic tuff. The investigated land surface was terraced relatively recently in order to plant a plum orchard. Geophysical investigations were performed using magnetic measurements of the total magnetic field, in reference base system with continuous recording (sampling intervals of 0.2 s, profiles spacing of 0.6 m). Due to noise induced by the low-voltage power line that crosses the archaeological site on the central-western part and to different constructions nearby, primary data were subjected to various types of filtering and processing (in SURFER 9 and ArcheoSurveyor). The results highlighted the northern and southern sides, whilst the eastern and western sides were only slightly underlined. Medium and large size rectangular structures were revealed parallel to the northern and southern limits of the fort, and ceramic material was indicated by magnetic anomalies with intensities ranging between 20-50 nT. Subsequent archaeological excavations revealed the existence of complex built structures, foundations, paving, vault remains made of brick, limestone and calcareous marl. The fact that they were found more than 1 m deep, and that beneath the soil layer there is a relatively thick deposit of mixed ceramic material and stones, explains the inconclusive results of the magnetic measurements, which did not succeed in defining the shape or size of the structures.

6. The underground medieval buildings from Filipestii de Târg are located on the first terrace of Prahova, west of its minor riverbed. The substrate consists of gravel and talus intercalated with lenses of resedimented reddish clay. Geophysical investigations consisted of magnetic measurements with continuous recording and sampling intervals at 0.5 s on transects at 0.6 m (Figure 4), and resistivity sections by applying Schlumberger electrical surveys. The grid were investigated with a gradient device and sampling intervals of 1 m. The results of magnetic prospection indicate the presence of different sized structures. They have an anthropic origin, which may lead to archaeological investigations in order to restore the old medieval domain. The electrical surveys allowed creation of a 3D image of the distribution of resistivity near the medieval mansion, which suggests the presence of a large buried structure. The roof of this construction has vault shape and it may represent part of a tunnel. In this case, geophysical investigations indicated that there are areas with archaeological potential beyond the brick walls of the cellar.

All these non-invasive investigations overlapped a series of regional or national level projects. They provided additional information useful to the exploration phase and to impact studies. They also contributed to familiarization with the methods and to understanding the role of this type of research, which has only recently been introduced in archaeological practice.

Figure 3: *Ciorani: geophysical investigation areas (magnetic field map).*

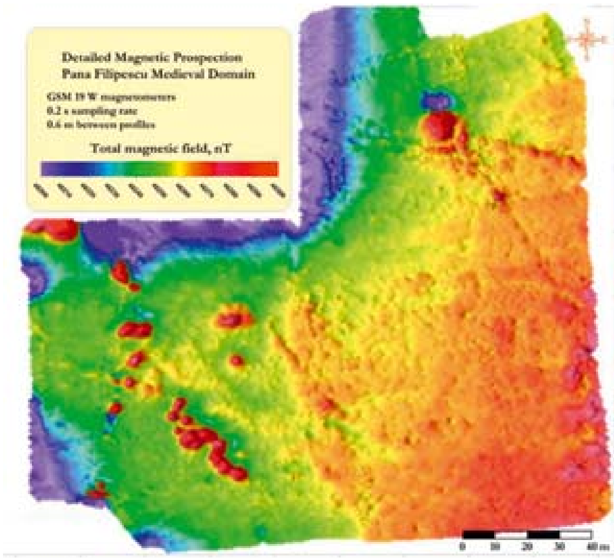

Figure 4: *Detailed magnetic prospection of the Pana Filipescu Medieval Domain.*

SETTLEMENTS OUT OF NOWHERE – EXTENSIVE ARCHAEOLOGICAL EVIDENCE FROM COMBINED GEOPHYSICAL PROSPECTION AND AERIAL PHOTOGRAPHY

T. Wunderlich, B. Majchczack, E.S. Mauritsen, M. Segschneider, H. Stümpel, W. Rabbel

ABSTRACT

Based on aerial photographs on the North Frisian Island of Föhr, Germany, an extensive prospection project was carried out, combining geomagnetics, GPR (Ground Penetrating Radar), ERT (Electrical Resistivity Tomography), electromagnetic induction and magnetic susceptibility measurements. Three distinct settlement sites from the migration period and the Viking age have been thoroughly investigated.

1. INTRODUCTION

In a Danish five-year project (An Aerial view of the Past, Olesen 2010) for aerial photography of archaeological sites on the west coast of Jutland (Denmark), the North Frisian Islands of Sylt, Föhr and Amrum (Germany) were also investigated. During these flights, several unknown archaeological sites were found, especially on Föhr. During the first flight in 2006, three settlement sites were discovered (Mauritsen *et al.*, 2009). On fields and grasslands around the villages Wrixum, Nieblum and Witsum, distinct anomalies of ditches, pithouses and longhouses were revealed and assigned to larger settlements of the first millennium AD.

The archaeological investigation of Föhr reaches back into the 19th century, while the complete mapping of all known archaeological sites occurred in the 1950s (Kersten and La Baume, 1958). The current state of research is comprehensive, but is mainly based on numerous burial mounds from the Neolithic up to the Viking age. Hardly any settlements were known and no major settlement was excavated. Therefore, the discoveries from aerial photography provided a great opportunity to extend the state of knowledge. The State Archaeological Department of Schleswig-Holstein and the Department of Geophysics at Kiel University have started a close collaboration for further archaeological and geophysical prospection at the three new sites on Föhr. The aim of the project is a comprehensive archaeological interpretation of the sites and a further development of geophysical methods.

2. GEOPHYSICAL MEASUREMENTS

During three campaigns in 2008, 2010 and 2012, the sites Wrixum, Nieblum and Witsum were surveyed by geophysical measurements. To cover a large area in short time, geomagnetic measurements using a 6-sensor fluxgate array were done first. The sensors were mounted on a handcart with a spacing of 0.5 m. Accurate positioning was achieved by using a differential GPS. The measured values were interpolated on a 20×20 cm grid and displayed in greyscale.

To gain information about the depth and geometry of anomalies, additional GPR and ERT measurements were conducted on smaller areas. Some boreholes were drilled for ground truthing and down-hole magnetic susceptibility measurements. These additional data were used for magnetic modelling of the anomalies, using a simple 3D-prisma or a 2D-model with a polygonal structure.

3. RESULTS AND DISCUSSION

3.1. Wrixum

No settlement areas were previously known on the higher moraine between the villages Wrixum, Alkersum and Oevenum. In the aerial photography, several accumulations of anomalies can be seen on an area of about 43 ha, which indicate a larger settlement system. The vegetation anomalies show systems of ditches or fences, forming farmsteads with longhouses inside. Several farmsteads are built alongside each other, whilst others lie isolated. Three areas with distinct aerial anomalies have been prospected with geomagnetics and GPR (Figure 1a). These measurements supported and expanded the aerial photo interpretations. The longhouses are especially clearly visible, down to the internal posts holding the roof of the three-nave houses. The longhouses have lengths of 40 to 60 m, providing a good indication that they date to the migration period. Houses of such length can be found along the North Sea coast between the 4th and 7th centuries AD. In addition, the structure of the farmsteads corresponds to similar sites in Denmark and the Elbe-Weser-Triangle. Small areas on selected anomalies have been further prospected using GPR, geoelectrics and electromagnetic induction to provide better insight into the deep structures of the anomalies. Furthermore, the relief models provided through LIDAR (Laser Detection and Ranging) revealed remains of wall structures, dividing the settlement (Figure 1b). In addition to the geophysical prospection, archaeological prospection such as field survey and metal detecting have been carried out, bringing a number of finds which help to confirm the dating of the site.

3.2. Nieblum

Close to the beach of Nieblum, a closed settlement of 8.1 hectares has been found, surrounded by a partly doubled ditch (Figure 2). The inside shows a number of pits or pithouses. On this settlement, a geomagnetic prospection was carried out, providing more features and the probability of multiple phases of the settlement. Field survey and metal detecting brought no significant finds, leaving the dating of the site unclear. The overall structure of the settlement and its short distance to a known graveyard of the roman period makes plausible a date in the 1st to 5th century AD, while the high number of pithouses might belong to a later settlement of the Viking age. Features like pithouses and longhouses of that period have also been excavated close by.

3.3. Witsum

On a sloping moraine close to a lowland are with water discharge into the North Sea, several anomalies can be found on the aerial

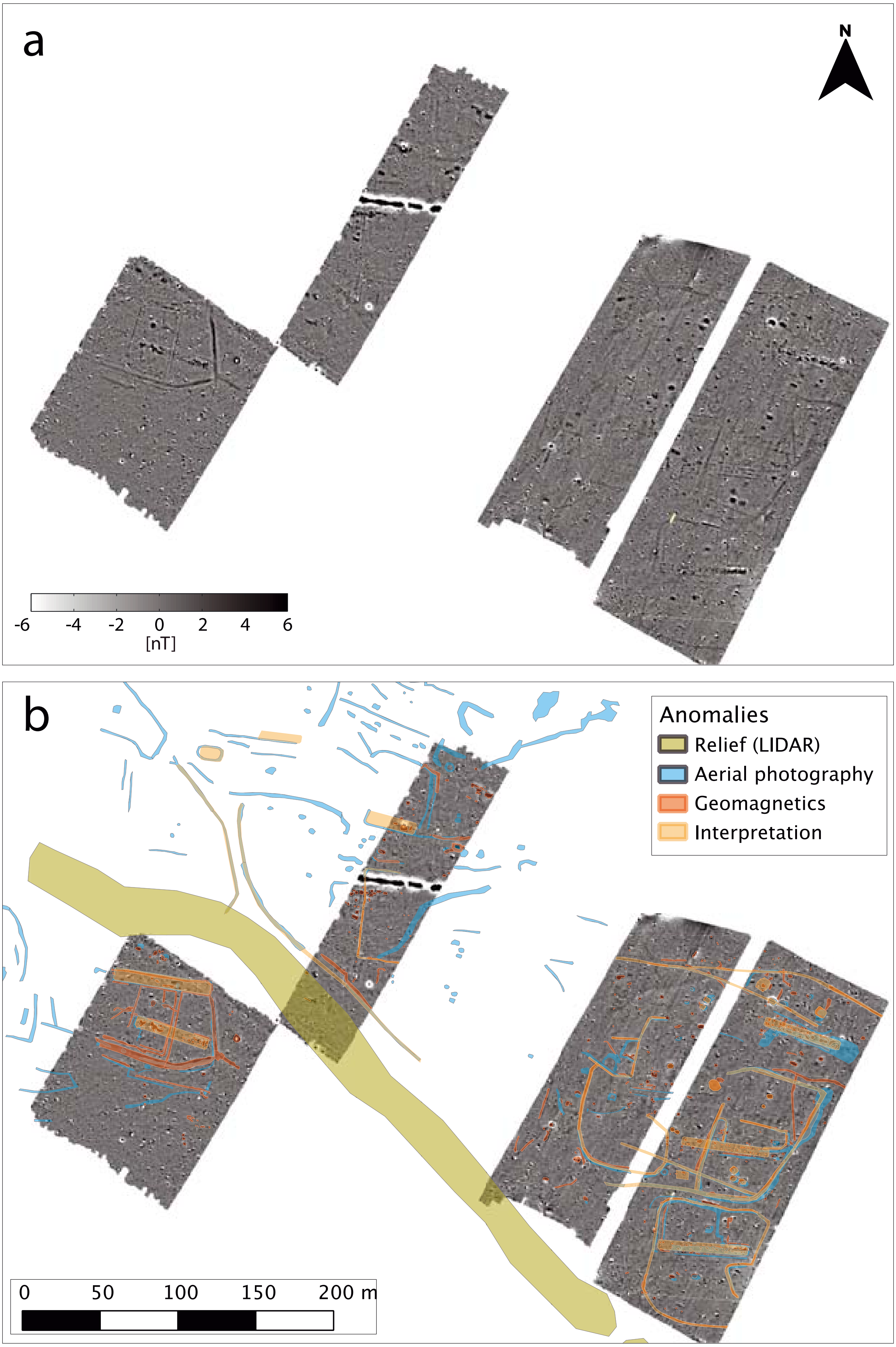

Figure 1: *Geomagnetic map of Wrixum (1a) and drawings of anomalies from LIDAR, aerial photography and geomagnetics (1b).*

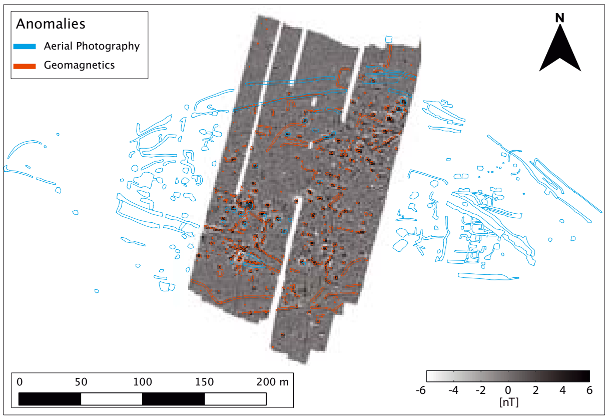

Figure 2: *Geomagnetic map of Nieblum and drawings of anomalies from aerial photography and geomagnetics.*

photographs in an area of about 10 ha. Unfortunately, the vegetation conditions were not optimal and therefore the whole area was mapped with geomagnetics. In addition, GPR and geoelectrical measurements were conducted on smaller areas.

The magnetic map shows a village-like settlement, separated by fences or ditches into parcels, which are densely covered by pithouses (Figure 3). The dominance of pithouses makes a Viking age date probable and suggests a commercial character of the settlement. The field survey yielded typical pottery, basalt for grindstones and a loom weight, and the metal detecting recovered a silver coin of the early 11th century AD. The settlement has access to the North Sea via the little river Godel, providing the possibility of a function as a site for crafts and trade. The prospection reveals no longhouses so far, but their existence should not be ruled out. This possible trading site fits well into the known archaeological landscape of southern Föhr in the Viking age, with several graveyards and the Borgsum ringfort close by. The location of the agrarian settlements is unknown so far.

In Witsum, the magnetic anomalies are stronger compared to Wrixum, i.e. the pithouses in Wrixum have anomalies of less than 20 nT, whereas in Witsum the pithouses produce anomalies of up to 60 nT. These strong magnetic anomalies are caused by material of very high magnetic susceptibility. Three boreholes were made in one pithouse and the magnetic susceptibility was measured to a depth of 110 cm with a depth resolution of 1 cm (Figure 4a). For comparison, a reference borehole outside the pithouse was made. Here only undisturbed material with very low magnetic susceptibility was found. The high magnetic susceptibility inside the pithouse is caused by burnt clay.

The anomaly can be modelled by a 3 m $\times$ 4 m box with a magnetic susceptibility that is 2300 e^{-5} SI higher than the surrounding sand. The susceptibility model is also shown in Figure 4a. The resulting anomaly fits very well to the measured data (Figure 4b). Thus, the anomaly can be explained by a shallow pithouse filled with high magnetic susceptibility material including burnt clay.

4. CONCLUSIONS

The aerial photographs provided an excellent foundation for large-scale surveying of an archaeological landscape with several new settlement sites. In some areas, the vegetation conditions were not optimal for identifying features. Therefore, an extensive geophysical prospection with geomagnetics on selected sites enlarged the database and yielded further archaeological data. Additional geophysical methods such as GPR and ERT proved to be successful to investigate the depth extent of the anomalies.

Through the interaction of the different prospection methods, the settlement in Wrixum was archaeologically determined to be a rural settlement from the migration period that closed an important gap in the settlement history of the island. The dominance of pithouses in Witsum suggest a possible trading site of the Viking age. Geophysical prospection results showed a complete settlement layout. The situation in Nieblum is similar, but the archaeological insight is less precise and needs further research in future measurements or excavation.

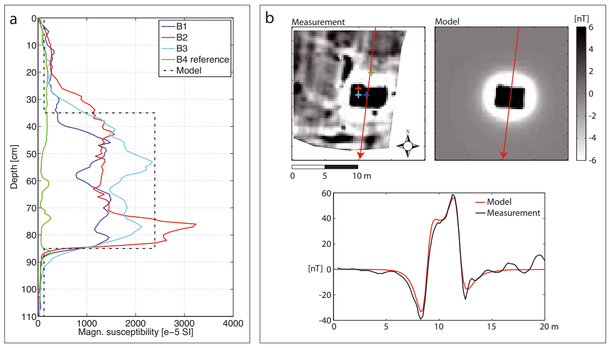

Figure 4: *(4a) shows measured magnetic susceptibility inside the three boreholes in the pithouse (B1-B3) and in the reference borehole (B4). The susceptibility profile used for modelling is also shown. (4b) is a measured and modelled magnetic map of an typical pithouse in Witsum. The location of the boreholes is marked in the measured map. For comparison, a profile crossing the anomaly is included.*

ACKNOWLEDGEMENTS

We would like to thank the participants of the INCA 2010 course (International Course on ArchaeoGeophysics) for help in geophysical data acquisition.

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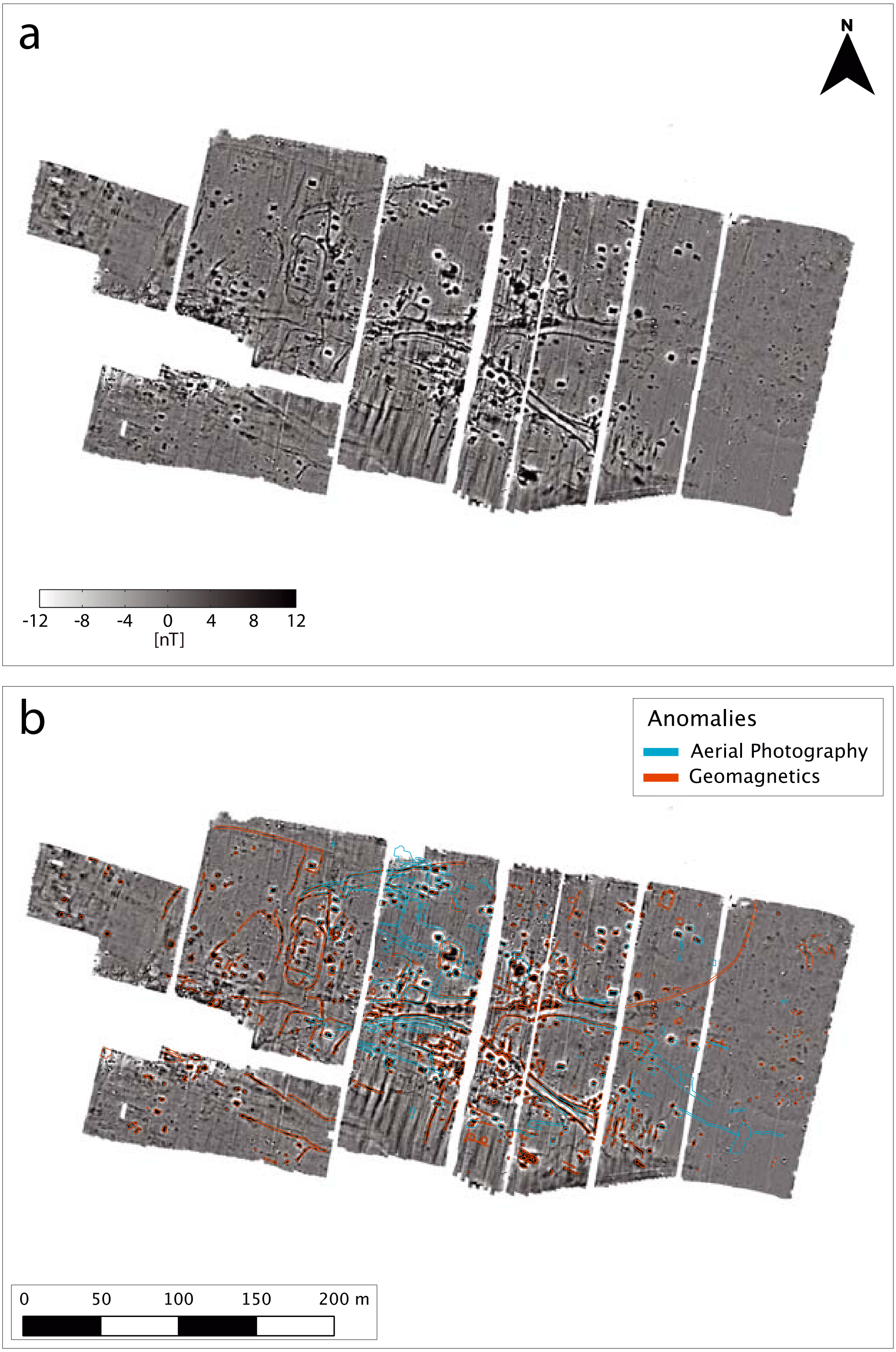

Figure 3: *Geomagnetic map of Witsum (3a) and drawings of anomalies from aerial photography and geomagnetics (3b).*

REMOTE SENSING TECHNIQUES IN THE STUDY OF CIVIL SETTLEMENT NEAR NOVAE (MOESIA INFERIOR)

M. Jaworski, P. Wroniecki, M. Pisz, A. Tomas, J. Pisz

The legionary base at Novae, like other Roman camps, was the heart of settlement complex consisting of a fortress, associated civil settlement (*canabae*), and elements of infrastructure. The land was in the hands of the army and was treated formally as public (*ager publicus*) owned by the imperial treasury (*fiscus*). Its limits were determined by a radius of one *leuga*, an ancient measure corresponding to 2.22 km. The civil settlement was most probably subordinated to the legate of the legion, but it was self-governing. *Canabae* residents were restricted in their right to resettle and could not own land, although they could rent it from the army. The army also supervised the land and installations essential to its proper functioning: pastures and meadows (*prata*), stone quarries (*lapicidinae*), brick and pottery kilns (*figulinae*), and workshops (*fabricae*).

Another settlement (*vicus*), very often located just beyond the boundaries set by the *leuga*, was subject to provincial administration and inhabited by people with the right to own land. The *vicus* could obtain municipal rank and have its own *territorium*. Settlements of this kind were established most often in areas of sparse local settlement. The existence of two settlements in the neighbourhood of legionary camps is referred to as settlement dualism characteristic of the second century AD. It remains an object of debate whether and when Lower Danubian *canabae* received town rights.

The residents of the first *canabae* of the Eighth Augustan legion probably left with the unit in the second half of the AD 60s. A more permanent settlement developed in connection with the longer presence of the First Italica legion. The second settlement was located 2.5 km to the east of the camp, at the Ostrite Mogili site.

Repeated field surveys and years of topographical observations have determined the location of the principal part of the civil settlement to the west of the army camp, where Bulgarian excavations revealed a large villa of official character (Figure 1). Even so, excavations of the fortifications east of the camp revealed finds dated to the pre-Roman period and first century AD. The field survey at Ostrite Mogili site have provided the chronological data for the *vicus*, which must have existed from the Flavian period to the mid-third century AD. Another issue debated by researchers working in Novae for the past few dozen years is the function of the so-called eastern extension. This area, lying to the east of the camp, was surrounded by a separate, additional circuit of defences, built most probably by the end of the third century AD. At that time, the camp and surrounding settlements had started to merge into one urban complex, which survived up to the end of the sixth century.

The idea behind the research was to investigate the landscape using an integrated scientific approach. All recorded data has been integrated into a unified GIS environment. This provides a tool with the ability to store data and visualize relations between different areas and results of various prospecting methods.

Topographical survey and DTM (Digital Terrain Models) allow recognition of the relations between various areas and their role in the past.

Visualizations of ERT and magnetic prospection results combined with aerial ortophotographs and satellite imagery will allow for a more accurate and deeper understanding of the underlying stratigraphy and should determine the nature and origin of the anomalies.

A series of low altitude aerial photographs were taken using a remote controlled camera platform attached to a helium balloon. In addition to acquiring geophysical data, field prospection and documentation imagery of the surveyed extension, a series of flights over other areas of the site were carried out. The photos help to show the entire topography of the surrounding area, architectural remains, but also the scale of devastation by treasure hunters.

High resolution (0.41 m) orthorectified satellite imagery from the WorldView-2 satellite has been used supplementary to aerial photographs, not only to serve as a base map for GIS or verification of the accuracy of archaeological plans but also as a prospection tool, and more importantly a way of documenting the state of preservation of the site.

The survey in 2012 was preceded by tests of the magnetic and earth resistance methods. The selected area was located in the so called "eastern extension" of the fortress, covering all of the available area of the extension that is, a total of over 2 ha. Magnetic prospection was conducted with a Bartington Grad 601-Dual fluxgate gradiometer and a caesium magnetometer G-858 Magmapper with RTK GPS (real-time kinematic GPS). Figure 2 shows results of the magnetic prospection on a rectified orthophoto. A visualization of measurements obtained with a fluxgate gradiometer may be identified with remains of ancient buildings. Further studies, using complementary methods (e.g. ERT) will allow for a deeper and more accurate understanding of the underlying stratigraphy and should determine the nature and origin of the anomalies and also allow for the precise location of other architectural features of the "eastern extension". Electro resistivity surveys planned in 2013 will verify these results and provide data from the lower layers

Apart from geophysical and aerial methods, a surface artefact collection survey was conducted with the aid of metal detectors. The prospection of 2012 covered an area of 2700 m^2 divided into three squares, each 30 m long, and searched with two metal detectors spanning sections 2.5 m wide at each run. Methodical prospecting in this manner produced a significant number of metal artefacts. The assemblage reflects the history of this particular area of Novae with Late Roman and Byzantine finds clearly dominating. The most numerous group of metal objects consists of iron and lead building elements. Most of the numismatic finds date to the fourth to sixth century AD, including an imperial seal of Justinian I. Their presence suggests that the "eastern extension" was still inhabited by the end of the sixth century.

The objective of settlement studies is to recreate the land-

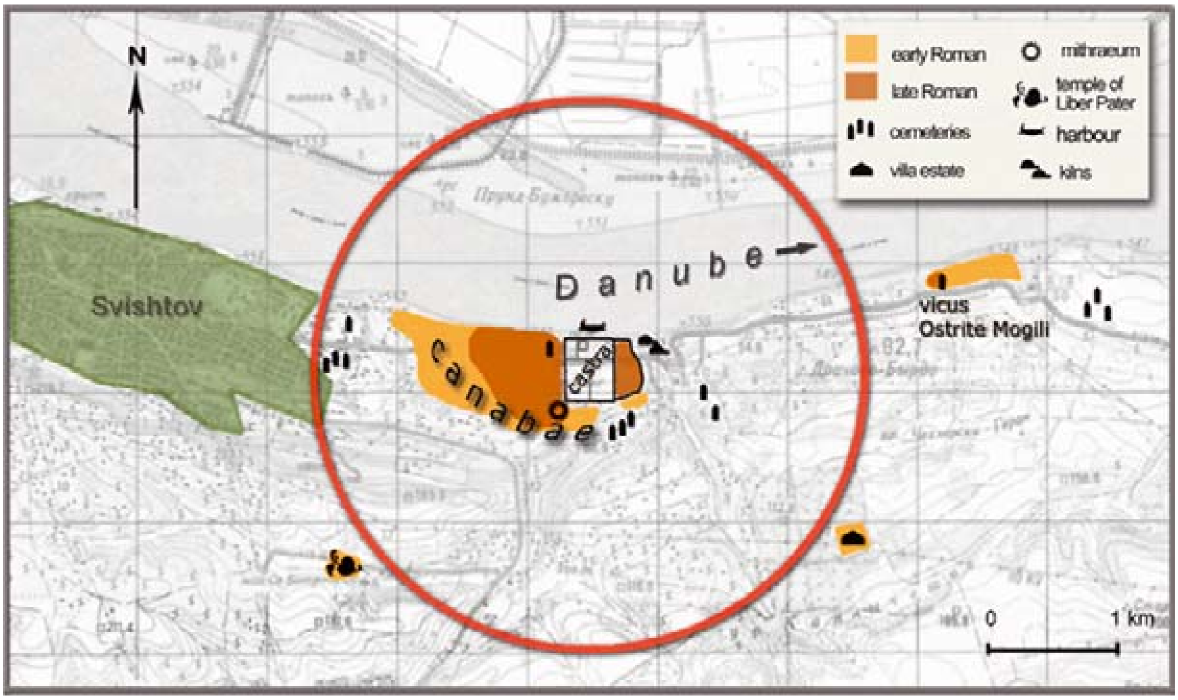

Figure 1: *Outline of the leuga with known sites in the vicinity of Novae.*

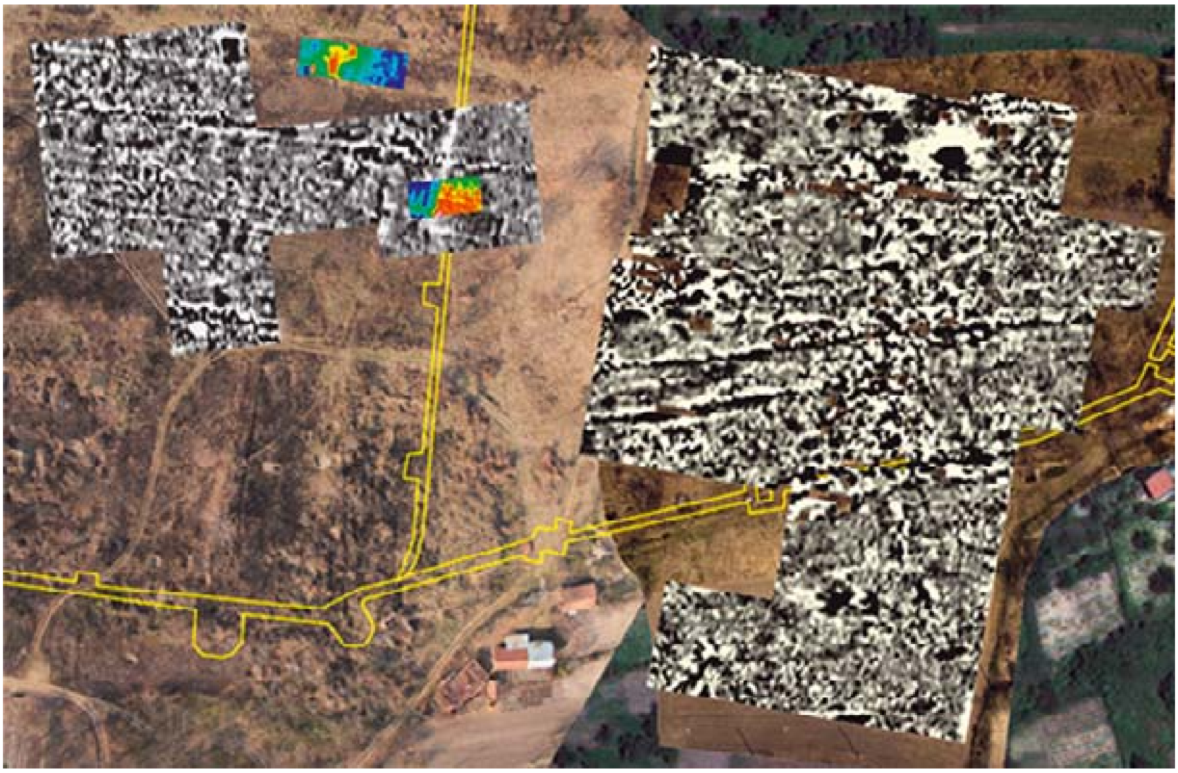

Figure 2: *Magnetic prospection results on rectified orthophotographs.*

scape and environment at a given time in the past. Research on Roman legionary camps, when limited to what is inside the fortress walls, produces a picture that is deprived of significant context; in this case, the civil settlements that accompanied the camps. A broad range of research methods exceeding the frame of traditional excavations is considered the most appropriate methodology in investigations of this kind.

AIRBORNE LASER SCANNING (ALS) AS A TOOL FOR MAPPING OF BURIAL MOUNDS IN THE AREA OF HEMERA FOREST (CZECH REPUBLIC)

J. John, O. Chvojka

This poster focuses on an assessment of the contribution of airborne laser scanning to the identification and documentation of a particular type of archaeological immovable monuments, i.e. prehistoric and early medieval burial mound cemeteries in the forest district of Hemera in South Bohemia. The application of airborne laser scanning (ALS) has resulted in the discovery of several previously unknown burial mound cemeteries, thereby demonstrating its important contribution to landscape survey. Thanks to ALS, about 20 burial mounds have been newly identified in the investigated area (Figure 1). As there are currently more than 300 burial mounds in the forest district of Hemera, the increase in the number of known specimens equals to approximately 5%. This may seem to be a relatively small number, but we have to take into account the fact that these are at least five new burial components, and furthermore are located in an area that has been intensely investigated in recent years. ALS, in combination with landscape survey of anthropogenic relics and metal detector prospection, proved to be a very powerful tool for both the identification and the documentation of burial mound cemeteries. Field verification of ALS data seems to be crucial for the interpretation of identified features, which may include also different natural and anthropogenic structures. Although field verification is rather time consuming, ALS unquestionably represents a great step forward for the methods of location and documentation of archaeological monuments in the landscape.

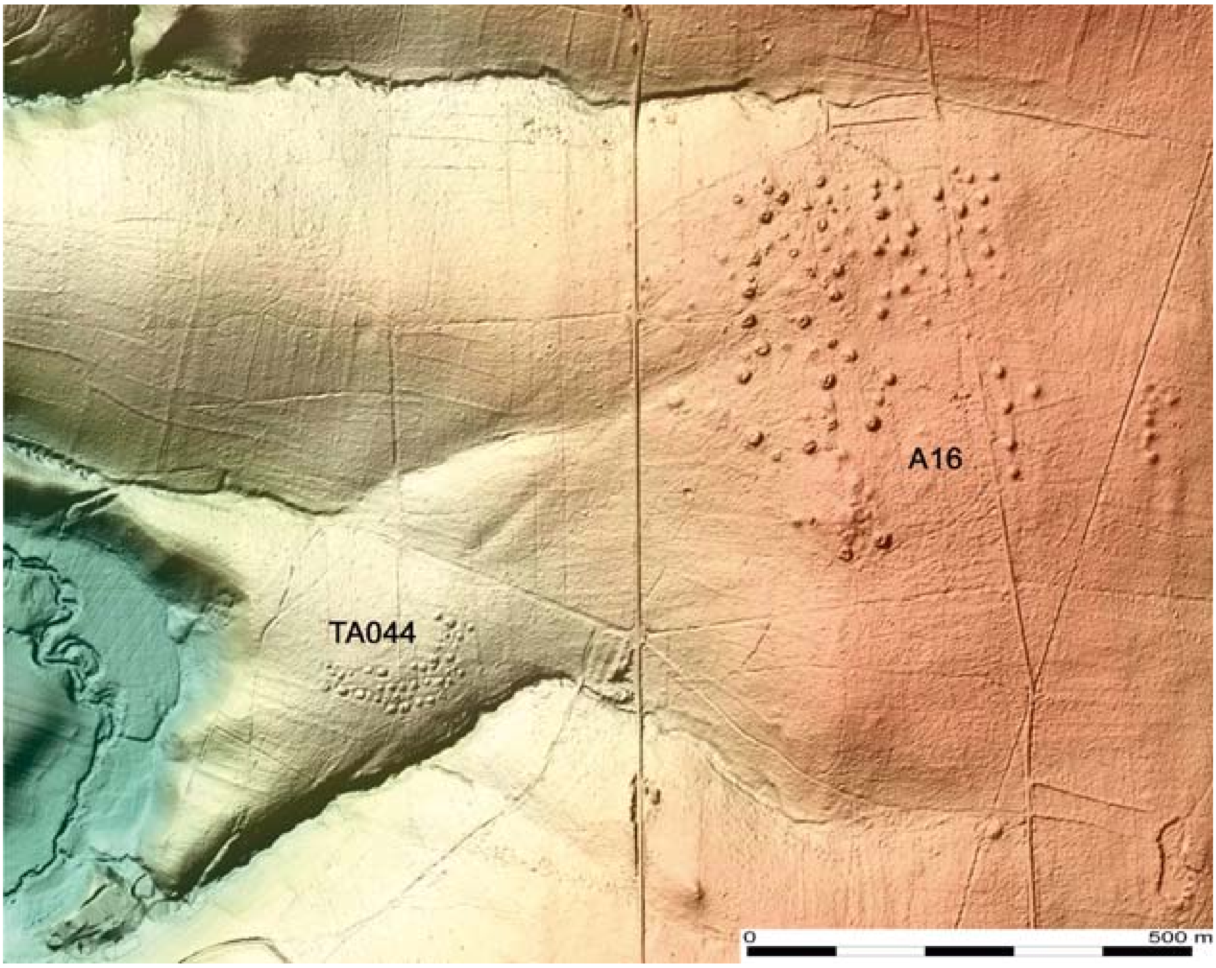

Figure 1: *Shaded terrain model representing the early medieval burial mound cemetery Na Blátě (TA 044) and the prehistoric burial mound cemetery Hošková (A16).*

APPLICATION OF NON-DESTRUCTIVE ARCHAEOLOGICAL METHODS IN RESEARCH OF PREHISTORIC AND MEDIEVAL MONUMENTS IN THE SOUTH BOHEMIA

J. John, P. Menšík, J. Hložek, L. Čapek, P. Baierl

Methods of non-destructive archaeological research have had a long tradition in the Czech Republic. However, their systematic development did not occur until the 1990s. The Department of Archaeology of the University of West Bohemia in Pilsen represents one of the few archaeological centres in Bohemia where methods of non-destructive archaeology are being developed systematically and on a long-term basis. The non-destructive archaeology forms an inseparable part of wider theoretical questions that stem from landscape, settlement and spatial archaeology. Archaeological research of the forested areas (barrow burial grounds, deserted medieval villages, remains of prehistoric and medieval mining) and upland sites (parts of upland settlements, prehistoric fortifications, hillforts and medieval castles and minor seats of nobility) are the main research subjects. Non-destructive methods provide us with various possibilities of preservation of the unique but unfortunately endangered cultural heritage and preventive preservation of individual archaeological monuments. This paper is focused on application of some methods and approaches of non-destructive archaeology that were conducted in the last decade during research of selected prehistoric and medieval settlement and burial areas and their components in the region of South Bohemia.

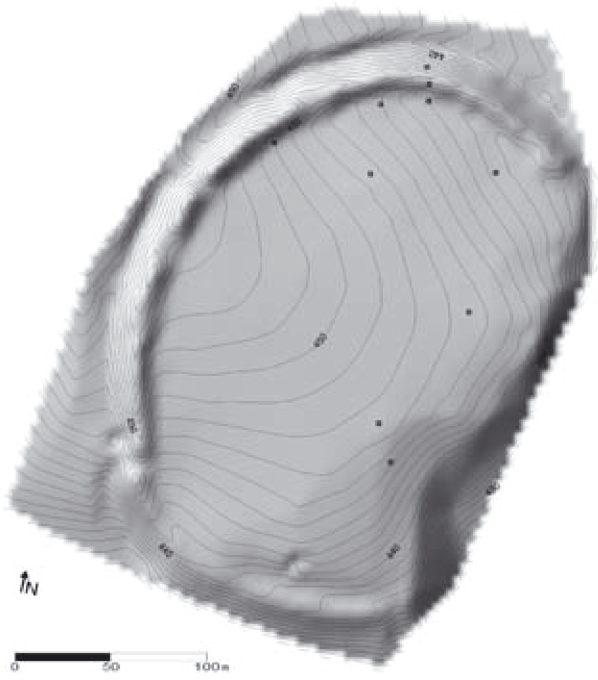

Figure 1: *Prehistoric and Early Middle Age hillfort of Svákov at Soběslav (Tábor district) documented through non-destructive methods. The area of the hillfort was mapped through aerial archaeology and airborne laser scanning (LiDAR). Furthermore, a 3D model of the hillfort relief was created via total station and data interpolation. Archaeological testing confirmed prehistoric residential activities and an Early Middle Age settlement from the second half of the 9th century.*

Surface surveys and geodetic – topographic documentation of the anthropogenic remains in the forested areas are significant parts of the non-destructive activities. Modern geodetic - topographic devices (total stations, GPS) are used for spatial documentation. All data is consequently processed in geographic information systems (GIS) or other software to produce planimetric ground plans as well as 3D elevation models of terrain relief. In South Bohemia, this research is focused especially on monitoring immovable monuments in forested areas (prehistoric barrow burial grounds, deserted medieval villages) and seats of nobility (castles, strongholds). Such geodetic localization of monuments does not only supply us with evidence and documentation but also enables us to solve formal and spatial relations in terms of individual components and their structures. Detailed spatial documentation is usually followed by other methods of archaeological prospection (geophysical survey, surface artefact collection, test pitting).

Aerial archaeological survey is one of the non-destructive methods used for documentation of archaeological monuments in South Bohemia. Aerial archaeology works by analysing oblique photographs of monuments, as well as with the possibility to compare these to the results of satellite digital scanning. Information gained through targeted aerial archaeological survey enables us to solve questions related to settlement and landscape

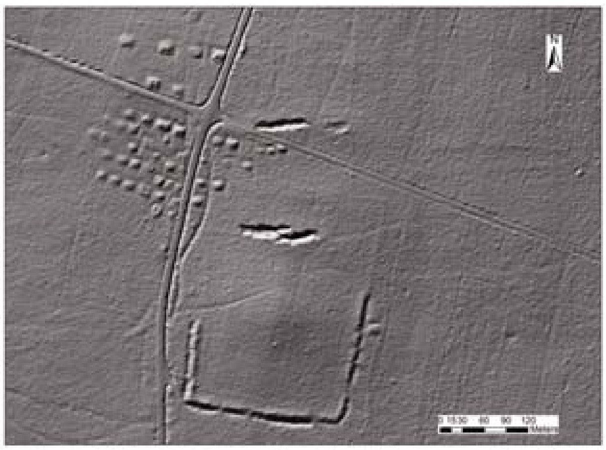

Figure 2: *Airborne laser scanning (LiDAR) in the landscape transect in the river basin of the Smutná River (Tábor district). Shaded digital model of relief (DMR) of the Early Middle Age line barrow burial-ground, with 59 barrows, and a modern rampart enclosure in the Radětice cadaster.*

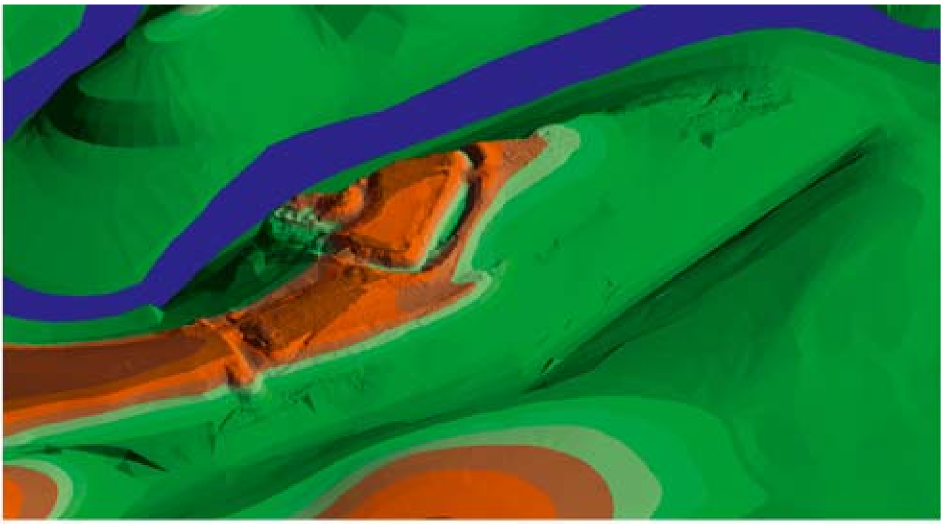

Figure 3: *Geodetic-topographic documentation and 3D visualization of the field remains of a vast castle and residential complex of the Příběnice (14th – 15th century) and Příběničky (13th–15th century) castles (Tábor district). The castles are divided by the Lužnice River. 3D visualization of the castle area and bailey fortified with a rampart and moat, and 3D documentation of the fortified area (siege camp) and communications (hollow ways) around the castle.*

archaeology. It is possible to identify formerly undocumented monuments that are visible only from the air on the basis of cropmarks (vegetation) or soilmarks.

Airborne laser scanning (LiDAR) is the latest technology used in remote sensing for scanning and mapping individual landscape transects or polygons in forested areas in South Bohemia. The LiDAR data is processed in a GIS or other software and transformed to shaded digital models of relief. Evaluation and interpretation of the LiDAR data enables us to identify many burial and residential areas and their individual components at a large scale and from various periods from prehistory up to the modern period.

Methods of geophysical prospection are frequently used in preliminary archaeological research. Geophysical, mostly geoelectric and magnetometric, methods of measuring can help solve various general questions. The survey serves as a method of identification, which can be especially useful on sites discovered through different procedures. Its primary target is to prove the existence of the presumed archaeological features, which are in their transformed form hidden under the present surface. Such monuments can be visible through different physical characteristics from their surroundings. Geophysical survey is also invaluable aid for targeted survey of activity areas (residential, burial and production), aiming to find answers to questions about structure and function of these areas.

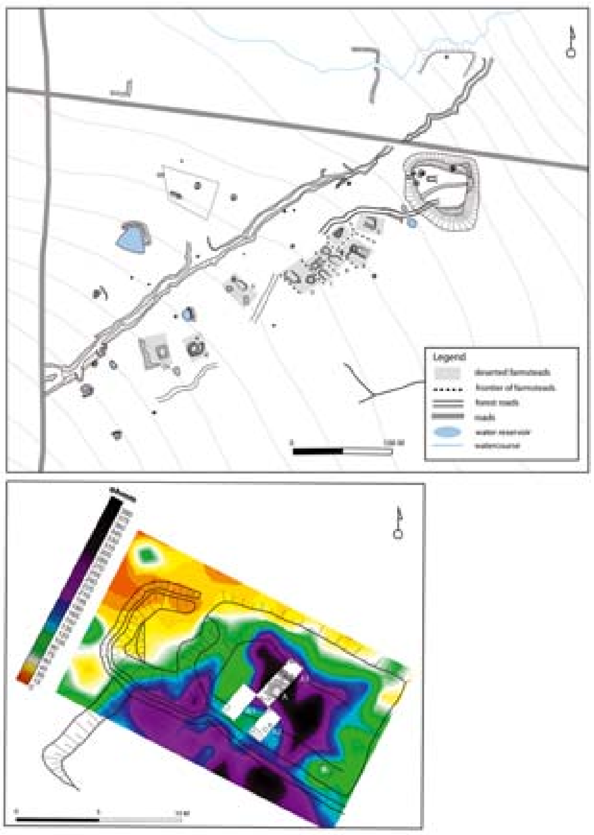

Figure 4: *Geoelectric resistance measurements in a feature of a medieval farmstead in the deserted village of Prochod (České Budějovice district). An archaeological sondage confirmed the presence of a room of a medieval three-part house, as indicated by the measurement results. The room was equipped with an oven.*

MANAGING AND PROTECTING THE WORLD HERITAGE SITE OF THE ROMAN LIMES – THE CONTRIBUTION OF GEOPHYSICAL SURVEYING

T. Becker, N. Buthmann, B. Zickgraf

1. INTRODUCTION

In 2005, the UNESCO World Heritage Committee decided that the former Roman Limes should become part of a Trans-National World Heritage named "Frontiers of the Roman Empire". The outcome of this is a long-term commitment to protect, explore, develop and present one of the world's largest archaeological monuments. The Upper German-Raetian Limes alone extends over 550 kilometres from the Rhine in the north-west of Germany to the Danube River in the south-east.

The Limes in Germany was built in different stages and has over one hundred large and small military camps and nine hundred watchtowers. In the province of Upper Germany, the border line has been designed with a wooden palisade and a rampart and ditch, while in the province of Raetia it was a stone wall.

Because of the geographic extent of this monument, and the plurality of the different components, protection and development is a complex task. The basis for all decisions in dealing with this monument is an accurate knowledge of its extent. For this purpose, different sources are evaluated and various methods of archaeological fieldwork are executed. In this context, one has to mention the documents of the excavations of the Reichs-Limeskommission from 19th and the beginning of the 20th century, and all modern survey methods. It should be noted, of course, that today only non-destructive methods are acceptable. Against this background, it becomes clear that geophysical surveys are especially helpful for precisely locating the remains of the Limes.

To show the benefits of geophysical surveys at the Limes, some examples from our work in Hesse are presented here. Furthermore numerous measurements in Rhineland-Palatinate and Baden-Württemberg have been performed. Ditches and watchtowers

Due to the magnitude of the Limes, conflicts between the protection of this monument and recent building activities are sometimes unavoidable. In order to resolve such a conflict in Ravolzhausen, the state office for the preservation of monuments decided to conduct a magnetometer survey. The course of the Limes and the positions of different watchtowers are shown very well by the greyscale plots of the survey (Figure 1). On the basis of these results, targeted excavations were carried out in the surrounding of the towers. Once the exact position and structure of the remains was known, it was also possible to reach an agreement and to redesign development plans. Taking the ancient structures into account, the proposed development area has now been implemented. In order to protect and to present the world heritage site, a park and a vegetated lane has been constructed around the watchtowers and along the ditch of the Roman border.

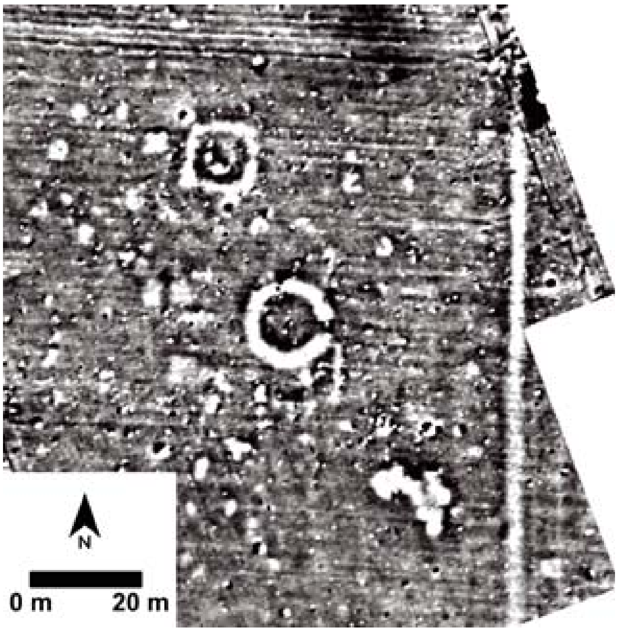

Figure 1: *Ravolzhausen (Hesse), greyscale plot of the magnetometer survey (white/black: ±2 nT), Fluxgate-Gradiometer Förster FEREX 4.032 DLG, 4 channels CON 650 (Institut Dr. Foerster, D); grid: 0.5 m × 0.2 m (crossline × inline).*

2. DITCHES AND WATCHTOWERS

Due to the extension of the Limes conflicts between the protection of this monument and recent building activities are sometimes unavoidable. In order to resolve this conflict in Ravolzhausen the state office for the preservation of monuments decided to realize a magnetometer survey. The course of the Limes and the positions of different watchtowers are shown very well by the greyscale plots of the survey. On the basis of the results targeted excavations has been carried out in the surrounding of the towers. Once the exact position and structure of the remains was known it was also possible to come to an arrangement and to redesign former planning. Taking the ancient structures into account the proposed development area has now been built. In order to protect and to present the world heritage site a park and a vegetated lane has been constructed around the watchtowers and along the ditch of the Roman border line.

3. THE COURSE OF THE LIMES

Another example from a site called Georgenthal shows that it is sometimes necessary to survey longer parts of the Limes. In this case, a golf course was planned in an area where one could expect a change of the direction of the Limes and where the exact

Figure 2: *Georgenthal (Hesse), greyscale plot of the magnetometer survey (white/black: ±8 nT), Fluxgate-Gradiometer Förster FEREX 4.032 DLG, 4 channels CON 650 (Institut Dr. Foerster, D); grid: 0.5 m × 0.2 m (crossline × inline).*

location was not known. Therefore, the magnetometer survey should show the whole run of the monument at that site. The data revealed both the course of the ditch and the smaller ditch of the palisade over a length of approximately 850 m, and the presumed change in the direction of the border line was identified (Figure 2). In addition, the foundations of two watchtowers were detected. Further planning can take into account the now well-known structures in order to preserve them and to integrate them into the system of the golf course.

4. SMALL MILITARY CAMPS

In addition to the Limes itself, other installations in the surrounding areas are of special interest. There are numerous military camps of various sizes along the former Roman border, frequently known only from 19th century investigations. Our knowledge about the exact location and arrangement of small camps is especially deficient. Because of that, the aim of the magnetometer investigation at the fortification at Kemel was to document the state of preservation and to check the excavation from the end of the 19th century. In contrast to the former investigative results, it is now possible to describe the whole situation of the two phases of military installations and their correlation to the Limes (Figure 3). Furthermore, one could observe the arrangement of the ancient buildings inside the camps. Even detailed observations were possible, such as the postholes of the gate towers. In this way, knowledge of the extent and structure of the systems are obtained, so that measures for conservation and tourism development can be planned and implemented.

5. FORT AND SETTLEMENT

Another example shows that along with the military installations, one should also examine the civil components of the border to understand the strategic and political dimension of the Roman frontier. At a site named Arnsburg-Alteburg, the northernmost Roman fort of the Upper German-Raetian Limes, a magnetometer and resistivity survey took place covering an area of more than 20 hectares (Figure 4). Although the basaltic bedrock affects the magnetometer survey, the results are more than satisfactory. In the data plots, one could observe the fortifications and the buildings of the fort and the remains of the civil settlement (*vicus*) in the central and southern part of the surveyed area. In addition the residential area with a main road and houses, it is also possible to identify public places and buildings like a representative official area (*forum*?) or sanctuaries. Furthermore, the survey data also shows a ditch around the civil settlement. This kind of fortification in connection with a Roman military *vicus* is only known in a few other examples. Most likely, this enclosure

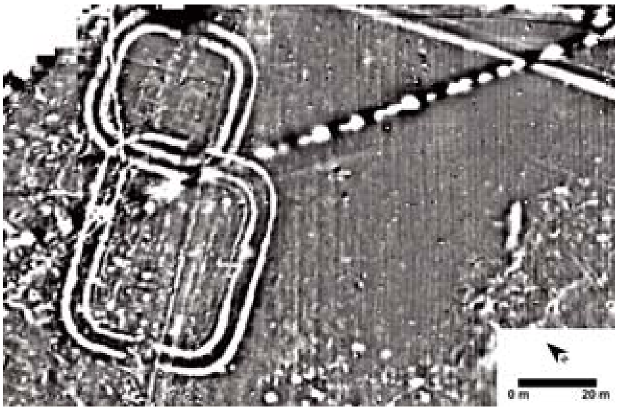

Figure 3: *Kemel (Hesse), greyscale plot of the magnetometer survey (white/black: ±8 nT), Fluxgate-Gradiometer Förster FEREX 4.032 DLG, 4 channels CON 650 (Institut Dr. Foerster, D); grid: 0.5 m × 0.2 m (crossline × inline).*

applied in a late phase of the settlement and is a consequence of the changed situation at the frontiers of the Roman Empire in the 3rd century AD. In view of the importance of this site for understanding the development of such places, and because the site is now well known, it is possible to develop a special program for the conservation of the whole complex.

6. COOPERATION

Finally, it must be noted that a lot of institutions, associations and people are working together for the development and the protection of this outstanding monument. Prospecting in particular would be impossible without the support and the cooperation of several institutions. Of particular note are the archaeological unit at the Hessian State Department for the preservation of monuments (hessenArchäologie im Landesamt für Denkmalpflege Hessen), and for the research at Arnsburg-Alteburg the Archaeological Society in Hesse (Archäologische Gesellschaft in Hessen e.V.). Representing other local authorities and voluntary associations, the municipality of Hohenstein and the Heimatverein Heidenrod e.V. are mentioned here.

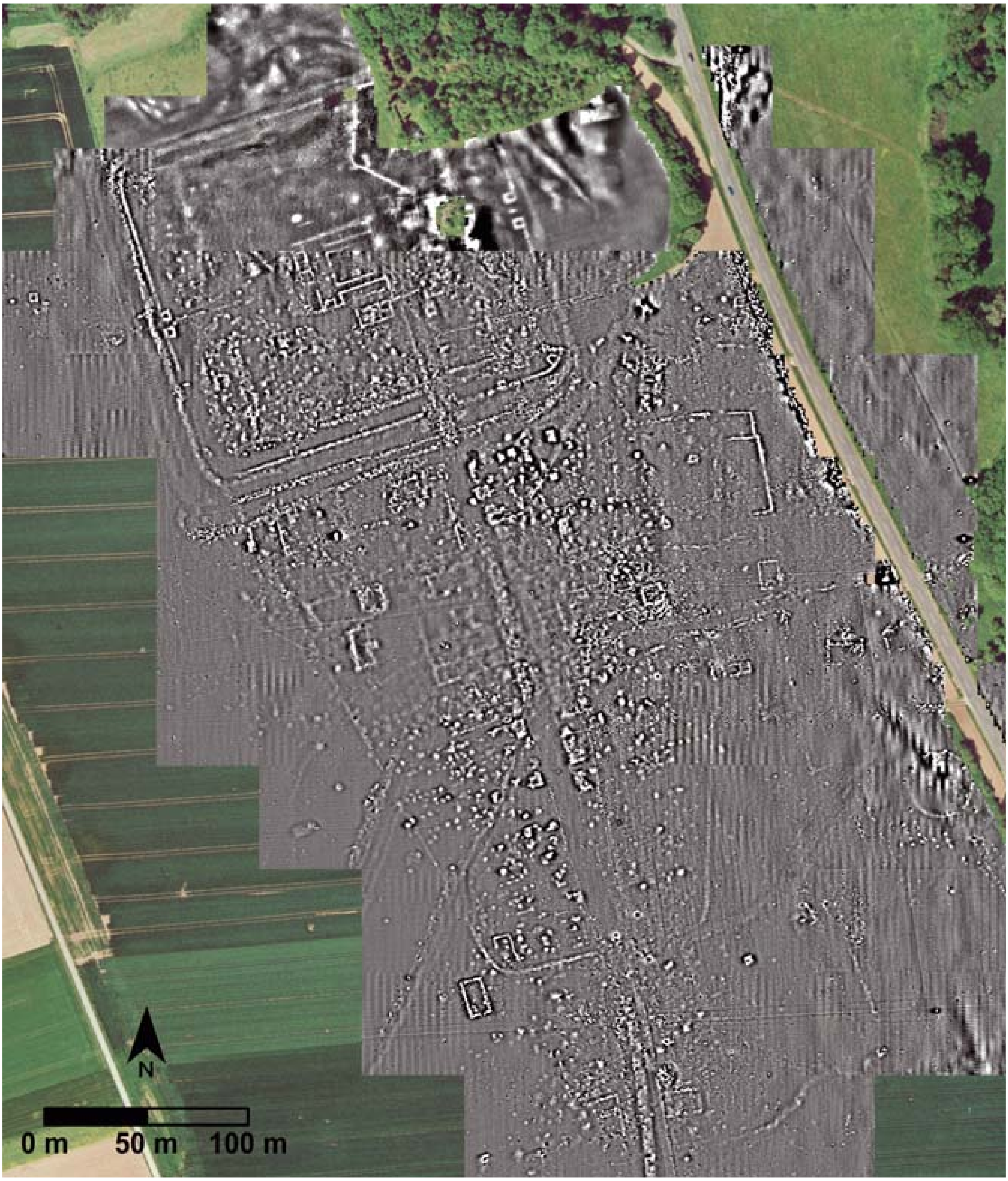

Figure 4: *Arnsburg-Alteburg (Hesse), greyscale plot of the magnetometer (high pass filter: white/black: ±18) and the resistance survey (northernmost part, high pass filter: white/black: ±18); Fluxgate-Gradiometer Förster FEREX 4.032 DLG, 4 channels CON 650 (Institut Dr. Foerster, D), grid: 0.5 m × 0.2 m (crossline × inline) and resistance meter RM 15 (Geoscan Research, Bradford, UK), twin-array; grid: 1.0 m × 0.5 m (crossline × inline).*

INTEGRATED GEOPHYSICAL PROSPECTION OF A LATE-MEDIEVAL MONASTERY IN LOWER BAVARIA

R. Linck, J.W.E. Fassbinder, F. Becker

ABSTRACT

Integrated geophysical prospection is a suitable way to get a detailed map of an archaeological site. Here, we begin with the discovery of a site by a routine aerial archaeology flight. For ground-based prospection, we employed magnetics, resistivity and ground-penetrating radar (GPR) to survey a late-medieval monastery in Bavaria. Whereas magnetics and resistivity prospection deliver a first two-dimensional image of the buried structures, GPR can provide depth information by producing depth-slices. The compilation of all surveys delivers the layout of the medieval monastery in detail, as well as supplying prehistoric and modern settlement traces.

1. INTRODUCTION

Integrated geophysical prospection together with the analysis of aerial photos offers the best possibility to get a substantial and comprehensive non-invasive map of an archaeological site. Each of the methods has its specific sensitivity to a special physical soil parameter. Here we present the case study of a medieval monastery in Lower Bavaria that illustrates the advantages of such an integrated survey.

The monastery is located several hundred metres from the modern village Aholming. Today, the name "Weihestätte" still reminds of the former medieval buildings, although the area has been used for agriculture for several centuries. The foundation of the monastery remains unknown. The first written evidence dates to 17 May 1381, when Ulrich der Chamerauer founded a benefice there. Therefore, we assume that at least the church must have already existed in the 1380s. In the middle of the 15th century, the monastery was renewed by Heinrich Nothaft zu Wernberg, but construction worked was stopped in 1501 by his successors, almost as soon as it was started (Mader and Ritz, 1926). Local traditions hold that, the monastery and the church were destroyed by a lightning strike in 1753, and afterwards the building material was reused elsewhere in the village. In the beginning of the 19th century, the area of the monastery was shown as a special field layout in the corresponding map of the Bavarian "Urkataster". Afterwards, the exact location of the former monastery was buried in oblivion. It was rediscovered in 1979 as a crop mark by the Bavarian aerial archaeologist Otto Braasch during one of his regular documentary flights for the Bavarian State Department for Monuments and Sites (Figure 1).

2. RESULTS

Since its rediscovery in 1979, the monastery of Aholming has been documented during all seasons by a huge set of aerial photos. These mainly show the outline of the church, and the monastery to the west of it as a negative crop mark (Figure 1). The building is surrounded by an enclosure, which occurs as a negative crop mark. Therefore, in the first publication and interpretation of the results by Christlein and Braasch (1982), the authors assumed that this is the trace of a wall around the monastery. Our geophysical measurements, however, indicate the occurrence of a ditch. Because of its layout, the ditch could possibly date to prehistoric times, or could be reused to surround the monastery. The enclosure encircles the remains of the medieval cemetery. Outside of it, an 18th century path is visible, which is noted in the contemporary map of the "Urkataster". The aerial photos show that the remains of the monastery only survived through a fortunate happenstance, as a nearby clay-pit was stopped only a few metres away because permission from the farmer was lacking. In another providential escape, the construction of a modern water pipeline again missed the archaeological site by only a few metres (Christlein and Braasch, 1982).

To get a more detailed map of the monastery, we conducted an integrated geophysical prospection project with magnetometry, resistivity and ground-penetrating radar in the late March 2011. This being the beginning of spring, the remaining melt water made the soil relatively wet. The value of the soil moisture has been 80 % of the capacity (Deutscher Wetterdienst, 2011). These conditions are quite suitable for resistivity prospection, but normally not very promising for GPR. However, from the middle of March on there has been nearly no rain, and the temperature was rising, so the moisture value was continuously declining. Therefore, even in these unfavourable conditions the GPR measurements were very promising. The hypothesis of poor GPR results at high soil moisture needs to be discussed at a higher level, although it is know that there can be a loss in resolution and penetration depth (Conyers, 2004).

While the archaeological site was prospected extensively with the magnetometer, we focussed the resistivity and radar prospection on the areas with stone foundations, as these methods can resolve best these structures.

The magnetometer measurements are highly disturbed by a metal fence in the west and the water pipe in the southeast. Nevertheless, the ditch can be traced very well (Figures 2a, 4). Surprisingly, in the interior of the earthwork only unspecific and undistinguishable anomalies of the church and the monastery are detectable, apart from some pits belonging to the medieval cemetery. This suggests that the walls had been constructed out of low magnetized rocks. The traces of a lightning strike and a resulting fire in the church could hence not be proved. Both the lightning strike and the scorch marks should otherwise be clearly visible in the magnetogram.

Whereas the ditch is the most prominent feature in magnetometry, it was only partly traceable by the other two methods. Especially in the GPR depth slices (Figure 3), only some vague traces appear, mainly in the northern part of the grid. This results is presumably related to the loess soil typical of this region. In the resistogram, the enclosure is also only slightly detectable because the enhanced soil moisture causes a suitable contrast in electric conductivity (Figure 2b). Both methods, however, reveal the walls of the monastery excellently. They had an average thickness of 1 m. The GPR time-slices prove that the

Figure 1: *"Discovery" aerial photo of 1979 of the monastery Aholming showing the layout of the church and the monastery and the surrounding ditch. Archive-Nr. 7342/100-2 Slide-Nr. 349-3. Photographer: Otto Braasch.*

archaeological remains are preserved in a depth between 50 cm and 100 cm. The east-west oriented church has a size of 26 × 12 m and a polygonal gothic apse in the east. Even the flying buttresses of the apse show up clearly. Like in the aerial photos, some further parallel walls became detectable in the interior of the nave. Together with another so far unknown apse and a squared altar fundament, they probably belong to the preceding church documented in 1381, as they are not oriented in the main axis of the newer building. Whereas the tower built at the northern side of the nave is traceable in both results, the sacristy and some side chapels built in the south are only discernible unambiguously in the resistogram. West of the church, the monastery building with a base area of 19 × 21 m had been erected. It is not constructed in the classic style with a central cloister and a circumferential conclave, but consists merely of several distinct rooms of varying size. The floor in the northeast room seems to be intact, as the area shows up as a high resistivity and a high reflection amplitude. Between the church and the ditch, some further stone structures of unknown use and origin were verifiable.

3. CONCLUSION

Through the results of our integrated geophysical prospection and analysis of aerial photos, a detailed map of the monastery of Aholming can be drawn. This documentation is essential, because this important archaeological site had already been largely lost for several centuries, and now faces possible total destruction by ploughing. As it is, the remains are only preserved to about 50 cm height, as shown in the GPR depth slices. The outcome of the survey is a prime example how geophysical methods and aerial archaeology perfectly complement one another because of their varying sensitivity on different physical parameters of the soil and the buried remains. Whereas magnetometers are sensitive to human or naturally caused anomalies in the earth's magnetic field, resistivity takes advantage of the differing electric conductivity, and GPR of the varying dielectric properties and therefore the reflectivity of the buried structures compared to undisturbed soil. Aerial prospecting depends on suitable weather conditions and suitable crops. Each of these parameters could be observed in Aholming: the magnetic anomaly is caused by the slow refill of the ditch and the differing conductivity and reflection amplitude by the stones of the monastery embedded in the loess soil. However, the finding of negative crop marks and the detection of a ditch remains as a contradiction that has to be solved by further research. So ideally, every archaeological site should be prospected by each method to get a comprehensive image of it and not to miss some findings only because of them not causing an anomaly of a distinct physical parameter.

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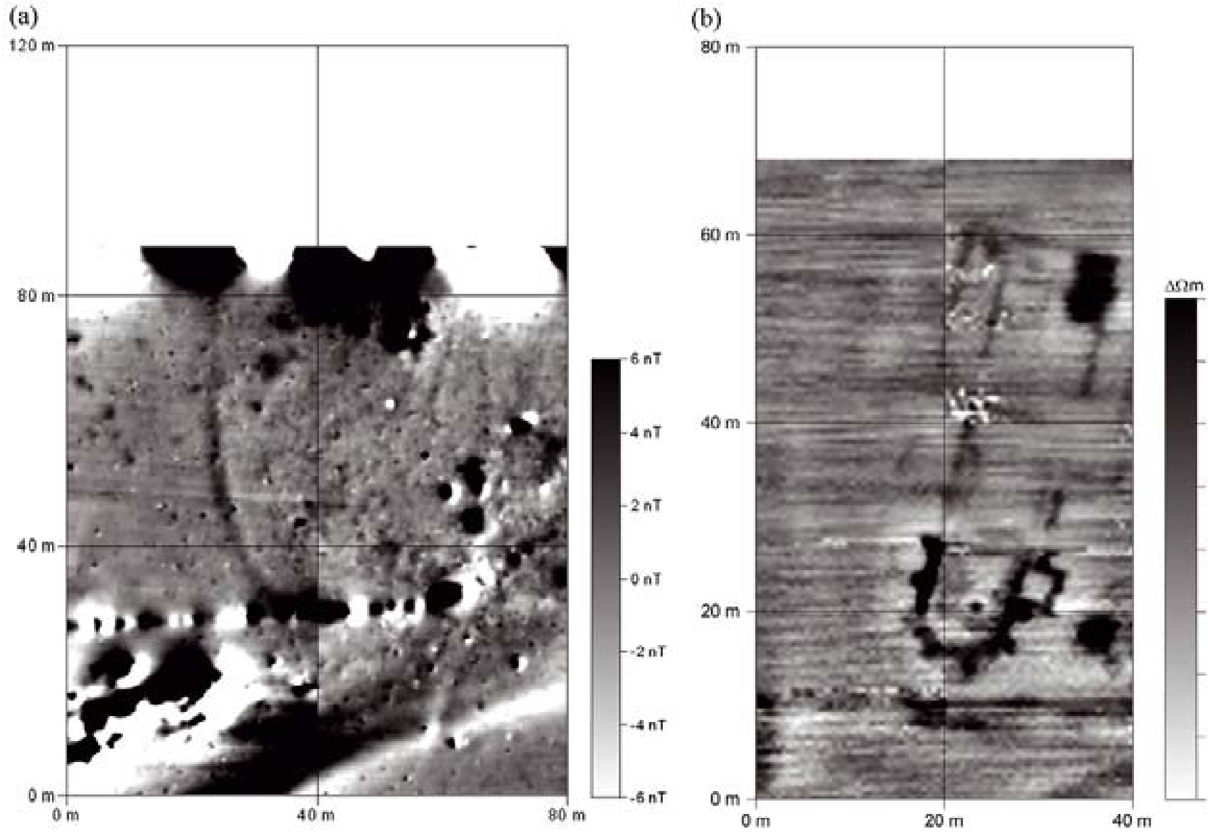

Figure 2: *(a) Magnetogram of the survey area. SM 4G-Special Caesium Magnetometer, duo-sensor configuration, sensitivity:* ±10 *pT, dynamics:* ±6 *nT, point density: 0.25 × 0.25 m. (b) Highpass-filter of the resistogram of the survey area. Geoscan RM15; sensitivity:* ±0.1 *Ohm metre; dynamics:* ±4Δ*Ohm metre; point density: 0.5 × 0.5 m. Archive-Nr. 7342/100-2.*

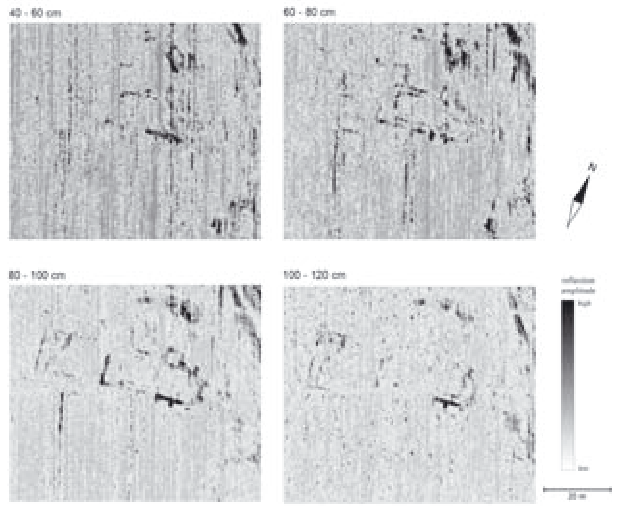

Figure 3: *Selection of GPR depth slices between 40 cm and 120 cm. Size of the area: 60 × 68 m. GSSI SIR-3000 with a 400 MHz antenna, sample interval: 0.02 × 0.25 m. Archive-Nr. 7342/100-2. In their northern edge, all three results again show the 19th century path, which was already known by the "Urkataster" and the aerial photos.*

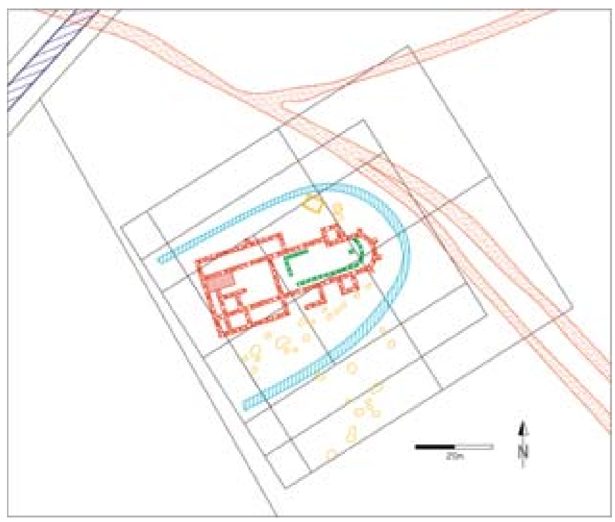

Figure 4: *Interpretation plan of the geophysical results. Blue: prehistoric ditch, green: remains of the first monastery, red: monastery of the 15th century, yellow: pits and walls of unknown origin and dating, brown: 19th century path. AutoCAD-Nr. 7342/100-2.*

ENVIRONMENTAL IMPACT ASSESSMENT: ARCHAEOLOGICAL PROSPECTING

L. Rocha, G. Branco

1. INTRODUCTION

Portugal, like most other European Union member states, has included in its legal system the EU legislation (*Directive 85/337/EEC of the Council of Europe, of 27 June 1985, and following*) relating to the procedures for Environmental Impact Assessments.

This Directive aims to: "*identify, predict and interpret the environmental impact which a project or activity would produce if it were to take place, as well as to prevent, correct and appraise the project or activity*" (Conesa Fdez.-Vítora, 2010, 75).

For these purposes, the proposing party (individual or public/private body) which is interested in implementing the project should submit an environmental impact study to the relevant body for licensing. This study is a technical document that identifies, describes and appraises the foreseeable effects of the project on the environment, which includes a description of architectural and archaeological heritage as human components of the environment.

In accordance with the legislation in force on the matter of safeguarding cultural heritage (*Law no. 107/2001 of 8 September 2001*), the description of architectural and archaeological heritage to be included in the environmental impact study must follow a specific method, formed by defining archaeological works, which can only be carried out by archaeologists who are duly authorised to do so by the supervisory institution.

The supervising institution for archaeological heritage issued a circular on this topic - *Terms of reference for Archaeological Heritage Descriptions in Environmental Impact Studies*[1] - which lays down the minimum methodological criteria for descriptions of archaeological heritage, considering the type and stage of the project being assessed. This method can be divided into 3 complementary stages:

1. Data collection – which is recommended to include: document-based and bibliographical research, consulting official body databases, toponymy and physiography analysis using maps;
2. Field work - carrying out systematic and/or selective archaeological prospecting in order to locate the evidence found in the previous stage, or identify new heritage elements;
3. Data processing – brief summary of the heritage elements found, with a view to creating a hierarchy of their scientific and heritage importance, identifying and assessing the foreseen impact of the project and proposals for minimising, compensating and monitoring measures.

Systematic and/or selective prospecting is the only field work considered indispensable for the description of architectural and archaeological heritage. This makes it possible to establish a link between previously acquired knowledge, available in other sources, and existing information in the specific area of the project, the target of the environmental impact assessment procedures. It is important to get to know the area, in order to safeguard it.

[1] Available at: http://www.igespar.pt/pt/account/formularios/circulares/

Figure 1: *Relationship between archaeological prospecting work performed in the context of archaeological prevention and research works.*

2. ARCHAEOLOGICAL PROSPECTING

The methods for describing architectural and archaeological heritage may include selective archaeological prospecting, to be performed when the project, which is the subject of the environmental impact assessment, has several possible alternative locations, so that the solution with the smallest environmental impact can be chosen.

Selective archaeological prospecting is understood to be a field walk through areas, selected based on specific criteria, which show archaeological potential based on the information and evidence gathered through research in books, documents, maps and others.

Systematic archaeological prospecting is understood as a field walk designed to visually identify and record all existing archaeological remains in the area foreseen for the project. The compilation of data available on the last 11 years (2000-2010) of archaeological activity in Portugal[2] shows that from 2002 onwards there was an increasing contribution of archaeological prospecting work performed in the context of preventative activities. This means, in most cases, that architectural and archaeological heritage description work was carried out, to be included in environmental impact studies.

In 2010, archaeological prospecting work carried out in the context of environmental impact assessment processes represented over 85% of contributions to inventories of existing archaeological heritage in Portugal, as opposed to archaeological pros-

[2] Compilation by the author, obtained by compiling the authorisation given for performing archaeological prospecting work, according to data available on *Endovélico*, the archaeological supervisory body's heritage database.

pecting activities performed in the context of archaeological research projects, with the aim of chronologically and culturally characterising an area.

Selective and/or systematic archaeological prospecting as a method for identifying archaeological remains has some limitations imposed, from the start, by an excessive dependence on visibility conditions of the ground. These limitations can cause consequences in terms of safeguarding archaeological remains, when the main objective is to describe, appraise and safeguard existing heritage in an area of land involved in the execution of the project.

As some authors recognise (Bakels and Kamermans, 2007), prospecting can only identify archaeological remains located up to a depth of 50 cm (arable soil), which is reduced drastically in non-cultivated areas, used for pasture and forests. As well as the use of the ground, the state of growth and type of vegetation, the results also depend on the time of year and the weather conditions under which the method is applied.

The fact that archaeological prospecting takes place in accordance with the timeframe for submitting the project for environmental impact assessment reduces its efficiency as a method for identifying archaeological remains.

These limitations mean that some countries do not consider archaeological prospecting an applicable method for managing cultural resources. For example, the Florida Department of Transportation exclusively allows diagnostic archaeological surveys - test pit sampling - whereas the Netherlands choose to collect soil samples - core sampling - that can reach a depth of up to 1.5m (Bakels and Kamermans, 2007).

One of the main issues raised when dealing with archaeological remains is connected with its interpretation as an archaeological site, which can be organized in a hierarchy according to the value of its heritage. Minimising impact in the execution phase of the project varies depending on this value.

The legislation on environmental impact assessments requires a description of archaeological heritage, understood as a significant set of evidence of past human activity. However, not all archaeological assets found during prospecting are significant for historical knowledge. For example, they could be archaeological material left in a secondary phase, depending on atmospheric agents and erosion.

Similarly, there could be sites which, depending on their state and the depth at which they are conserved, are undetectable through archaeological prospecting, meaning they are not taken into account in the relevant minimisation measures used in the execution of the project.

A research project is currently under way, supported by one of the authors of this paper (GB), which aims to assess the contribution of work carried out in the context of environmental impact procedures to archaeological knowledge in the Central Alentejo.

The preliminary data collected for this research, totalling 79 environmental impact studies from between 1995 and 2008, produced an inventory of 1535 heritage elements. Of these elements, 30% are buildings and architectural structures, 67% are archaeological remains and 3% are undetermined remains.

Dealing specifically with archaeological heritage, around 40% of the heritage assets are "*scattered remains*", i.e., material remains found at the surface of the earth during archaeological prospecting, which do not have sufficient characteristics to allow a functional or chronological conclusion to be made.

Concentrating on data on "*scattered remains*", around 19% were subjected to intervention - archaeological surveys – as part of projects to minimise impact performed in the area. The intervention made - for a total of 79 archaeological works authorised - mostly (66% of cases) did not show preserved archaeological structures or contexts.

3. CONCLUSION

In Portugal, the methods for creating descriptions of architectural and archaeological heritage to be used in environmental impact studies follows the methodological criteria defined by the supervisory body for archaeological heritage.

This method requires selective or systematic archaeological prospecting to take place, as field work designed to confirm the evidence and information gathered in bibliographical research, and to identify new heritage elements.

Heritage elements identified in the area which is foreseen to be affected by the project are attributed a cultural value. According to this value, minimising measures are proposed, whose costs will be covered by the project owner, to be put in place during the execution of the project itself. A project currently taking place in the Central Alentejo which intends to assess the contribution of environmental impact studies to archaeological knowledge has shown that prospecting as a preferred archaeological diagnostic method is not sufficient in adequately assessing the archaeological potential of an area affected by a project.

Around 66% of archaeological works performed in projects on archaeological remains classified as "*scattered remains*" did not reveal preserved archaeological structures or contexts. 34% revealed significant archaeological sites and, since they were subjected to intervention as part of the project, could produce delays and last-minute alterations in the execution of the project. It is important to recognise the limits of archaeological prospecting, above all when it is carried out under the pressure of a project, used with the aim of safeguarding archaeological heritage which, undeniably, will be affected by the project. It is important, therefore, to invest in knowledge and complementary diagnostic methods.

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TOWARDS AN INTEGRATION OF LASER SCANNER SURVEY AND GEOPHYSICAL PROSPECTION: AN EXAMPLE FROM THE NURAGIC SITE OF MONTE 'E NUXI-ESTERZILI (SARDINIA, ITALY)

G. Ranieri, D. Schirru, A. Trogu, A. Saba

1. AIMS AND INTRODUCTION

The examination of an archaeological, architectural or environmental asset today requires an interdisciplinary approach from a variety of specialists. To understand the structure of the soil and subsoil, which is the first phase of an archaeological research project, collaboration between archaeologists and geophysicists is essential. Indeed, it is well-known that geophysical methods are the fastest and cheapest way to detect archaeological remains in areas "hidden" from view. This study had as an objective the integrated high-resolution geophysical survey of the "Nuragic Sanctuary of the Waters" at Monte Enuxi of Esterzili (Sardinia, Italy) (Figure 1).

The site, although relatively small, has all the signs of the nuragic habitat. In particular, environmental resources and cultural identity exist together here. Its privileged location on the top of Santa Vittoria Mountain, the climate and the isolation in which it has been found for thousands of years, makes it a particularly interesting case study. This study was designed to contribute to the knowledge and appreciation of the site.

2. ARCHAEOLOGICAL FRAMEWORK

Characterized by an imposing shale Palaeozoic massif, mount S. Vittoria rises over the territory of Esterzili, overlooking it from 1,212 m above sea level. In the past, protected by thick woods and studded with springs, the mountain was one of the preferential Nuragic settlement places, both for its strategic position along the course of the Flumendosa and for the precious metal resources: copper, lead and zinc. Thanks to these features, a sanctuary village rose on the top of it, in the site of Monti 'e Nuxi, starting from the Recent Bronze Age (14th century BC). The settlement reached its apogee during the Final Bronze Age-late Iron Age (12th to 6th centuries BC). Archaeological research

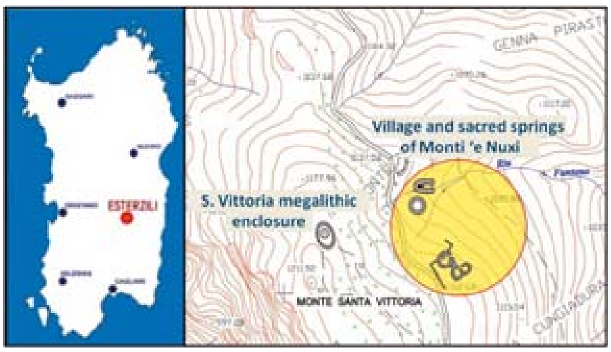

Figure 1: *Site location of Monti 'e Nuxi, with the main features highlighted.*

Figure 2: *Stone architecture from the site of Monti 'e Nuxi.*

at the site began in 2007, continued through the years 2009-2010, and is currently still proceeding, because vast areas of the village have yet to be explored. At the moment, there is evidence of four sacred fountains and about ten huts: one of them, the "meetings hut", stands out because of its monumental dimensions. The area is, moreover, enclosed by a megalithic wall that stretches for hundreds of meters, accessible through two doors, one uphill and the other downhill (Figure 2).

3. METHODS

A multidisciplinary high-resolution geophysical integrated exploration of the Monti 'e Nuxi Sanctuary has been developed to provide the necessary tools to integrate the different databases produced by applied geophysical survey, chemical analysis of groundwater, conductivity measures of in situ groundwater and laser scanner survey. A survey of the surrounding area was performed with non-destructive methods, in order to identify additional sources, to establish the link between the waters of different sources and connect the geophysical survey with a laser scanner map, for the integration of the previously excavated areas with the subsoil, and for a possible global reconstruction of the archaeological area for museum purposes. Because all the archaeological area is rough and irregular, the most appropriate methods for prospecting were those of electrical resistivity tomography (31 profiles) and electromagnetic in the frequency domain (1,850 square metres). The whole area was also measured by laser scanner survey.

The electromagnetic prospecting has revealed that the area is heavily altered and full of crashes, probably due to natural causes. Except in a few cases, where it was possible to recognize for example the distribution of water in the three sources upstream, or walls that evoke the idea of a fence of a sacred area, the EM prospection did not give very consistent results. Instead, the electrical prospecting has clearly emphasized structures that suggest the existence of another source and a wall, likely a con-

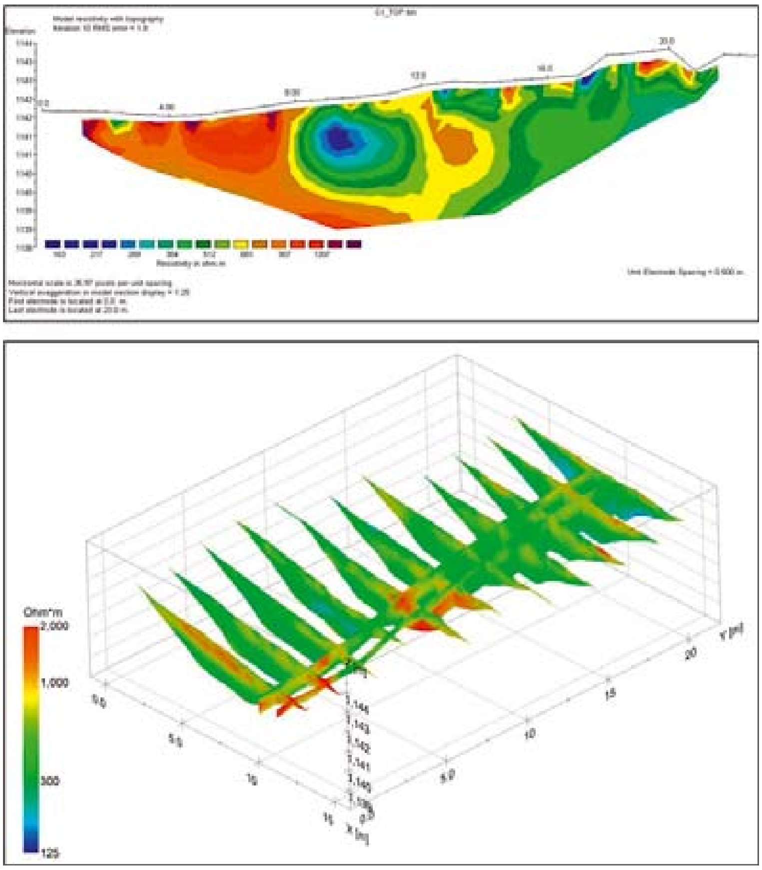

Figure 3: *Some results of the ERT surveys.*

tinuation of one recently excavated and that seems encircle the entire area.

The tomographies run upstream and downstream of the group of sources has allowed us to establish the paths of the water, with both sources feeding the outflow downstream (Figure 3).

A significant results is the possibility of developing joint digital representations of laser scanned and geophysical measurements, which allow us to show the data in a "different reality", which will be extremely useful to the archaeologist and where it is possible to "surf" as in an internet browser (Figure 4).

4. MAIN GOALS

The first goal has been defining the geological and hydrogeological surface structures on the site, along with the geometry and physical nature of the buried buildings. Achieving this goal will be certainly a decisive factor in future excavations aiming to explore areas that gave significant results in the terms of architectonic structures and remains of material culture. A second goal has been to produce an evaluation of the state of decay in the prehistoric structures, in order to suggest policies of preservation for a future protection and enhancement of the archaeological site.

5. CONCLUSIONS

The examination for a better knowledge of buried relics (subsurface geomatic model) consisted of an integrated use of two geophysical methods for medium-small depth survey: electromagnetic prospecting (EM) and electrical resistivity tomography (ERT). A survey with such techniques has allowed us to determine the geometry of relics, highlighting the most damaged areas, and also to reconstruct the structural settings of the parts where underground circulations of fluids is particularly prominent. For the knowledge of surface structures (geomatic oversurface model), surveys have been carried out on a micro-scale through non-invasive measurement techniques like 3D survey with terrestrial flight-time laser scanner. The prospection made it easier to outline anomalies and critical states that are essential to diagnosing and recognising the threat factors related to the interactions of water and archaeological structures.

This seems to be borne out by chemical analysis and by topographic survey performed with laser scanner. The sources 2 and 4 are certainly linked together, while the sources 1 and 3 appear distinct and clearly differentiated from the other two. Of great interest (not only archaeological) is the finding of the water temperature in the sources 2 and 4, the lower limit of the temperatures of the so-called thermal waters.

Not least, finally, the appearance of the museum could be developed jointly by the acquisition digital laser scanner - geophysical measurements-that allow you to make a representation of reality "different", which will be extremely useful to the archaeologist and in which you can "surfing" as the internet browser.

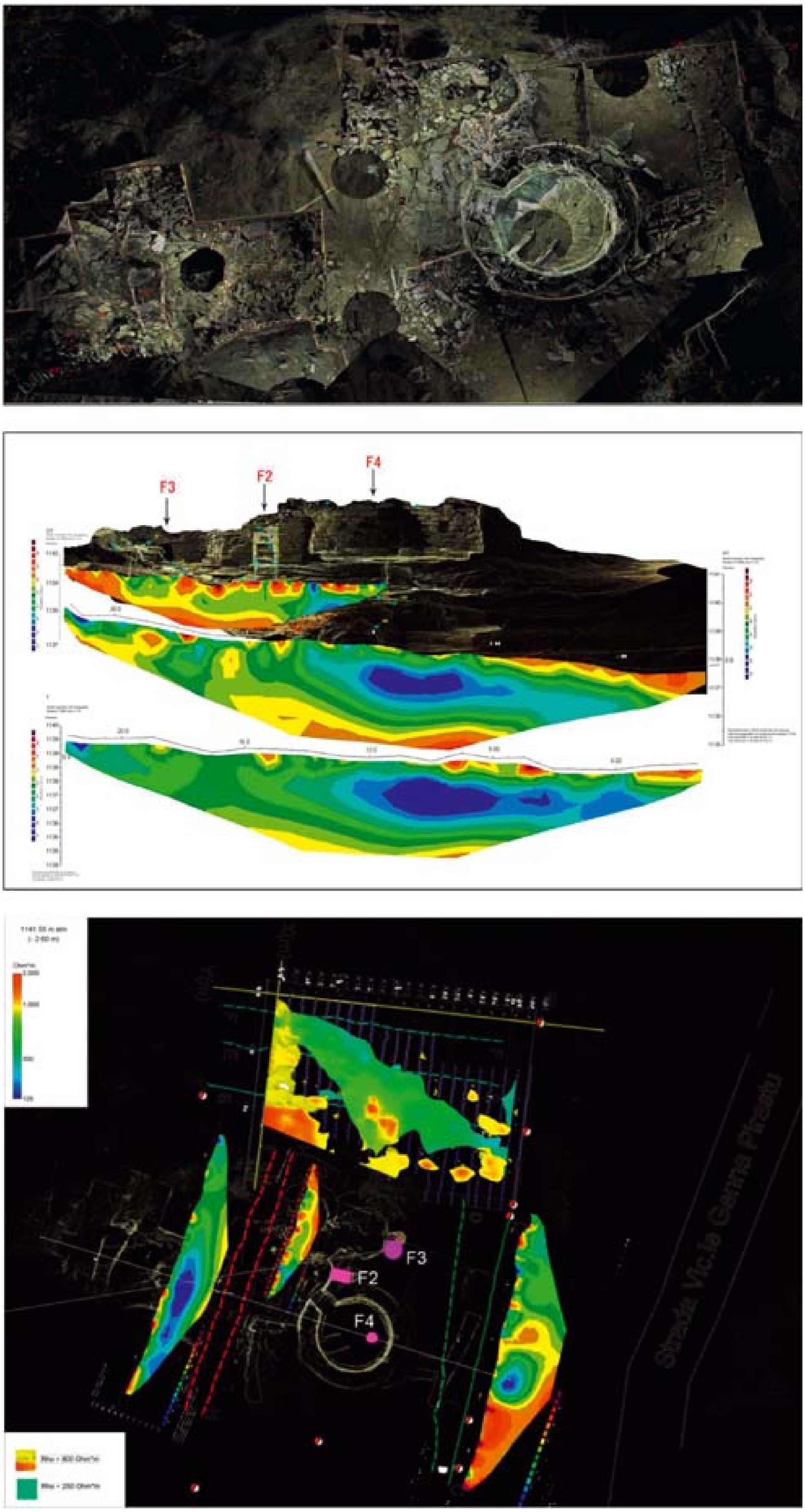

Figure 4: *Joint representation of ERT and Laser Scanner results.*

INTEGRATED GEOPHYSICAL SURVEY AT KATARINKA MONASTERY (SLOVAKIA)

D. Wilken, T. Wunderlich, W. Rabbel, H. Stümpel, R. Pašteka

1. INTRODUCTION

Katarinka (St. Katharein) is the name of an abandoned and partly destroyed Franciscan monastery from the early 17th century situated in the Lesser Carpathians in western Slovakia. It was closed in the late 18th century, and was then exploited for construction material. From 2009 to 2011, a comprehensive geophysical campaign was conducted at Katarinka. The primary objective of the campaign was to find the locations of foundation walls of the main building. Furthermore, historical charts show multiple adjoining buildings and structures, including eight chapels, a cemetery, a hostel for pilgrims and garden terraces, the true locations of which are not known.

To achieve these goals, we performed Ground Penetrating Radar (GPR), geomagnetics and Electric Resistivity Tomography (ERT). By employing multiple geophysical sensors, multi-method campaigns and high-resolution positioning it is possible to survey large areas at high-resolution with a minor expenditure of time. The backbone of prospection is geomagnetics (Neubauer, 2002), which is now typically performed with multi-sensor arrays (e.g. Hill *et al*., 2004 Rabbel *et al*., 2004). In many cases, it is reasonable to complement this by GPR, geoelectric, electromagnetic induction (EMI) or seismic methods (e.g. Erkul *et al*., 2011; Niewöhner *et al*., 2010). The reasons for this are mainly the lack of contrast in magnetic susceptibility, the missing depth resolution of magnetics and the blanking of signals having an archaeological origin by high-susceptibility near-surface anomalies (e.g. Niewöhner *et al*., 2010).

In this work, we will introduce the methodology of the campaign beginning with GPR and ERT measurements performed to image the foundations of the main building, and then describe a geomagnetics and GPR campaign performed to image adjoining buildings. The following processing section additionally comprises the application of topographic semicircle superposition GPR migration. Many authors point out the need for migrating GPR data (e.g. Heincke *et al*., 2005). The processing of GPR data commonly includes topographic correction as a time shift using a velocity estimate. Lehmann and Green (2000), for example, stated that conventional elevation corrections might not be feasible if the topographic change is of the same order as the depths to the target structures. They proposed a topographic migration by modifying the surface integration boundary of Kirchhoff migration. In this study, we implemented a much more simple approach based on semicircle superposition (Schneider, 1978). We tested the feasibility of this approach at one test area in Katarinka. We will then present the results, first for the main building and second for the surrounding area of Katarinka monastery.

2. METHODOLOGY

To image the foundations of the main buildings of Katarinka monastery we performed GPR measurements on multiple areas along the archaeological model. These areas can be seen in Figure 1. A 200 Mhz antenna was used in the areas KAT-G2-6. GPR processing includes the common processing steps described below. In the case where the topographic change of an area is larger than penetration depth of GPR, topography migration should be applied (Lehmann and Green, 2000). This was done in the area KAT-G2.

In the case that GPR cannot be performed due to strong covering of vegetation and extremely steep topography, we acquired ERT profiles. Each profile contains 32 electrodes of 1 m distance. Measurements were done in dipole-dipole as well as Wenner-alpha geometry.

To find adjoining buildings of the monastery, the geophysical campaign was extended to most of the area around the monastery using first geomagnetics (KAT-M1) with an array of six Foerster sensors (0.5 m distance) with dGPS positioning. Some smaller areas were then remeasured using GPR (KAT-G7-11 & KAT-G1). Here two 400 Mhz antennas were used simultaneously. GPR processing includes the common processing steps described below.

3. DATA PROCESSING

Magnetics: The vertical gradient of the vertical component of the magnetic field is measured using six fluxgate magnetometers with a gradient distance of 0.65 m and a sampling frequency of 20 Hz. Accurate positioning is achieved by a dGPS giving a coordinate every second. For each profile, a mean value is subtracted and the values are plotted in a map with pixel resolution of 20×20 cm and interpolated.

GPR: The common GPR processing consists of (1) setting of local coordinates and transformation to UTM coordinates, (2) averaging of traces resulting in 2 cm trace distance, (3) adjusting of time zero to correct for the antenna spacing, (4) background removal by subtracting a mean trace. An advanced processing step was migration as described below, which was only applied where necessary. Adjoining radargrams were spatially interpolated and amplitudes were summed in time intervals to result in time-slices. The velocity of electromagnetic waves was estimated by fitting hyperbolae of diffractions in various radargrams. In this study, we additionally implemented a simple migration approach based on semicircle superposition and thus diffraction of energy (Schneider, 1978). The basic idea of semicircle superposition is that the energy recorded at travel-time t at a receiver position x may be reflected from all scattering subsurface points on a half-circle with the radius (t/2)v (v is the GPR velocity). The recorded energy is thus smeared along this circle in the x - z (depth) domain. In our migration algorithm, this circle smearing is done only along a circle section that is defined by an assumed aperture of the antenna and oriented regarding the topographic slope.

ERT: The measured data were pre-processed by deleting values with negative measured apparent resistivity or with standard deviation larger than 10%. Due to considerable topographic variation, the height and horizontal location of each electrode were measured in the field and the determined coordinates were assigned to each measured value. The inversion of the apparent

Figure 1: *Map of the measured areas of the campaigns and an archaeological model of the main building based on the visible remains of the monastery (Herceg, 2009).*

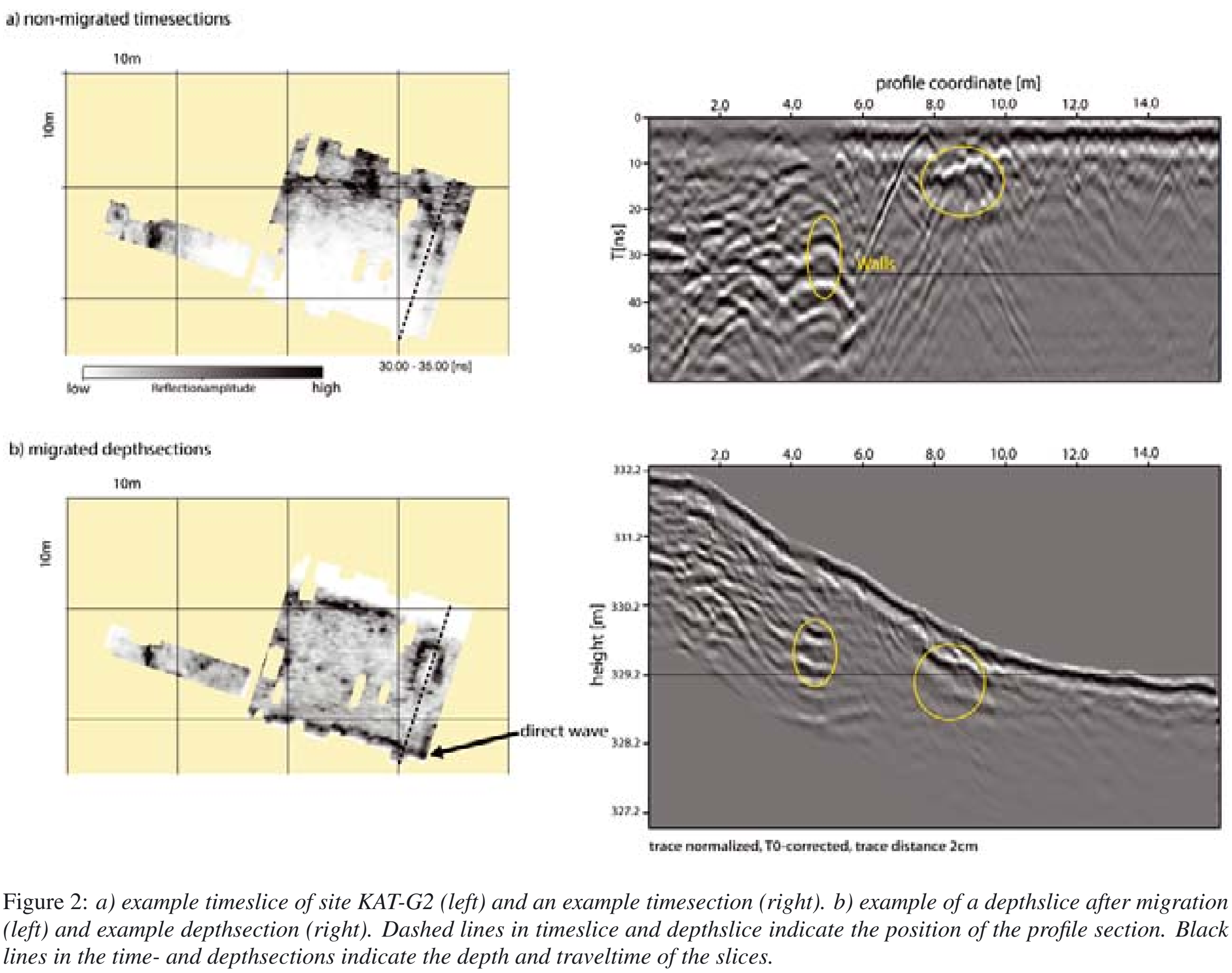

Figure 2: *a) example timeslice of site KAT-G2 (left) and an example timesection (right). b) example of a depthslice after migration (left) and example depthsection (right). Dashed lines in timeslice and depthslice indicate the position of the profile section. Black lines in the time- and depthsections indicate the depth and traveltime of the slices.*

Figure 3: *a) Magnetic map. Circles indicate the most obvious disordered accumulations of dipolar anomalies. The rectangle marks a lightning strike. b) Main building GPR results. The time interval for timeslices as well as estimated velocity are shown in grey boxes.*

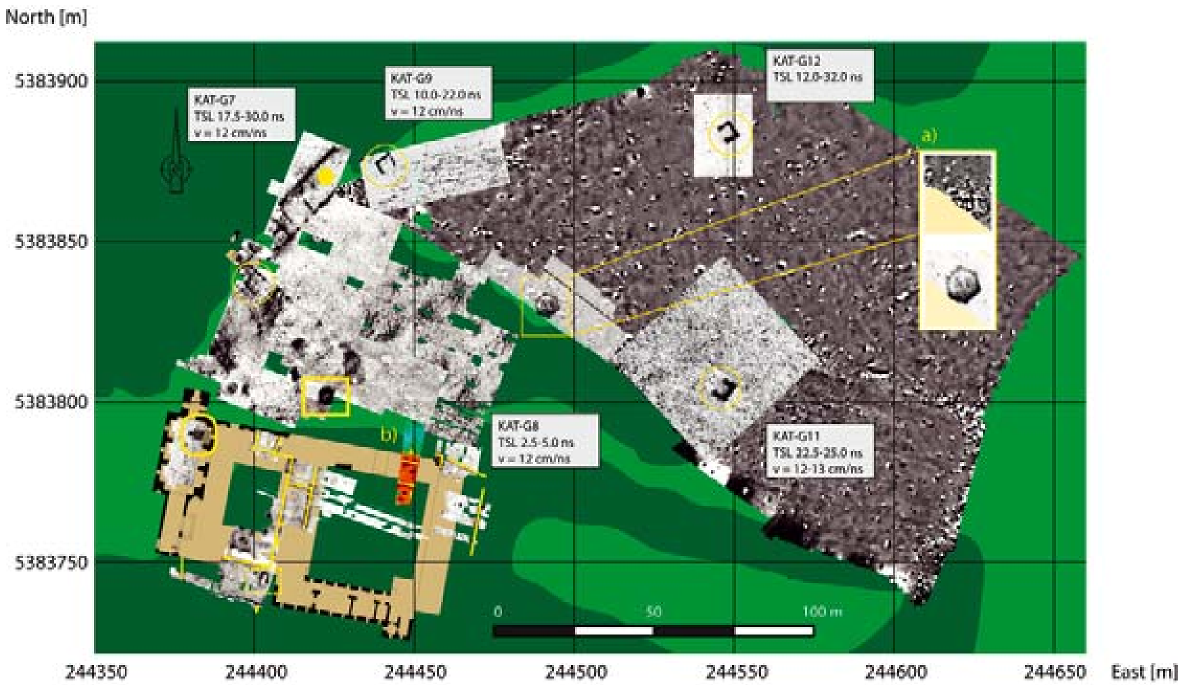

Figure 4: *GPR timeslices showing the significant reflection events. The time interval for timeslices as well as estimated velocity are shown in grey boxes. Underneath the magnetic map is plotted. The inset a) shows a comparison between magnetic and GPR results at one chapel position. Additionally an interpolated ERT depthslice is plotted (b) showing parts of the northern main building walls.*

resistivity pseudosections was done using the program Res2dInv (Loke and Barker, 1996), which takes into account the topography and exact global coordinates of each electrode.

4. RESULTS

As KAT-G2 shows topographic variation of up to 5 m, we will at first introduce the results of semicircle circle segment migration of this dataset. Figure 2a shows an example time-slice of 30 to 35 ns of the non-migrated data after common preprocessing. In the eastern part of the time-slice, two parallel linear reflection events are observed. In the northern part and in the western branch of the area, strong linear events can be identified. The right part of Figure 2a shows an example time section connected by the dashed line in the time-slice. Figure 2b shows a corresponding depth section of KAT-G2 after migration. The depth slice shows a clear rectangular structure where the two parallel structures were in the time-slice. Furthermore, both linear events in the northern and western part of the area are much more focussed after migration. The resulting depth section can also be seen on the right side of Figure 2b. Two clear reflection events of nearly the same depth can be assigned to the walls of the rectangular structure.

All other GPR sites dealing with the monastery main building are measured in areas with less topographic relief . Time-slices for the areas KAT-G1 & 3 to 6 are thus shown besides the migrated depth-slice of KAT-G2 in Figure 3b. The travel time range of the time-slices was chosen by the observed visibility of linear (wall) events. The plotted results show multiple linear events that are orientated parallel to the archaeological model and some events indicating inside walls of the main building. Inside the church, a known crypt (Pasteka and Zahorec, 2000) was imaged. In the area KAT-G2, a rectangular structure is observed.

The magnetic map of the adjoining area in the north shows four accumulations of strong dipolar anomalies (circles in Figure 3a) and linear clustering of anomalies in the south-eastern part. No clear building structures can be observed possibly due to the masking effect of the strong amplitudes. The rectangle in Figure 3 marks a lightning strike.

The accumulations of bipolar anomalies in the magnetic map are interpreted as disarrayed bricks probably from destroyed buildings. As we expect foundations below these bricks, small areas around the magnetic anomaly accumulations were measured by GPR (Figure 4). Most of the GPR results shown in Figure 4 are time-slices of greater thickness, summing the reflection energy to a footprint of the visible buildings being as much complete as possible. Under all accumulations in the magnetic map we found small buildings of about 5×5 m, three that have a U-shaped form (KAT-G9, 11 and 12) and one being a hexagonal building. In the area north of the monastery (KAT-G7 and 8) a long rectangular building with several partitions has been found. In area KAT-G8, no structures were found except the roots of trees (that stand in the gaps of the time-slices), which can be seen quite obviously in the shallow time-slices.

5. DISCUSSION

Figure 4 shows a combined image of GPR, ERT, and geomagnetic results. Inset 4a shows an example of a clear foundation structure of a chapel that is well resolved by GPR but masked in geomagnetics by anomalies from shallow objects. The GPR examination of all such magnetic anomalies finally revealed four U-shaped structures that are identified as open chapels (yellow circles) as well as a hexagonal building that was mentioned as a centre chapel (yellow rectangle). Three additional buildings of unclear origin were found. The largest visible object in the northwest might be explained as being a hostel for pilgrims. Others are a square object (thick yellow rectangle) and a rectangular object that was identified after successful GPR migration (dashed rectangle). Despite common full waveform migration approaches, the method used here assumes that only scattering affects the wave energy distribution. We argue that if the geometrical effect due to topography (radiation direction) and scattering are the dominant contribution affecting the amplitude, the approach leads to appropriate results. This assumption can be made if the background velocity is constant, no strongly damping material is observed and the spreading loss is mainly compensated by the initial gain curve. To be able to interpret the walls position of the main building, five parallel ERT profiles were done in areas that were not accessible by GPR. The results are shown as a depth-slice (Figure 4b). ERT and GPR results of the main building are interpreted with regard to the archaeological model. Most of the wall positions must be altered based on the geophysical results (Figure 4 yellow lines). The campaign revealed many locations of expected adjoining buildings but also gives new insights to the area, showing new structures that were not expected due to historical sources.

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We would like to thank Peter Herceg and Dr. Ivana Kvetanova and all helpers from Katarinka.

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GEOPHYSICAL SURVEYS AT THE EASTERN AREA OF JEBEL BARKAL ARCHAEOLOGICAL SITE, NORTHERN SUDAN

M.A. Mohamed-Ali, F.A. Omer, A.H. Abou, M.H. Elkabashi

Jebel Barkal is one of most important archaeological sites in northern Sudan, an isolated sandstone butte (Mohamed-Ali *et al*., 2010), which became the chief cult centre of the ancient Sudanese kingdom of Kush (ca. 800 BC-400 AD). Jebel Barkal is the site of numerous ruined palaces, temples, and pyramids (Kendall, 1982). This paper reports on geophysical results from Jebel Barkal as a continuation of an ongoing archaeological prospection project in Sudan. An example of a such work was reported in Meroe, the Capital city of Kush Kingdom (Mohamed-Ali *et al*., 2012). In early 2012, we carried out magnetic survey of about one hectare using a fluxgate gradiometer (FM256) in the eastern area of Jebel Barkal. The main goal of the survey was to prospect for extensions of the archaeological building structures discovered by non-archaeologists while digging trenches for communication cables along the old road connecting the towns of Karima and Merowe (Figure 1). The magnetic survey included the Natakamani palace, so as to resolve its internal details and to control the interpretation of magnetic data in other areas.

The resulting map (Figure 2) shows Natakamani palace and its internal structures, exactly as revealed from previous excavation (Donadoni,1990; 1993) and extended these features in the nearby areas. The magnetic map shows the existence of building structures (rooms and corridors) of mud brick, fired brick and stone blocks. These building structures extended northward and southward in unexcavated areas along the road. The weakness of magnetic contrast may be attributed to collapse and destruction of the mud-brick buildings due to the intensive traffic in the past along the road. The existence of a stone block rectangular room in grid H05 revealed by magnetic map (Figure 2) was verified by electrical resistivity tomography (ERT) profile1, which was carried out with an electrode spacing of 1 m. The inversion of ERT data were done up to only 3 iterations using the trial version of Res2Dinv, the inversion result of profile1 (Figure 3) shows rectangular bodies of high resistivity (1500 Ω·m) that might be associated with the same stone-block walls shown in the magnetic map. These stone walls are embedded to depth up to 0.5 m in sandy mud soil of low resistivity (5 Ω·m).

Figure 2: *Magnetic map of the study area, including Natakamani palace area and part of the Karima-Merwoe old road.*

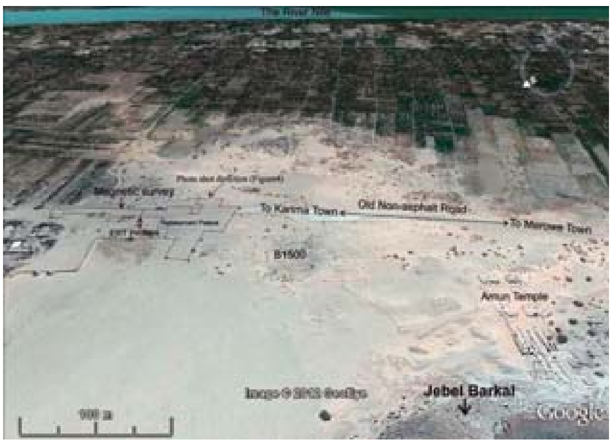

Figure 1: *Locations of geophysical surveys in the study area in the eastern area of Jebel Barkal, Northern Sudan.*

Continuation of the geophysical prospection in the current site is planned for the next year so that all features revealed by the geophysics can be used to fill the gaps in the site map, which is contemporaneously being prepared, based on excavations (Figure 4) carried in the past years, by the archaeologists and students from the Department of Archaeology, University of Dongola, Karima, Sudan.

ACKNOWLEDGEMENTS

The authors appreciate funds given for the project by the Sudanese Higher Education Ministry, Research Project Pro-

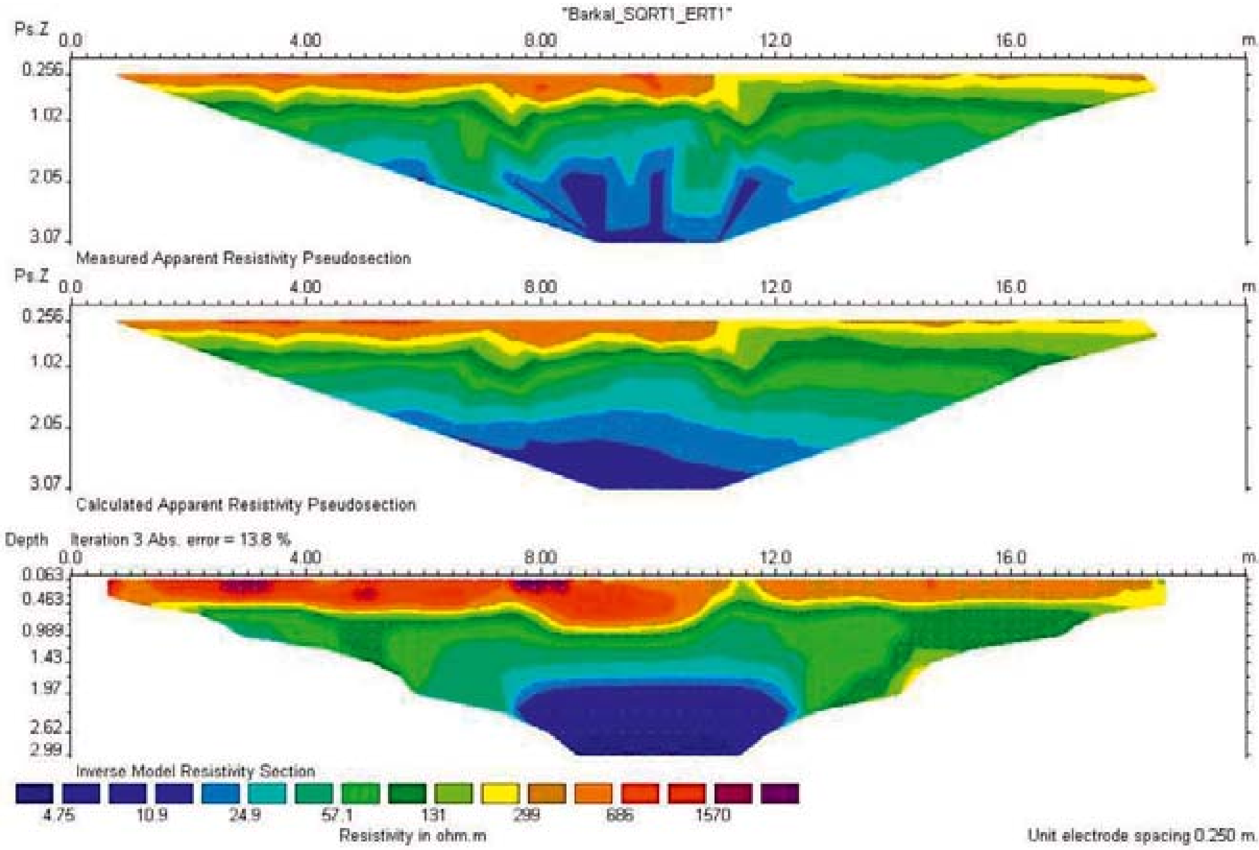

Figure 3: *The inversion result of ERT profile1 carried across magnetic grid H05 (Figure 2).*

gramme. Thanks are due to NCAM and Prof. Roccati and Prof. Ciampini from the Italian Mission at Jebel Barkal for cooperation and giving permission to work on the site.

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Figure 4: *Photo showing overview of the excavation carried out at grids H07 and I07 by the academic staff and student of final year 2011 in the Department of Archaeology, Faculty of Art, University of Dongola, Karima, Sudan.*

RECONSTRUCTING THE SPATIAL LAYOUT OF THE CHURCH OF ST. LAWRENCE, SIGTUNA, SWEDEN USING GROUND-PENETRATING RADAR AND PHOTOGRAMMETRY

A. Viberg, J. Schultzén, A. Wikström

1. INTRODUCTION AND BACKGROUND

The town of Sigtuna, situated in eastern central Sweden (Figure 1), was founded in the late 10th century and has been referred to as the first medieval town in Sweden. Sigtuna is home to many churches and church ruins which have attracted the interest of many scholars in the past.

The church in focus for this article, St. Lawrence, was first mentioned in a testament dated 1311 A.D. (Douglas 1978 and references cited therein), but it was founded significantly earlier than that. A runestone embedded in the foundation of the church suggests a TPQ of late 11th to early 12th century AD (Schück, 1957, 200f; Tuulse, 1968, 41; Bonnier, 1987, 21). According to a 19th century geographical description the church was damaged in the assault on Sigtuna in 1187. Again citing no sources, the author goes on to describe that, at least in the 16th century, St. Lawrence was a three-aisle church (Tham 1850:98f). This claim, however, is not supported by current archaeological research. According to the earliest historical map of Sigtuna, dating to the year 1636, the church of St. Lawrence consisted of a nave, west tower and church porch (sw. vapenhus) extending towards the south. There are several theories on the original function of the church. It has been suggested that St. Lawrence was the Episcopal church of Sigtuna (Schück, 1957, 197ff). According to Schück, the evidence for this lies in the dedication to St. Laurentius, which has its parallels in Old Uppsala and Lund, both Episcopal churches. Another interpretation is that it served as the parish church (Kyhlberg, 1991, 217). Yet a third theory suggests that St. Lawrence was a town church for the inhabitants of Sigtuna (Janse, 1916, 11; Sjögren, 1929, 249; Floderus, 1941, 112; Andrae, 1942, 129; Nordström, 1988, 19f) or became so after having first been a country parish church (Ros, 2001, 163). The church was abandoned during the reformation c. 1529 by order of King Gustav I, when all congregations in Sigtuna were merged into one. At that time, the church of St. Mary, previously the Dominican brethren's church, was adopted as town church (Strömsten and Svanberg, 1976; Viberg and Wikström, 2011). Indeed, the church of St. Lawrence seems to have been decommissioned at least before 1586, when it was transformed into a school (Douglas, 1978, 49).

Figure 1: *Map of Sweden showing the location of Sigtuna.*

According to Martin Aschanaeus, one of the first antiquarians of the Swedish National Heritage board, some additions were made to the tower during the reign of Johan III of Sweden (1568-1592) (Gihl, 1925, 17). A part of the west tower is still standing (Figure 2) and these additions might still be visible as the two remaining windows are lined with brick, which certainly was not an original feature. In 1658 a fire partly destroyed the building (Hilarion 1847:37). It was never rebuilt after this and the church of St. Lawrence was left to deteriorate until it was declared a protected monument in 1828. However, as nature rarely respects the laws of men, in 1832 lightning struck the tower, destroying the south-west top corner together with one of

Figure 2: *Photogrammetric 3D-model of the west tower of St. Lawrence. Model by Joakim Schultzén.*

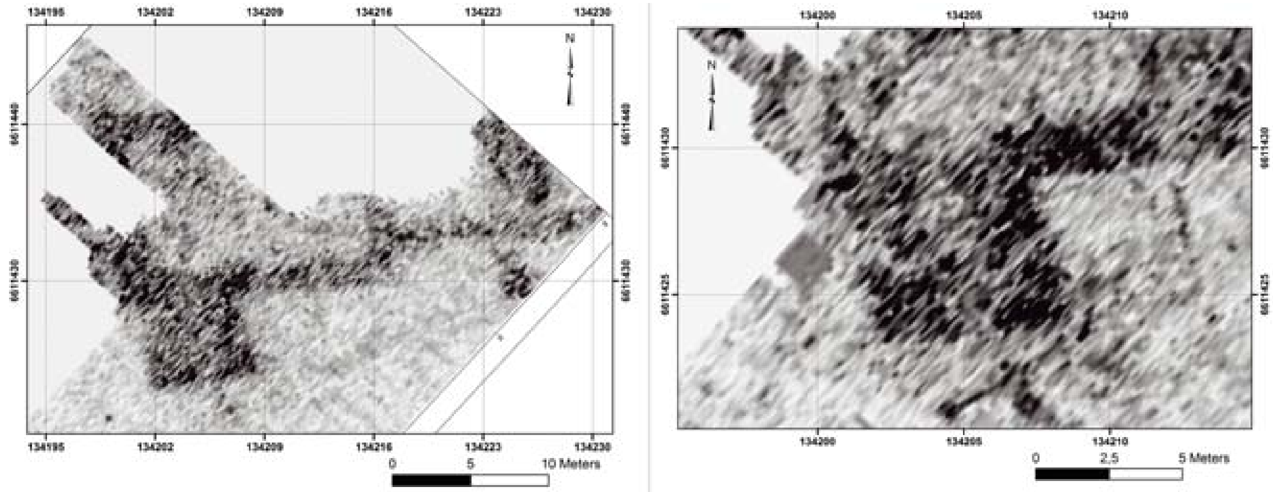

Figure 3: *(left) GPR depth slice of 2 ns thickness (c. 1 m below ground) showing the spatial layout of the church. (right) Detail of GPR depth slice of 2 ns thickness (c. 0.7 m below ground) showing the church porch and the entrance to the church.*

the originally three windows in the tower (Hilarion 1847:37).

Because of the limited evidence available; knowledge on the church's spatial layout has been uncertain. Limited excavations have been conducted in the area and a somewhat different spatial layout than what is indicated by the 1636 map have been suggested by Lars Redin (see Ros 2001, 161 and references cited therein), but as the size of the excavated area was relatively small, it was difficult to produce conclusive evidence regarding the spatial layout of the church.

With the purpose of producing a more accurate spatial layout of the church of St. Lawrence, a ground-penetrating radar (GPR) survey was carried out in 2010 on the lawn east of the standing remains of the west tower. The actual tower was also documented digitally using Photogrammetry to produce complementary information important for the understanding of, for example, the thickness of the walls, the orientation of the church, building material etc.

2. METHODS

The GPR survey was carried out using a 500 MHz antenna connected to a ProEx system manufactured by MALÅ Geoscience. The data was collected every third centimetre inline in transects separated by 0.25 m. Data processing and filtering was performed in Reflex 2D/3D. The survey area was 40.5 m wide and up to 32 m long, depending on the limited accessibility in the area surrounding the ruin.

The photogrammetric reconstruction was accomplished by taking overlapping pictures (ca 60%) 360° around the tower using a Nikon D2X with a 24 mm f/2.8 Nikkor lens. These pictures were then undistorted to compensate for the flaws that all lenses have due to their curvature and sensor alignment. In the system used for this model, Agisoft Photoscan, the function "undistort" was performed after the first alignment of the photos. This produced a second set of undistorted photos that was used instead of the originals. The mask function was then applied to the photos in order to exclude possible black areas that appeared on the edges of the undistorted photos since the images was retracted towards the centre. Also, the mask function was used in order to exclude highly contrasting areas, such as sky or very light or shiny objects in the background, from the alignment and the geometry building process. In the first alignment the system located reference points between the photos. After this the photos were combined, producing a geometric 3D-mesh, also referred to as a TIN (Triangular Irregular Network). On top of this a photo texture may be applied. There are different methods of creating a texture, but generally it is made up of a patchwork of the included photos. The result of the photogrammetric reconstruction is presented in Figure 2.

3. RESULTS AND DISCUSSION

The GPR results clearly reveal the spatial layout of the church (Figure 3). The church consists of a nave in the west and a choir in the east. The inside of the nave measures roughly 9.5 × 14.5 m and the outside measures c. 12 m × 17.5 m. The eastern choir measures c. 9 × 6-8 m and the thickness of the walls generally seem to be between 1 and 1.5 m. However, it is possible that the walls of the superstructure were thinner than the foundations they rested upon; the remaining walls of the tower which would have connected to the nave are just over 1 m thick.

There is a square anomaly centred north-south in the western part of the nave. The radar reflections from this anomaly fade quickly further down, at depths where the wall foundations are still clearly visible. This would indicate a thinner anomaly, such as a stone slab as opposed to a pillar foundation, which ought to penetrate to a deeper depth. It could be interpreted as a stone-covered grave chamber or perhaps more likely the foundations for a large baptismal font. In medieval times, the font was often positioned in the west nave opposite the entrance to the church (Källström, 2006, 190). However, the possibility that the anomaly represents a pillar foundation cannot be excluded. Ultimately, only an excavation could shed some light on this question.

Attached to the southern nave wall is a rectangular structure, which most likely is the church porch where the entrance was situated. In Sweden this is called a "weapon's house", as this would have been the place to leave any weapons before entering the church. The location of the church entrance is also revealed by an opening measuring c. 1.6 m in the southern wall of the church porch (Figure 3). The church porch would not have been part of the original layout, as no evidence exists for these structures prior to c. 1250 AD (Bonnier, 1987, 149f, 157f).

It is interesting to note that two walls seem to extend towards

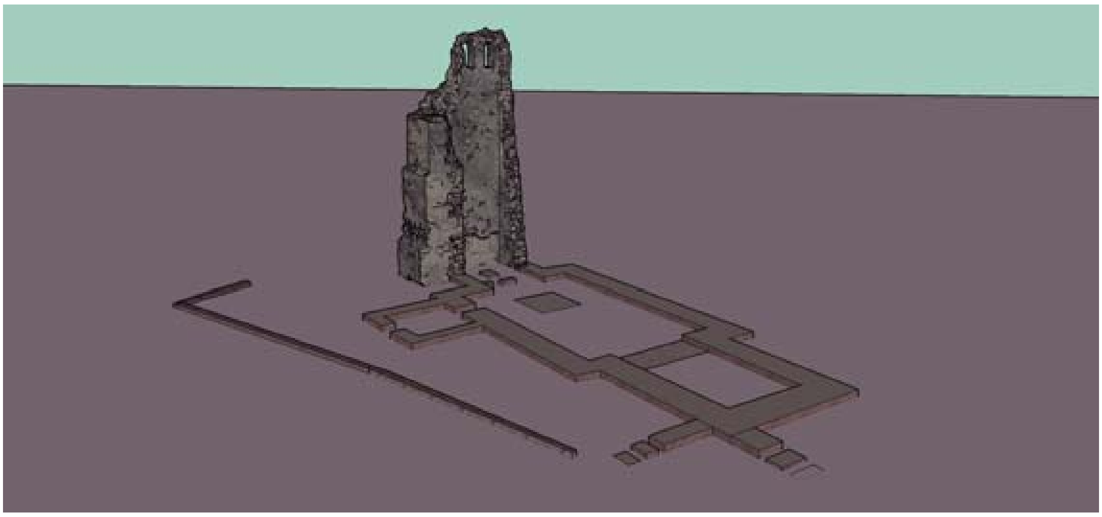

Figure 4: *The reconstructed layout of St. Lawrence based upon the GPR results in combination with the photogrammetric model of the remaining tower. The reconstruction includes features from the entire span of the church's existence and is not to be viewed as the layout at any specific point in time.*

the south and east from the corner of the choir. This might indicate the presence of a smaller building attached to the choir. It could also be an angled buttress or possibly a buttress to the south and a continuation of the choir to the east. If, however, these are indeed the foundations of a building, it would almost certainly not have been part of the original church, as there are no known parallels in Romanesque church architecture for such a layout. More likely, it is the remains of an extension, perhaps added in the 16th century when the church was transformed into a school. This question is difficult to definitively answer, as these walls seems to extend below the pavement south of the survey area.

The data also contain evidence of the remnants of a probable boundary wall enclosing the church to the south and west. On top of this boundary, just outside the church porch, a probable smaller building is visible in the GPR data. This building is, because of its location on top of the boundary, most likely of a more modern date.

4. CONCLUSIONS

When combining the GPR data with the photogrammetric reconstruction of the western tower a more complete picture of the church's spatial layout emerges (Figure 4). This interpretation takes remains situated both above and below the ground into consideration and, as such, permits a more accurate reconstruction to be made. The results could also allow archaeologists to carry out targeted excavations in the area or allow them to abstain completely from intrusive excavations, as the town's extensive urban cultural deposits would make any archaeological digs an expensive venture. The combination of geophysics and photogrammetry could therefore be recommended for investigations of other similar remains in the area in order to get an updated overview of the presence as well as the condition of the many buried remains of medieval churches in Sigtuna and elsewhere.

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SŁAWSKO – THE PRINCE'S WORTHY SEAT? NON-INVASIVE ARCHAEOLOGICAL SURVEYS

W. Raczkowski, M. Bogacki, W. Małkowski, K. Misiewicz

In the early Middle Ages, according to the opinions of historians, Sławno played an important political role in Pomerania (now North Poland). Prince of Sławno was mentioned in many documents (the oldest reference comes from 1119 AD), and the Land of the Sławno Duchy stretched from Koszalin to Lębork, Miastko and Bytów. During the 12th and 13th centuries, Sławno became a major center of the Racibor dynasty (Spors, 1983).

Previous archaeological studies located the fortified settlement near the present village of Sławsko (district Sławno). This settlement was levelled to the ground, probably in the middle of the 19th century due to the melioration, drainage and preparation processes of the riverside meadows for farming purposes (agriculture, livestock). Some scattered references indicate the presence of various wooden structures, iron tools and pottery shards in this area. The flattened remains of the settlement, as well as its location on the river meadows, seriously limits the use of traditional archaeological methods.

Verification archaeological works were carried out there in 1968. The results of these works have shaped the current idea of the location and dimension of the stronghold. It was assumed that settlement was fortified, in a ring-shaped construction of c. 120 m diameter, and the surrounding moat up to 20 m wide (Łosiński *et al.*, 1971).

Aerial photographs taken in 1997 (Figure 1) led to a critical reflection on current knowledge and methods of construction, of hypotheses concerning the state of preservation of buried remains and possibilities of reconstruction of its original plan. The ring shaped settlement lies a few dozen meters south of the place designated by archaeologists. Additionally, the diameter of the fortification (without the moat) is estimated at 70 meters. How it could be, then, that this rather small settlement was used as an ancestral seat of Prince of the Sławno?

This question was the starting point for a more detailed analysis combined with non-invasive surveys of the settlement itself and its surrounding area. These include an advanced analysis of aerial photographs from 1997, modern orthophotomap, detailed topographical measurements and geophysical surveys[1]. Field studies conducted in 2011 focused on the search for the remains of fortifications with use of the Bartington 601 dual flux-gate gradiometer and the Magmapper G858 caesium magnetometer combined with a RTK GPS. Multilayer resistivity profiling was used for gathering data on possible depths of features located by magnetic surveys. All maps presenting the results of geophysical surveys and topographical measurements were localized in the UTM 33N coordinate system.

Magnetic maps present changes of values of the total vector of the intensity of Earth's magnetic field (Figure 2 A) and disposition of values of the gradient of its vertical component (Figure 2 B) resulted by the presence of buried archaeological remains. Complementary measurements of the vertical component of the total vector of the Earth magnetic field was carried out with the aim was to calibrate the results obtained from caesium magnetometer. In the case of the surveyed site, gradiometer measurements localized features lying no deeper than 1 m. It was possible to separate anomalies caused by features lying close to the surface from all anomalies registered with the use of caesium magnetometer.

Data concerning the depth of the buried objects were verified on the most promising areas with multi-level electro-resitivity profiling. Measurements were conducted using a dipole-dipole measuring system with an AC-ADA05T device. Different distances between measuring and current probes (D= 2, 4 and 6 metres) enabled gathering information about the distribution of apparent resistivity values with the penetration of current equal to 1, 2 and 3 metres (Figure 3).

A second type of map (Figure 4) contains information about the shape of the terrain surface, including all terrain discontinuities (riverbanks, escarpments, slopes, ditches), and changes that may have anthropogenic origins or natural reasons, such as the course of the river Wieprza oxbows. A Digital Terrain Model (DTM) was constructed from elevation data of the points measured with the magnetometer (work interval, every 0.1 seconds). RTK GPS measurements made with a precision of $\pm$ 15 mm and collected for 40,000 points per ha made it possible to observe very small terrain discontinuities on land that is now covered with a uniform layer of vegetation.

Comparison of the geophysical surveys and the DTM brings us closer to answering the question: where was the Sławno fortified settlement originally built, and what was its structural design? The indication of dwelling location is possible after recent fieldwork, and the general properties of the architecture, such as line of the inner and outer ring of fortifications or moat could be also determined (Figure 2 C D). The surface of settlement

Figure 1: *Aerial photograph of the site made in 1997 by W. Rączkowski.*

[1] The project was financially supported by Ministry of Culture and National Heritage (no 1548/11), Sławno Community and the European project ArchaeoLandscapes Europe (no 2010-1486 / 01-01).

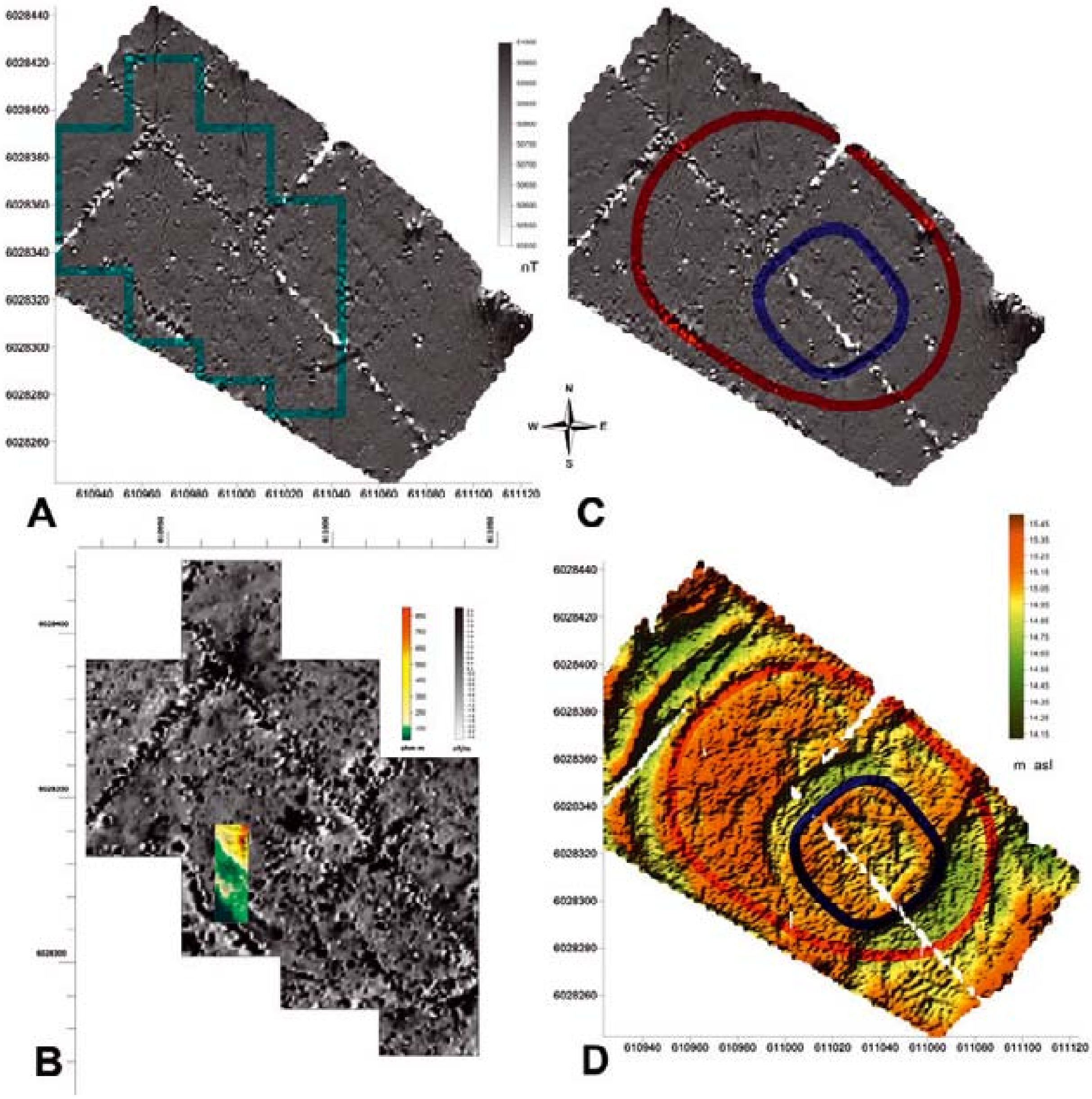

Figure 2: *Maps illustrating the results of non-invasive archaeological surveys: A. Registered values of the total vector of intensity of Earth's magnetic field B. Measurements of the gradients of vertical component with map presenting the result of resistivity survey Reconstruction of the extent of the site on the base of magnetic survey C and topographical measurements D.*

is nowadays almost completely levelled, but the relatively small terrain differences (in the range of 1 m), can be measured and recorded using GPS (XYH) coordinates simultaneously with the geophysical magnetic measurements Due the geophysical survey, we now have information about not only the location and depth, but also about the character and state of preservation of the remains. Strong dipole-dipole anomalies, confirmed by low values of apparent resistivity registered in the same places, appear when heavily burned structures are the sources of detected anomalies. Moreover, the concentration of archaeological objects is visible as a group of anomalies lying close to each other on the magnetic and electric survey maps. Based on the analysis of all collected data, it is possible to plan further activity on the surveyed site. It is easier to locate trial pits and to limit large-scale excavations the minimum necessary for dating and reconstructing the sequence of layers preserved on the site. Acquired data should also contribute to preparing a conservation program for the local National Heritage Management office.

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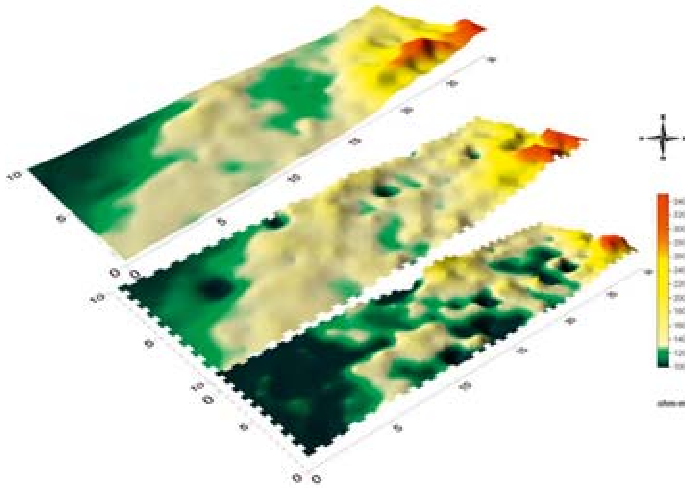

Figure 3: *Maps of the apparent resistivity measured with the distance of current probes D equal subsequently 2, 4 and 6 m.*

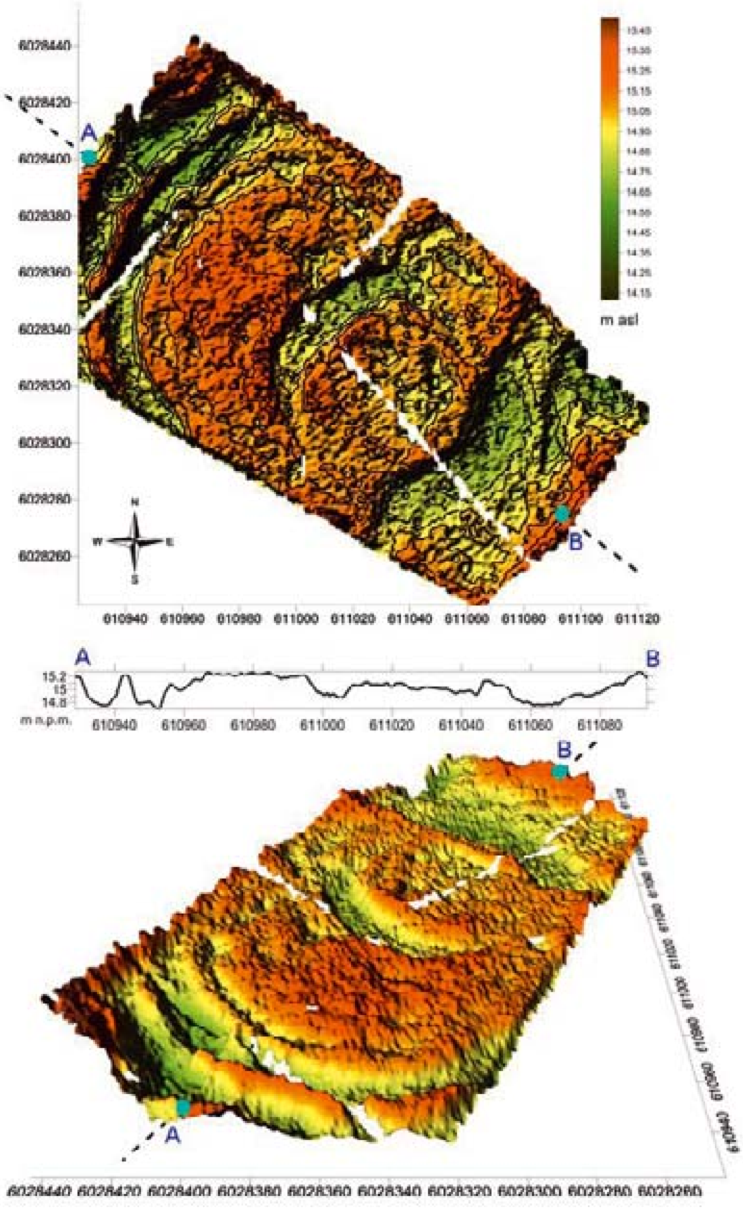

Figure 4: *DTM of surveyed field.*

WHAT CAN SOIL MARKS TELL US? UNDERSTANDING THE INFLUENCE OF BURIED ARCHAEOLOGICAL REMAINS ON THE SPECTRAL PROPERTIES OF SURFACE SOILS

Y.J. Choi, D. Jordan, T. Wagner, T. Mahr

The colour of soil surfaces above buried archaeological remains sometimes differs from the natural background soil colour because archaeological strata are mixed into the surface soils. Such differences are detectable in reflectance spectra recorded in airborne hyperspectral images in the visible and near-mid infra-red regions. Thus, such remote sensing techniques can be used to detect buried archaeological remains. However, the origin of the reflectance spectral properties of buried remains is complex, and while archaeologists routinely record the colour of archaeological strata during excavation, the way these colours influence those of the soil surface above has not been widely studied. This limits the potential of airborne hyperspectral imaging as an archaeological prospection technique because it cannot be targeted at sites and soils where it is most likely to be effective and because the reflectance spectral variations it records cannot be confidently interpreted unless they form clearly recognisable patterns. This is significant because airborne hyperspectral imaging is expensive and targeting it at sites where it can be most effective is essential if it is to be efficiently used. Moreover, the spectral information which airborne hyperspectral imagery provides is of limited value unless we understand the various properties and influences. Otherwise, it only indicates where there are variations but tells us little about their meaning.

This study aims to clarify where and how hyperspectral remote sensing can identify buried remains as changes in the reflectance spectra of bare soil surfaces. The study is analysing the way in which the reflectance spectra of archaeological deposits form and change in the ground and how these spectral properties become detectable at the ground surface.

Spectral measurements have been taken, using a portable spectrometer with range of 350-2500 nm and resolution of 1 nm. The measurements were taken at an archaeological site in Calabria, Italy, where late prehistoric archaeological remains were identified as surface concentrations of pottery and as geophysical anomalies. Measurements were made along two, orthogonal 50 m lines, which crossed the soil overlying the archaeological site and the natural background soil to each side. Spectra were recorded from bare soils surfaces, at a range of spatial scales, along each 50 m line across the natural soil and the archaeological site. The reflectance spectra of the natural soil surface and the surface overlying the archaeological remains were then compared. Spectral measurements were also recorded from each stratum as the archaeological remains were excavated, both in plan and in section (Figure 1). These spectra were then analysed, along with detailed geoarchaeological and geophysical analyses of the same strata, in the field and laboratory, to clarify the origins of the spectral variations observed and the processes by which they were transferred from the buried strata to the soil surface.

This detailed study of a single site is being carried out as part of a wider analysis of the processes that have formed archaeological remains, and the properties that can be detected by prospection methods, across the wider landscape. The conclusions of this are being compared with those from contrasting landscapes to explore the potential and constraints on prospection under different conditions (Figure 2).

Figure 1: *Recording a reflectance spectrum above an exposed archaeological stratum during excavation.*

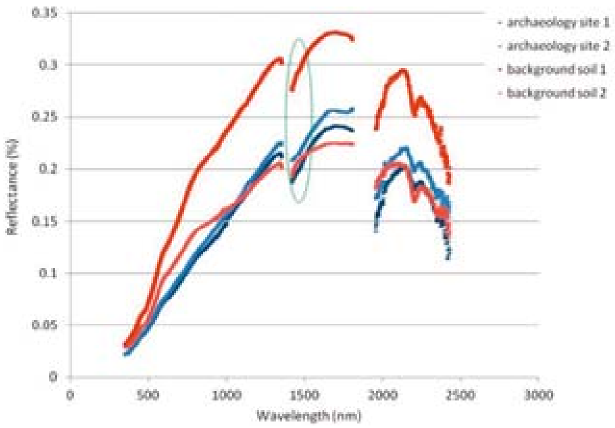

Figure 2: *Contrasting reflectance spectra of the soil surface at the archaeological site and the adjacent natural soil surface. For example, around 1500 nm (green circle), the archaeological site soil spectrum has a convex form while the natural soil spectrum is concave. The gaps in the spectra are the result of both instrument and atmospheric effects.*

This project is one part of a wider collaboration between the Johannes Gutenberg University Mainz, the Max Plank Institute for Chemistry, the National Museum of Hungary and the Universities of Leuven and Groningen.

THE NEOLITHIC FLINT MINE OF ARNHOFEN IN LOWER BAVARIA, SOUTHERN GERMANY: AERIAL ARCHAEOLOGY, MAGNETOMETRY AND GROUND-PENETRATING RADAR SURVEYS

J. Koch, J.W.E. Fassbinder, R. Linck, K. Eisele, M.M. Rind

1. INTRODUCTION

Situated in an estuarine environment on the hilly landscape of the upper Danube region, the Neolithic flint mine of Arnhofen is a monument with international significance. Numerous tools made from the premium fine-grained, banded grey tabular flint are recorded from many prehistoric sites since the Early Neolithic. Regular flint mining in Lower Bavaria appears to begin with Linearbandkeramik communities. While the Middle Neolithic period witnessed the greatest intensity of mining, raw material from Arnhofen was distributed over a broad area of more than 500 km, into different cultural spheres of Central Neolithic Europe: towards the Danube river and the Rhine-Main area to the Middle Elbe-Saale region in the north, to Bohemia in the east and further down the Danube river to distant Neolithic settlements in Lower Austria. At the foothills of the Franconian Alb, more than one thousand mining shafts testify the remarkable prominence of the typical Arnhofener Plattenhornstein (Figure 1).

2. ARCHAEOLOGICAL EXCAVATIONS 1984-2008

Discovered within recent gravel mining activity during the 1970's, the Neolithic flint district of Arnhofen was primarily subjected to rescue excavations under the tutelage of the Bavarian State Department for Monuments and Sites. In 1998, M. Rind initiated a priority program, coordinated by the Kelheim County Office, for substantial excavation campaigns in order to get new information regarding prehistoric mining technology. As a result, more than 600 mining shafts with a diameter of 0.7 – 2.2 m and a maximum depth of 8.5 m were documented by the end of 2008. Covered by thick sand, a remnant of the Freshwatermolasse and gravel strata deposited by the river Abens during the Quaternary, the Arnhofen flint deposits were secondarily transferred into unique geological circumstances readily accessible for the benefit of mankind.

3. ARCHAEOLOGICAL PROSPECTION 2011-2012

As recent archaeological investigations focused on detailed studies of limited sections in the late 1990s, the whole extension of the Arnhofen mining district has been estimated to cover a maximum area of 28 ha. Re-evaluation, however, suggested a minimal surface of at least 40 ha and included more than 130,000 mining shafts, although the original boundaries have not yet completely been identified by previous transactions. Therefore, a new project funded by the German Research Foundation was started in 2011 in order to fully investigate the original extent of this unique prehistoric site by combining both geophysical and archaeological survey methods.

Figure 1: *Arnhofen. Pit shafts of the Neolithic chert mine uncovered during former excavation seasons.*

4. AERIAL ARCHAEOLOGY, MAGNETOMETRY AND GROUND-PENETRATING RADAR SURVEYS

During 2011-2012, geophysical measurements were conducted using two Caesium-Magnetometer Smartmag SM4G-Special at a maximum distance of 1.5 km from the former excavation site. While the southern boundary was already detected within the archaeological zone, the results of our prospecting campaigns are able to revise the westernmost extension of the Arnhofen chert district. In an area where no visible features were recorded by aerial archaeology, the magnetometer data indicates clear evidence for mining activity spreading to the very south of the modern village (Figure 2a). Due to the secondary gravel overburden at the very top of the pithead and the recent layers of humus topsoil, investigations of subjacent Neolithic features are exclu-

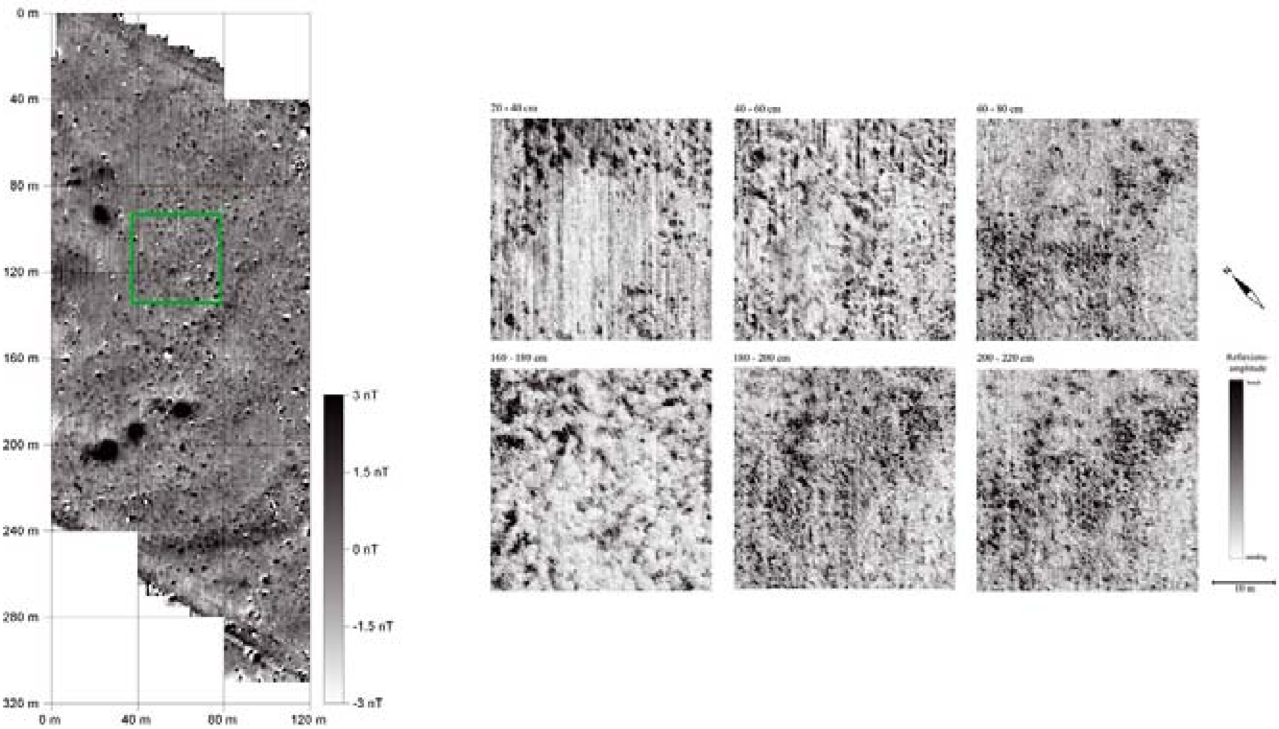

Figure 2: *(a) Magnetogram of a newly discovered mining zone in the westernmost area of the Arnhofen chert district. Caesium-Magnetometer Smartmag SM4G-Special in a duo-sensor configuration, dynamics* $\pm$ *3nT in 256 greyscales, sensitivity* $\pm$*10 pT, sample interval 0.5* $\times$ *0.25 m, interpolated to 0.25* $\times$ *0.25 m, 40 m grid. (b) Map of a complementary ground penetrating radar survey supporting the results of previous magnetometer measurements as a detailed case study in 2012. Depth slices between 20 – 80 cm and 160 – 220 cm. GSSI SIR-300 with 400 MHz-antenna, sample interval 0.02* $\times$ *0.25 m, 40 m grid.*

sively reserved for non-invasive geophysical prospection methods. Beside numerous mining shafts, there are few settlement patterns that can a priori be associated to Neolithic fireplaces or seasonal dwellings.

The interpretation of the substantial magnetometer data as showing archaeological features of the Arnhofen chert mine is verified by the results of a complementary ground-penetrating radar survey conducted as a detailed case study in 2012 (Figure 2b). While recording the extension of single emerging anomalies in a maximum depth of 240 cm, it turned out that the Neolithic pit shafts are visible in varying profundities depending on a greatly alternating consistency of different backfilling. Areal overlays of pithead stocks can firstly be distinguished in the upper parts, and separated from antecedent anthropogenic structures and naturally occurring geology in the lower parts.

While the northern boundary is yet unknown, the overall extent of the Arnhofen mining area can be completely revised. Thanks to vital evidence from aerial archaeology, the factual dimensions can already be estimated to extend over more than 2.0 km in total (Figure 3). Comparing the density of features surveyed by aerial prospection to the results of our magnetometer measurements, there is a huge increase in the number of structures related to Neolithic mining activity (Figure 4). Besides the very homogenous patterns of strata, varying geological circumstances caused heterogeneous backfilling of single mining shafts that could provoke both positive and negative magnetic anomalies, which can best be detected by highly sensitive geophysical prospection methods.

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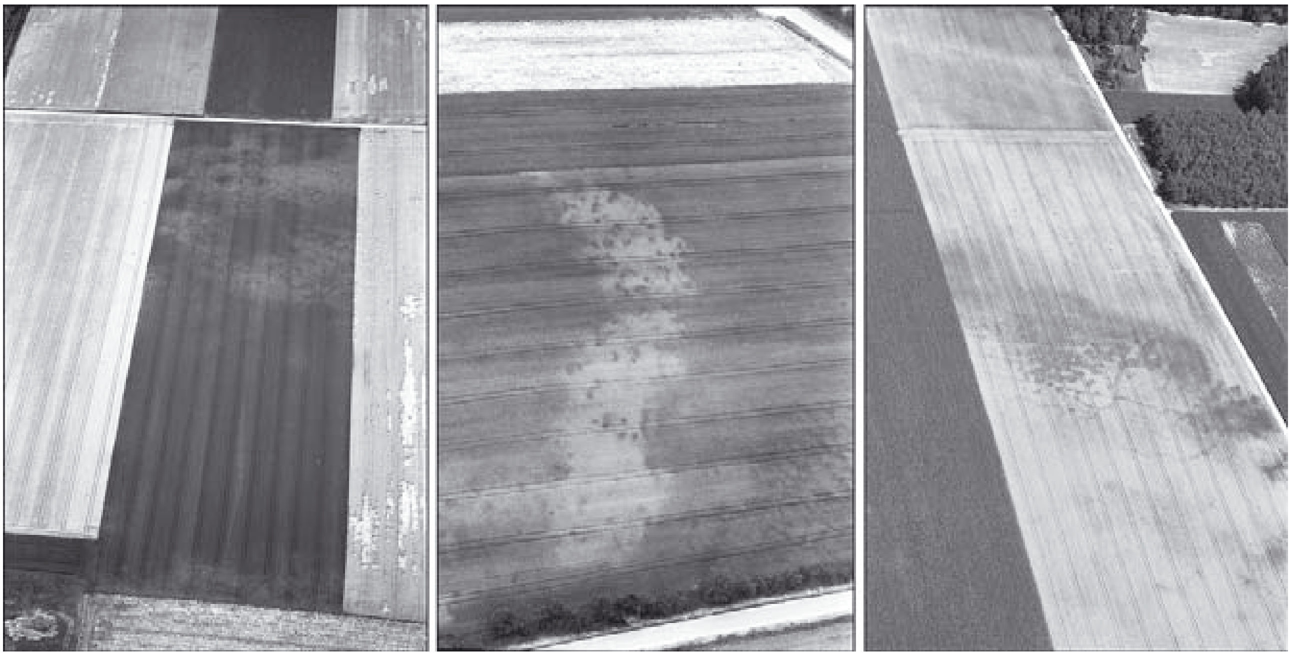

Figure 3: *Various clusters of Neolithic mining shafts recorded by aerial archaeology. BLfD ZII Aerial Archaeology, archive no. 7136/079/8010-21, 7136/079/4387-11, 7136/079/5065-25.*

Figure 4: *Further mining zone in the northern part of the Arnhofen chert district surveyed by aerial prospection and geophysical measurements: Pit shafts as positive crop marks in aerial view supplemented by magnetometer data. BLfD ZII Aerial Archaeology, archive no. 7136/079-05/8463-24, and BLfD ZII Geophysical Prospection, Caesium-Magnetometer Smartmag SM4G-Special in a duo-sensor configuration, dynamics $\pm$ 3nT in 256 greyscales, sensitivity $\pm$10 pT, sample interval 0.5 $\times$ 0.25 m, interpolated to 0.25 $\times$ 0.25 m, 40 m grid.*

NEWLY DISCOVERED SETTLEMENTS OF THE LATE BRONZE AGE AND EARLY IRON AGE IN SOUTHWEST TAJIKISTAN: PRELIMINARY EXCAVATION RESULTS AND FIRST SITE MAPS BASED ON MAGNETOMETER PROSPECTION

J.W.E. Fassbinder, J. Koch, M. Teufer

1. ARCHAEOLOGICAL BACKGROUND

The Bronze Age period of southwest Tajikistan was until now only known from findings in burial sites (Виноградова, 2004). Beside this, merely four Bronze Age sites – Kangurttut, Teguzak, Dachana and Tašguzar – were archaeologically investigated in more detail (Виноградова 2004; Виноградова *et al.* 2008; Пьянкова, 1994; Пьянкова, 2001; P'jankova, 1999; Vinogradova, 1999). Dating to the late Bronze Age period (ca. 1700-1500 BC), the architectural remains of these settlements consist mainly of stone foundations and pit houses.

In the framework of a cooperative contract between the Eurasien-Department of the German Archaeological Institute DAI, the Russian Academy of Science, the Tajikistan Academy of Science and the Department of Geophysics of the Ludwig-Maximilians-University Munich, an archaeological and geophysical survey was undertaken to uncover further Bronze Age and early Iron Age settlements in the lower Jah-Su-valley.

One of these newly discovered settlements was found in the northeast of the modern village (Kišlak) Saridžar (coordinates 38°08'33"N/69°52'18"E) (Figure 1). The site is situated on the north-eastern border of the Jah-Su valley on a loess terrace, which is known as the Chordža Sartez landscape. The Jah-Su valley in the south and two deep erosion trenches in the east and the west enclose and form a natural shelter of the site. In total the settlement terrace is ca. 230 m wide in the east-west direction and roughly 300 m long. In the north, the area adjoins to the loess hills of the Chordža Sartez.

The first test excavations were undertaken in 2010 to confirm the dating of the Saridžar 2 site to the late Bronze Age. Two larger excavations took place in 2012, which revealed at least three settlement periods. These excavations concentrated on two areas of the site; one (A) on the south-western border, the other (B) on the eastern border of the settlement. In area (A) were found the remains of a large stone structure of at least 20×20 m. Inside these remains were found numerous sherds as well as Bronze objects.

Beneath this stone architecture, in a depth of 1.2 m, a further archaeological period was uncovered. Here large walls and fundaments made of rammed earth and mud bricks were found. Very probably they form a ground plot of a large building. However, only additional excavations can verify this.

In the excavation area (B) further mud brick and rammed earthen constructions were discovered and unearthed; the function and the layout of the complete building remains undetermined. Nevertheless this finding proves for the first time, that such structures did occur during the late Bronze Age in Tajikistan. These extraordinary findings in Saridžar 2 can be compared to a similar architecture that was found and associated with the Bronze Age in Southern Uzbekistan and Northern Afghanistan.

A change in the architecture and settlement structure took place during the early Iron Age, confirmed during an excavation, as well as by a magnetometer prospection, at the archaeological site of Karim Berdy (Тойфер and Худжагелдиев 2010; Teufer *et al.*, 2013 in press).

Karim Berdy is situated ca. 14 km southwest of the Saridžar 2 site on the hills of the Chordža Sartez landscape. This settlement consist of pit houses with numerous waste pits and has a structure, that was previously known only from the Chust-culture of Ferghana (Заднепровский, 1962; Заднепровский, 1997) and the Burguljuk-culture in the Taškent-Oasis (Дуке, 1982). Both cultures can be ascribed to the early Iron Age.

A further early Iron Age site was discovered ca. 7 km southwest of Saridžar 2 close to the village Kuduk. The site is situated on a hill 1120 m above the sea level, in the Chordza-Sartez area (coordinate: 38°04'56"N/69°47'37"E) (Figure 2). The area has an extension of ca. 150 m in the north-south direction and ca. 40 m in the east-west. Test excavations on the site revealed sherds very similar to those from the site of Karim Berdy. Some ceramic findings can be ascribed to the Jaz I and Kučuk I periods (Тойфер and Филимонова, 2012, 193-196).

2. FIRST RESULTS OF THE MAGNETOMETER PROSPECTION

For the magnetic measurements we used the Caesium Smartmag SM4G-Special magnetometer in a duo-sensor configuration. The total field magnetometer enables us to detect magnetic anomalies with the highest possible resolution of ± 10 Picotesla (pT) combined with a comparatively high spatial resolution of 25×25 cm. The diurnal variations of the Earth's magnetic field were reduced to the mean value of all data of each 40×40 m square and later matched to the data of the whole area. The duo-sensor configuration allows the detection of archaeological structures with the highest possible sensitivity of the instrument and the highest signal to noise ratio with respect to the archaeological anomalies. However, this configuration is also very susceptible to artificial and technical disturbances and rapid variations of the Earth's magnetic field. In Tajikistan, the application of the magnetometer in an uncompensated configuration was possible, since the surveyed sites are overall far from any modern technical installation.

3. SARIDŽAR 2

The site Saridžar 2 was discovered by the archaeological survey of Mike Teufer in the year 2010. It is located on a spur that forms a natural fortification more than 120 m above the river valley of the Jah-Su (Yaksu) River on an excellent location to control the ancient trail along the river valley from Uzbekistan to Afghanistan. The site is accessible only from the north. In the east, south and in the west there is a steep slope of 20 to 100 metres height. The geology of the surveyed area consists mainly of

Figure 1: *Photo of Saridžar 2 from the north, showing the topographical situation of the site on the border to the Jah-Su River valley.*

loess with a high clay content on which a para-brown earth has developed. This results in a respectable contrast of the magnetic volume susceptibility of ca. 1000×10^{-6} [SI] units in the archaeological layers and the topsoil, compared with magnetic susceptibility values of ca. 200×10^{-6} [SI] units in the undisturbed loess (all measurements were performed by the Kappa-meter SM30 Zh-Instruments). The whole area is still intensively used as farmland. The resulting magnetogram of the area is therefore dominated by large plough furrows, which were deeply carved into the topsoil. In the north of the area, we have evidence for a fortification ditch (Figure 3). The detailed structures of this fortification appear a bit vague, since they are covered by a modern field boundary that follows to the old structures. In Saridžar 2 we measured additionally the magnetic susceptibility on a downhole profile of the excavation trench. The data varies only erratically between 1400 and 900×10^{-6} [SI] units with depth from 20 to 160 cm. This explains why the archaeological features show up so faintly on the magnetogram of this site. Only highly magnetic features such as fireplaces, kilns and pits, which are filled by burnt material, show extraordinary magnetic anomalies (ca. $\pm$ 40 nT). Nevertheless the site seems to be widely and extensively used as a settlement site. This was confirmed by a test excavation, which revealed for the first time large adobe brick constructions and fundaments from the late Bronze Age period at southern Tajikistan.

In the North of the settlement and only 150 m away from the settlement, the site faces the slope of a hill. Here we performed another magnetic survey and located the burial ground related to the settlement. The magnetogram revealed the entrance pits of the catacombs, which were carved into the loess soil. Such burial rites are very typical for this archaeological period, it was therefore more or less clearly assumed that such graves had to be expected at this area.

4. KUDUK

The archaeological site of Kuduk is a hilltop settlement that covered the small and elongated platform of a hill between Kuljab and the Saridžar 2 on the right side of the Jah-Su River valley. From the site, one has a distant, but still excellent overview of the river valley. The settlement consists of an elliptical shaped area of maximum ca. 150×40 m and it is circumscribed by steep slopes. Merely a small archaeological test excavation and the remaining fundaments of an old electrical tower disturbed and limited the magnetic prospection of the entire area.

The result of the magnetometer prospection, although partly disturbed by the old iron constructions and the excavation trench, revealed clear traces and evidence of an intensive settlement activity that was very similar to the Karim Berdy site (Figure 4). Numerous rectangular and square shaped pits and linear structures cover the total area of the hilltop settlement. Traces of a fortification were not detected and remain very unlikely with respect to the topographical situation of the site.

5. CONCLUSION

Traditional archaeological surveys combined with detailed and sensitive magnetic prospection efficiently provide us with site maps of new archaeological settlements in difficult and nearly impassable landscapes. Aerial archaeology, although one of the most efficient archaeological prospecting methods, would be necessary to get a quicker and more better overview of the archaeological sites in Tajikistan, but remain impracticable in the current political situation.

Figure 2: *Photo of Kuduk hilltop area from the south-east, illustrating the topographical situation of the archaeological settlements.*

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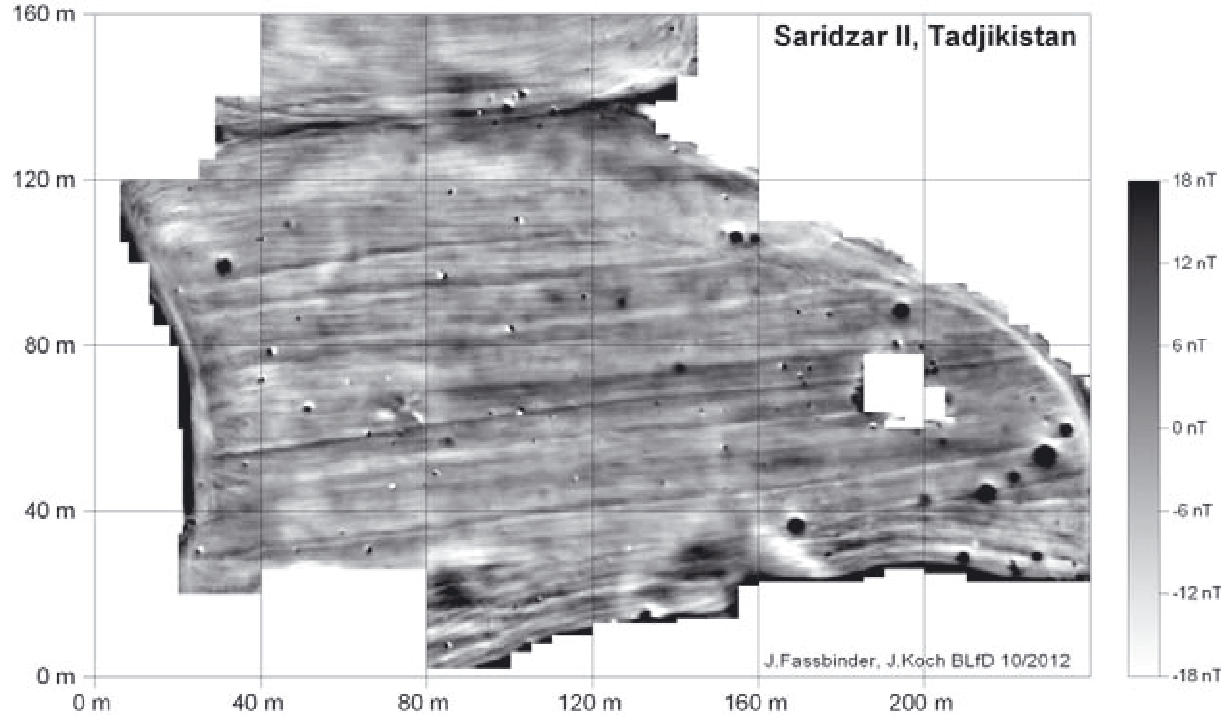

Figure 3: *Saridzar. Magnetogram of the fortified settlement. Caesium Smartmag SM4G special magnetometer in duo-sensor configuration, sensitivity ± 10 pT, total Earth's magnetic field ca. 51,610 ± 20 nT, dynamics ± 18 nT in 256 grey values from black to white, grid size 40 × 40 meter, sampling density interpolated to 25 × 25 cm.*

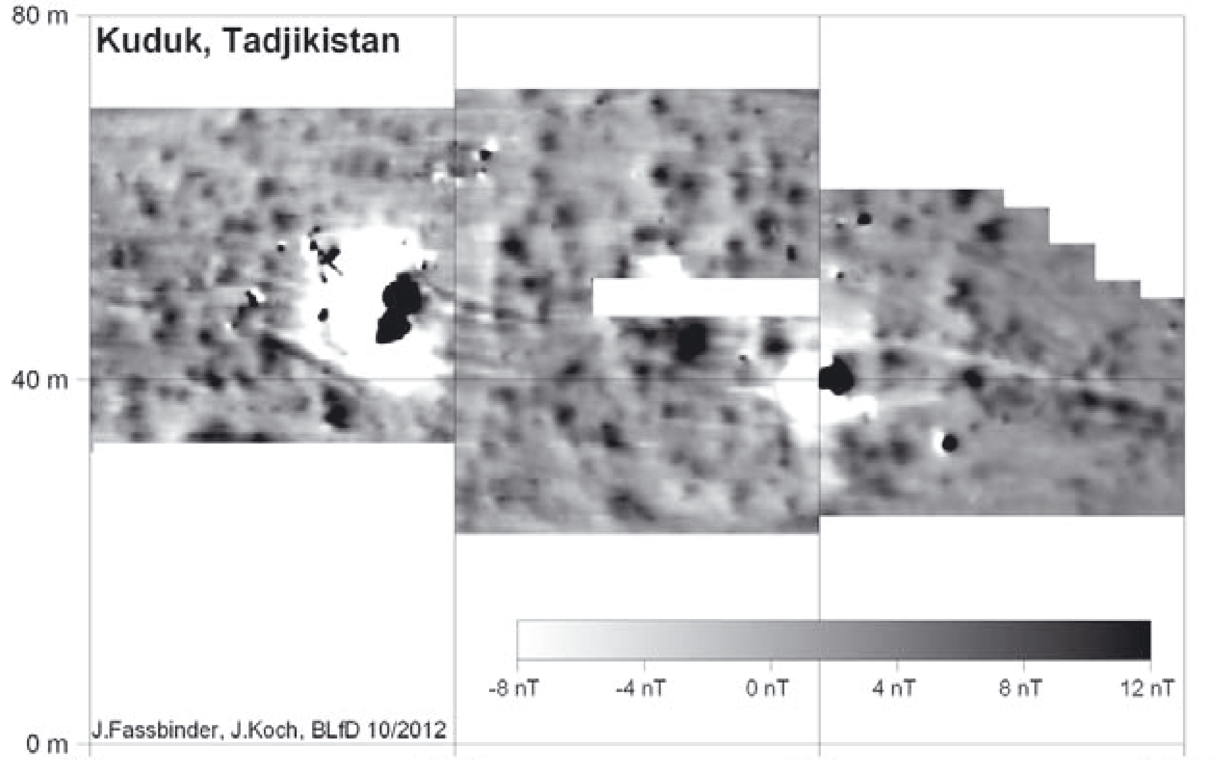

Figure 4: *Kuduk. Magnetogram of the Early Iron Age hilltop settlement. Caesium Smartmag SM4G special magnetometer in duo-sensor configuration, sensitivity ± 10 pT, total Earth's magnetic field ca. 51,550 ± 20 nT , dynamics -8/+12 nT in 256 grey values from black to white, grid size 40 × 40 meter, sampling density interpolated to 25 × 25 cm.*

AN INTEGRATED GEOPHYSICAL SURVEY AT PELTUINUM (ABRUZZO, ITALY). A CASE STUDY IN GPR PROCESSING

S. Hay, S. Kay, R. Cascino, A. James, M. Berry

In October 2012, the British School at Rome (BSR) launched a new project to explore the urban layout of the Roman town of *Peltuinum*, 20 km to the southeast of L'Aquila in central Italy. Building upon a decade of research into the investigation of Roman towns in central Italy through non-destructive methods, the BSR's project aims to map, through a range of techniques, the urban plan of the town.

A preliminary season, generously financed by the *Soprintendenza per I Beni Archeologici dell'Abruzzo*, saw the application of a gradiometer and ground-penetrating radar survey (GPR). The magnetometer survey covered approximately 4 ha in a central area of the town and revealed a palimpsest of roads and buildings. In order to extract a more detailed and comparative plan, two areas, chosen on the basis of the results of the gradiometer survey, were targeted for GPR survey. Challenged by the similar alignment of the modern plough lines and the orientation of the underlying archaeology, two test areas were surveyed at different angles to address the effect of the modern agricultural traces on the successful collection of data. In both cases, data was heavily affected by striping, caused by the agricultural activity and therefore, with the assistance of Dean Goodman, a Fast Fourier Transform (FFT) filter was created for GPR-Slice 7.0 to reduce the effect of this striping. The resulting effect of the application of this filter on our data is presented here.

FIRST MAC INTERNATIONAL WORKSHOP ON ARCHAEOLOGICAL GEOPHYSICS

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1. INTRODUCTION

The Archaeological Museum of Catalonia (MAC) and SOT Archaeological Prospection organised their first international workshop on archaeological geophysics from 21-25 May 2012. The International Society of Archaeological Prospection also supported the workshop as part of its regional outreach activities. Held at the archaeological site of Ullastret, 20 km east of Girona in northern Catalonia (Spain), the 5-day workshop was mainly aimed at archaeologists to introduce them to the concepts of archaeological geophysics (from basics to state-of-the-art technology) and to demonstrate the processes by which an archaeological interpretation is created.

The organisers assembled an impressive line-up of presenters to cover all relevant topics. These ranged from archaeological overviews of the region and the test site in Ullastret, to the explanations of basic geophysical principles, integration of techniques and data interpretation, and logistical considerations that must be taken into account when planning a geophysical survey. As always, participants enjoyed the day-long practical fieldwork and experienced first-hand the challenges that must be addressed when setting out a survey area, measuring control points and avoiding interference between different instruments.

2. SITE DESCRIPTION

The MAC Ullastret site consists of two Iberian settlements, Puig de Sant Andreu and the Illa d'en Reixac, and the necropolis of Puig Serra.

The fieldwork took place at the "Illa d'en Reixac", a lacustrine plain of circa 3-3.5 ha situated on a small hill northeast of Puig de Sant Andreu. Surrounding the site, there is a 200 ha lake that has dried up in the second half of the nineteenth century.

The first excavations at Illa d'en Reixac were conducted by Doctor Oliva in 1965. Based on the information collected until now, the settlement dates to the 7th century BC and it was abandoned in the 2nd century BC due to the Roman occupation during the Second Punic War.

The site is currently under excavation and is not open to the public. Approximately an area of 3000 m^2 has already been excavated as visible on the right side of Figure 1.

3. STATE-OF-THE-ART TECHNOLOGY FOR HIGH-RESOLUTION MAPPING OF LARGE ARCHAEOLOGICAL SITES

Multi-receiver EMI survey

The multi-signal EMI survey (Simpson *et al*., 2009) was conducted with a DUALEM-1S sensor towed by a quad vehicle. This instrument combines one transmitter coil (T) with two receiver coils at 1 m and 1.1 m from T and two different orientations: horizontal coplanar (HCP) and perpendicular (PRP) respectively. Both coil pairs allow measuring the apparent electrical conductivity (ECa) and the apparent magnetic susceptibility (MSa) simultaneously. The ECa measurements range from 0.5 m (PRP) up to 1.5 m (HCP) below the soil surface, whereas the MSa measurements are mainly influenced by the first 0.5 m below the surface.

The ARP© system
(Automated Resistivity Profiling, Geocarta, Paris)

The ARP© is a system for continuous measurement of apparent electrical resistivity. It is able to acquire data at three different depths of investigation.The system is towed by a quad-bike The surface area that can be mapped in a day with a single operator varies from 3 to 8 ha depending on the surface conditions (spatial resolution of 0.1 m × 1 m). Positioning is solved by using a dGPS unit. It was designed in 2001 and nowadays it is of common use for pedological and archaeological applications (Dabas, 2009).

The IDS STREAM X GPR System

The so-called STREAM X system for large-scale archaeological prospection (Novo *et al*., 2012) comprises a vehicle-towed trolley that transports a 1.68 m wide GPR massive array. The 'black box' (comprising two modules) contains 16 dipoles oriented parallel with respect to the forward direction (vertical polarization), with a spacing of 12 cm and working at the frequency of 200 MHz. STREAM X data acquisition is driven by a control unit that guarantees high acquisition speed. The system can be driven up to 15 kmh^{-1}.

Multi-channel fluxgate array and LEA D2 digitizer

A new multi-channel digitizer for fluxgate gradiometer arrays was also presented (Zöllner *et al*., 2011). It is characterised by a very high measuring resolution, broadband ADCs, sampling rates up to 500 Hz and flexible GPS interfaces. Extense field test with several sensor types have been carried out since 2010. LEA D2 digitizer is designed for the operation of up to 10 fluxgate magnetometers in archaeological prospection. Several digitisers can be combined for the use of more than 10 magnetometers.

4. CONCLUSIONS

The 1st MAC international workshop has been an excellent opportunity for participants to see modern instruments in action and also allowed the collection of multiple data-sets for the whole test site. The data were then combined in a project-GIS and interpreted jointly as part of the workshop. The lively interpretation discussion between archaeologists and archaeological geophysicists showed how geophysical data are not the final results, but require sophisticated archaeological interpretation. Archaeologists were amazed to see the many different answers that could be deduced from the data, even to questions that had not been asked. The test site, Illa d'en Reixac, turned out to

Figure 1: *Illa d'en Reixac aerial photography taken from the eastern side. Author: F. Didierjean*

be an Iberian town on a former lake's central island, approximately 4 ha in size and dating to the 6th-2nd century BC. The data showed clearly the layout of streets and buildings, and a full discussion will be published in a monograph about the workshop and its findings.

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THE PARNASSUS PROJECT: ARCHAEOLOGY AND ENGINEERING COLLABORATION ON ERT USE IN BUILDING CONSERVATION

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The Parnassus Project was set up in 2010 as a multidisciplinary approach to the investigation of the effects of extreme weather on cultural heritage, involving the Engineering, Hydrography and Archaeology departments at the British Universities of Bath (now moved to University College London), Bristol and Southampton respectively. The project members from engineering and archaeology have worked closely together using a range of technologies from each discipline to analyse buildings in this context.

Buildings are three dimensional environments and assessing the effects of climate change needs to reflect this. The pooling of knowledge and equipment has led to the use of a wider range of technologies than would be in use by either discipline alone. Those technologies include total station survey on buildings using AutoCAD and TheoLt to consider stability and proximity to water and 3D AutoCAD models in AutoDesk's FEM structural analysis software to model structural response to increased flood risk and exposure.

Moisture content on and within historic walls can play an important role in their survival, and the penetration of driving rain, coupled with freeze-thaw action, can be considerably destructive. As part of the project, test walls are being subjected to intense weathering under laboratory conditions to assess the damage caused by driving rain. In order to apply the results to existing historic structures, ERT has been undertaken on the walls of Winchester Cathedral, a Norman and medieval Cathedral, and Odda's Chapel, a Saxon chapel near Cheltenham, with the purpose of measuring moisture content, retention and penetration. The monitoring was undertaken during different seasonal environmental conditions over a six month period, both internally and externally. Both of these sites have stone walls with rubble infill so it was hoped that moisture content would vary between the surface ashlar and the rubble fill as well as variations over different stones and mortar, therefore indicating the structure of the walls as well as moisture ingress patterns.

This paper will consider the results of using Electrical Resistance Tomography (ERT) on the walls of heritage buildings. The results of the ERT have so far provided data that indicates that the technique can provide insight into a number of different environmental processes taking place in the wall fabric. Initial comparison of the resistivity plots from different days show a complex and often counter-intuitive response to the environmental conditions on the day of survey. Interestingly though, a correlation between the changing condition of the surface of the stone and electrical response is observed. Further work is still being carried out to correlate the results with long term weather conditions preceding the surveys at each site. In addition we will compare the data with the information collected at Odda's Chapel using rain and temperature remote monitoring sensors, in situ during the survey period. The results of test surveys to detect known different building phases in the masonry and brickwork have also yielded exciting results, manipulation of the processing being crucial in obtaining plots which reflect the wide variation in resistance measurements.

The initial results of this work show that the technique of using ERT on walls has a future for use as both a conservation tool in building fabric preservation, and a prospection technique for detecting different phases in historic building masonry construction.

INTEGRATING ARCHAEO-GEOCHEMICAL METHODS FOR INTRA-SITE ARCHAEOLOGICAL PROSPECTION

R.B. Salisbury

1. INTRODUCTION

Archaeological prospection traditionally makes use of one or more methods; most commonly surface collection, geophysical survey and aerial remote sensing. Surface collection has perhaps the longest history of use as a means of identifying archaeological resources, dating back at least several centuries before archaeology developed as a scientific discipline, and remains a commonly employed method when suitably ploughed fields are available. Geophysical prospection methods are now widely used in archaeology, especially within Europe, with new cutting-edge developments arising regularly (e.g. Trinks *et al.*, 2010). Likewise, the state-of-the-art in aerial remote sensing is changing rapidly, due to increasingly sophisticated technology, interpretative tools and methods (e.g. Doneus *et al.*, 2013). Each of these methods gives a different view of the archaeological remains. Geochemistry offers another prospection option, which provides an alternate and complimentary prospection method, especially when integrated into a suite of prospection methods. Unlike the largely non-destructive and non-intrusive methods of terrestrial and aerial remote sensing, archaeological geochemical prospection, as now employed, is minimally intrusive. However, the results gained, both at the intra- and inter-site scale of analysis, make the minor impact to archaeological materials acceptable. Furthermore, geochemical methods reveal a different part of the archaeological record – anthropogenic changes to soils, features such as food preparation areas, and the remains of cultural soilscapes (Salisbury, 2012). In addition, methods are being developed to extract archaeological data from airborne hyperspectral data.

2. SOIL CHEMISTRY AS PROSPECTION METHOD

Archaeological soil chemistry is both a scientific discipline with some historical time-depth, and a discipline still working to be completely accepted within archaeology. The earliest developments for soil chemistry came from agricultural soil chemistry by Carl Sprengel and Eugene Hilgard and the chemist Justus von Liebig. These early works provided the base for a serendipitous discovery by Olaf Arrhenius in the 1920s. Testing for agricultural phosphates in Sweden during the early twentieth century, Arrhenius discovered that phosphates found in the soil could relate to human activity (Arrhenius, 1929). While focusing on soil quality for sugar beets, he also observed that high levels of phosphate correlated well with prehistoric settlements. He expanded the method to identify archaeological sites – his maps are still used in Sweden today – and even tested his method at Native American sites. German geographer Walter Lorch applied Arrhenius's methods systematically to prehistoric sites in Central Europe (Lorch, 1940). Lorch sampled along regular transects through prehistoric settlements, and graphed the results to reconstruct settlement patterns. He interpreted his findings by comparing graphs of density and distribution, and argued that different profiles represented distinct subsistence economies.

Soil chemistry surveys remain an important tool in Scandinavian archaeology, and the chemical analysis of sediments collected during excavation has been employed extensively in Central and South America, Scandinavia and England. However, application of this method for prospection has lagged in much of the world. Here, it proves fruitful for twenty-first century investigations at Neolithic and Copper Age settlements in eastern Hungary, and is now being applied in Lower Austria.

Of all chemical elements, phosphates have proven especially useful for archaeological prospection, largely because of the relative ease of extracting and measuring available phosphorous (Pav), the stability of P in most soils and the speed at which results can be made available. Elemental concentrations of phosphorus are elevated through human inputs of plant and animal remains, bone, metabolic by-products and other organic refuse into the soil. Other human activities elevate or deplete other soil components, including lipids, proteins, pH, magnetic susceptibility and several chemical elements.

The simplest, most straightforward way to collect sediment samples from unexcavated contexts is by coring or augering. Samples are taken systematically, generally along transects or in a grid pattern. Testing interval varies depending on desired results, with closer interval testing of 5 – 10 m typically preferred for intra-site spatial analysis, and larger intervals of 25 – 50 m for surveying whole landscapes.

The simplest and least expensive way to conduct Pav surveys is via a ring-chromatography test based on the methods of Gundlach (1961) and Eidt (1973). The process involves a fast weak-acid digestion (ascorbic and dilute hydrochloric acids) and the addition of ammonium molybdate to produce spots, or rings, and radiating lines. Relative size and darkness of the blue spot, length of radiating lines, and the time it takes the spot to appear all indicate the quantity of Pav in the soil. The test reveals levels of Pav relative to other points in the site and to local background levels, and so long as on-site values are higher than off-site values, the method serves to delineate site boundaries and some intra-site patterns. More quantitative methods using portable colorimeters allow greater analytical power, with a related increase in cost and training.

3. THE CASE STUDY OF CSÁRDASZÁLLÁS, HUNGARY

The case study comes from the site of Csárdaszállás 8, located on the south side of palaeochannel of the Hármas-Körös River in Békés County, Hungary. This is a very flat landscape, with little or no erosion but subject to extensive and long-term plough agriculture. Prior to this research, the site had been identified through field walking during the Hungarian Archaeological Topography surveys (MRT). Csárdaszállás 8 is a multi-component site covering approximately 7 ha, with the ceramic material from several periods, including the Late Neolithic Tisza phase, with a distinct Tisza locus containing at least one wattle and daub house. The locations and dimensions of the various occupation phases within the site were not known.

Field methods involved the collection and analysis of soils samples, surface collection and magnetometer survey. Samples were collected with an Oakfield soil probe, a light, inexpensive, hand-operated device. Samples were taken at 10 m intervals using a rectilinear grid system for continuous and systematic sampling across the whole site. Off-site samples were taken to establish culturally sterile stratigraphic and geochemical signatures. Samples were taken from within the cultural layer(s) and the subsoil, and large undifferentiated horizons were subdivided into arbitrary levels with multiple samples taken. In cases where no cultural horizons were identified, samples were collected from the base of the plowzone. Sediments were analyzed for Pav, pH and multi-element chemistry using ICP-MS (Salisbury, 2012).

Timed collection of 10 m square units was employed as controlled intensive surface collection on the ploughed fields to identify activity areas, horizontal extent and chronological variation on the surface.

Geomagnetic survey was conducted using a Gemsys GSM 19GW Overhauser magnetometer set up as gradiometer with a resolution of 0.01 nT and absolute accuracy of 0.2 nT. The total area surveyed at Csárdaszállás 8 was 0.75 ha, over part of the Late Neolithic occupation. Fifty-metre grids were sampled in a zigzag pattern with transverse and sample intervals of 1 m. Snuffler software was used for filtering the data. All datasets were combined in a GIS for data management, spatial analysis and display (Salisbury et al., in press).

The initial goal of the Pav survey was to define the extent of primary occupation areas within the site and discriminate distinct loci, and relate these to the known cultural components from Csárdaszállás 8. Three discrete loci were identified, and data from the field walking supports this interpretation. A possible fourth locus, or extension of the central locus, is suggested and requires additional analysis. This provides an example of why multiple methods must be integrated; one method alone is insufficient to resolve this problem.

Figure 1 is an interpolated probability map of Pav from the site of Csárdaszállás 8, with data derived from ring-chromatography tests of cultural layer and base of plowzone. The western and eastern loci both show very high levels of Pav. Several samples from the cultural layer in the central locus have lower values, but are still higher than off-site control samples.

Magnetic anomalies in the centre-east locus indicate the remains of at least three major features ca. 8×20 m in size (Figure 2). These anomalies are strong enough (up to 60 nT/m gradient) to allow interpretation that these are the remains of buildings that were burned down. These structures are surrounded by several pits with a linear anomaly in the south-western corner of the magnetogram. Fill in several of the pits had elevated P values, suggesting storage or disposal of organic matter. Multi-element data suggest the presence of food preparation areas near the houses. Ceramic and burnt daub densities, combined with the soil chemistry and geomagnetic data, suggest that there are intact features under the plough soil.

4. FURTHER APPLICATIONS

Further applications of the method are being developed both at Csárdaszállás and within the Kreuttal Prehistoric Landscape case study in conjunction with the Ludwig Boltzmann Institute for Archaeological Prospection. The Kreuttal landscape is significantly different from that of the Körös Basin. Whilst the Körös is a very flat and low-lying region, the Kreuttal has very hilly topography, and the archaeological sites have been subject to acute erosion. Therefore, there is great concern over the potential loss of all archaeological data for many settlements in the region. Initial geochemical survey conducted in the Kreuttal indicates that at least some of the chemical signatures of past human activity are preserved. Comparing and contrasting these two very different landscapes provides an excellent test of archaeo-geochemical prospection methods.

There is need for innovation in archaeo-geochemical methods. The state-of-the-art for fast, large-scale survey remains largely restricted to methods developed for agricultural chemistry. Recent advances in AHS technology provide an opportunity to develop a high resolution, non-intrusive method for archaeo-geochemical prospection. In addition, interpretations of multi-element data rely on matching several chemical signatures to specific features and anthropogenic inputs, and the existing case studies are largely restricted to Central and South America. Experimental and ethnoarchaeological studies using Central European soils and domestic and agricultural practices are necessary to refine these methods.

5. CONCLUSION

Minimally and non-intrusive methods have been successfully integrated to explore the features and boundaries of human habitation within small, dispersed farmsteads in eastern Hungary. This integrated approach has allowed us to define different activity zones, predict site preservation and begin to discuss site formation processes. The methods employed here should be applicable to most archaeological landscapes, and are especially useful for sites that can not or will not be excavated.

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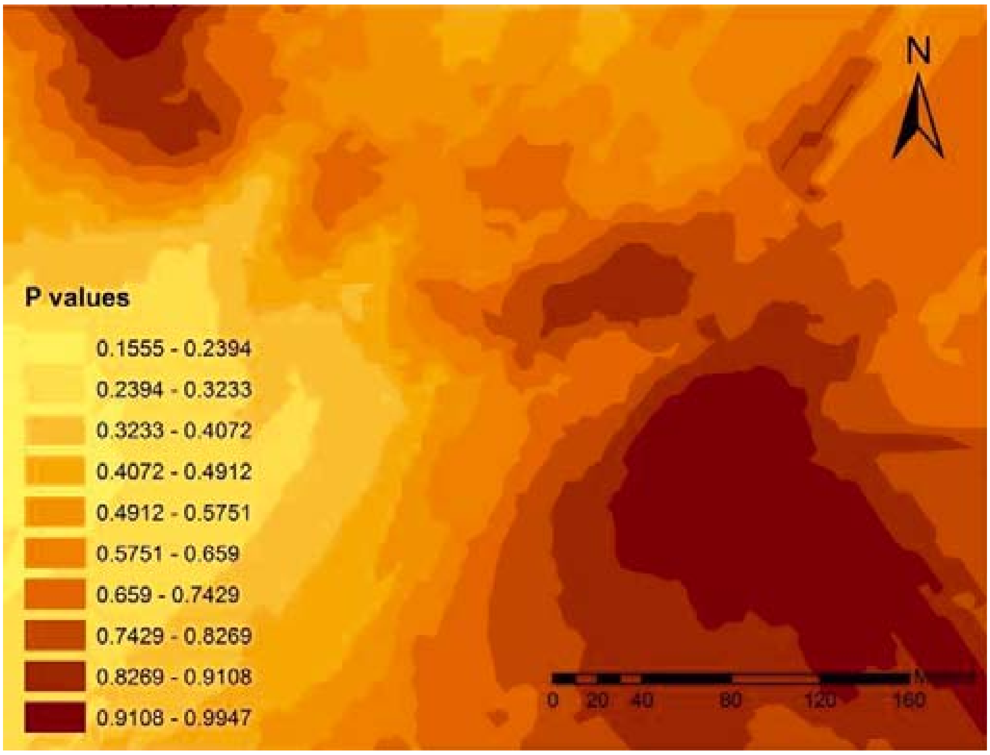

Figure 1: *Interpolated probability of available phosphates at Csárdaszállás 8 derived from ring-chromatography test results.*

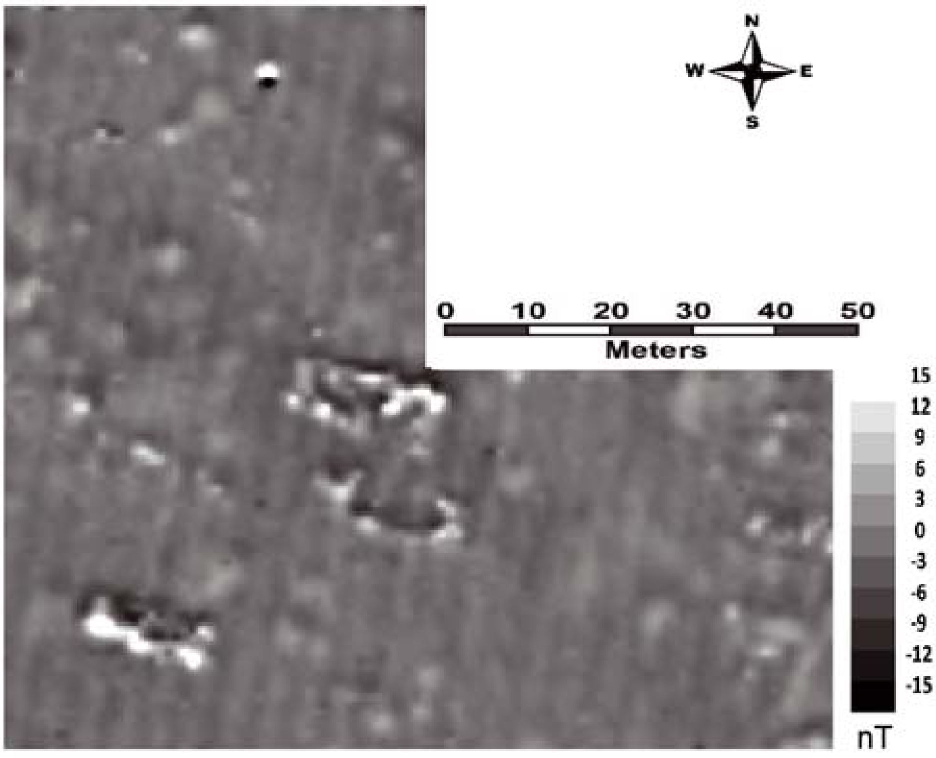

Figure 2: *Magnetogram from the Late Neolithic locus at Csárdaszállás 8.*

PROSPECTING KREUTTAL/AUSTRIA - EROSION AND ACCUMULATION

M. Kucera

The Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) hosts the Kreuttal case study as one of a number of national and international projects. Due to the fact that it is situated only 30 minutes to the north of Vienna by automobile, many key questions of the LBI ArchPro's research program are focussed on this area. A mainly wooded mountain ridge heading N-S separates the "Bay of Korneuburg" (*Korneuburger Bucht*) from the Viennese Basin (*Wiener Becken*), forming a first natural barrier to the eastern planes. The valley of the Russbach (Kreuttal), which gives the case study its name, cuts this ridge and thus connects the mentioned areas. For the LBI ArchPro case study, an area was defined covering this mountain ridge and its slopes for a length of about 15 km. Due to its strategic importance and fertile soil, it has been settled partly densely through most of the time since the Early Neolithic, with settlements, grave fields, hill-forts and monumental ring ditches spanning from the Neolithic to modern times. Some of these sites are in an amazingly well preserved state whereas others seem to be in danger of being destroyed by erosion. From a technical and methodological point of view, this area is suitable for the application of many different prospection methods. The dataset collected so far combines remote sensing (Airborne Hyperspectral and Laser Scanning, Aerial Archaeology), geophysical prospection, historical maps, field walking and geoarchaeological results. Among other key investigations concerning geoarchaeology, geology and field walking, recent studies were carried out to investigate erosion and accumulation processes in specific areas. This could be done by combining different datasets for closer integrated interpretation.

It is obvious that once a feature is detected, especially using geophysical prospection techniques, it has to be seen as real. On the other hand, having no evidence might mean that an archaeological site has simply been covered due to accumulation processes. Even a single event can cause transportation of an enormous amount of material, as documented after a thunderstorm in May 2011 in the area (see Figure 1). Therefore, erosion and accumulation have been and still are transforming the archaeological landscape.

In applying large-scale geophysical prospection using motorised magnetometers, one gets a larger overview of a specific area. In 2011, the LBI ArchPro began continuous measurements, thus far covering an area of about 2.3 km^2. In combination with other datasets, it was possible to investigate erosion and accumulation processes in greater detail.

Firstly, palaeochannels and erosion lines detected by geophysical prospection or aerial archaeology might get a closer interpretation by visualising their location together with height lines. The surface of a landscape is under constant transformation, and might change in such a way that main erosion lines are modified through time. It can be argued that palaeochannels that still appear to be situated in a rill are younger than others that are not. Therefore, spatio-temporal information of the features observed within one method can be extracted in combination with another dataset. In the same way, geological structures in general are easier to interpret.

Secondly, it was observed that features documented on the basis of aerials from the 1980s were only partly visible within the recent datasets from geomagnetic surveys. Additionally, these features were documented on recent aerials as well, whereas the old features seem to be gone. The location of these features, which belong to a presumably Iron Age settlement, along a slope within the surrounding erosion lines might indicate the destruction of some features within 30 years due to erosion. Field walking and geoarchaeological surveying will allow a more detailed analysis of the observed phenomenon.

Finally, unusually large erosion rills could be observed at the northern slope of a hill south of Kreuzstetten in the most northern part of the study area. From a geological point of view, this phenomenon seems to be outstanding in the region, although the geology slightly changes in this area. Historical analysis might show that in this case these erosion lines were initiated by extensive forest operation that transported wood from the wide plateau to the village of Kreuzstetten in medieval and modern times.

These results underline the importance of an integrated interpretational approach for a closer understanding of the change of archaeological landscapes. Although a landscape seems to be quite static, it could be seen that this is not true even for short-term observations. Fascinatingly enough, it is possible to get a more detailed understanding of recent erosion and accumulation processes as a by-product of the investigation of passed landscapes.

Figure 1: *Erosion surface in an agricultural field in the Kreuttal area, created by a single thunderstorm in May 2011.*

LARGE SCALE, HIGH RESOLUTION ARCHAEOLOGICAL GEOPHYSICAL PROSPECTION: A SOURCE FOR PALAEOENVIRONMENTAL DATA

P. Schneidhofer, R. Cannell

The successful application of archaeological geophysical prospection (AGP) towards the investigation of archaeological landscapes depends on a comprehensive understanding of the palaeoenvironmental settings of the study area. On a general methodological level, this dependency concerns survey design and geoarchaeological evaluation of survey outcome. In order to fully understand the development of archaeological landscapes, however, it is necessary to incorporate palaeoenvironmental data as an important component into the interpretation of archaeological features.

Environments are not stable, but are dynamic systems that change over time through a wide variety of interrelated factors, processes and characteristics involving weather, climate, soils and sediments, as well as geomorphological, ecological, and hydrological factors and past and present human activities (Grotzinger *et al*., 2008). Palaeoenvironmental reconstruction currently is based mainly on coring and test trenching in order to gain information on and access to underlying soils, sediments and geology. This methodology results in two-dimensional, largely interpolated data sets, which is a serious limitation for the understanding of palaeoenvironments as three-dimensional dynamic systems.

During the last two decades, archaeological geophysical data acquisition has advanced remarkably in terms of speed and resolution, allowing for the first time extensive 3D multi-method approaches (Linford, 2006; Leckebusch, 2003) and hence the archaeological prospection of entire landscapes (Trinks, 2011). Distinct archaeological features thereby form only a small part of large-scale, high-resolution AGP data sets; the majority of geophysical data is often devoid of (visible) archaeological data. Nevertheless, these empty areas contain valuable information regarding pedological, sedimentological, palaeohydrological and geological processes. Consequently, such processes result in and are displayed as continuous (e.g. stratification) as well as distinct palaeoenvironmental features (e.g. geological outcrops, old river systems or former wetlands) exhibiting different electric and magnetic properties, which respond to the various geophysical measurement systems.

Commonly, AGP studies pay little attention to anomalies or features not interpreted as archaeology and rarely mention or investigate them within the scope of archaeological survey projects. Studies concerned with the reconstruction of palaeoenvironments in geology, sedimentology and geoarchaeology have repeatedly used geophysical techniques such as seismics, ground penetrating radar and resistivity (Bristow *et al*., 2000; Neal *et al*., 2002). However, spatial coverage is limited to few isolated profiles and resolution remains mostly low in favour of penetration depth. More importantly, visualization and interpretation of the geophysical data are not exploiting the three-dimensionality of data sets.

Large scale, high-resolution AGP data sets, in contrast, certainly show potential for palaeoenvironmental reconstruction (Dalan and Bevan, 2002), although to what extent this is possible remains unexplored. Arising questions include type and resolution of palaeoenvironmental data available as well as evaluation of the actual contribution towards the understanding of archaeological landscapes. As a first step to answering these questions, the pilot study presented here addresses technical and methodological aspects of palaeoenvironmental data analysis.

For this purpose, a large scale, high resolution AGP data set from Norway has been selected. Gokstad is situated in the province Vestfold, Norway, and accommodates a rich archaeological heritage, including Norway's largest known Viking Age ship burial. In 2009, the research project "Gokstad revitalized", led by the Museum of Cultural History at the University of Oslo, was initiated in order to investigate the ship burial in its wider context (http://www.khm.uio.no/prosjekter/gokstad/). The core study area Heimdal extends over approximately 3.5 ha and was surveyed during autumn 2011 and spring 2012 by Archeo Prospections® using magnetometry and ground penetrating radar (Figure 1). The interesting sedimentological situation of Heimdal along a former shoreline, accessible through ongoing excavations as well as borehole surveys as part of Gokstad revitalized, offers an excellent database for in-depth palaeoenvironmental investigations.

The methodology presented here pursues an iterative approach comprising the initial AGP data, integrated (palaeo)environmental data sets as well as additional field data. AGP data analyses thereby specifically focuses on the development of new extraction, visualization and interpretation techniques using geographical information systems as well as specifically designed software for geotechnical and environmental purposes. The aim is to fully meet the requirements of reconstructing palaeoenvironments as dynamic, three-dimensional bodies. In spring and summer 2012, extensive borehole surveys have been carried out at Gokstad. Together with subsequent sedimentological and chemical analyses, these data are used to create a comparative dataset in order to verify and correct the palaeoenvironmental interpretation of the initial AGP data. This data set also serves as an extendable database for future palaeoenvironmental interpretation and modelling of future study areas. Repeated cycles of AGP data analyses and ground checking are applied to allow a refined correlation of both data sets.

Preliminary results of the methodological approach at Gokstad (Figure 2 and 3) encourage further research regarding refined methodological approaches and more detailed analyses of both AGP and field data sets. In the light of recent and future technological innovations, it is safe to say that the use of AGP data for palaeoenvironmental reconstruction presents a promising new and complementary way to better understand the development of archaeological landscapes, and hence will increase the quality of archaeological interpretation.

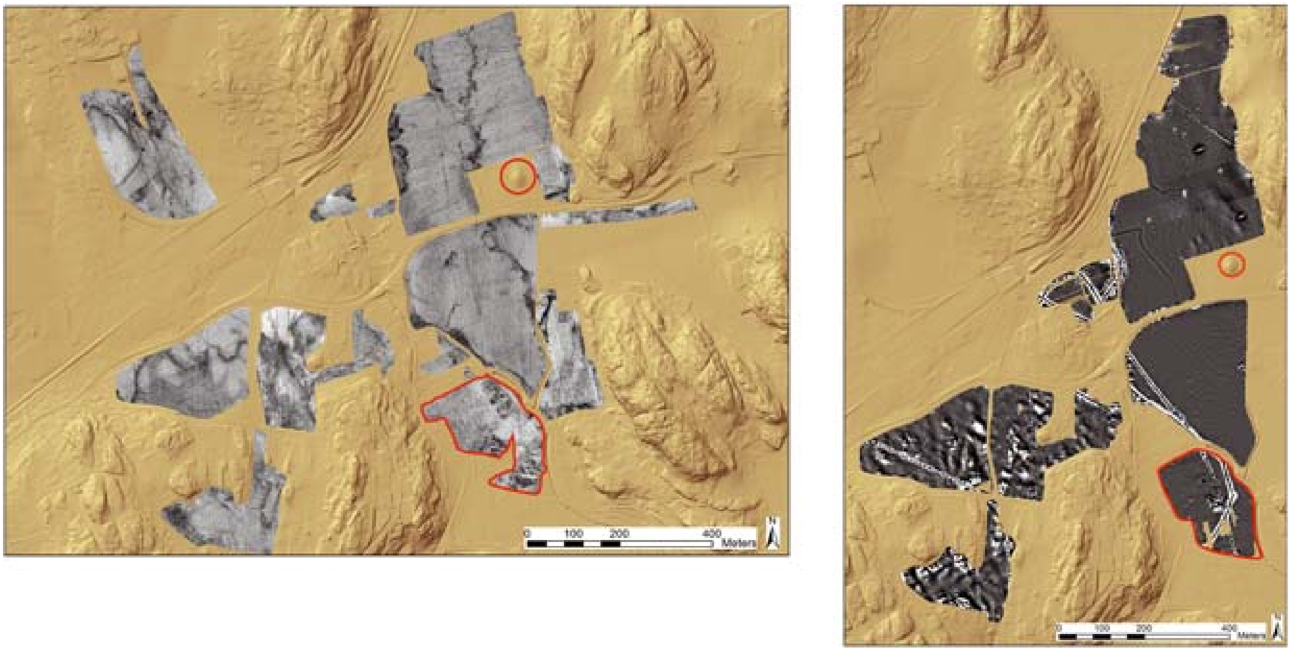

Figure 1: *Large scale, high resolution magnetometry and ground penetrating radar surveys covering the archaeological landscape around the Gokstad mound. The core study area Heimdal is marked red towards the south (ALS data kindly provided by the Norwegian Mapping Authority).*

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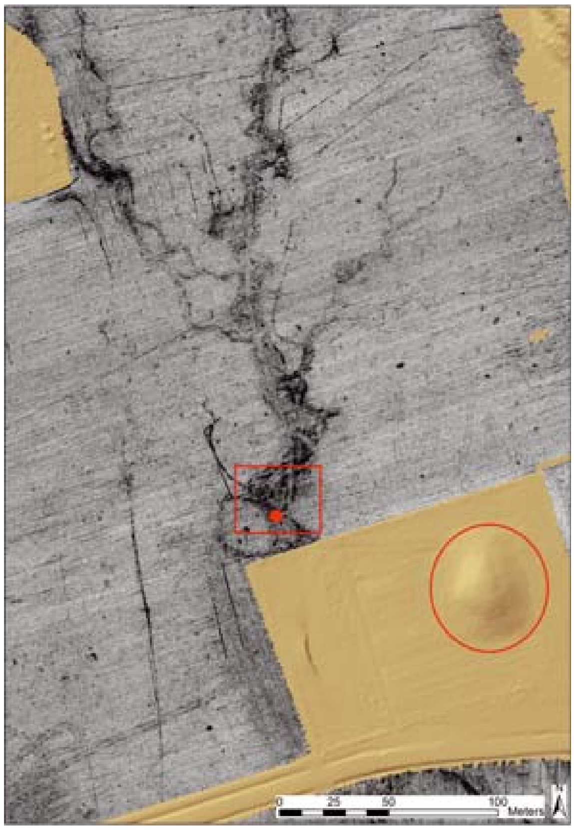

Figure 2: *GPR raster image of a palaeochannel near a burial mound with one of the core sample locations used to collect comparative sedimentological data (ALS data kindly provided by the Norwegian Mapping Authority).*

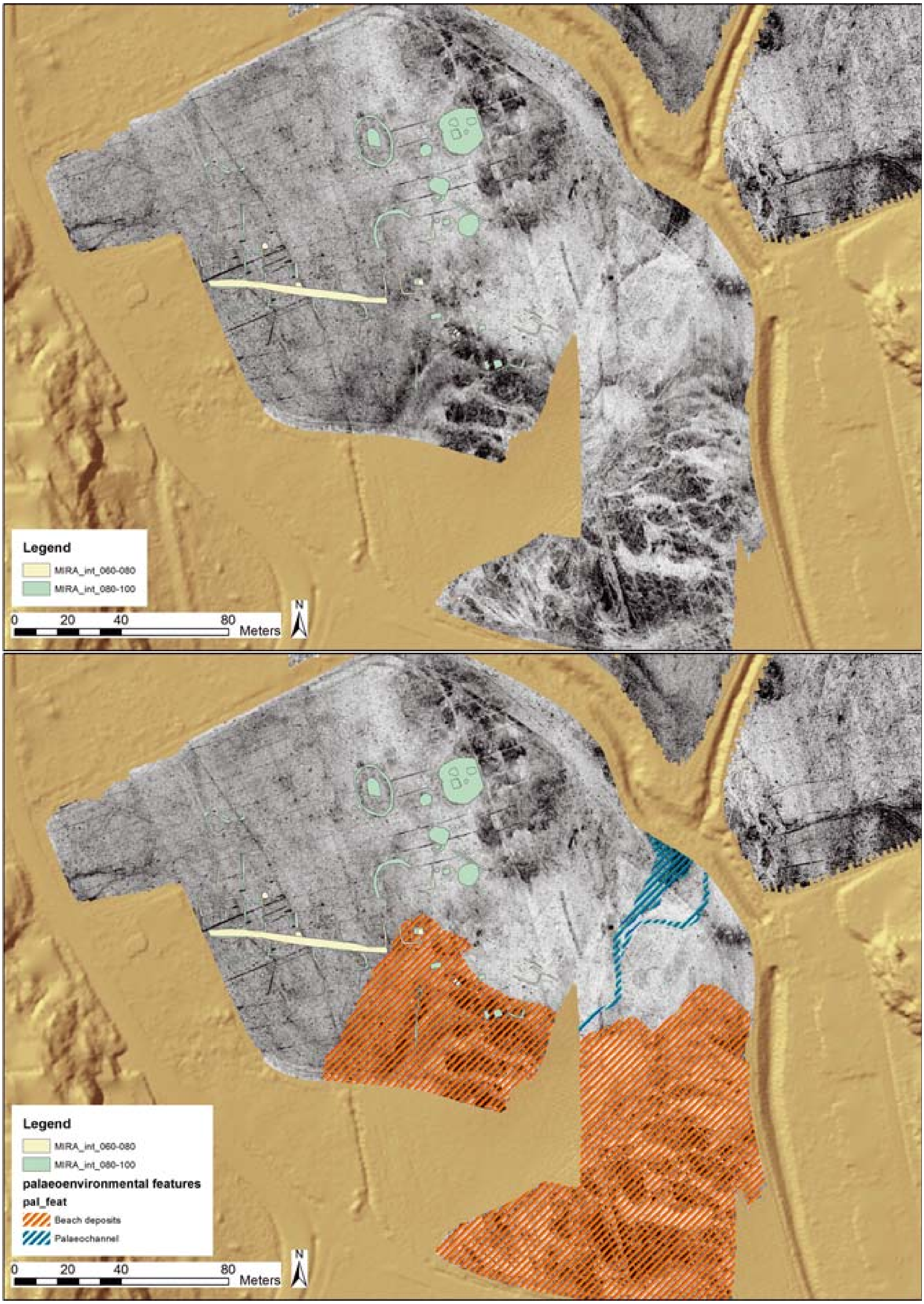

Figure 3: *(a) GPR raster image of the core study site Heimdal with (b) clearly visible palaeoenvironmental features covering a substantial part of the survey area (ALS data kindly provided by the Norwegian Mapping Authority).*

LONG TERM INTEGRATED ARCHAEOLOGICAL PROSPECTION ON THE STUBERSHEIMER ALB – GIVING MEANING TO A MARGINAL LANDSCAPE

K. Kastowsky-Priglinger, R. Schreg, I. Trinks, E. Nau, K. Löcker, W. Neubauer

At first sight the Stubersheimer Alb, which is part of the Swabian Alb in Germany, might seem historically largely unaffected. Thus far no upstanding historical monuments have been found and no major historical events have been recorded in this area. It isexactly this rather marginal situation, however, that provides the opportunity for intense research on the structural changes of medieval rural landscapes. Here it is possible, by the means of landscape archaeology, to deal with long-term changes without any dominant influences of specific historical disturbances, such as the foundation of a town or monastery, the effects of a military battle or the personal interests of some noble families. Certainly the Stubersheimer Alb was not an isolated landscape, and we know of some interaction with the surrounding towns of Geislingen and Ulm, monasteries, the role of the earls of Stubersheim as the predecessors of the regional important counts of Helfenstein and also the impact of the battle of Nördlingen in 1634, fought out about 50 km away. Nevertheless, the Stubersheimer Alb is a predominantly agrarian landscape providing an excellent case study on the changes of medieval rural landscapes. We can learn (1) about settlement changes between the era of Roman occupation and the Migration period, (2) about the shifting location of early medieval settlements, (3) about the medieval village formation of the 12th and 13th century, (4) about the settlement desertion during the late medieval crises, as well as (5) about the social changes in early modern villages.

There have been already various research activities investigating these questions at the Stubersheimer Alb. A historic-geographical study in the 1970s examined the role of rural lower classes using examples from the Stubersheim Alb. A rental from 1415 gives deep insights in local manorial structures. A scientific edition has been prepared and provides information about land use practices and former settlements. In the surroundings of the three existing villages of Stubersheim, Schalkstetten and Bräunisheim (Figure 1), there have been at least five additional settlement sites, all abandoned in the late Middle Ages.

Archaeologically, there has been important fieldwork done by amateur archaeologists. Albert Kley documented several medieval settlement sites as well as some prehistoric sites. More recently, field walking around the villages of Stubersheim, Schalkstetten and Bräunisheim in 2003 and 2006, in the framework of archaeology classes at Tübingen University directed by Rainer Schreg, resulted in various evidence of archaeologically interesting areas. Some recent rescue excavations by the state department of cultural heritage added valuable information.

In contrast to the more fertile areas of the Southern Alb near Ulm and Blaubeuren, with a dense early Neolithic landscape, settlements at the Stubersheimer Alb with its higher elevation, harsher climate and a problematic water supply started during the Urn field period of the late Bronze Age. Evidence of some Roman settlements could be identified. We also know of several early medieval settlement sites in the periphery of the modern villages of Stubersheim, Schalkstetten and Bräunisheim and we learned about the role of some iron smelting. However, archaeological evidence of the late medieval abandoned settlements known from written sources such as the 1415 rental is rather scarce. Unfortunately, there was only one deserted medieval site named "Wolfgerswilare" that could be roughly located by surface finds dating to the high Middle Ages.

These differing archaeological, historical and geographic sources led to many open questions and the conclusion that large-scale archaeological prospection is necessary to fill in the many gaps and potentially be able to produce more detailed insights into the history of this rather marginal landscape.

Becoming a partner of the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) in 2010, the RGZM chose Rainer Schreg's project of the Stubersheimer Alb as a case study area. In contrast to other case studies, with some high potential sites within their study area, it seemed desirable to focus on landscapes with less or only marginal archaeological evidence. This is necessary for testing and developing new strategies of research within so-called "empty" landscapes.

In the spring of 2011, the first surveys could be conducted using large-scale magnetometry and detailed ground penetrating radar (GPR). Within eight days, an area of more than 1.2 km^2 could be surveyed with high resolution magnetometry. Two systems operated in the field with 50 cm and 25 cm parallel sensor spacing. The systems are pulled by motor vehicles, and measurements taken with 5- and 10-channel Foerster fluxgate probes. After first pre-processing of the magnetic data, selected archaeologically interesting areas where chosen for additional 8×8 cm high resolution GPR measurements applying a MALÅ Imaging Radar Array consisting of 16 radar antennae (400 MHz). The GPR system is pushed by a small tractor. Both systems, magnetic and GPR, use GPS for accurate positioning of the measurements (Schreg *et al*., 2011).

The measured areas are scattered around the case study area with emphasis on Bräunisheim due to weathering and field conditions. The processed data showed a variety of differing magnetograms revealing a number of archaeologically interesting areas as well as evidence of the geological distinct characteristics of the Stubersheimer Alb. The "Juranagelfluh" – a Miocene stream sediment – potentially influenced the areas of settlement due its possibility of ground water collection within the otherwise dry karst landscape. This first campaign provided insights in some known Roman sites, but it also led to the discoveries of new sites, among them a possibly Roman courtyard and one of the formerly missing medieval settlements. This paper presents the latest research and interpretational approaches.

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Figure 1: *The case study area around the villages Stubersheim, Bräunisheim and Schalkstetten including the surveyed areas, campaign 2011 (©LBI ArchPro).*

MAGNETIC MODELLING AT SITE AND LANDSCAPE SCALE

J. Kainz

Buried archaeological sites are a rare and precious part of our cultural heritage, and are often threatened with destruction. Their investigation and management should involve minimal damage or destruction. Due to this, archaeology has a need for fast and accurate mapping of such buried anthropogenic traces, in order to preserve and manage them or in other cases to plan the most cost-effective form of excavation or investigation. Therefore, various non-invasive archaeological prospection methods, such as geophysical prospection techniques and remote-sensing, are generally used to map archaeological structures in the subsurface.

Magnetometry is the main archaeological prospection method, due to its rapid data collection, the general applicability of the technique to shallow investigation, and the high data resolution which can be achieved (Neubauer, 2001; Gaffney, 2008). Due to the geophysical nature of the magnetic readings, magnetometer data cannot be taken as an image of the physical reality of the subsurface (Aspinall *et al.*, 2008, 64). The sensors presently used are set to measure the vertical gradient of the horizontal component of the Earth's magnetic field, hence the response resembles a derivative of the total field response (Gaffney, 2008, 318). As a result, magnetic data principally is represented in a two-dimensional plane, i.e. as a map of archaeological structures without using the full potential of the magnetic data. Therefore, three dimensional modelling of magnetometry data can allow for new archaeological insights and interpretations. This paper will apply the methodology used by Eder-Hinterleitner and Neubauer (1997) to investigate the possibility of magnetic modelling for archaeological features at a 'site' scale with the view to extending such to a landscape scale. An area in the Kreuttal, Austria, containing a multi-period archaeological landscape, will be used as a trial for the magnetic modelling in order to explore whether this can provide new insights for a more comprehensive archaeological analysis.

Since the beginning of magnetic prospection, research has been undertaken to simulate the shape and form of magnetic anomalies (Linington, 1966a, 1966b; Scollar, 1969). This research has formed the basis for reconstructing three-dimensional models of archaeological structures from their magnetic anomalies (Oehler, 1987; Wang and Hansen, 1994; Herwenger, 1996; Dittmer and Szymanski, 1995; Allum *et al.*, 1995; Eder-Hinterleitner and Neubauer, 1997). A major goal therefore must be to tap the full potential of such data by reconstructing magnetic anomalies, not only just for individual archaeological structures but also on a 'site' or landscape basis. Samples need to be taken for the modelling process, and these can be used for geoarchaeological investigation, which will provide further information for the interpretation of the features.

Due to the geophysical nature of the magnetic readings, magnetometer data cannot be taken as an image of the physical reality of the subsurface (Aspinall *et al.*, 2008, 64). Since the magnetic sensors used are set to measure the vertical gradient of the horizontal component of the Earth's magnetic field, the response looks like a derivative of the total field response (Gaffney, 2008, 318). This therefore needs to be considered when interpreting magnetic measurements as well as the potential for further information about the archaeological feature. In terms of archaeology, this limits the interpretation of magnetometer data to a two-dimensional plane, as seen in a magnetogram. The potential lies within modelling of magnetometer data in a three-dimensional plane, and work in this direction has been undertaken (Scollar, 1969, 1990; Linington, 1966a, 1966b; Oehler, 1987; Wang and Hansen, 1990; Dittmer and Szymanski, 1995; Allum *et al.*, 1995; Herwenger, 1996; Eder-Hinterleitner and Neubauer, 1997, 2001; Neubauer, 2001b).

Eder-Hinterleitner and Neubauer (1997, 2001; Neubauer, 2001b) applied a specific magnetic modelling approach to a Neolithic ditched enclosure (Figure 1). The approach was based on dipole assemblage models of earlier works and used magnetic susceptibility values of previously excavated ditched enclosures. By means of an iterative process, the method automatically adjusted the model parameters to find the best fit resembling those of the magnetometer survey. The three dimensional model of the ditched enclosure recreated the dimensions (depth and shape) of the unfilled ditch very closely to that of the real dimensions of the ditch (Figure 2). Furthermore, it is possible to create models without certain layers, as for example the topsoil, which may provide new insights and enhance the interpretation. Cores will be taken from the different anomalies to obtain magnetic susceptibility measurements for the modelling. In addition to the magnetic susceptibility measurements, geoarchaeological investigations of the samples will be undertaken. This will allow for further distinction of the features, as well as their fills, to allow for an understanding of the different contexts and their formation and post-depositional processes.

The trial work will assess magnetic modelling for archaeological 'sites', with a view to expanding such work to landscapes in the future. This will examine sampling strategies for obtaining the necessary data for the modelling, as well as the additional information which can be obtained from the samples via geoarchaeological investigations. The work will allow for an assessment of magnetic models of archaeological features, and whether these allow a more comprehensive archaeological interpretation from the magnetic data. Furthermore, the work will combine such analysis with the physical properties of the individual features.

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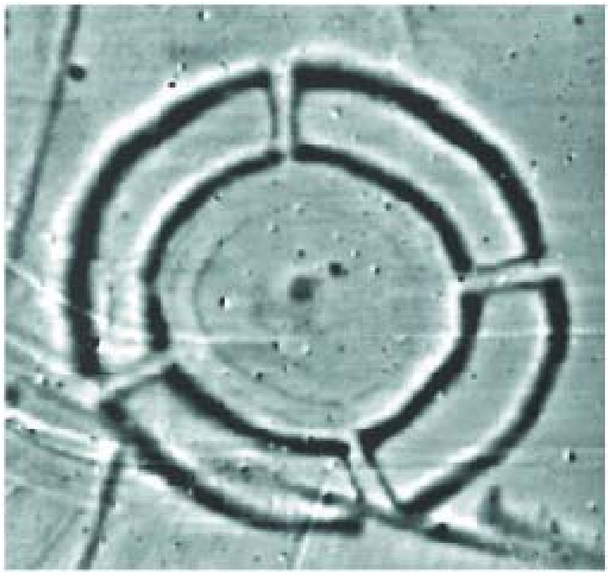

Figure 1: *Magnetogram of the ditched enclosure Steinabrunn, Austria (105 $\times$ 110 m; $\pm$ 5 nT) (Neubauer 2001b).*

Figure 2: *Three dimensional model of the ditched enclosure Steinabrunn, Austria (Neubauer 2001b).*

ARCHAEOLOGICAL PROSPECTIONS IN THE NORTHERN MARCHE REGION (ITALY): NEW AERIAL AND GEOPHYSICAL SURVEYS BETWEEN MISA AND CESANO VALLEYS

F. Boschi, E. Giorgi, M. Silani

The present paper concerns the latest research carried out by the University of Bologna in the northern Marche region. In fact, the institution has here a long tradition of studies of landscape archaeology and excavations, which started over 20 years ago.

In 2010 a new season of research begun, encouraging a new project of archaeological prospections, which involves systematic aerial surveys and integrated geophysical explorations along the Valleys of the rivers Cesano and Misa.

The main objective of the project is to actively investigate the occupation history within the both valleys, mapping all the archaeological evidence from Prehistory up to the Middle Age, with a particular attention reserved to the populating and principal occupation patterns during the Roman period.

A multidisciplinary approach has been applied, using non-destructive methods such as remote sensing application (in particular, active oblique aerial photography throughout the valleys and intra-site geophysical research), traditional artefact surveys, in combination with a systematic geomorphological study of the research area.

In the first two years of the project, the integration of historical and modern aerial photographs, finalized aerial photogrammetry, new aerial and geophysical surveys allowed us to identify numerous new sites and to gather new important information on the two main roman towns of the middle valleys: the *municipia* of *Suasa* and *Ostra*. *Suasa*, in the Cesano Valley, was probably born as *praefectura* or *conciliabulum* and became *municipium* after the 49 B.C. The centre shows a slow decline since the 3rd century: the abandonment appears to be due to a continue occupancy of some spaces within the urban area, used or as cemetery or as quarry areas, at least until the 6th century (Giorgi, Lepore, 2010, pp. 55-61; Dall'Aglio, De Maria, Podini, 2007).

Ostra, in the Misa Valley, had a similar genesis but with a greater continuity of life until the beginning of the Middle Ages (Dall'Aglio, Silani, Tassinari 2012).

In both cases the adopted research strategy brought us to discover several buildings of the urban and suburban areas, previously unknown, letting emerge in the same time new elements for the comprehension of the urban pattern, the ancient topography and, more in general, on the Romanization process in this territory.

Active aerial photography from a low flying aircraft, taking oblique, digital, images, is one of the major survey techniques being applied with success in the project (Figure 1). Next to this, integrated geophysical surveys have been undertaken in several sites and, in particular, with an intra-site analysis' level, in both the roman towns.

At *Suasa*, started in 2009, magnetometry, electrical resistivity and ground-penetrating radar maps were produced on a large part of the site at different scales of analysis (Boschi 2010). Extensive surveys were accomplished through integrated magnetic and heart resistance methods. The magnetic measurements were carried out employing an optically pumped Potassium gradiometer (GEM Systems GSMP-35). That system was reconfigured in a vertical gradient setup to increase the sensors resolution, by measuring closer to the ground surface, while keeping them at a vertical distance of 1.30 meters. Earth resistance measurements were made using the Automatic Resistivity Profiling system or ARPs (Geocarta©) (Figure 2). The GPR system was used for intensive 3D surveys, for exploring beneath the surface of floors in mosaic and opus sectile of the domus dei Coiedii, a rich urban private building, which was discovered and excavated during the previous years of activities in the site.

The latest aerial and geophysical surveys allowed to recognize the presence of different orientations in the urban pattern, recently also confirmed by the excavations, which possibly reflect different phases of life of the centre (Figure 3).

New data, derived from monitoring flights in 2012 over *Ostra* concerns a number of traces, mostly cropmarks, observed north-west and north-east to the urban core, as well as in some probable sub-urban sectors. Revealed from the air are several linear strips (wide between 3-5 m) of cropmarks indicating a regular system of urban roads (Figure 4). The most wide of these, with a different orientation, is attributable to the road that from the city of *Sena Gallica* (in the lower valley, on the Adriatic Sea) run up to *Sentinum*, in the hinterland. In addition, some impressive traces are referable to almost four new buildings and complexes, before unknown, revealing a rich and complex buried archaeological record (Figure 5).

Extensive magnetic surveys are actually in course on the entire surface of the site. The preliminary results are particularly encouraging, and are actively contributing to the detailed characterization of the urban texture.

Significantly, the archaeological prospections which we have been carrying out on the two cities have been revealing different urban and topographical patterns, which probably reflect important diversities also in the genesis of the centres and in their role in the occupation of this ancient landscape.

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Figure 1: *In the upper part (a, b), interesting cropmarks documented in the urban area of Suasa during the summer of the 2003. Below (c, d), aerial oblique photos taken over the Cesano Valley during the recent aerial surveys 2010-2012, with other archaeological evidence documented or discovered from the air.*

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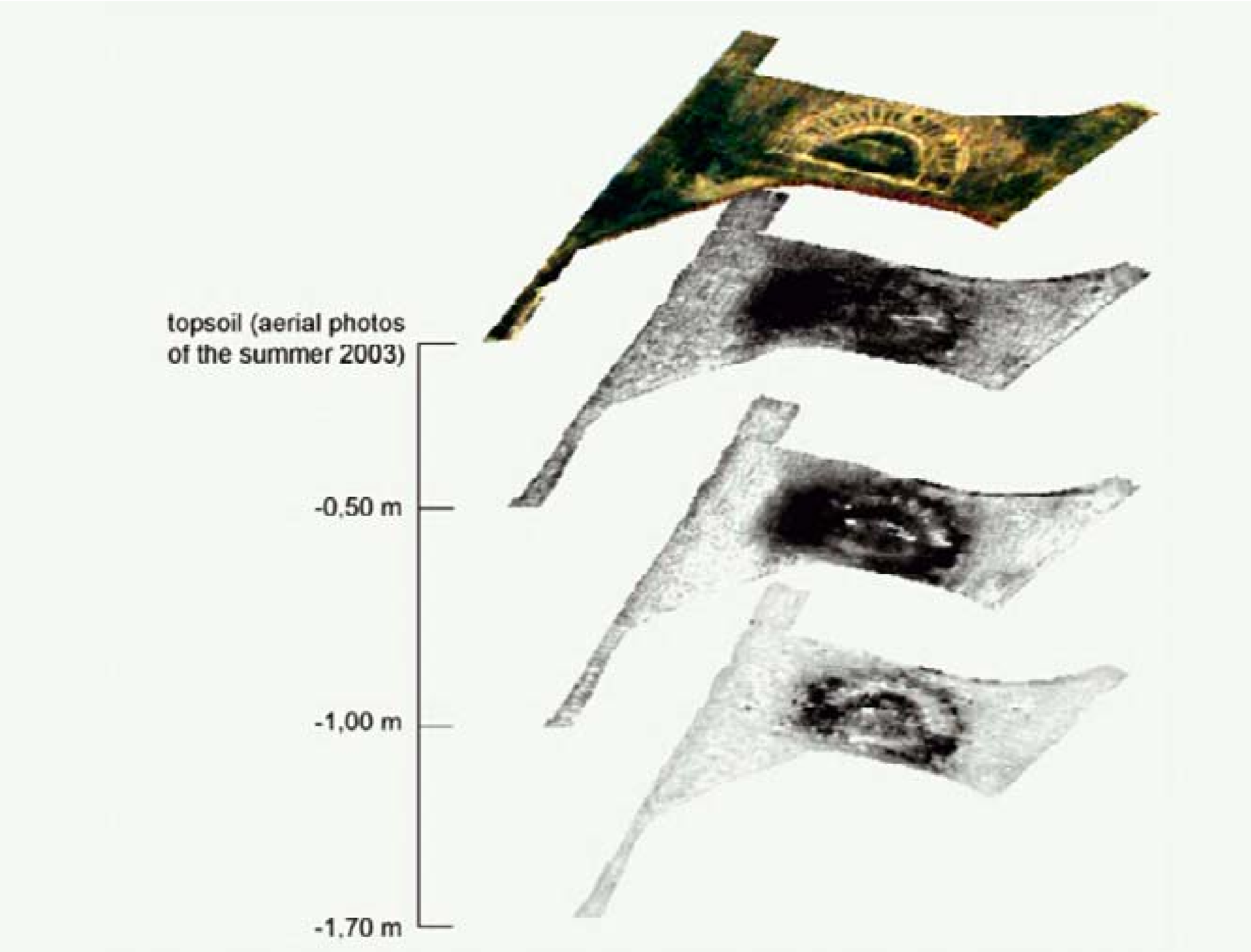

Figure 2: *A detail of the ARP survey in the area of the theatre at Suasa (by Geocarta©, Paris; in collaboration with So.Ing, Livorno).*

Figure 3: *Oblique aerial photos taken in the area of Ostra during the aerial surveys 2012 (by F. Boschi).*

Figure 4: *Oblique aerial photos taken in the area of Ostra during the aerial surveys 2012 (by F. Boschi).*

Figure 5: *Oblique aerial photos taken over Ostra during the aerial surveys 2012 (by F. Boschi).*

THE STONEHENGE HIDDEN LANDSCAPE PROJECT – DATA ACQUISITION, PROCESSING, INTERPRETATION

K. Löcker, E. Baldwin, W. Neubauer, V. Gaffney, C. Gaffney, A. Hinterleitner, P. Garwood, I. Trinks, M. Wallner

1. INTRODUCTION

It is not necessary to introduce the Stonehenge Hidden Landscape Project (SHLP), as this has already been done by the project team (this volume). Nevertheless, for the subject of our talk we have to point out the main aims of the project as a case study site of the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) and its partner organisations.

The area around Stonehenge is highly suitable for testing novel motorized geophysical prospection systems. Firstly, there is the vast size of the fields, grassland and cropland mainly owned by the National Trust and farmed by only a handful of tenant farmers. This makes it quite easy to cover large areas with motorized systems in a short time. Secondly, the geological conditions surrounding Stonehenge favour geophysical prospection, as the chalk soils, with intercalated bands of flint, provide sufficient geophysical contrast to archaeologically relevant features for both methods tested: magnetometry and ground penetrating radar (GPR). Thirdly, there exists a large quantity of preceding geophysical prospection data to which the SHLP data can be compared in various ways – mainly by spatial sampling density, acquisition accuracy and speed as well as processing.

2. DATA ACQUISITION

Aims of the case study in terms of data acquisition are the implementation and testing of motorized geophysical prospection systems and the in-house development of the logging and navigation software LoggerVis. Additionally, hand portable GPR, magnetometry and resistance systems have been used either to cover areas that are not accessible by motorized systems or to survey specific features of interest. Before the first field work campaign in July 2010, all the equipment had solely been tested in lab conditions or at small test sites in Austria. Therefore, it was this first campaign that had to prove the reliability of the new systems. Problems with software, power supply, positioning, and cable connections had to be dealt with before real tests concerning positioning accuracy, survey workflow and speed could be carried out. It was a lucky coincidence that during one of these very first tests an unknown hengyform monument was found, and became very famous later that year.

In the first year, a total of about 48 hectares with magnetometry and with some 33 hectares of GPR were prospected by motorized and hand-carried systems combined. After testing and improving the equipment elsewhere during the following months, the return to Stonehenge landscape in 2011 was mainly to find the best fitting surveying and processing workflow for large-scale geophysical archaeological prospection in the UK. Except for some problems with the rough terrain, over which one of our two magnetometer trailers broke, we experienced far less trouble with the equipment. It was possible to cover an unprecedented total area of 2.25 km^2 with magnetometry and another 33 hectares with GPR in merely three weeks in the field.

For 2012, two field work campaigns have been carried out in order to cover as much as possible of the project area using magnetometry. No GPR was used that year, which will be made up for in the 2013 campaign when all the magnetometry data will be processed and suitable areas chosen. In spring 2012, two motorized systems were in use and we managed to cover 1.75 km^2. We started the autumn campaign with three systems and used the time to set up a fourth motorized magnetometry system so that in the last week four systems were operating. Thus, we could cover 2.9 km^2 in about four weeks. Problems were reduced to some power supply issues, but we managed to break one of our towing vehicles, an all-terrain quad bike, in the rough terrain. In total an area of 4.65 km^2 could be prospected by magnetometry in 2012, and in the first four field campaigns the covered area sums up to 714 hectares of magnetometry and 66 hectares of GPR.

Parallel to the development of the motorized systems, the logging and navigation software LoggerVis has been tested and adapted in the field. This software has been written by the LBI team from scratch and allows logging and displaying magnetometry and GNSS raw data, as well as aiding in navigation by showing tracks and displaying background information as aerials or maps.

When dealing with this immense coverage, there appear two immediate problems: data processing and archaeological interpretation. Only by improving existing in-house developed software is it possible to deal with the huge amount of data produced during these fieldwork campaigns.

3. PROCESSING

When in the field for long periods, it is advantageous to be able to process collected data quickly in order to check whether the data are correctly measured and error free. If there are any problems, these could then be corrected while still in the field. Processing is not a big problem when dealing with small amounts of data, but tends to get bigger as the quantity of raw data increases. The average size of raw data we produce in a field campaign today varies between about 50 to 150 Mbytes per day with magnetometry and 10 to 20 GBytes per day when using GPR. These raw data have to be stored and processed in the field.

To be able to handle these huge amounts of raw data it is necessary to have both powerful hardware and capable processing software. While the hardware is just a problem of money, the processing software needed is not purchasable anywhere on the market. We are using and improving APSoft, an in-house development of our partner ZAMG, which has been devised and adapted to constantly changing needs over the last 17 years or so. This software package has been extended to the capability of processing large amounts of data and resampling these data using RTK GNSS positioning into georeferenced, regular 2D and 3D raster data sets. With APSoft we are able to produce first visualisations of measured data in sufficiently short time in

Figure 1: *GPR (left) and magnetometry (right) systems in use at Stonehenge.*

the field, as well as to apply sophisticated filters and image processing techniques for generating corrected and cleaned pictures used for archaeological interpretation or publication.

4. INTERPRETATION

After the first wave of joy at observing nice pictures representing square kilometres of archaeological landscape in unprecedented detail, the certainty sets in that all these countless features visible in the data have to be drawn and connected to some database in order to produce maps of the Stonehenge landscape through space and time. Before, this task would have been accomplished by importing the georeferenced raster images of our data into a GIS environment, and drawing all visible anomalies and archaeologically relevant features by hand. However, this is not sensible when dealing with these huge volumes of data. It is therefore necessary to think of some forms of automated or at least semi-automated classification and vectorisation of the data.

We are currently working on finding and creating the best tools and a reasonable workflow for the classification of magnetograms as well as of 3D data blocks. First results are promising, and are already speeding up the interpretational work significantly. The tools and the workflow will be incorporated into APSoft and ArchaeoInterpretor, a GIS toolset generated by the LBI ArchPro for the purpose of holistically interpreting whole archaeological landscapes.

Figure 2: *The rough terrain takes its toll: broken equipment in 2011.*

Figure 3: *Combined magnetograms of the 2010 - 2012 campaigns covering a total of 714 hectares so far.*

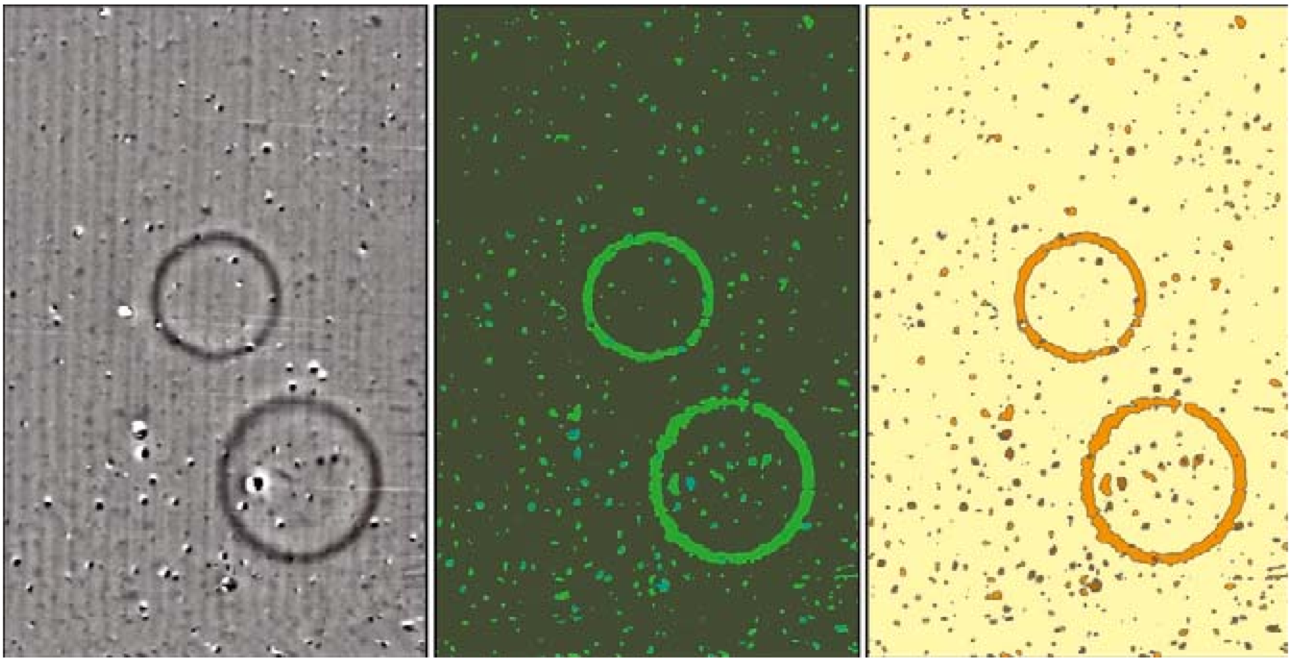

Figure 4: *First results of the semi-automated classification and vectorisation. Left: The magnetogram as raster image. Middle: The classification as grid. Right: The vectorised features as polygons.*

SOIL GEOCHEMISTRY AS A TOOL AIDING GEOPHYSICAL PROSPECTION ON AN ARCHAEOLOGICAL SITE IN SAGALASSOS (SW-TURKEY)

K. Dirix, P. Muchez, P. Degryse, B. Mušič, J. Poblome

ABSTRACT

While several authors have argued that soil geochemical analysis holds potential as an archaeological survey technique, only limited research regarding this topic has been carried out in the field. In this paper, the possibilities and limitations of the technique are investigated by a geochemical prospection on two scales in a large industrial area at the Roman to Byzantine city of Sagalassos (SW-Turkey). Geochemical data are combined with geophysical results to explore to what extent both techniques can complement each other. Results indicate that large scale chemical prospection with cell sizes of 100 m is capable of detecting human influence on soils by anomalous values of Cu, K, P and Zn, although the data are too coarse to aid geophysical interpretation. However, in a more detailed grid with cell sizes of 20 m, geochemical data proved to be a useful tool in distinguishing anthropogenic from geological anomalies in the geophysical record.

1. INTRODUCTION

Over the last century, the application of geophysical prospection techniques in an archaeological context has become standard practice (e.g. Aspinall *et al.*, 2009). Conversely, multi-element soil analyses have only scarcely been integrated into archaeological survey programmes (Oonk *et al*., 2009). On the other hand, there has been a long history of chemical analyses of excavated archaeological soils, with numerous studies reporting on a wide variety of elemental enrichments and depletions associated with ancient anthropogenic activities (e.g. Barba, 1994; Entwistle and Abrahams, 1997). In these studies, it has been stated that geochemical prospection has a future as an archaeological prospection tool, because it adds an extra dimension to the interpretation of survey results and has the capacity of giving functional information on structures detected using geophysical techniques (Wilson et al., 2008). In the current study, a suburban area in Sagalassos (SW-Turkey) was selected to investigate the potential of geochemistry as an archaeological survey technique, aiding the interpretation of geophysical data.

2. STUDY AREA

Since 1985, ancient Sagalassos in southwest Turkey has been the focus of an interdisciplinary, archaeological research project coordinated by the KU Leuven (Waelkens, 1997; Martens *et al*., 2012). The 'Eastern Suburbium' under study, previously referred to as the 'Potters' Quarter', is situated to the east of the monumental city centre and comprises an area of 6 ha, covered with ceramic waste products (Mitchell and Waelkens, 1988). Former archaeological and archaeometric research revealed that the area was an important production centre for red slip ware, active at least from the 1 century to the 7 century AD (Poblome *et al*., 2002). Other attested activities and structures, linked to different phases of occupation of this area, include waste disposal, agricultural terraces, artisanal workshops, a necropolis, a church, water infrastructure, a road etc. From a geomorphologic point of view, the area is gently sloping towards the south. To the north, the site is bordered by an east-west oriented limestone range (Figure 1). Ophiolitic mélange deposits are underlying the area. An important topographical feature is the so-called 'central depression', which is about 100 m across and opens towards the southeast, with a slope varying between 16 and 26 percent. In the northeastern flank of this depression, a stepped open mining system of a clayey ophiolitic weathering layer was discovered (Degryse, Poblome, *et al*., 2003). Thickness of unconsolidated material in the suburban area varies significantly, reaching depths of more than 8 m in the centre of the depression.

3. METHODOLOGY

Soil samples were collected in two grids. The coarse grid (ES1), with cell dimensions of 100 $\times$ 100 m, encompasses the entire area of the Eastern Suburbium, and stretches out beyond its eastern border. This way, geochemical trends from an onsite to an offsite area can be studied. A total of 50 samples were collected in this grid. The detailed grid (ES2) focuses on an area within the central depression that contains large numbers of ceramic slag, and where the magnetic readings show a distinct anomaly (Figure 2). This grid has cell dimensions of 20 $\times$ 20 m; a total of 70 soil samples were taken. After drying, crushing and sieving, the samples were dissolved using hot acid Aqua Regia. The samples were analysed for Al, As, Ba, Ca, Cu, Co, Cr, Fe, K, Mn, Mg, Na, Ni, Pb, P, Sr, Ti, V and Zn by inductively coupled plasma optical emission spectrometry (ICP-OES), using a Varian 720-ES apparatus. Multivariate statistics were used to unravel the resulting multi-component dataset.

4. RESULTS AND DISCUSSION

Coarse grid (ES1)

Figure 3 depicts the spatial concentration distribution of five variables, together with the result of a hierarchical clustering analysis. These plots reveal that K, P, Cu and Zn are enriched in the area corresponding with the major activity area of the Eastern Suburbium, and its southern slopes. Spatial mapping of the clustering results demonstrates that the samples allocated to Cluster 1 occur in the area where K, Cu, P and Zn also are enriched, indicating that these samples are both spatially and statistically correlated. P shows values up to 313 ppm, while regional background values for soils developed on limestone and ophiolitic sequences report maximum concentrations of 160 ppm (Degryse, Muchez *et al*., 2003). This result suggests that the enrichment of P can be sought in the past activities that took place in the eastern suburbia of Sagalassos. In addition, concentrations of K and

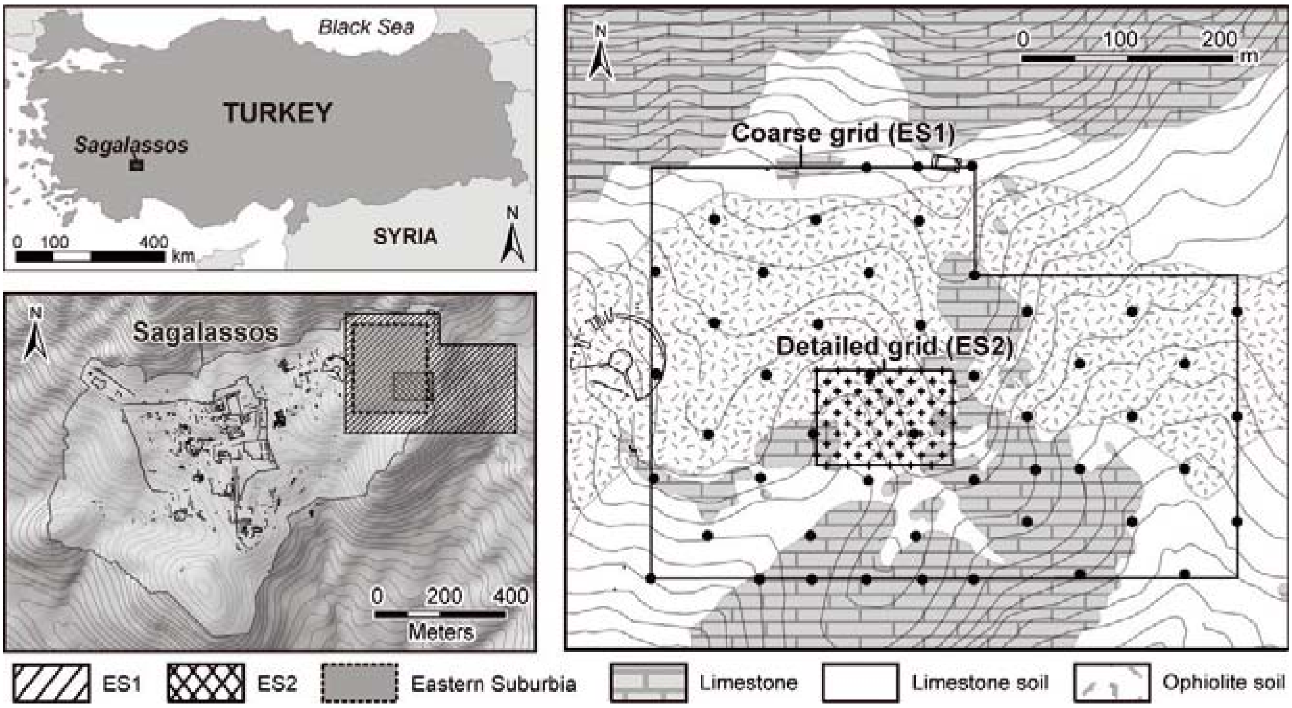

Figure 1: *Geographical and geological setting of the area under study, and map of the sampling grids.*

Cu are higher than local background values, while the concentration of Zn remains below bedrock values. This can be explained by the higher mobility of Zn (Levinson, 1980). The observation that the anthropogenic signal extends outside of the main activity area suggests that there is no one to one relationship between the location of ancient activities and the position of chemical soil anomalies. Instead, the activities resulted in a halo of humanly influenced soils around the eastern suburbia. Another process that has to be taken into account is the southward transport of polluted material by erosion processes during periods of heavy rainfall. Because of the dispersed nature of the anthropogenic signal, it is not possible to apply it as an interpretational tool for the structures revealed by magnetic prospection. The differences between clusters 2, 3 and 4 are geologically controlled. This control is discussed in the results of the detailed grid (ES2).

Detailed grid (ES2)

In grid ES2, cluster analysis groups the samples into four main clusters, all with a clear spatial focus (Figure 4). Cluster 1 concentrates in the depression in the west of the grid and can be distinguished from the rest of the data by its high median concentrations of P, K, Cu and Zn. This cluster thus corresponds with Cluster 1 in grid ES1, and can be interpreted as a group of samples influenced by ancient anthropogenic activities. Cluster 2 corresponds with a limestone hill in the southwestern part of ES2, and contains samples enriched in As, Al, Ba and Pb, reflecting weathered limestone. Clusters 3 and 4 are located in the eastern area of the grid, geographically overlapping with a distinct magnetic anomaly, formerly interpreted as a large building structure. However, geochemical data suggest that both clusters are enriched in Co, Cr, Fe, Mg, Mn, Ni and V with respect to the rest of the grid, indicating that the data are part of a larger mafic anomaly already visible in grid ES1. The most straightforward interpretation for this observation is an increasing influence of ophiolitic mélange deposits, present in the subsurface of the area. However, as the association of Fe, V and Ti has been found in metallurgical waste material in other parts of the territory, these results could also indicate the processing of iron at this location. While geochemistry alone cannot exclude this second possibility, test excavations in the summer of 2012 confirmed that ophiolitic material was indeed present at a depth of less than 30 cm at this location.

5. CONCLUSION

Anomalies of Cu, K, Zn and P are indicative for past human activities at both grids under study. In the coarse grid with cells of 100×100 m (ES1), no direct relationship exists between locations where these elements are enriched, and the activities that took place at that exact location. Instead, ancient activities have resulted in a halo of humanly influenced soils around the study area. Consequently, in this grid, geochemical data cannot be used as an interpretational tool for structures revealed by geophysical techniques. However, in a more detailed grid with cells of 20×20 m (ES2), geochemical survey data help distinguishing human from geological anomalies in the magnetic record. This result demonstrates that in well-defined cases geochemical data can be applied as a relatively fast and low-cost technique aiding geophysical prospection at archaeological sites.

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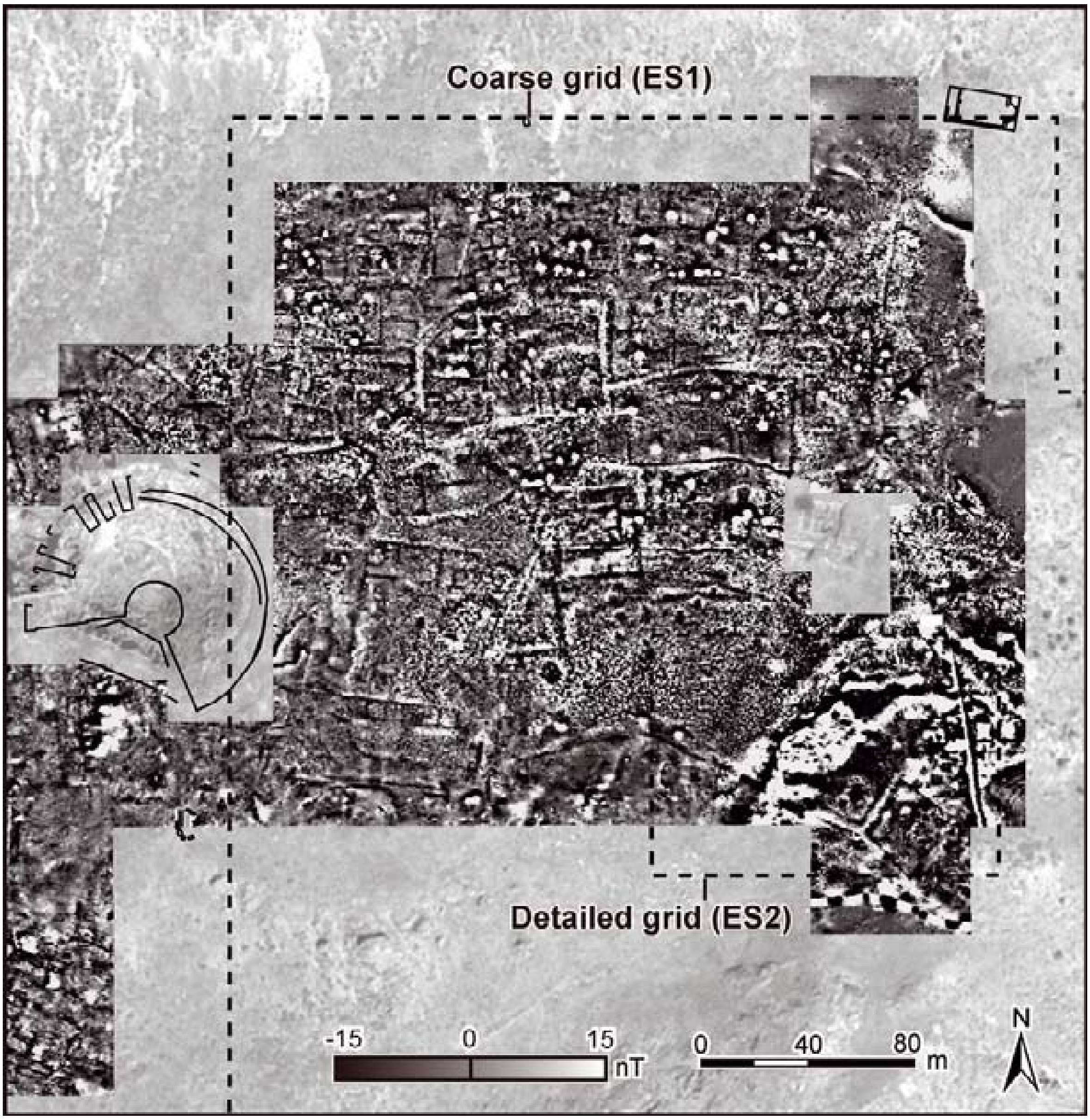

Figure 2: *Magnetic data of the study area, collected using a Geometrics G-858 magnetometer (pseudogradient-mode). Dark structures are interpreted as walls and passageways. White dots indicate the presence of furnaces.*

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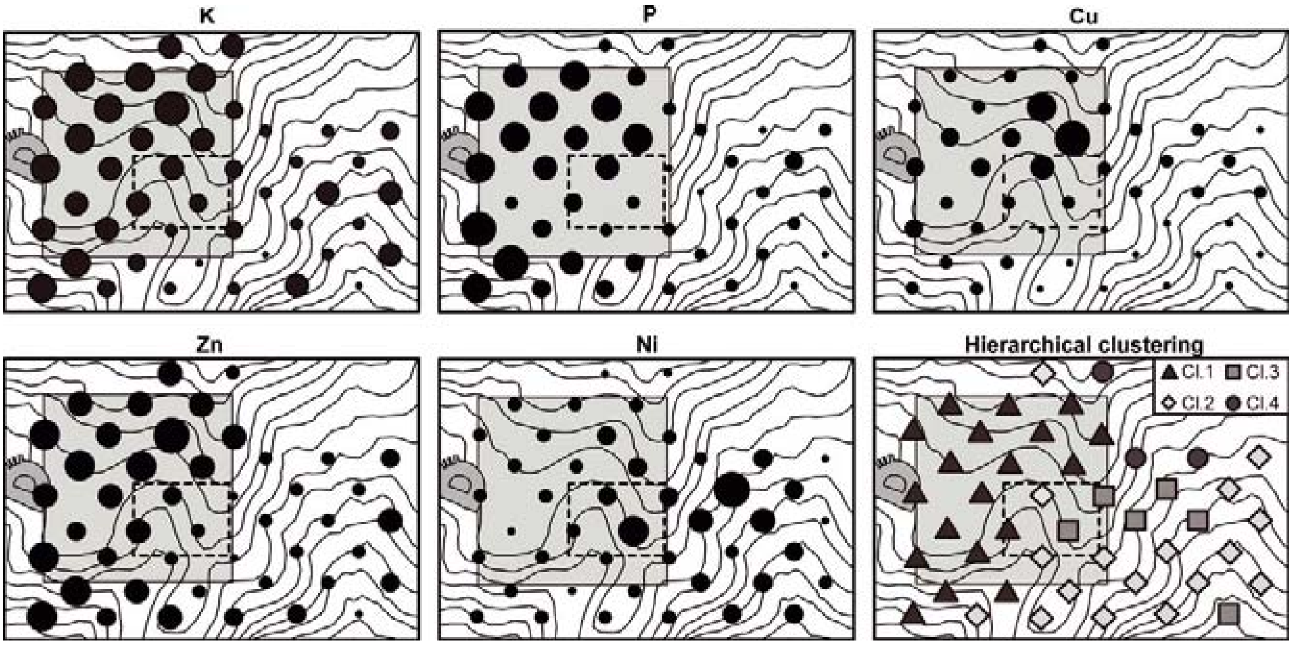

Figure 3: *Concentration distribution of K, P, Cu, Zn, Ni and sample clusters in grid ES1. Curved lines reflect topography, gray squares reflects the main activity zone, dashed area marks the outline of grid ES2. Dot sizes are proportional to concentration values. Hierarchical clustering was carried out using Wards' clustering method.*

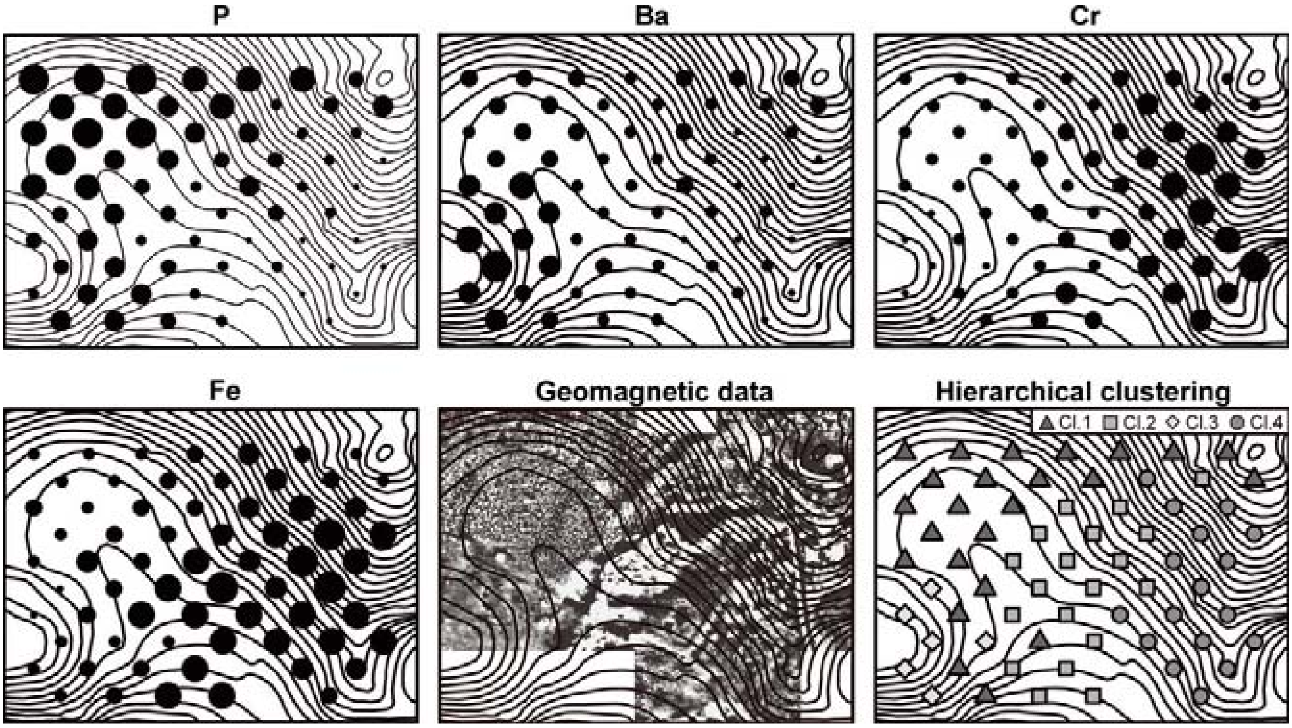

Figure 4: *Concentration distributions, cluster distribution and magnetic data in grid ES2. Curved lines reflect topography. Dot sizes are proportional to concentration values. Hierarchical clustering was carried out using Wards' clustering method.*

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SPATIAL ANALYSIS OF MAGNETIC SUCSEPTIBILITY AND GEOCHEMICAL DATA ON NEOLITHIC SITES IN SERTEYA, NORTHWEST OF RUSSIA

A.N. Mazurkevich, M. Kulkova, J.W.E. Fassbinder, D. Hookk

1. INTERPRETATION OF MAGNETIC DATA IN THE SERTEYAN ARCHAEOLOGICAL MICROREGION

The Dnepr-Western Dvina (Dnieper-Daugava) interfluve is a territory known for the presence of glacial lakes that formed during the Holocene. The area was always rich in fish and wildlife, and was the scene of hunting and fishing activity and small settlements since the Stone Age. Therefore, it is rich in archaeological sites (Mazurkevich *et al*., 2011). These sites form so-called "archaeological micro-regions". One such micro region is situated along the Serteya River, a tributary of the Western Dvina. The Serteya river and its environment (Figure 1), inherited from the swampy lacustrine hollows, became the focus of our research. The landscape of this region, the glacial and glacial-melt forms and deposits, are well-preserved and have never been destroyed by modern agriculture. Predominant sandy deposits and soils make it difficult to find a sharp and strong magnetic contrast between archaeological structures and the adjacent geology. Such circumstances complicate the interpretation of magnetometer measurements and the resulting magnetograms. To facilitate and to simplify these interpretations, by separating the remnant and induced magnetization, we applied additional magnetic susceptibility measurements. Furthermore, we applied geochemical analysis to evaluate and to understand the magnetograms (Mazurkevich *et al*., 2009; Hookk *et al*., 2010).

So far, it has not been possible to find a direct correlation between extrema in magnetic susceptibility, magnetometer data and geochemical values (Hookk *et al*., 2011; Mazurkevich *et al*., 2012). Nevertheless, the experimental work aims to help us to gain a better understanding of the sites and yields a comprehensive interpretation of the results.

2. ARCHAEOLOGICAL AND GEOCHEMICAL DATA

Various types of archaeological sites have been found in the Serteya micro-region, including Middle-Late Neolithic pile-dwellings and fish-traps located in peat bogs and under water in the river, as well as Neolithic settlements in peat bogs. Numerous fragments of material culture are perfectly preserved, thanks to the anaerobic conditions. Early Neolithic remains situated on sand banks along hollows give few finds; organic materials, traces of constructions, pits and fireplaces have been very poorly preserved in the sandy soils. Pedogenic processes at these monuments proceed very slowly (Mazurkevich *et al*., 2012), and the cultural layer does not exceed 10-30 cm. However, they also conceal valuable information about the life of the ancient population: multiple methods are required in order to reveal this invisible evidence of the past that is hidden in sands. During investigations of the cultural layer by archaeological excavations, ongoing since 2003, particularly on the sites Serteya 3-3, L, XXXVII, XXXVI, the following methods were applied: 3D fixation of finds for detailed spatial analysis, geochemical analysis of samples from the cultural layer, magnetic prospection and kappametry. Kappametry allows selection of some levels with different traces of magnetic anomalies, as well as separation, by level, of the anomalies summarized/overlapped during the preliminary magnetic prospection. The geochemical methods, combined with the spatial analysis of the distribution of finds, make the distinction of different horizons of habitation possible on these sites (Mazurkevich *et al*., 2009; Hookk *et al*. 2010, 2011). With the use of geochemical methods, the complex of chemical components and microelements accumulated in the cultural layer and caused by human activity (P_2O_5, CaO, K_2O, MnO, Ba, Sr, Rb) was defined. The distribution of chemical elements and groups of elements on the site help to characterize different functional zones. The analysis of finds distribution and its correlation with geochemical anomalies allow the correct interpretation of the functional zones and the structure of the settlement. The spatial and typological analysis of the archaeological material enabled the creation of a microchronology for the site.

3. MAGNETIC METHODS AND EXPERIMENTAL DATA

For the magnetometer measurements, we employed the Cesium Smartmag SM4G-Special magnetometer in a duo-sensor configuration. This total-field magnetometer enabled us to detect magnetic anomalies with the highest possible resolution of ± 10 Picotesla combined with a comparatively high spatial resolution of 25×25 cm. The diurnal variations of the Earth's magnetic field are reduced to the mean value of the calculated data in the 40×40 m square. This configuration is very sensitive to artificial and technical disturbances and rapid variations of the Earth's magnetic field. Therefore, it is well adapted to forest areas as well as to uneven and bumpy areas such as peat bog sites. The application of the magnetometer in an uncompensated configuration yields the highest signal to noise ratio with respect to the archaeological anomalies, and is possible since these sites are far from any technical installation (Figure 2).

For the magnetic susceptibility measurements, we applied the Kappamete SM30 (Zh-Instrument, Czech Republic). This instrument works with an oscillator frequency of 8 KHz, and the diameter of the measurement coil is 5 cm. Roughly 90% of the resulting data are due to the magnetic properties of the volume of half the space beneath the receiver coil. The sensitivity of the instrument is 10^{-7} [SI] units. Such sensitivity allowed us to trace magnetite or maghemite even in small volume concentrations of less than 0.002%. For a better understanding, and for comparison of the results with the magnetic prospection, the susceptibility values were visualized in grey shade pictures at a sampling rate of 50×50 cm. The sampling rate of 25×25 cm on the site Serteya XXXIV in 2012 evidently gave more contrast and images that are more detailed.

In order to get a clear picture of what the kappameter measured in the cultural layer, we decided to undertake additional research. This was not purely experimental, and we took into

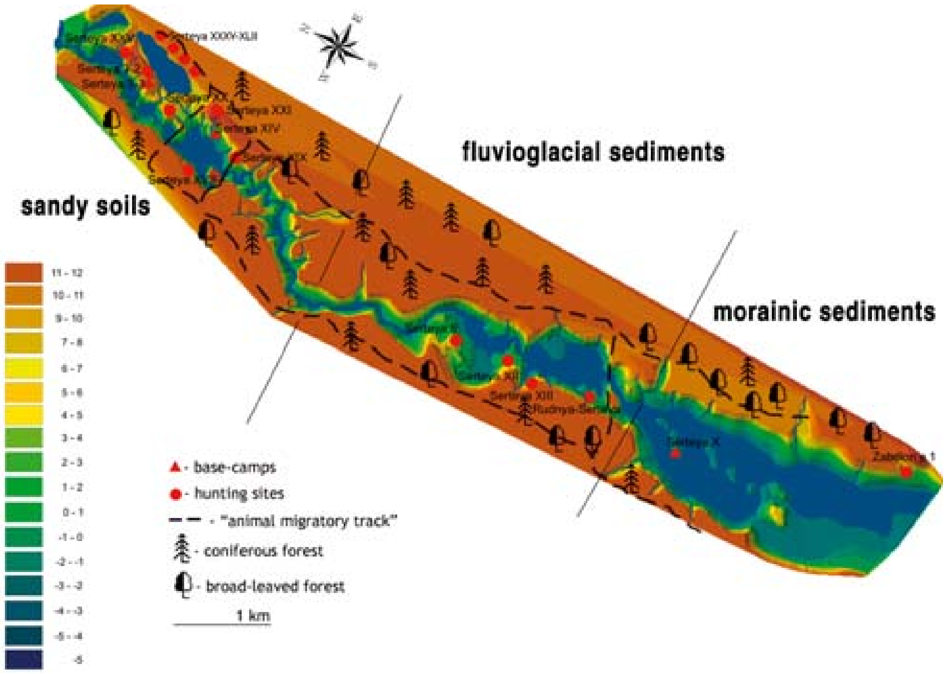

Figure 1: *3D model of Serteyan microregion with archaeological sites.*

account previously described experiences (Le Borne, 1960; Linford and Canti, 2004). The experiment was organized in real field conditions (Figure 3). A bonfire was made 100 m away from the site, at the same attitude, with topsoil removed, and supported for three days. The total burning time of the pine firewood is equal to 8 hours. The result of the process presents a dark spot with a diameter of 40 cm. The value of the magnetic susceptibility on this spot before firing was 0.164 and after became 0.642. A second bonfire in which organic remains (oats) were added gave a value 0.894.

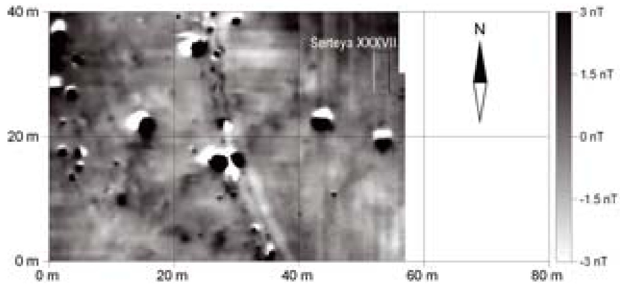

Figure 2: *Magnetogram of the Site XXXVII and environments.*

4. DISCUSSION

The advanced study was conducted at the Early Neolithic site Serteya XXXVII, which was inhabited many times from 7000-6000 BC. The samples for geochemical analysis were taken from the light sand at a depth of 40 cm. Factor analysis of the elements revealed those that we take to be the most important, some of which we discuss here. Concentration of the iron oxides Fe_2O_3 and FeO appear around the roots of plants and can mark the remains of rotted stumps (Fassbinder et al., 1990, 1993). High levels of these Fe_2O_3 and FeO oxides also correspond to the locations of long-term fires. Accumulation of the element Pb takes place either on hearths or in big humus deposits. As a rule, the distribution of Pb is correlated with element K_2O accumulating in ash or heat features. The accumulation of Cu due to recovery conditions, possibly, corresponding to the root holes or ash and heat features.

The spatial analysis of the geochemical data, the magnetic susceptibility measurements, and the stratigraphy of finds and the plan of pits gave us an appropriate interpretation of the site (Figure 4). The magnetic anomaly near the east wall of the trench (at the level 300×250 cm) can be explained as a concentration of ash or small hearth not visually identified during the excavations. An anomaly at the level 150×150 cm corresponds to the root pit and at the level -150×150 cm we suppose the accumulation of calcined bones and deep fire pit, destroyed by root pits. The approach described herein, correlating the spatial analysis of magnetic susceptibility and geochemical data with the distribution of finds and objects in the cultural layer, allows researchers to reconstruct site structure and the functions of the separate locations. The experimental data on magnetic susceptibility and geochemistry make possible more accurate interpretations of magnetograms.

ACKNOWLEDGMENTS

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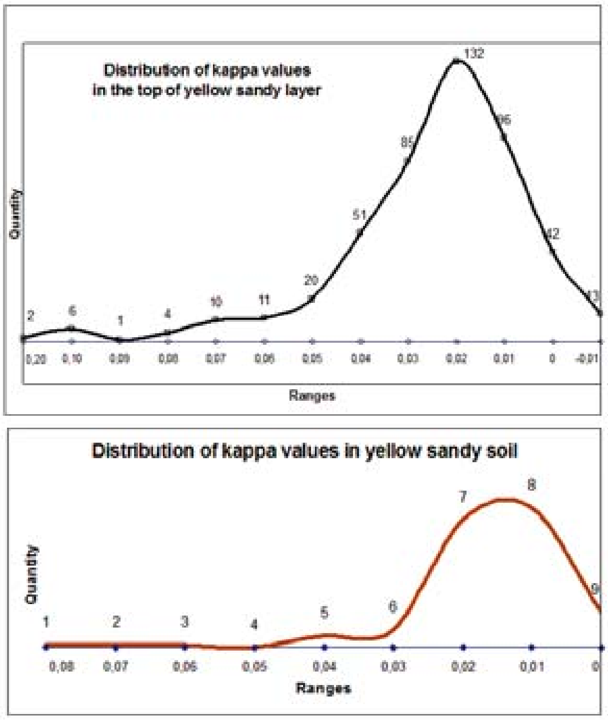

Figure 3: *Distribution of magnetic volume susceptibility data (all kappa values ×10^{-3} [SI]-units).*

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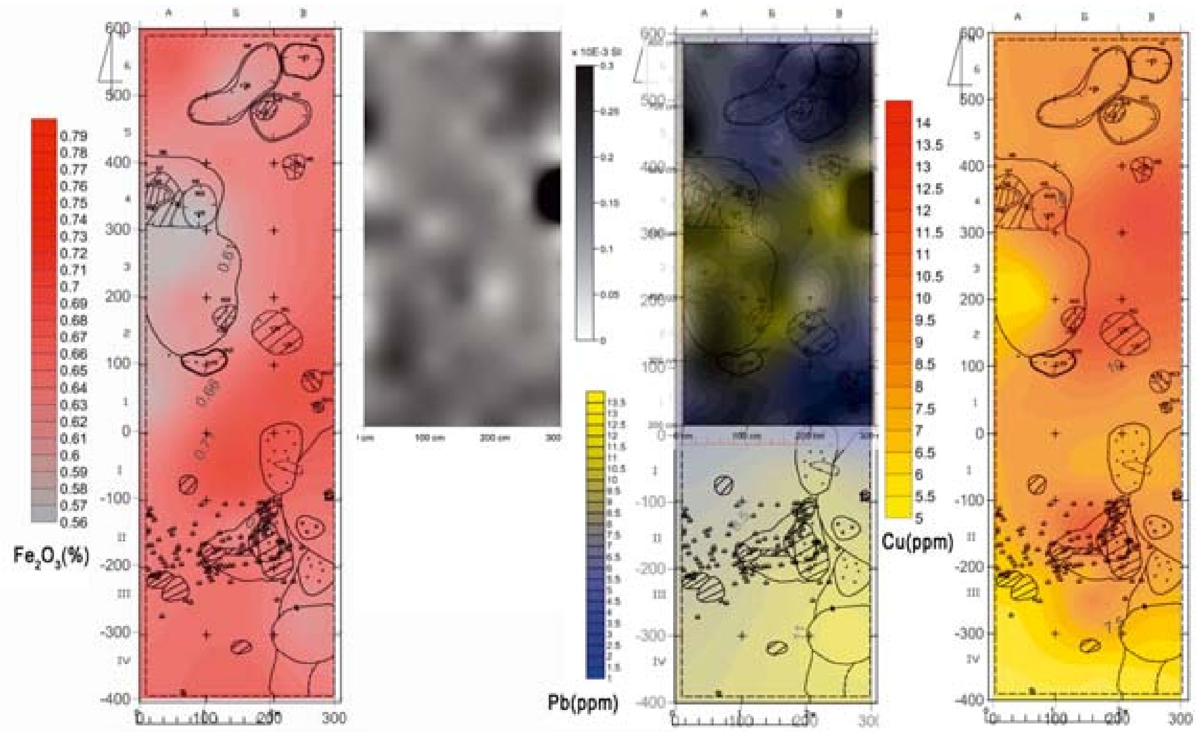

Figure 4: *Site Serteya XXXVII. Distribution of magnetic volume susceptibility data (all kappa values ×10^{-3} [SI]-units) and elements Fe_2O_3, Pb, Cu on the plan of trench with marked places of pits and calcined bones.*

DEVELOPING AN INTEGRATED PROSPECTION APPROACH FOR THE ARCHAEOLOGICAL EVALUATION OF ALLUVIUM COVERED LATE PLEISTOCENE-EARLY HOLOCENE LANDSCAPES: FIRST RESULTS FROM DOELPOLDER NOORD (BEVEREN, BELGIUM)

J. Verhegge, T. Missiaen, P. Crombé

1. INTRODUCTION

This paper presents the current prospection strategies and developments for evaluating prehistoric archaeological landscapes in the Scheldt polder region (Province of Antwerp, Belgium). The importance of palaeolandscape reconstruction for prehistoric archaeology has already been stressed by Brown (1997). But whilst protecting them, the burial depth of archaeological sites below alluvial plains also increasingly prohibits their detection using traditional near-surface approaches. For deeply stratified alluvial sequences, palaeolandscape reconstruction strategies combining borehole data and geophysical techniques have been proposed by Bates *et al.* (2007) and others. In Flanders, however, archaeological evaluation of alluvial plains is mostly done only through hand-augering (De Clercq *et al.*, 2011). Our project is aimed at integrating existing geophysical survey techniques in the archaeological evaluation process of alluvial landscapes.

2. RESEARCH CONTEXT

In the past decades, large parts of the Scheldt polders were destroyed during of the expansion of the Antwerp harbour. Impromptu salvage excavations had to be performed, as no archaeological evaluation had been done in advance (Crombé, 2005). As new construction works are planned in the near future, a cost-effective archaeological evaluation strategy has to be developed.

3. THE PREHISTORIC LANDSCAPE DEVELOPMENT AND HUMAN OCCUPATION

The topography of the late Pleistocene-early Holocene time-slice of the Scheldt polders consists of SW-NE oriented aeolian cover-sand ridges connecting sandy Flanders to the southwest and the Pleistocene parts of Holland to the east. A combination of Holocene sea-level rise and changing regional fluvial influences caused these late Pleistocene sands to be covered by Late

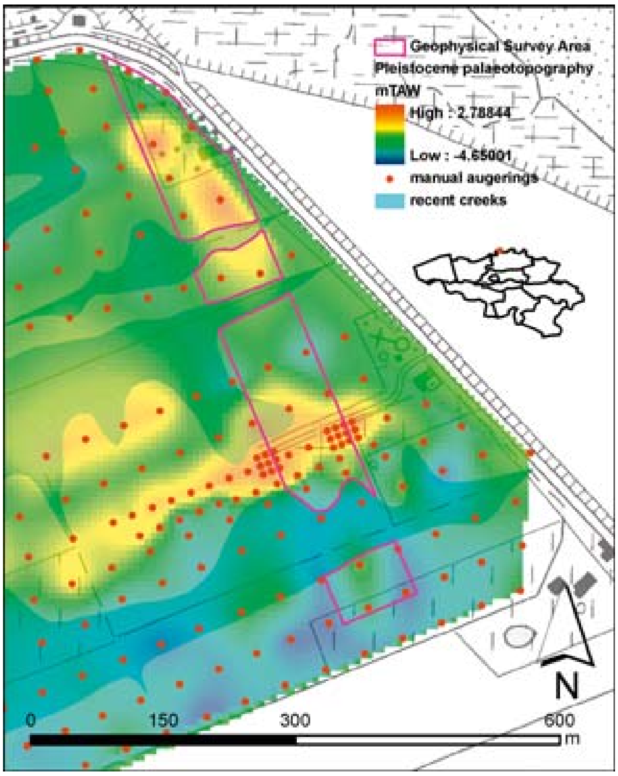

Figure 1: *Location of the survey area and known Pleistocene topography at Doelpolder Noord.*

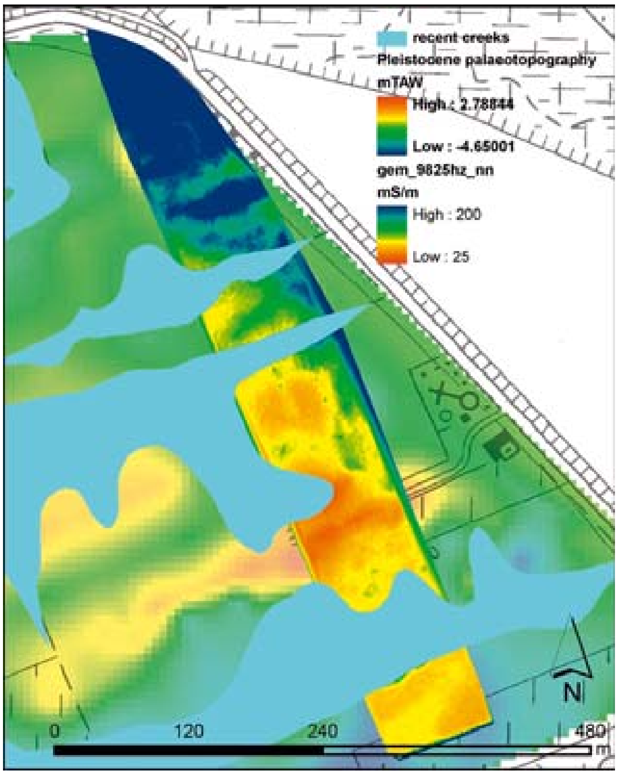

Figure 2: *GEM conductivity data of the survey area at a 9825Hz induced electromagnetic field.*

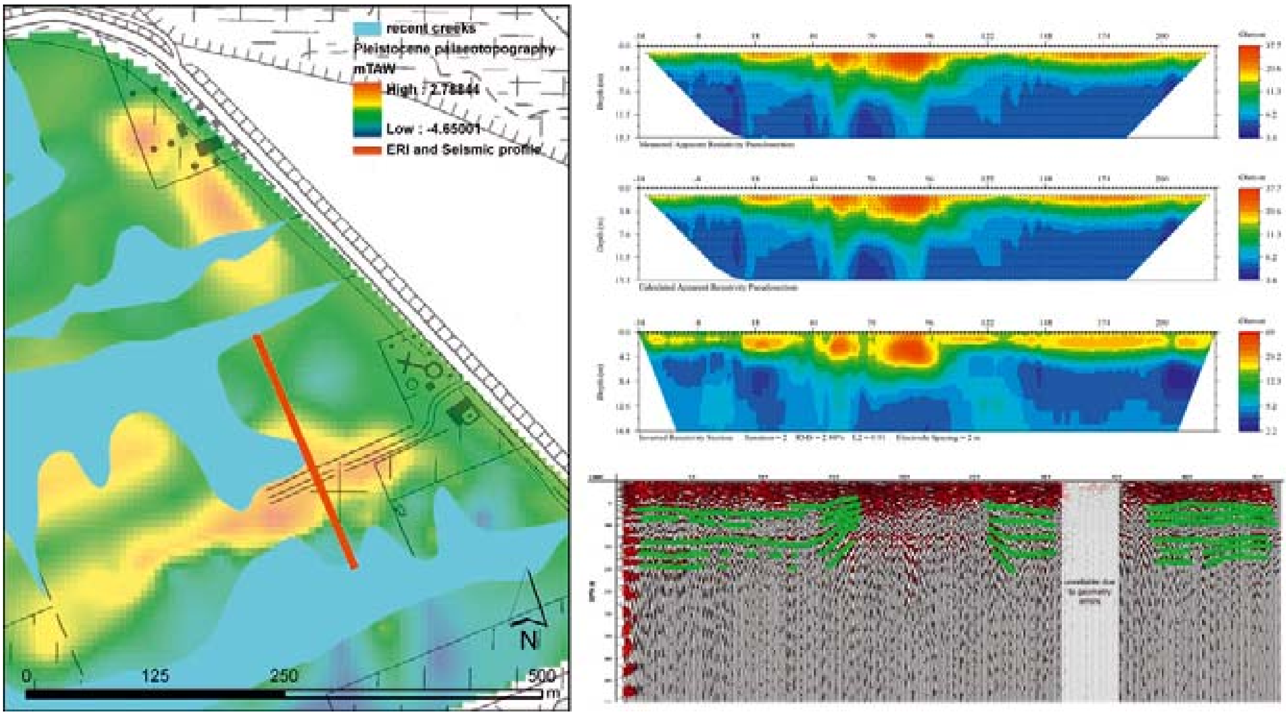

Figure 3: *Modelled electrical resistance profile and land seismic survey profile across the selected microsandridge.*

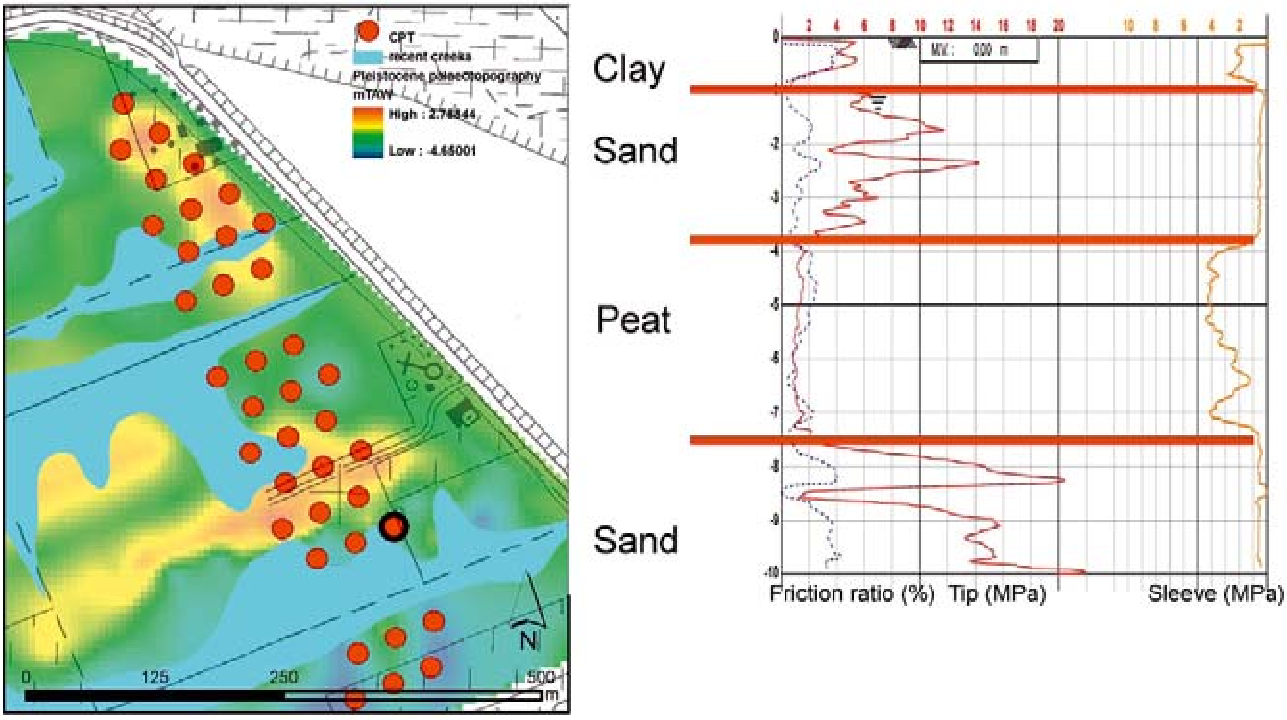

Figure 4: *CPT profile on the flanks of the sandridge.*

Atlantic 'alder carr' basal peat from ca. 7640-6620 cal BP onwards. Subsequently, organic old sea clay was deposited in low topographic positions from ca. 6550 cal BP to ca. 5650 cal BP. Mid Holocene Holland peat growth restarted between ca. 5680 cal BP and ca. 4880 cal BP (Deforce, 2011). Later sedimentation consists of marine deposition of sandy clays and clayey sands, but is less relevant to the prehistoric occupation of the landscape.

4. ARCHAEOLOGICAL RELEVANCE

Excavations have shown that the undulating Pleistocene topography below the Scheldt polders is well-preserved, and that nearly all tops and flanks of (micro-)sand ridges within this undulating landscape contain archaeological sites ranging from Final Palaeolithic to Early Neolithic times with varying site locations, -sizes and -densities through time. These sites often do not contain any structures but can be characterized as scattered artefact assemblages. After analysis, it was found that these sites are important for the understanding of late Mesolithic hunter-gatherer responses to climatic change as well as for verification of proposed Mesolithic-Neolithic transition models (Crombé, 2005).

5. SURVEY AREA

The survey area (Figure 1) chosen to test the available methods is situated on the left bank of the Scheldt-river, about 1.5 km from the Dutch border. A 90 m by 700 m transect through the nature reserve of Doelpolder Noord was selected, based on a palaeotopographic reconstruction by 500+ manual corings (Klinck *et al.*, 2007). This transect contains a Pleistocene wind-blown microsandridge buried about 2 m deep, flanking an 8 to 9 m deep depression in the Pleistocene sands.

6. METHODOLOGY

The currently used archaeological prospection strategy of full-coverage landscape survey to search for Stone Age sites in the alluvial plain of the Scheldt optimally exists for an initial reconstruction of the palaeolandscape development as a basis for subsequent archaeological evaluation. First, the geological layering is recorded through hand-augering in a 30 to 50 m grid, using a 7 cm Dutch auger for sandy textures or 2 to 3 cm gauge auger for clayey soils and peat layers. This grid spacing is required as important micro-sandridges are of similar dimensions. Nevertheless, the interpolation between auger points only allows a semi-accurate delineation of possibly preserved site locations, making the design of an archaeological sampling strategy prone to errors. In a subsequent archaeological evaluation phase, the relevant strata on topographical positions, possibly containing archaeological sites, are sampled and samples checked for archaeological indicators. Grid size, auger diameter and mesh size of the sieve can vary according to the aims, means and time available. Optimally, sampling is performed using a 10 to 12 cm diameter Dutch auger in a 10 m staggered grid. Samples are then sieved using a 1 mm mesh to obtain the smallest archaeological direct or indirect indicators such as flint chips, burnt bone fragment or charred hazelnut shells. If required, the grid size can be decreased locally to 5 m (De Clercq *et al.*, 2011).

In both phases of the evaluation process, it is impractical and costly to collect large numbers of samples by hand at greater depth. Large-scale augering survey down to the Pleistocene depth is even physically impossible without expensive mechanical aids, if overlying sediments are sandy and below the groundwater level.

As surface geophysical survey techniques allow the collection of large numbers of data points at greater survey speed, it was assumed that their inclusion in the palaeolandscape reconstruction could facilitate the process whilst achieving a higher horizontal spatial resolution. This could also improve archaeological sampling design. Because of their lower vertical resolution and the complex geological stratigraphy, additional coring information is still required however. Electrical conductivity derived from the quadrature phase response of an induced electromagnetic field can be related to texture, moisture and electrolyte content variations of the measured soil volume (Simpson, 2009). A hand-carried Geophex GEM-2 sensor was used in horizontal coplanar coil orientation to collect continuous data on lines 2.5 m apart at 1 m from the surface. Measurement positions were tracked using a handheld GPS. By varying the frequency of the induced electromagnetic field, the sensor is theoretically sensitive to different depth extends.

Electrical resistance imaging data (ERI) (Samouëlian *et al.*, 2005) were collected using an AGI Supersting R8 in an inverse Schlumberger configuration. Measurements were collected along lines located 10 m apart and along the sections, electrodes were positioned 2 m apart. The resulting data were processed using Earthimager 2D software.

Seismic survey measures the time, which is converted to depth, between the transmission of a seismic wave into the soil and the reception of its reflections and refractions on interfaces of differing acoustic impedance. The first trials with land seismic measurements were carried out by Deltares using S-waves. A portable S-wave vibrator source was used with a sweep frequency from 10 to 240 Hz. The geophones, set 1 m apart, were contained in a flexible cable that was dragged over the field. To limit the number of deep augerings to be done for calibration and interpretation of geophysical data, electrical cone penetration tests (CPT), measuring depth, tip resistance and sleeve friction of a cone forced into the ground were deemed well-suited (Thooft, 2007). Interpretation is done using classification charts, pre-existing knowledge of the stratigraphy or by a limited number of (mechanical) augerings. The data could also be collected as a gridded survey technique where geophysical techniques are ineffective but no high spatial resolution is required for archaeological purposes (e.g. deep depressions).

In order to verify the presence of archaeological sites, the top of the sandridge was sampled manually as deeply as possible using a 10 cm Dutch auger on a 10 m grid. These samples were wet sieved through a 1 mm mesh and checked for archaeological indicators. In a second phase, a transect showing archaeological indicators was recently sampled both manually on the top using the same auger in a 5 m grid and mechanically on the deeper flanks.

7. RESULTS

The first EMI results allow a detailed delineation of Pleistocene micro-sandridge, archaeologically the most relevant feature, as a low conductivity anomaly. The GEM (Figure 2) data reveal a lot of detail showing even a small increase of conductivity centrally through the top of the micro-sandridge, correlating to a small bowl. This ridge is surrounded by a band of higher conductivity values, indicating the presence of conductive peat on the flanks of the ridge in the measured soil volume. More to the north, the GEM mapped a possible gully with crevasse deposits. The depression in the Pleistocene sands could not be distinguished from the average depths because the sandy sediments on top of the peat within the main part of the sensor range. In the northernmost part of the survey area, the signal is probably disturbed by salt intrusions.

The ERI was less successful in mapping the sandridge. The ERI detected the sandridge above groundwater as a high resistance feature but below groundwater, no resistive sandy feature could be detected. Large surface variations due to recent land-use have hampered good results as well (Figure 3). The first tests with terrestrial shear wave reflection profiling clearly show the top-Pleistocene topography and a large number of additional reflectors (Figure 3).

A series of 40 cone penetration test was collected (Figure 4). It was found that the peat has a much smaller tip resistance than the under- and overlying sands, thus allowing a straightforward manual classification. The existing soil classification charts (Thooft, 2007) do not allow an automated interpretation however, as the peat layer is considered clay to silty clay, possibly due to the compaction. The construction of a local classification chart could possibly resolve this.

Only the top of the ridge could be sampled manually, up to a depth of 2.5 m. At greater depths, samples could not be retrieved from the borehole. Nevertheless, several samples contained archaeological indicators.

8. CONCLUSION

It can be concluded that EMI survey allows rapid and detailed mapping of the Pleistocene palaeotopography for archaeological evaluation purposes. Interpretation can be aided by a limited number of corings to identify the anomalies. ERI was far less successful due to the high groundwater table. Land seismic survey had good results but is slow and expensive. The CPTs were successful at detecting the required surfaces. Because of their cost-effectiveness, they could serve as an excellent calibration tool for the EMI data or as an independent gridded survey technique.

The current archaeological sampling methods are well suited at limited depths. Mechanical augering has to be performed at greater depths where loose sands above the peat impede sample collection but requires an accurate palaeotopographical model to be cost-effective.

Future work includes geophysical modelling of EMI data, dating of the peat development using 14C, pollen analysis of a peat profile and analysis of archaeological samples collected mechanically during the last summer campaign.

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TAKING INTO ACCOUNT THE DEPTH VARIATIONS OF THE BEDROCK FOR THE INTERPRETATION OF THE SURVEYS ACHIEVED IN THE EASTERN AREA OF THE SITE OF PUIG CIUTAT, BARCELONA

R. Tamba, R. Sala, P. De Smedt, E. Iriarte, E. Garcia, M. Van Meirvenne

1. INTRODUCTION

After a preliminary campaign performed in 2006 and presented at the ISAP international congress of 2007 (Sala and Lafuente, 2007), the archaeological site of Puig Ciutat was investigated within a multi-disciplinary research project combining GIS analysis, geophysical exploration and archaeological works. The first results, including the magnetic data acquisition, showed a complex environment where the geological background had a major impact on the archaeological interpretation of the survey results (Garcia *et al*., 2010). In this context, a specific survey methodology, together with adaptive processing, had to be applied in order to be able to visualize the data related to archaeological layers. We combined detailed ground-penetrating radar (GPR) surveys with lithological coring and a multi-receiver electromagnetic induction (EMI) survey. The integrated analysis of these data will form the basis of a comprehensive reconstruction of the archaeological setting of the site.

2. GPR SURVEY

A high-resolution GPR survey was conducted in the eastern part of the settlement. We used a RIS MF HI-MOD system from IDS with frequencies of 600MHz and 200MHz to survey profiles 0.2 m apart. Along these profiles, data were acquired every 0.02 m and no filter was applied during acquisition. A total of 0.44 ha was covered in 1.5 days.

Data were visualized by computing time slices after the processing (Goodman *et al*., 1995). The results showed several types of features: linear features that were identified as superficial and deep ploughing, linear features partially visible interpreted as walls, large continuous reflections identified as the bedrock and areas of low amplitude reflections that could indicate paths (Figure 1).

An excavation was conducted over the main detected feature confirming the presence of 3 walls and the large anomaly identified as bedrock (Figure 2).

The excavation also showed that the building material and the bedrock are of the same nature. A fourth wall was detected during the excavation that closes the area into a room that was not identified by the GPR survey. As the walls are directly built onto the bedrock at varying depth, one possible process was then to map the variations in depth of the bedrock in order to take them into account during the GPR slicing. Additional data were needed in order to do that.

3. CORE LOGGING

As additional data were needed to map the bedrock depth variation, core logs were taken to gain detailed insight into the stratigraphy at sampling locations. The cores were homogeneously distributed over the GPR-surveyed area (Figure 1). An Eijkelkamp percussion gouge was used, which renders continuous core samples in 1 m sections. A total of 12 logs were extracted. Eight gave a bedrock depth between 0.30 and 0.60 m while four others showed a depth between 1.5 and 2 m.

4. MULTI-RECEIVER EMI SURVEY

The EMI acquisition was performed using a DUALEM-1S sensor towed by a quad vehicle. This multi-receiver instrument has one transmitter and two receiver coils recording both the apparent electrical conductivity (ECa) and magnetic susceptibility (MSa) at each measurement location. The different coil orientations (i.e. in horizontal coplanar (HCP) and perpendicular (PRP)) and separations (i.e. 1 m and 1.1 m inter-coil separation) allow recording ECa and MSa of different soil volumes simultaneously. For the ECa measurements, this results in measured depths from 0.5 m (PRP) and 1.5 m (HCP) below the soil surface. The survey was conducted by driving over the site across parallel lines, 0.75 m apart, with an in-line resolution of 0.25 m.

5. INTEGRATED DATA PROCESSING

Joint data analysis will be based on the geomorphological characteristics from the site. By including detailed information about bedrock depth and soil variations based on the different geophysical data and core logs, the influence of the geology will be taken into account for interpreting the archaeology at the site. The first step in this analysis will include the cross-correlation between the geophysical information and the stratigraphic core logs. The resulting data will be used to set the kriging parameters of the depth of the bedrock. Once the bedrock horizon defined, a selection on the GPR data will be performed in order to exclude data below the bedrock. The slicing will be the performed using overlapped windows regularly distributed or using the stratigraphy analysis of the intermediate layers if available.

6. CONCLUSIONS AND PERSPECTIVES

The proposed methodology is adapted to limited areas with a complex geomorphology. The main focus is to give a solution that is effective in terms of acquisition and processing time. It requires the determination of the parameters necessary to describe the geomorphology and remove its influence from the GPR data. Although the visualization of the constructive structures should be improved, some features could still be partially described or not identified due to a low contrast or insufficient penetration of the signal. The mapping of the constructive structures could then be completed by the integration of additional geophysical data.

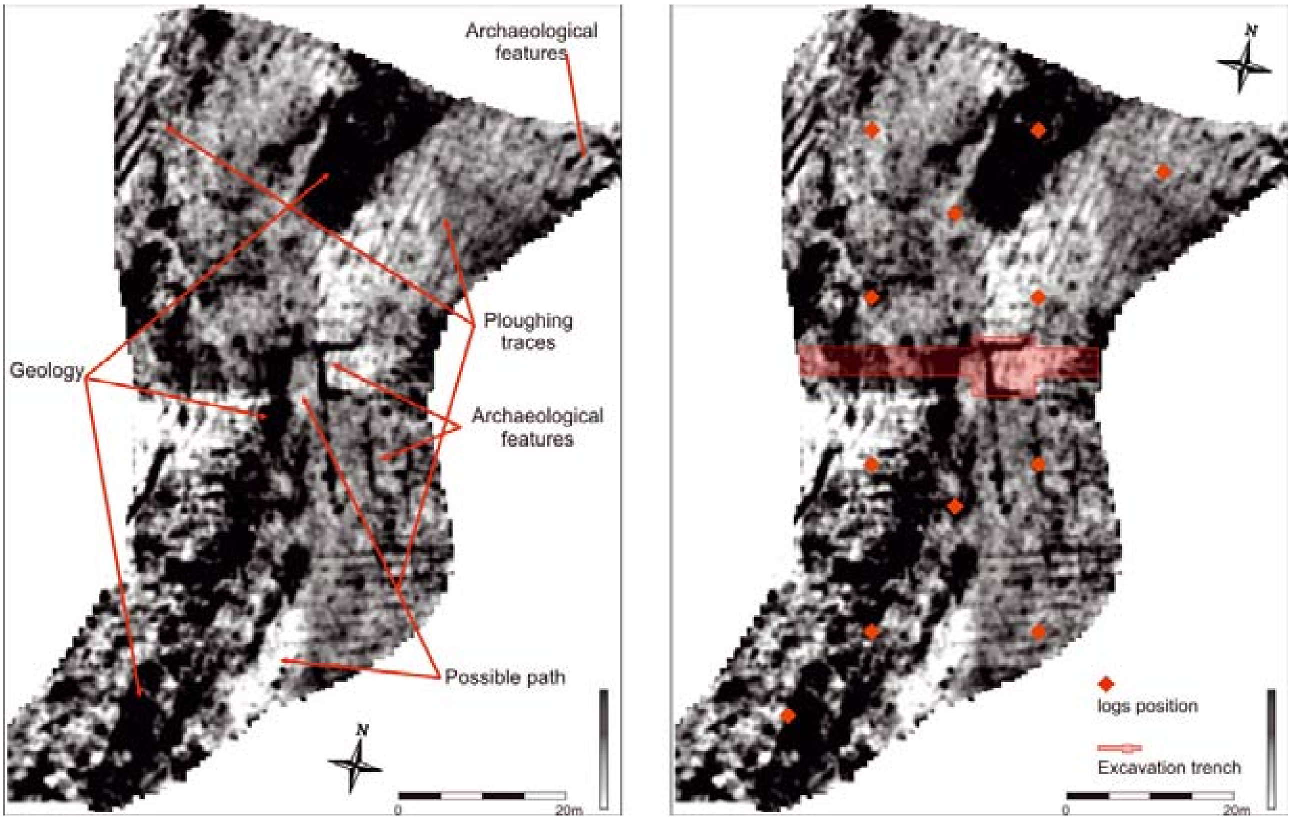

Figure 1: *GPR slice for depth included between 0.45 and 0.55m: interpreted anomalies (left). Cores and excvation trench positions.*

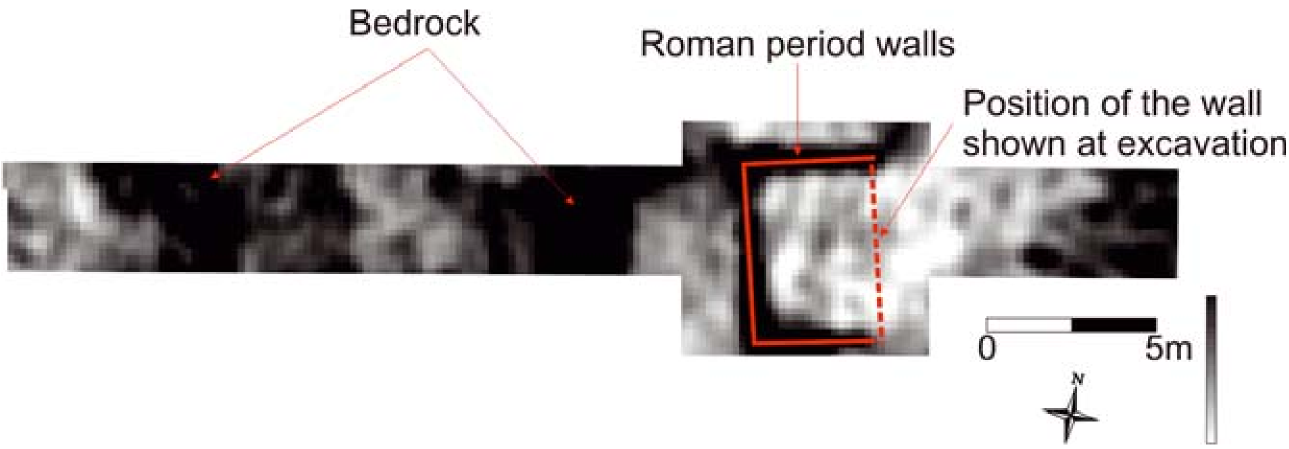

Figure 2: *GPR slice in the excavated area.*

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UNRAVELLING A COMPLEX OF ENCLOSURES. AN INTEGRATED PROSPECTION APPROACH FOR A DESERTED HISTORIC FARM-COMPLEX AT KLEIT, MALDEGEM (FLANDERS, BELGIUM)

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1. INTRODUCTION

Oblique aerial prospection in the region between the modern towns of Bruges and Ghent (Flanders, Belgium) has yielded some 70,000 aerial pictures of cropmarks and other features related to archaeological and landscape features. Up until now, the interpretative research on this aerial imagery has mainly focussed on more or less clear-cut and clearly visible features such as Bronze Age burial mounds of the ring-ditch type (Ampe *et al*., 1996; *De Reu et al*., 2011) or presumed Roman road systems flanked by two ditches (Vermeulen and Hageman, 2001). However, a vast number of pictures remains unstudied, even though they show features related to deserted settlements dating back at least to Roman or Protohistoric times. An even larger number of sites, often characterised by ditched enclosures, most likely dates to the High and Late Medieval period (ca. 11-15th centuries AD). During this period, the historic heartland of Flanders witnessed an exponential growth in population. From the late 11th century AD onwards, the need for agricultural resources and raw materials led to even poor land rapidly being reclaimed for logging, peat extraction, agriculture and pasturing. As written sources extensively demonstrate, borderlands were transformed into a dynamic production landscape characterised by a network of market oriented estates and farm settlements (Verhulst, 1995). Assessing this phase of medieval landscape colonisation still remains a major scientific challenge in Flemish archaeology. Equally unexplored is the subsequent partial abandonment of the exhausted parts of this exploited landscape. Although in the last decade some of these farms have been excavated (e.g. De Clercq and Mortier, 2002), a substantiated insight into the morphology, landscape setting and economy of these farmsteads is still lacking.

2. SURVEY METHODOLOGY

A significant improvement of scientific information on these settlements can be acquired through the development of an integrated multi-disciplinary prospection methodology, combining aerial photography, geophysical techniques such as magnetometry, electromagnetic induction (EMI) and ground penetrating radar (GPR), field survey, test-pitting and archival research. Starting from a well-documented case-study in the village of Kleit (Maldegem, Flanders, Belgium), and broadening our dataset with new data from other Pleistocene and even submerged landscapes at Aalter, Damme and other sites in Northern Belgium, we will further adjust our methodology in the following four years by refining it according to the complex and diverse nature of the types of soils and sites involved. The first results of the research are very promising, as was demonstrated by a combined application of aerial image analysis, a fluxgate gradiometer and a multi-receiver EMI survey (Dualem-21s sensor in a mobile configuration) on a 3 ha large site at Maldegem-Kleit, Belgium (De Clercq *et al*., 2012). The landscape and pedological context of the site is rather complex, as part of it lies on the shallow quaternary sand deposited on top of a tertiary clay substrate, while other parts are situated directly on top of the outcropping tertiary substrate. The results demonstrate the complementary nature of the applied survey techniques. The EMI-survey showed a large potential for mapping the archaeological variability in these areas. The obtained apparent electrical conductivity (ECa) and apparent magnetic susceptibility (MSa) data partly confirmed the aerial observations and complemented these with new features relating to enclosures, ditch systems and pits that were previously invisible on the aerial imagery. Furthermore, the EMI-data allowed a reconstruction of the palaeo-topography which enabled assessing the landscape context (Saey *et al*., submitted). Fluxgate gradiometer data also showed a large subsoil variability that partly coincides with the aerial photographs and MSa data. However, a straightforward archaeological interpretation of these data has remained impossible until now.

In addition to the geophysical survey, intensive field surveys have been conducted at the site. Two fieldwalking campaigns were organised in the autumn of 2011 and in the spring of 2012. For these surveys, a spacing of 1 m between survey lines was chosen to achieve a full coverage of the surface. This increased the chances of recovering the grey to black coloured ceramics characteristic for the pre 15th century AD period and obtaining a maximum number of finds.

The field survey has proven to be of great value to our understanding of the site. More than 370 finds were recovered and georeferenced with a RTK-GPS system, mostly consisting of ceramics from the late Medieval period. Potential clusters of finds are identified by means of a Kernel density estimation performed in ArcView 10.0 and related to aerial and geophysical imagery (Figure 1). The find distribution shows a well-defined cluster at the SE-part on the field, in a zone where the EMI-based palaeotopographical reconstruction indicated a thick, well-drained sand-layer, and hence the most suitable place for settlement location. The ceramic finds distribution in this area, including fragments of classic household-pottery such as jugs and cooking-jars, correlates with an area on the aerial imagery that seems to be bordered by a rectangular ditch-system or enclosure. This structure proved to be of shallow depth in EMI-measurements. EMI-data also suggested the presence of pits in this area, again suggesting settlement activity. The finds date the cluster mainly in the 12th to 14th centuries AD, for the first time suggesting a more firm late Medieval date for the complex.

The ceramic distribution on the rest of the surface is rather evenly scattered, notwithstanding a clustering of sherds on the western part of the field. This seems more vaguely to correspond with the large enclosure revealed by aerial photography and both EMI and magnetometry surveys. Again, the pottery evidence points to a late Medieval date of the site. The trape-

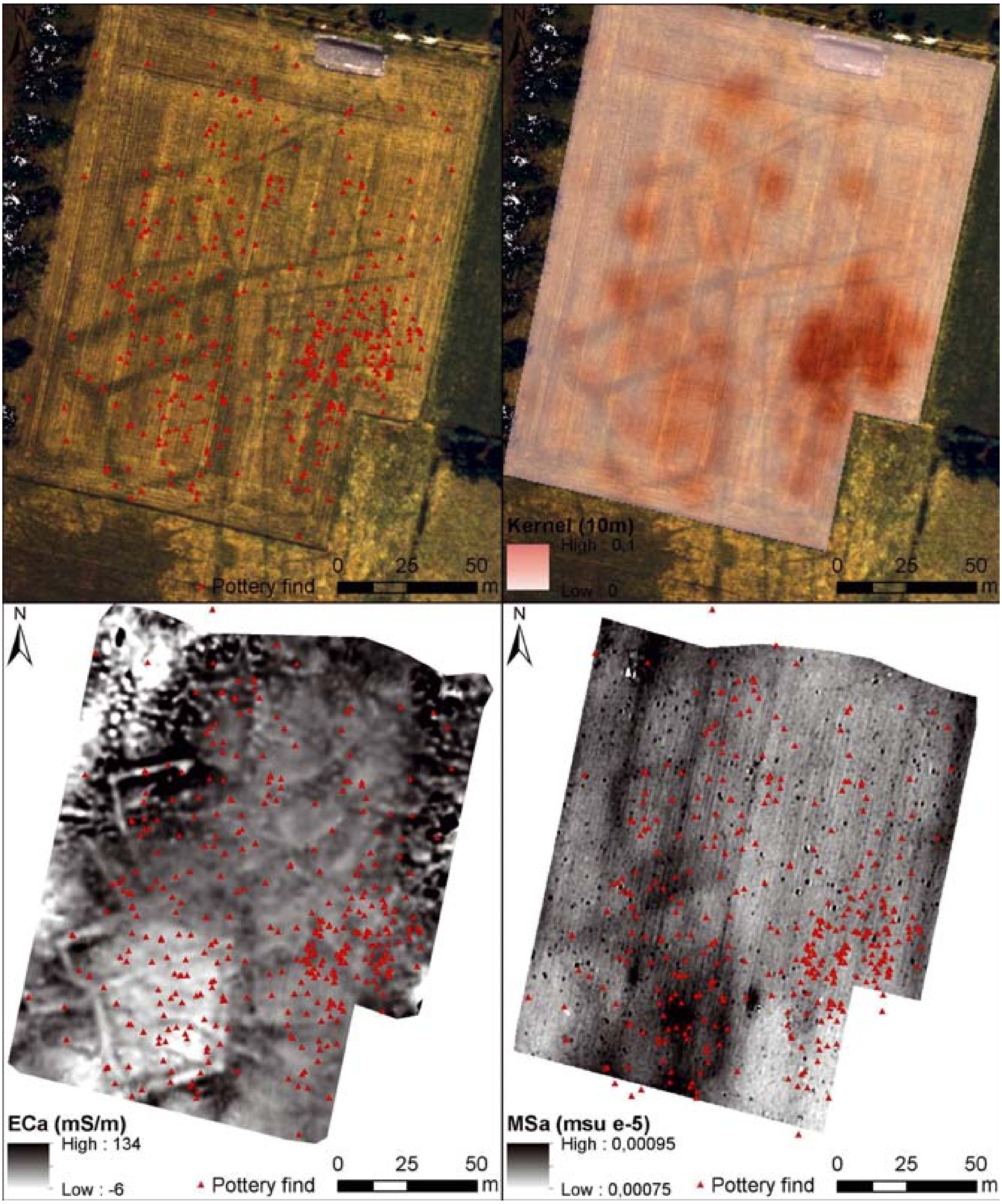

Figure 1: *Distribution of field survey pottery finds plotted on one of the georeferenced aerial images (photograph 55332, Department of Archaeology, Ghent University) (upper left), ECa of the overlying quaternary sand (Saey et al. submitted) (bottom left), MSa of the topsoil (bottom right) and a Kernel density estimation of the pottery finds (upper right).*

zoidal enclosure in the northern part of the field, only visible in aerial photography, remains difficult to grasp by other techniques. Fieldwalking only revealed a low density of late Medieval sherds on top of it. Two pottery fragments of probable Roman date were recovered in the most southern part of the field. In this area a system of ditches and probable tracks was revealed only in EMI-survey. It could point to the presence of a Roman road or enclosure-system.

The chronology of the finds and the form of the larger enclosures leaves little doubt about the late-Medieval date of the larger part of the complex. Similar large enclosures are known in the literature as 'moated sites' (Verhaeghe, 1981).

3. DISCUSSION AND INTEGRATION WITH ARCHIVAL DATA

In view of these archaeological and archaeo-geophysical elements, archival research was set up to search for possible maps and written accounts of the farms. The area is well-documented by archival records because of the presence of the "Papinglo'–estate, about 500 m to the southeast. This monastic outer court was founded in the late 12th century AD by the Black Monks of the powerful abbey of Saint-Bavo of Ghent (De Smet and Verstraete, 1951). Historical research revealed a detailed map of the possessions and land-use of the abbey, drawn in 1567. Apart from forest, wasteland and fish-pounds, the map clearly shows two large enclosures to the northwest of the Papinglo-estate. Their inner surfaces are drawn empty and the written accounts indicate that these originally were farms bought by the abbey and added to the Papinglo-estate in 1409. The documents even revealed the name of the farms: The Wallen' ('the moats') situated near the 'Bijstierveld' ('poor field'), and west of it 'Ruekenswal' (moat of the Rueken's family') on the 'Broosloosbilck' ('higher field of the Broosloos-family'). It is known, that the important Bruges' family Broosloos invested heavily in land reclamation from the 12th to 14th centuries AD. The eldest known owner of the farm complex was Jacob Van Damme, a Bruges burgher who sold the estate in 1372 to the future inlaws of Jan Broosloos. The name Ruekens probably points to a tenant-farmer, working the farm for the Broosloos family or who possessed it during the late 13th century AD.

4. CONCLUSION AND FUTURE PERSPECTIVES

Field survey data and archival accounts are fully in line with each other and point to the late Medieval date of the complex. The shape of the larger enclosures (moated sites) as revealed by the complementary nature of archaeo-geophysical research and aerial photography confirms this hypothesis. As for the smaller, linear enclosures and ditch systems, we cannot advance to a sounder hypothesis yet, as other surveys still need to be conducted. In the months before the Vienna conference, a GPR-survey using a stepped frequency radar with a 13 antenna array from 3d-radar will be used on the site, followed by test-pitting on specific areas of interest, hence providing an archaeological *in situ* feedback. The position of these pits will be defined according to questions arisen from comparative analysis of all non-invasive techniques used.

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APPLICATIONS OF ACOUSTIC, MAGNETOMETRIC AND TOPOGRAPHIC SUBMARINE DEVICES FOR A METHOD OF UNDERWATER ARCHAEOLOGICAL RESEARCH

B. Wirtz, P. Pelgas, E. Miejac

The development of littoral bands on areas of potential archaeological significance obliges us to reconsider the methods we employ for archaeological prospection. Three examples illustrate these new orientations. In 2010, a project on the Castro–Urdiales' harbour and its surroundings (Cantabria), concerning more than 178 hectares, required geophysical prospection in turbulent waters. It was intended to give priority to geographic referencing of all the data, to determine the most effective method in light of environmental and financial constraints.

Indeed, the treatment of multi-beam sonar data emphasizes discreet reliefs that are not visible on the first maps. These relief anomalies represent a new domain for archaeology, by the variety of objects that can be clearly observed. Besides small objects on the surface of the seabed, multi-beam sonar can show larger objects that are buried and thus inaccessible to side sonar. In the case of Castro Urdiales, the number of visible anomalies produced by the standard sonar method was 54, compared with 130 revealed by the multi-beam investigation.

In 2011, Inrap began submarine exploration by the creation of a department dedicated to preventive underwater operations. Two recommendations were sent out by the State (Drassm, Ministry of Culture) for large-scale exploration: more than 100 hectares for a new road on the coast in the Reunion Island, and a little more than 200 hectares for the extension of the Calais harbour. For areas of this size, visual prospecting by divers was not feasible, especially in a restricted time allotment; these projects would have required months of prospecting, often in unfavourable sea conditions. On these two operations, therefore, the State requested geophysical prospecting with side-scan sonar and a magnetometer.

Anomalies were revealed from three devices. If the micro-reliefs of anomalies with the multibeam sonar were perceptible after data processing, an exploration of the raw data exposed new anomalies, verification of which are in progress.

Two types of anomalies were recorded on the operation of the coastal road on Reunion island; the first ones with the side-scanning sonar, the second with the magnetometer. The anomalies of the sonar images were perceptible by their shade. In the case of magnetic anomalies, more than two thousand targets were recorded because of iron-magnetic rock.

The Magsalia process, which is used to enhance the detection of submerged magnetic objects, produced two magnetic tomographies in global 3D from the raw survey data. The first tomography shows location and the other one measures magnetic susceptibility. In the case of La Réunion, the geologic nature of the ground presents a maximal difficulty for the process. Nevertheless, the exact locations of small rocks buried in the sediment open a way to the location of artefacts buried in marine sediment when they are magnetically discreet and inaccessible to the other types of marine geophysics.

Anomalies could be buried under several meters of sediment, and this represented a significant technical constraint. Therefore, targets were privileged which were buried under two meters deep. The impossibility of making systematic soundings at the bottom in the marine sediment required the use of a high precision measuring instrument. In this case, the use of a marine positioning system consisting of four GPS units fixed to buoys and receiving signals from an acoustic transmitter used on the bottom allowed an accuracy of about 1 metre for the transmitter.

The divers sent to the target simultaneously verified the dependability of the anomalies and the reliability of the positioning: this modus operandi saves time. This process brought to light mostly geological anomalies rather than anthropological ones.

The prospection operation in Spain took place with a Reason Seabeat 240 Khz multi-beam sonar fixed to the hull of a ship and coupled with an inertial power plant to compensate for the roll. The device makes 4 in 40 profiles per second and up to 5,600 probes per second. For 10 m of water, the device can cover 50 m of bottom; for 250 m of bottom, water of 45 m depth is required. At Castro-Urdiales, a digital model of ground was obtained with a swath of 1 m $\times$ 1 m and was available in real time on the boat. This allowed us to perceive the micro-relief. Every bathymetric plan is recorded with an interactive 3D visualization.

With 100 probes per square metre for a stitch of 0.20 $\times$ 0.20, the average probe by stitch is obtained by 4 average probes in which we deducted the errors. 79,000,000 useful probes gave a final image of 44,000,000 average probes, all geo-referenced, with the objective being to produce a high-resolution map for the localization of maritime cultural heritage. The "ground-truthing" by divers within the next year should provide us with information that will allow better understanding of the raw data and post-processing data.

ANCIENT TRAFFIC ROUTES IN THE SUDANESE WESTERN DESERT – AN ARCHAEOLOGICAL REMOTE SENSING PROJECT

J. Eger

This paper presents the results of a M.A. thesis using remote sensing data and historical survey records to reconstruct ancient traffic routes in the Sudanese western desert north and south of Wadi Howar. Our knowledge about probable north-south trade routes in that region has primarily been based on written records like the tomb biography of Herchuf, and the later records about the so called Darb al-Arbain. But, as I want to show with this paper, archaeological data acquired by evaluating satellite imagery combined with some older archaeological material found within the records of several desert travellers reveals that the western desert (even today a place not as remote as it looks at the first glance) was crossed by several short-, middle-, and long-ranged traffic routes.

The M.A. thesis this paper is based on was planned while the author worked at the University of Cologne excavations at the remote desert fortress Gala Abu Ahmed, and one of the major aims of the project was to find out more about the ancient communication systems this Iron Age building was integrated in.

While evaluating the data, however, it became clear that not only the routes leading to and from that fortress, but also several other routes of different periods (up to medieval times) could be reconstructed from the remote sensing data. Even other archaeological sites not previously known to the scientific community, including a monastery complex close to Gebel al-Ain at the border to northern Kordofan, were discovered during the data evaluation. Later, some results of the work were ground-checked by a long range reconnaissance survey from Wadi Howar to Gebel al-Ain during the 2011 University of Cologne expedition to Gala Abu Ahmed.

Therefore, the results of the M.A. thesis project exceeded expectations by the discovery of some new and remarkable archaeological sites. Besides that, the work could also contribute to the development of the prospecting methods used during the research, by adapting them to the special topographical conditions of the Sudanese desert.

At first, survey data and the results of the remote sensing analysis showed that the most prominent evidence for ancient traffic within the region are traces of animal paths. As in other regions of the Sudan, at least some of these seem to be quite old. Ethnological information acquired from the modern western desert nomads suggests that many of those traces are probably from donkeys and not camels, since donkeys are better suited to rocky terrain with hard soil, while camels prefer soft sand where they can walk more easily. These traces offer the possibility to reconstruct ancient traffic activities on a small scale, but a reconstruction of long-distance routes by alamat and other direct evidence proved difficult under the specific conditions of the region. Anyway, chains of activity centres (combined with some remarkable agglomerations of animal traces) are equally able to prove the existence of lines of communication during different periods of history.

Most interestingly, the reconstruction of those complex lines of communication shows that they are mostly concentrated south and southwest of the Wadi Howar. To the west, scattered clusters of activity also prove some communication. The lines of communication between the fortress and the river Nile are visible, but not very clear. Most interestingly, almost no traces of ancient traffic were recorded to the north to the Wadi Qa'ab from where a similar fortress is known. Of course, there must have been (as today) some amount of direct communication to the north and northeast, but it seems that those directions were not the most prominent traffic routes.

To the west, since the early archaeological survey projects carried out by the University of Cologne, several sites of settlement and/or camp structures are known. Most are from prehistoric times, when the Sahara was much more densely populated, but also from later periods. Obviously, the middle and upper Wadi Howar was, in antiquity, an area used quite extensively by a predominantly mobile or semi-sedentary population. The introduction of the camel made continued use of that area as a habitat possible during the middle ages, as demonstrated by some medieval sites not far from Gala Abu Ahmed, and continuing until today. During our research in the Wadi Howar, we often met members of the Kababish tribe with remarkable herds of camels grazing from the scrubs of the Wadi. The traffic routes of the area might be influenced by the nomadic lifestyle of the desert dwellers, and show not a long-ranged linear concept of traffic (like from a trade or military route), but a short- to middle-ranged and criss-crossed communication pattern oriented around the grass resources of the area.

The communication routes to the south show some comparable characteristics, but also some indications of more linear and long-ranged traffic patterns, even if that region also lacks some direct traces of road organization like alamat, road pavements or hydreumata. Some of the donkey tracks documented south of Wadi Howar were obviously oriented to natural landmarks, like passages through old dune fields or passes through rock ridges. Additionally, several activity centres like stone rings, tumuli and concentrations of ceramic finds were located around those natural landmarks. Especially at a natural pass around a rock ridge roughly halfway between Wadi Howar and the more fertile areas around Gebel al-Ain, some archaeological sites document human activity during several periods of history. Those activity centres lead more or less directly to the western side of the Gebel al-Ain plateau. There, at the southern end of that presumable ancient traffic route, several formerly unknown archaeological sites were discovered, proving that this area was quite densely populated during antiquity and, especially, the medieval period. Those sites discovered by remote sensing analysis consist mainly of tumuli and box grave cemeteries, but also of settlement structures. The most prominent of those settlement structures is a Christian complex – most probably a monastery – with a church of sandstone blocks, a large residential building, several box grave cemeteries and a defending wall.

The archaeological sites discovered by remote sensing analysis, the ground-check survey based upon it, older survey data collected mainly by former projects of the university of Cologne, and information extracted from old maps and survey reports were put together into a GIS, enabling an analysis of the topographical distribution patterns of activity centres and traffic indications.

Along with the remarkable discovery of this monastery far from the Nile valley, the concentration of medieval material like box graves around the Gebel al-Ain proves that this plateau was a major regional centre during that period. A large number of tumuli shows that this is also true for earlier times, like the so called post-meroitic period (or 'rural Meroitic period' after more recent research). The ground check of some random sample areas around the Gebel al-Ain monastery also revealed that so called cleft burials are to be found here, dating back to the so called Napatan period and thus roughly contemporary to the fortress of Gala Abu Ahmed.

From this quantity of data, the reconstruction of ancient traffic organization and their routes is rather difficult, but at least partly possible. The role of the area south of Wadi Howar as a traffic route is mainly determined by tube-like, broad and linear passage through a dune barrier circa 30 km south of the Wadi, which blokes the way from the lower Wadi Howar southwards at almost every other route. The abovementioned archaeological finds make it quite likely that this route was in use at least from the Napatan period onwards. The activity centres around the natural pass around a ridge halfway between Wadi Howar and Gebel al-Ain are difficult to date after only a small-scale survey without any archaeological digging. However, the track marks are much more typical for donkeys than for camels, and the ceramic material found associated with the sites make a pre-medieval date most likely. Therefore, these findings can probably be connected to the Iron Age (Napatan?) material found north and south of the route. The medieval presence also found north and south of the route might indicate that there was also some traffic there during that period, but since the camel was then fully introduced to the regional economy, at a micro-topographical level of trans-desert routes might have shifted from more rocky surfaces to the soft sand, where camels can walk more easy. These would have left fewer traces than the donkey routes on the rocks, which are not as susceptible to weathering and other changes of the soil surface structure.

Interestingly, to the north, where a similar fortress like Gala Abu Ahmed is known from the Wadi Qa'ab. only very few traces of ancient traffic installations were found during the satellite image analysis and a ground survey carried out by the University of Cologne in 2011.

As the authors M.A. thesis in general, this paper can only present a preliminary state of research. A more detailed analysis would require an area-wide coverage of the territory, first to do more than a random ground check, and second due to the fact that the discovery of cleft burials and ceramic concentrations during the ground check survey revealed that Napatan material might not be visible by remote sensing data analysis, and so activity centres and traffic routes of that period might still only be discovered by ground survey.

Additionally, the comparison between the remote sensing and the ground check survey data showed that there is a gap of precision between those two methods of data acquisition, but that the area is much too large to do a traditional ground-based survey. Therefore, the inauguration of a new, large-scale survey project, including middle-ranged remote sensing platforms like microdrones, could be a possibility for future research on the topic.

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FROM THE AIR TO THE ATOMIC LEVEL OF A DITCH: INTEGRATING GEOPHYSICAL AND GEOCHEMICAL METHODS AT THE PREHISTORIC CROPMARK SITE AT FORTEVIOT (PERTHSHIRE, SCOTLAND)

C. Cuenca-García, R.E. Jones, A.J. Hall, T. Poller

1. INTRODUCTION

It is generally appreciated that the detection of archaeological features through geophysical survey can vary depending on local geological and soil conditions; however, the influence of these variables has rarely been explained satisfactorily. Presented here are the results of a comparative analysis exploring the relationship between soil chemistry and the detection of archaeological features by routine geophysical survey techniques over a cropmark site in Perthshire, Scotland.

The results not only provide a nuanced understanding of the character of the archaeological features surveyed, but also begin to develop a better understanding of how the setting of a site may affect geophysical and geochemical datasets. This case study forms part of a NERC PhD project that investigates the integration of geophysical and geochemical methods at five contrasting archaeological sites in Scotland (Cuenca-Garcia, 2010).

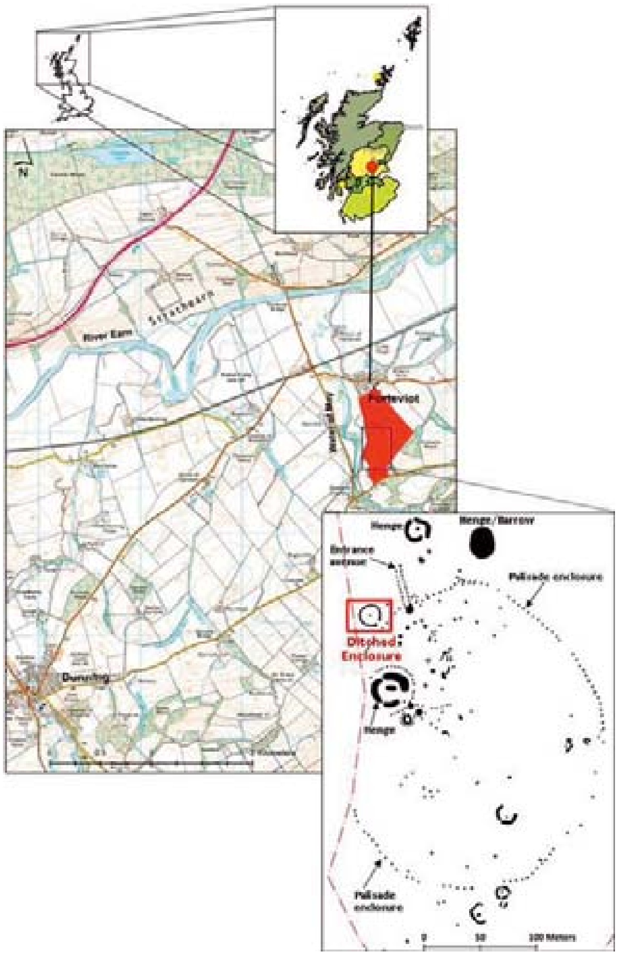

Figure 1: *Location map of Forteviot (red) near Perth in Scotland. The inset shows the transcription of the cropmarks recorded by aerial photography (in black) and highlights the ditched enclosure (red rectangle).*

2. THE SITE

Cropmarks identified by aerial photography at Forteviot indicate an extensive early prehistoric ceremonial landscape built in earth and timber and now recognised to be one of the most important Pictish royal centres of Scotland. Successive flights also revealed an early medieval cemetery in the vicinity.

The site is located in Strathearn in southern Perthshire, one of the most agriculturally fertile regions in central Scotland (Figure 1). Forteviot lies over sedimentary bedrock (Old Red Sandstone), glacio-fluvial sand and gravels superficial deposits and well-drained brown soils. Since 2006, the SERF project has been exploring the factors involved in the creation of such a significant centre of ceremony at Forteviot in the third millennium BC and its later reuse as a royal centre during the Pictish period (Driscoll *et al*., 2010). A key objective was to characterise the cropmark complex by targeted archaeological excavations.

3. THE PROBLEM

Prior to excavations by SERF, initial gradiometer and earth resistance surveys were carried out. The results were disappointing by comparison with the aerial photographs in that they yielded little beyond confirming the cropmarks. The gradiometer data, acquired at 1 m or 0.5 m traverse spacing in zig-zag mode, was characterised by very faint and negative responses indicating the ditches. The performance of earth resistance survey (1 m $\times$ 1 m sampling interval) was similarly rather poor. The problem, therefore, is what reasons lie behind the poor results of the geophysical surveys at Forteviot. Would other routine prospecting techniques provide better results?

4. METHODS

Multi-technique geophysical surveys and soil surface sampling for geochemical analysis were carried out in spring and summer 2010 in order to detect the ditched enclosure (Table 1). The surveys and soil sampling were conducted both prior to and after the plough soil was stripped (0.30/0.40 m thick) to assess the effect of the topsoil on the results. Further soil sampling of the exposed ditches, to characterise the soil physical and chemical properties of the ditch fill deposits, was carried out during excavation.

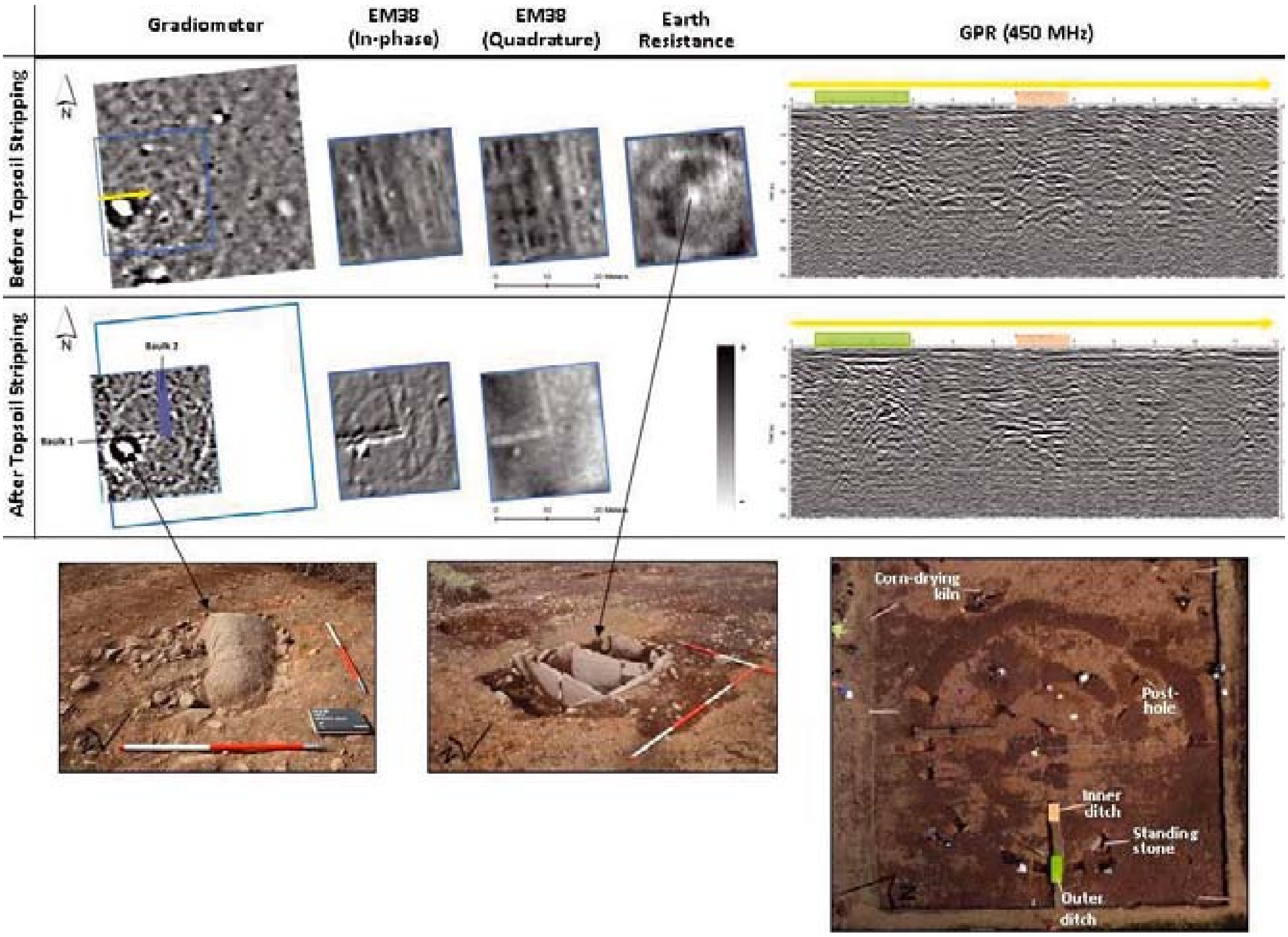

Figure 2: *Results of the multi-technique geophysical surveys (before and after topsoil stripping), and related archaeological features confirmed during the excavation. The yellow arrow on the gradiometer results shows the location of the radargram. Following topsoil stripping, the exposed ditch deposits were mapped using a differential GPS and their locations are indicated in the radargram and aerial photograph with the green (outer) and brown (inner) bars.*

5. RESULTS

5.1. Multi-technique geophysical results

The targeted feature was detected by the geophysical surveys either as a single or double (outer and inner) ditched enclosure (Figure 2).

The gradiometer survey only resolved the double enclosure when the traverse spacing was reduced to 0.25 m. It revealed two concentric negative magnetic anomalies: an outer ditch and a segmented, less coherent inner ditch. The character of the anomalies suggested rather weak contrast between the ditch and surrounding soil. The survey also detected other positive magnetic pit-like anomalies which were confirmed, on excavation, to be a post-hole and a possible corn-drying kiln (Figure 2). After topsoil stripping, the gradiometer survey revealed sharper anomalies due to the enhanced magnetic contrast between the ditch deposits and the surrounding soil, which had been slightly masked by the topsoil.

Earth resistance revealed a single concentric low resistance anomaly (the outer ditch) and a central pit-like low resistance anomaly. The latter proved to be an unusual triple cist burial. The anomalies detected were the least truncated features of the enclosure.

The quadrature component (conductivity) of the FDEM survey detected a faint trend anomaly similar to the earth resistance technique. The in-phase response (magnetic susceptibility-MS) also showed a weak single concentric trend. The results of the quadrature component failed to detect the enclosure after topsoil stripping because of the instrument's lower sensitivity (in vertical mode) to near-surface features and the drier survey conditions. However, the in-phase results revealed the double ditched enclosure fairly well in spite of the vertical mode being used.

The GPR survey technique revealed two concentric high amplitude anomalies (outer and inner ditches) both visible in the radargrams and the time-slices. The outer ditch showed strong reflections towards the base and innermost side of the ditch cut. Some radargrams showed reflections related to the inner ditch at different depths suggesting earlier phases or re-excavation of the inner ditch. This could explain the segmented and less coherent character of this feature in the magnetic data, as well as the failure of the earth resistance survey since the higher truncation of this feature may have affected its capacity to retain moisture. The re-working and different depths of the inner ditch in places were confirmed on excavation. After topsoil stripping, the reflections produced by the ditches were accentuated. The uppermost deposit of the outer ditch gave very strong linear reflections.

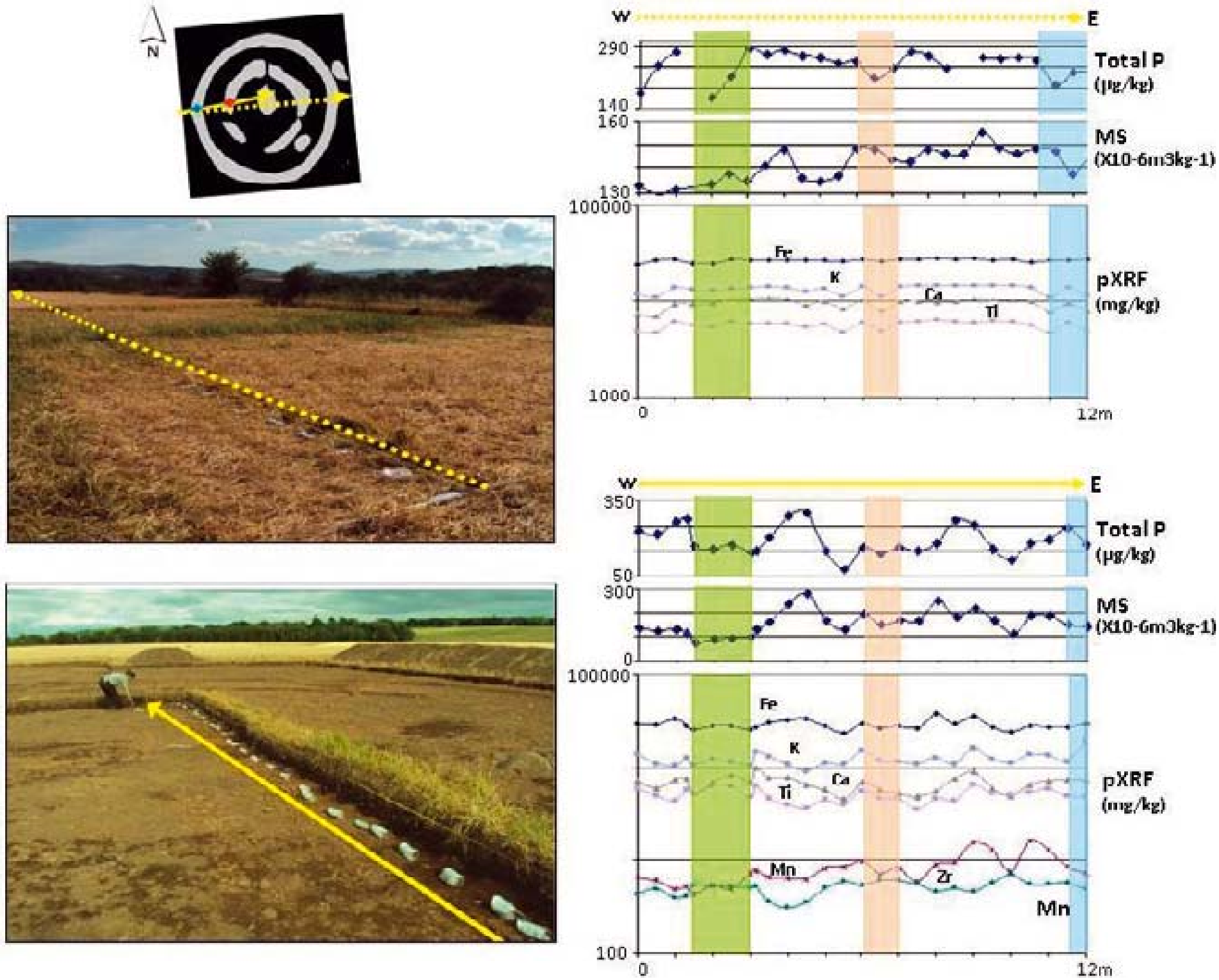

Figure 3: *Surface soil sampling and selected results of the W-E sampling lines collected over the ditched enclosure before and after topsoil stripping (dotted and solid yellow arrows). The green, brown and blue bars mark the location of the outer and inner ditches, and the triple cist burial respectively.*

5.2. Soil Physical and Chemical Analysis

The general increase in MS towards the centre of the monument (Figure 3), despite the lower MS measured inside the ditches, may be caused by the effect of material ploughed from features such as the cist burial with enhanced MS. The outer and inner ditches gave depleted total P values.

The concentrations of Fe, K, Ca and Ti showed high variability over the ditches. Mn showed enhanced values towards the centre of the enclosure. The ditches were also enriched in Mn (Figure 4). Lower MS, total P, and Fe, K and Ca values were measured in soil over the outer ditch. This feature also had slightly enhanced Ti. These responses were confirmed in the section samples, which did not show any significant enhancement of common anthropogenic trace elements (Figure 4).

Inside the outer ditch there was a higher organic matter content, possibly produced by the increased biomass of deeper roots from the crops at this point. Since higher organic content increases water retention, this may be linked with the results of resistance survey. Furthermore, the LOI results showed a peak (Figure 4) in association with the uppermost deposit of the outer ditch (deposit 1 in Figure 4). The contrast between this deposit and the reddish subsoil exposed during topsoil stripping was critically dependent on the presence of moisture. Indeed, the strong linear GPR reflections recorded after topsoil stripping (Figure 2) may have been caused by the moisture contrast caused by deposit 1.

The samples from the outer ditch's exposed section showed a greater variation in chemical composition at the innermost side of the cut of the outer ditch (deposit 3 in Figure 4). Here, the cut of the ditch (where the sands and gravels were more cemented) lies at a greater angle than does the outermost cut of the ditch. The strong high amplitude reflections of the outer ditch may have been produced by this sudden change in soil texture (cementation/induration).

6. CONCLUSION

The weak negative magnetic anomalies of the initial gradiometer survey were caused by the nature of the topsoil, subsoil and an inadequate survey resolution. The topsoil contained highly magnetic stony material derived from intense ploughing of the un-

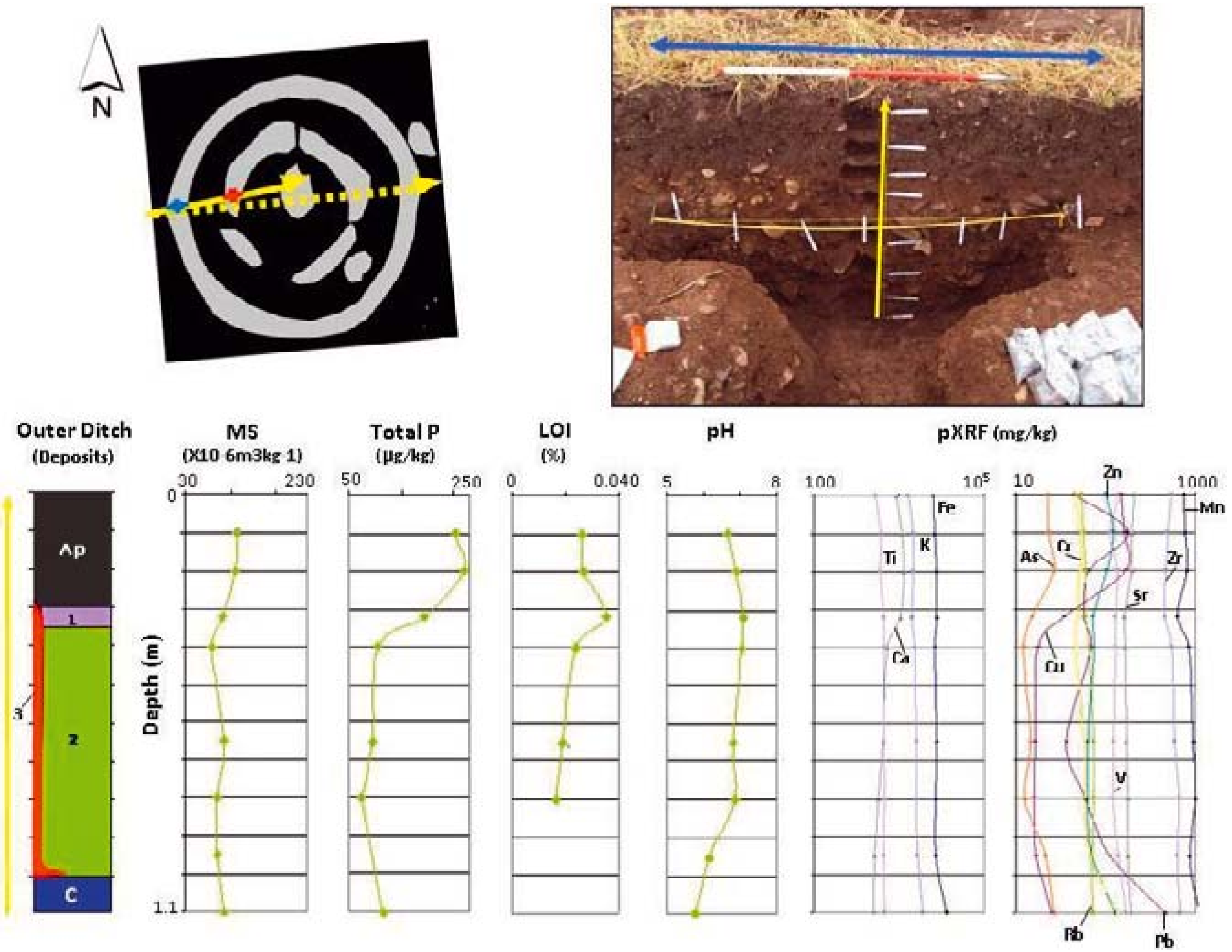

Figure 4: *Selected results of the soil sampling carried out the exposed north facing section (blue double arrow) of the outer ditch.*

derlying glacial parent material. This resulted in 'noisy' datasets that obscured the contrast between the ditch deposits and surrounding soil.

There was no MS enhancement or enrichment of common anthropogenic trace elements in the ditch deposits, which partially explains the characteristic negative magnetic response instead of the more usual positive response. The ditches at Forteviot were associated with a ritual site and so their deposits were not subjected to either continuous MS enhancement or an input of anthropogenic elements as at settlement sites, thereby contributing to their negative magnetic responses.

The ditches show slight depletions of major elements (e.g. Fe), as well as an enrichment in Mn and Ti. This is due to mineralogical changes in Fe-Al-Ti oxides inside the ditch caused by various processes: land management; accumulation of organic matter; increased moisture retention; and redox reactions. These effects also lead to the relatively low MS values of the ditch deposits compared to the higher MS of the topsoil and the even higher MS of the subsoil. Therefore, changes in the mineralogical composition of the ditch deposits and the nonexistent anthropogenic enhancement are the factors behind the negative magnetic contrast revealed by the ditch features at Forteviot. The less truncated character of the outer ditch (in comparison to the inner ditch) and its higher organic matter content explains its higher capacity to retain moisture in comparison to the surrounding soil, hence its detection as a low resistance feature. The anomalies detected were very informative and greatly complemented the gradiometer results.

The GPR survey produced the most informative results as it gave depth estimation, high resolution mapping, and an approximate truncation level of the ditches. The correlation of these results and the soil physical and chemical analysis provided key information relating to the character of the ditch deposits.

The EM38 instrument attached to the GPS provided the most rapid survey. The quadrature component in vertical dipole of the EM38 instrument demonstrates its potential in identifying archaeological features expected at c. 0.5–1 m, such as at Forteviot, since the noise created by the plough layer was outside the maximum sensitivity range of the instrument. Therefore, this technique may be the best first option to use in extensive and exploratory surveys at sites such as Forteviot. However, the FDEM results produced the lowest resolution anomalies.

Repetition of the geophysical surveys after stripping the topsoil in preparation for excavation allowed detection of further features. This approach can be used to increase the effectiveness of archaeological excavation by showing potential targets that were not exposed on the stripped surface. A general MS and Mn enhancement of topsoil samples indicating the presence of the

Survey/Analysis	**Aim**	**Instrument**	**Sampling**
Gradiometry	Detect targeted ditched enclosure	Bartington Grad 601-2	– 0.5m traverse & 0.125 m in-line (parallel mode) – 0.25 m traverse & 0.125 m in-line (parallel)
Earth Resistance		Geoscan RM15 (0.5 & 1 m probe spacing)	0.5 m traverse & 0.5 m in-line (zig-zag mode)
Frequency Domain Electromagnetics (FDEM)		Geonics EM 38 (+GPS)	1 m traverse & 1 m in-line (parallel, in-phase & quadrature components/vertical dipole)
Ground Penetrating Radar (GPR)		Sensors & Software PulseEKKO 1000 (450 & 225MHz)	– High resolution survey (450 MHz): 0.25 m traverse & 0.05 m in-line (parallel & step modetime-window=150ns, stacks=16, samples=200ps) – Single GPR lines using 450 MHz: 0.05 in-line (time-window=60ns, stacks=16, samples=200ps)
RTK-GPS	Map soil samples, exposed archaeological features & survey grids	Leica 1200	
Magnetic Susceptibility	Characterise MS & elemental concentrations in soil surface & open sections to identify enclosure	Bartington MS2	– Two perpendicular lines (N-S & W-E) sampled across the targeted enclosure. Soil samples taken at 0.10-0.15 m from the surface and at 0.5 m before topsoil stripping. Control samples collected from outside the survey area. – Immediately after topsoil stripping, samples collected at 0.5 m or less (over exposed ditches). – Samples taken from the four sections at 0.10 or 0.20 m spacing.
Total Phosphate (Total P)		Fisherbrand colorimeter	
Multi-element Analysis		Portable XRF (pXRF): Thermo Scientific Niton XL3t GOLDD	
		ICP-OES: Varian Vista Pro	
Loss of ignition	Determine organic content		
pH/Conductivity	Estimate soil acidity/conductivity	Hanna HI991301 Portable meter	
Soil Texture	Describe soil horizons & archaeological deposits		

Table 1: *Summary of the geophysical techniques and soil geochemical analyses carried out at Forteviot.*

enclosure was a useful outcome of the geochemical survey.

This case study has illustrated how the results obtained from geophysical and geochemical methods can be better understood when they are integrated because of the complementary information they each provide.

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CONTEXTUALISING A MONUMENTAL BURIAL – THE GOKSTAD REVITALISED PROJECT

J. Bill, E. Nau, W. Neubauer, I. Trinks, C. Tonning, L. Gustavsen, K. Paasche, S. Seren

It is a paradox in Norwegian archaeology – and perhaps also elsewhere – that some of the most outstanding archaeological monuments at the same time remain some of the least investigated. In the case of the Viking Age ship burial from Gokstad at Sandefjord, excavated in 1880, part of the explanation is the finding and subsequent excavation of the even more impressive Oseberg ship burial in the years 1903-04, which was to overshadow the Gokstad find for more than a century. But the paradox is caused by more than a shortage of research resources – it is also a result of changes internal to archaeology and cultural heritage management. Much archaeological knowledge is today gained from large-scale, full excavations prior to extensive infrastructure projects, and we have learned to think of the past in terms of complexes and landscapes, rather than in terms of single monuments and structures. But not only do large infrastructure projects usually avoid places with monumental archaeological heritage – complete destruction through excavation is rarely, if ever, an option when it comes to the investigation of such monuments. Therefore the use of non-destructive methods, and especially near-surface geophysical prospection techniques, becomes of paramount importance when we attempt to bring our knowledge about such sites on a par with that of the more anonymous traces of the past revealed in front of the construction machines. The Gokstad revitalised project, focussing on a site which currently is under consideration for UNESCO's World Heritage List, is a good example for how much geophysical archaeological prospection can contribute to the study of sites with high preservation value.

The Gokstad Revitalised project[1] was initiated in 2008 in cooperation between the Museum of Cultural Heritage at the University of Oslo (MCH), the Cultural Heritage services (CH) in Vestfold County and the Vestfold Museums. The aim of the project is to set the Gokstad burial amid the social, cultural and political changes that occurred in the eastern part of Norway in the Viking Age by applying new scientific methods to the study of the finds from the burial, of the burial mound itself – and by expanding the scope of research to the local landscape and settlement. Funding was achieved from Anders Jahre's Humanitarian Foundation along with MCH, Vestfold County and Sandefjord Muncipality, and in 2011 it was possible to move from archive studies and artefact analyses to field work, which will continue until 2013. At present the project involves researchers and labs from six different European countries, working within a range of different disciplines and topics from geophysics and soil analyses over dendrochronology to biochemistry. The goal is to present the results of the project in publications and special exhibitions within a five-year horizon, and to incorporate them into a new permanent Viking Age exhibition which is planned to be established in an extension of Viking Ship Museum in Oslo.

The research design of the project is concentric, making the social identity of the deceased man and its staging in the burial ritual the project's focal point. Through an investigation of the biography and network of the deceased, as far as it can be learned from studies of his remains and of the objects that followed him into the burial, it is hoped that a more well-founded understanding of the societal background for the construction of this and other monumental burials in Viking Age eastern Norway can be established.

The field work of the project serves the same purpose and focusses on three different targets: geophysical prospection, targeted coring and subsequent excavations. The burial mound itself, which was only partially excavated in 1880, and which had been investigated by GPR earlier, was target of a systematic coring campaign, aiming at understanding the construction history of the mound and to explore its undisturbed turf layers as an archive over the location's environment at the time of the construction of the mound just around AD 900.

For the geophysical prospection a consortium of partners of the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) was set up, combining ZAMG Archeo Prospections®, the Vienna Institute for Archaeological Science (VIAS), NIKU and RAÄ in a collaborative work group.

Within the framework of the LBI ArchPro's case study Larvik/Vestfold first test surveys were carried out on selected areas at the site of Gokstad. These initial surveys served as a pilot study to test the recently developed survey devices under different archaeological and geological settings.

Motorized fluxgate magnetics and motorized high-resolution multichannel GPR (Figure 1) were the survey methods used. A motorized 10 channel fluxgate magnetometer

Figure 1: *Top: The 16-channel MALÅ Imaging Radar Array (MIRA) in front of Gokstad burial mound. Bottom: The 6-channel SPIDAR GPR system.*

[1] http://www.khm.uio.no/english/research/projects/gokstad/ (accessed April 1st 2013)

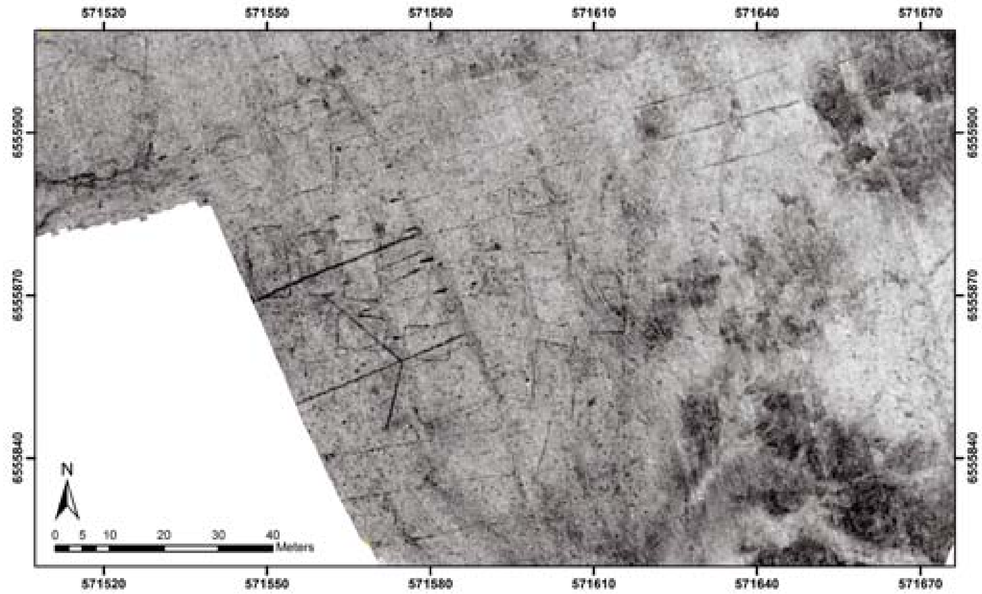

Figure 2: *Heimdal site – settlement area. A MIRA GPR depthslice from approximately 40 – 80 cm depth. The strong linear structures are mainly drainage trenches. The archaeology can be seen inbetween.*

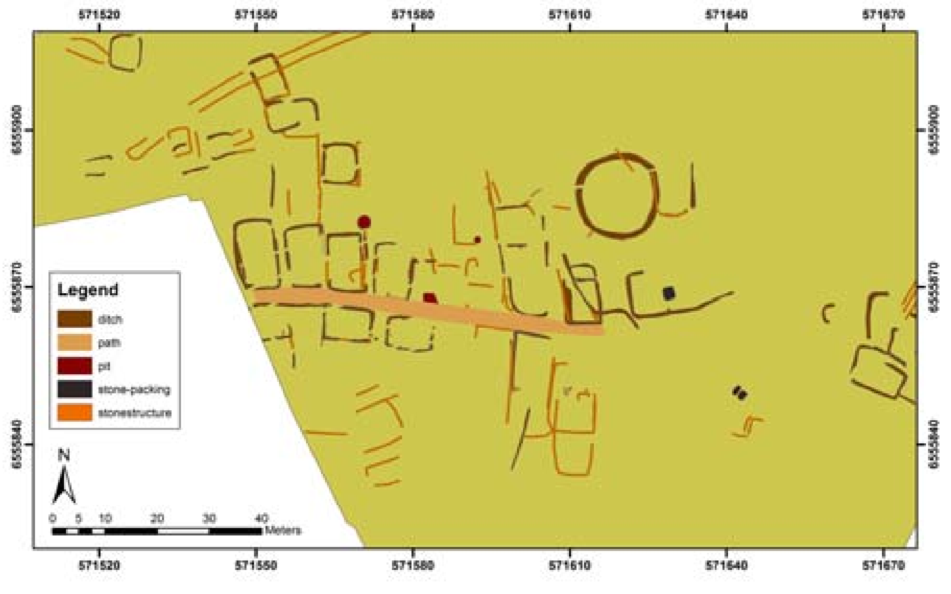

Figure 3: *Heimdal site – settlement area. Archaeological interpretation of the MIRA GPR data volume.*

array (Förster PNC system) with 25 cm sensor spacing and a constant measuring frequency of 60 Hz was employed to survey an area of about 20 ha within 2.5 days. The magnetic surveys concentrated on the areas directly north and south of the mound.

The GPR surveys were carried out using a motorized multichannel SPIDAR array (Sensors & Software) with 6 PulseEKKO Pro 500 MHz transducer pairs mounted with a cross-line spacing of 25 cm and sampling with an in-line trace distance of 5 cm. Two areas of in total 3 ha size were selected for the GPR survey and measured within 2 days.

With both prospection methods special attention was directed towards an area located some 500 m south of the mound, where in around 900 AD the shoreline of a protected bay in the outer, western part of the Oslo Fjord could be found. Here traditional field surveys had already in 1995 established the presence of a Viking Age crafts production site with an associated group of small burial mounds, one of which had been excavated already in 1944. This site, which is called the Heimdal site after one of the farms to which the land once belonged, was the target for excavations in 2012.

The geophysical survey campaign in 2011 showed few non-natural features north and immediately south of the Gokstad burial mound. Some possible sunken huts were observed to the north, and close to the mound the remains of a further mound, earlier only known from crop marks, were identified. However, on the Heimdal site a surprisingly dense and structured pattern of man-made features was discovered, including two rows of somewhat rectangular structures on either side of what appears to be

Figure 4: *Areas in the vicinity of Gokstad burial mound covered using both multichannel GPR devices: the 6 channel SPIDAR and the 16 channel MIRA system.*

a road (Figures 2 & 3). Foot-trenches and fillings from several burial mounds could also be observed, as well as large, apparently empty areas in between. However, the majority of discovered features were only observable in the GPR data, whereas the magnetic data did show only few of them, leading to further questions about their composition and condition as well as to possible processes they may have been exposed to.

Due to these rather convincing prospection results, especially regarding those from the Heimdal site, the project plan for extended large-scale geophysical archaeological prospection surveys of the entire Gokstad area was developed. In April, May and September 2012 prospection surveys were conducted in order to cover as much of the area around Gokstad mound as possible. Priority was given to fields that are located within the visibility of Gokstad mound, based on the assumption that the mound was part of a larger, complex site, including also buildings or constructions of political or religious importance. It was planned that in case of the surveys indicating the presence of such structures, these should be the targeted by research excavations planned for 2013.

In 2012 the range of deployed systems was extended by a motorized 16 channel 400 MHz MALÅ Imaging Radar Array (MIRA) system with 8×4 cm trace spacing, providing considerably increased spatial resolution, and by a second motorized 10 channel fluxgate array. Within 20 days of fieldwork a total area of 49 ha was prospected using magnetomety, and about 56 ha with both GPR devices, to our knowledge the largest area surveyed with GPR on a single site so far (Figure 4).

The huge amount of collected data is actually being properly processed and will be subsequently interpreted archaeologically within a GIS, including all other relevant, georeferenced data, such as accurate topographical information and historical maps; as well as geological and pedological maps.

The geophysical surveys in 2012 took place prior to, as well as following an excavation campaign conducted in June to August. The first area that was surveyed with the MIRA system was the outstanding Heimdal site, both in order to extend the coverage beyond the extension of the site, and to improve the resolution of the earlier acquired GPR data. This aim was achieved and a considerably more detailed archaeological interpretation map could be produced for use as basis for the planning of the archaeological excavations.

So far, it is especially in the investigation of the Heimdal site that the combination of geophysical prospection and subsequent archaeological excavation has been investigated. Three larger trenches have been opened at the site, in addition to several smaller ones that were dug primarily for the extraction of dateable material from individual structures. Preliminary analysis shows that in the very clayish, western part of the site the correlation between the geophysically observed and the archaeologically excavated features is very good in the x,y-plane, and somehow less accurate in the z-plane, which can easily be explained by small scale changes in the actual velocity of the GPR signal.

Furthermore, additional in-situ measurements of the apparent magnetic susceptibility were conducted during the excavation process, which should lead to a better understanding of the visibility, respectively non-visibility, of archaeological features in the magnetic prospection data.

The use of geophysical prospection methods has already now been of principal importance for the success of the Gokstad project, making it possible to plan and conduct targeted excavations with high precision, causing less destruction of the site than in case of traditional settlement excavations. The full potential of the combination of the two prospection methods used has, however, not been explored yet. Potentially, the comparison of the geophysical data with the excavated features should make it possible to interpret yet unexcavated features with greater confidence. An important experience gained so far is also the observed great impact of changing soil and humidity conditions on the efficiency of the geophysical prospection methods, even within short distances, as encountered at the Heimdal site.

THE GROUND PENETRATING RADAR SURVEY ON HERAION TEICHOS ACROPOLIS (TEKIRDAG-TURKEY)

M. Kucukdemirci

ABSTRACT

This project, which is still been in progress, compares and integrates ground penetrating radar and magnetometry methods on Heraion Teichos Acropolis, where an ancient Thracian city has been unearthed for the first time. This contribution summarizes the preliminary results of GPR survey carried out in September 2012 at this archaeological site.

1. INTRODUCTION

Over the past decade, ground-penetrating radar has been recognized as being well-adapted to the non-destructive survey of archaeological sites (Gaffney *et al*. 2004; Neubauer *et al*. 2002; Seren *et al*. 2004) . This work will present such an application of ground penetrating radar on the Acropolis of Heraion Teichos.

The ancient harbour city of Heraion Teichos is situated at modern Karaevlialt, 18 km from Tekirdag in the north west of Turkey (Figure 1). Founded as a colony of Samos and dedicated to Hera, it was occupied into the Roman period. Archaeological excavations, which have been conducted since 2000, have unearthed the first evidence for an ancient Thracian city at this site.

2. GEOPHYSICAL METHOD AND DATA PROCESSING

Ground penetrating radar (GPR) systems are uniquely suited for shallow subsurface investigations of archaeological sites. Considering the depth of the buried archaeological structures under the ground at the acropolis of Heraion Teichos, it was thought that the application of GPR would be feasible.

Radar data were collected using a GSSI SIR 3000 with 400 MHz bistatic antenna set to constant transmitter-receiver offset. The area of the acropolis was divided into 12 grids, most with dimensions of 20 $\times$ 20 m as shown in Figure 1. Measurements were taken by zigzag measurement method on parallel profiles with 0.50 m intervals. All radar measurements were recorded with 60 ns time window, 8 bits dynamic range and 512 samples per scan. The velocity is calculated by hyperbola analysis on the raw field data and determined as 0.07 ns-1. The data processing was using Gpr-Slice software v7 (Goodman 2010).

Some basic data processes such as regaining, Dc drift removal and background removal were applied on raw radagrams to produce more substantive information. The post processing gain was applied to amplify the deeper reflections. The background removal process was applied to remove the horizontal band found in raw radargrams by computing the average radar scan across the profile and then subtracting from every scan.

After the radargrams were processed, the next step was to create a useful image from this data. Some of the most comprehensible and welcome images for archaeologists are time slice images, which represent the amplitudes of the reflections at a specified time or depth. Ten time slices were generated by using 5 ns time windows with 15% overlapping of each slice for all grids. The resampled amplitudes were gridded using the inverse distance algorithm with a search radius of 0.75 m and with a 0.2 stagger length. The 3*3 low pass filter was applied on the time slices. Because structures are often not buried at equal depths, making thin slices may only show parts of these structures on the time slice maps. To make a comprehensive image of reflections at different time or depth levels, overlay analysis was implemented for the depth between 0.20-1.5 m and these images are represented in Figure 2 and Figure 3. Besides 3D volumes were generated by isosurface rendering and the possible surfaces were calculated with 80% isosurface value.

3. RESULTS

The area is divided into two parts in the representation – the east and west part of the acropolis – to give detailed information. The overlaid time slices of 12 grids on Heraion Teichos Acropolis for the depth 0.20 – 1.5 m were represented in two maps shown in Figure 2-3. The continuous archaeological features, which are at different depths under the ground, look more meaningful in the overlay. In the maps, the possible archaeological structures for all grids were marked with arrows. In grid Gab8910, the main archaeological structures can be detected, with the possibility of an archaeological wall, and many anomalies characterized by presence of archaeological remains can be detected in grids Fgh67 and Fij67 (Figure 2). In grid Hab67 and Hcd67 (Figure 3), the GPR measurements were taken on the profiles which have 0.25 m intervals. Because of this, the GPR reflections in these areas look detailed but also consist of tiny reflections. In other grids, the main structures look coarser. In grid Hab89 and Hcd89, anomalies that can be defined as main walls in the area can be seen.

4. CONCLUSIONS

Ground Penetrating Radar (GPR) for archaeological sites is becoming a most versatile geophysical tool in Turkey, as demonstrated in this case study on GPR application at Heraion Teichos acropolis. The area investigated is characterized by the presence of many anomalies due to wall remains trending in different directions and of different dimensions. Although the results of GPR method appears quite useful for this area, due to the limitations of this method in cases such as limited penetration, poor dielectric contrast between the archaeological structures and surrounding medium, and complex properties of the archaeological site, it is essential to apply different geophysical methods in this archaeological site to get more reliable information. Due to the aim of this work, the proposed next step is the application of magnetic methods at this site.

Figure 1: *The location of the Heraion Teichos Acropolis (Tekirdag-Turkey).*

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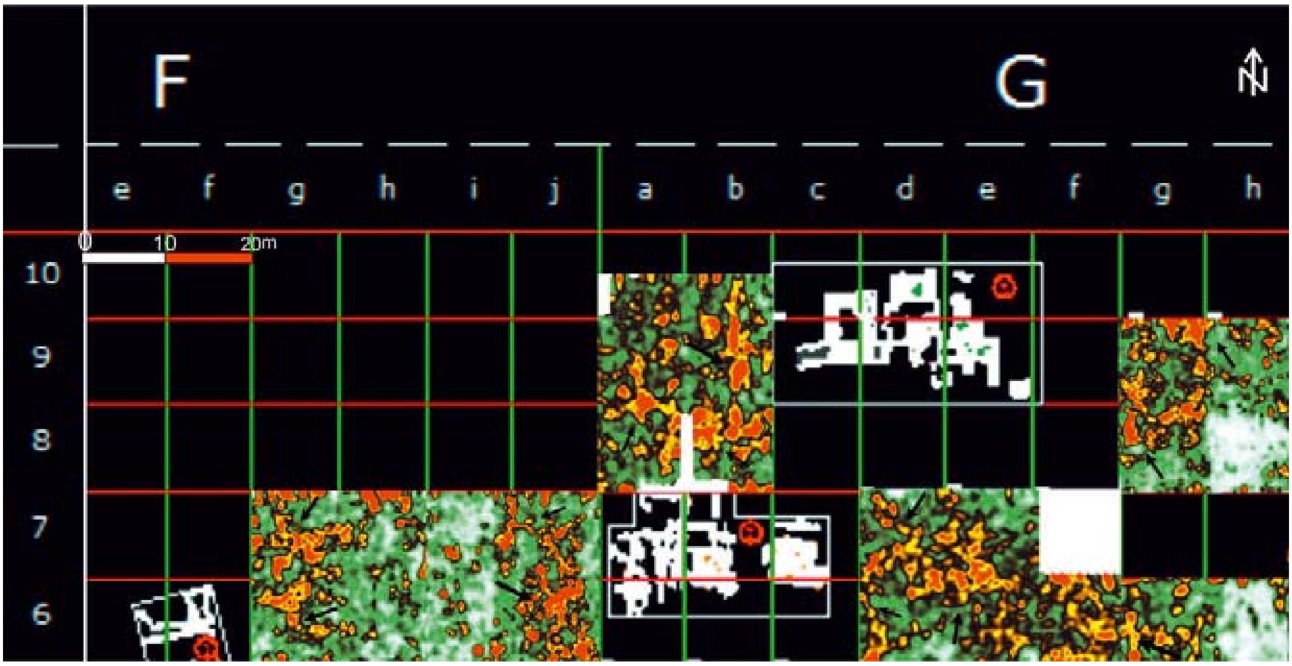

Figure 2: *2 dimensional time slice maps (overlaid 0.20-1.5 meters) for west part of Heraion Teichos Acropolis.*

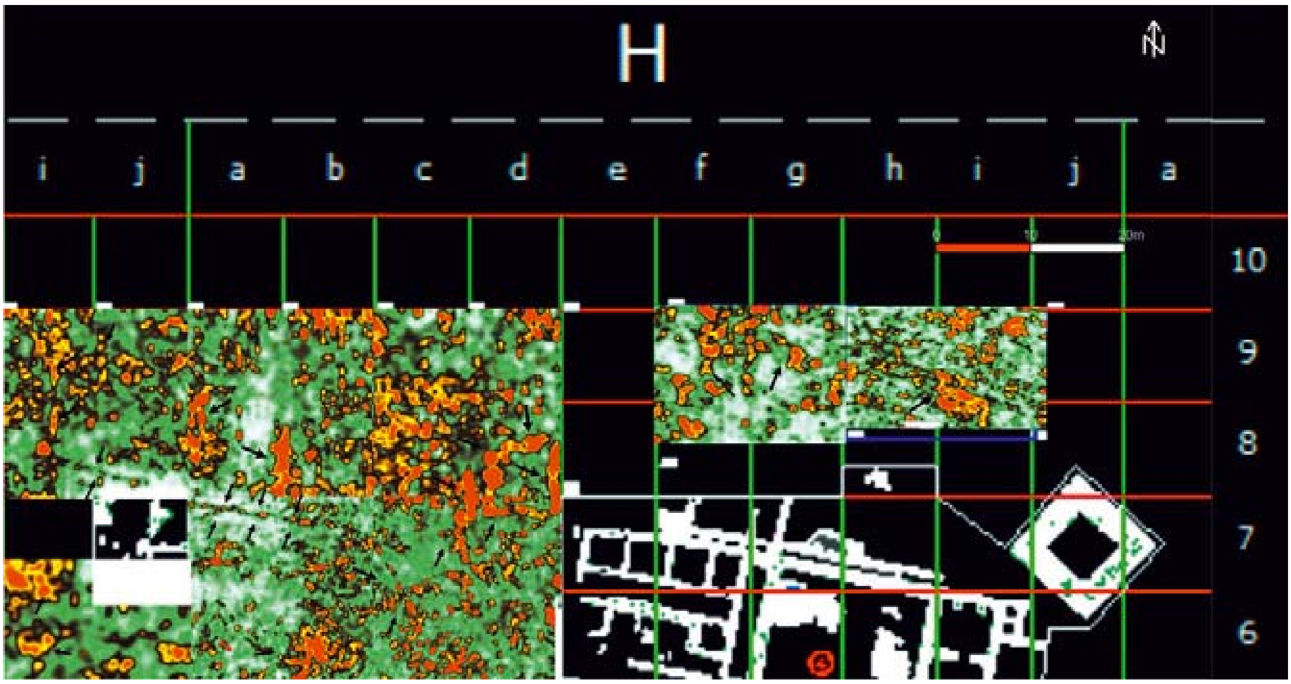

Figure 3: *2 dimensional time slice maps (overlaid 0.20 -1.5 m) for east part of Heraion Teichos Acropolis.*

3D-GPR PROSPECTION IN POMPEIOPOLIS – A METROPOLIS IN THE ROMAN PAPHLAGONIA

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ABSTRACT

The Roman city Pompeiopolis situated in Northern Anatolia was the metropolis of Paphlagonia. The archaeological site was almost completely surveyed in 2007/08 using a caesium magnetometer, a technique useful for gaining a quick yet detailed overview of an archaeological site. Ground-penetrating radar, however, generally yields more specific information on buried stone structures. In 2012, we carried out a three-dimensional radar survey in Pompeiopolis. The survey covered three distinct areas of the ancient city, including several monumental buildings of the Imperial period. The investigation confirmed the exact position of several known structures and determined their architectural layout. It thus provides a solid basis for further archaeological excavation.

1. INTRODUCTION

Pompeiopolis is located on the so-called Zımbıllı Tepe at the west bank of the Amnias River, outside the modern town of Taşköprü, ca. 300 km northeast of Ankara (Figure 1). Founded in 63 BC, after Pompeius' conquest of the Pontic Kingdom, the new Roman city experienced its heyday in the second and third centuries AD and was mentioned by several ancient authors, such as Strabo, Ptolemy and Hierocles. In the second century, Pompeiopolis was awarded the title of metropolis of Paphlagonia. It is also recorded in the Peutinger Table, as a major stopover between the cities of Gangra and Sinope on the Black Sea coast with a pictogram that indicates the relatively importance of the city in the region. As Pompeiopolis does not receive mention from the Middle Byzantine periods onwards, it can be assumed that the city was abandoned after the 7th century AD. It sank into oblivion for several centuries before being rediscovered in the early 19th century by a French consul in Sinope (Summerer, 2011).

In 2006, the Institute for Classical Archaeology and the Department of Geophysics of the Ludwig-Maximilians-University Munich started a geophysical survey project under the direction of Lâtife Summerer to complement the archaeological surveys and excavations of the site. As the area of the Roman city was never built over in later periods, Pompeiopolis provides ideal conditions for the application of geophysical prospection methods.

2. RESULTS

2.1. Magnetometry

Almost the entire area of the Zımbıllı Tepe was surveyed by magnetometry in 2007/08, resulting in a first preliminary city plan. Pompeiopolis had a size of approximately 28 ha and it did not follow the Hippodamian grid plan typical for many Roman towns of the West. In fact, many of the city's streets are bent and the major buildings of the town follow varying orientations. However the cityscape is dominated by several public areas and monumental buildings typical of a Roman town, such as a forum, a macellum, a bathhouse, theatres and several temples. The magnetogram shows the distinct constructions very clearly (Figure 2). At the southeast slope of the Zımbıllı hilltop a monumental building of 60 × 35 m was identified. As it lies approximately 8 m above the city center, the negative magnetic anomaly to the southeast must be indicative of a massive limestone or marble construction that was interpreted as a perron. To the south, the geophysical map indicated the presence of a Roman agora with a size of ca. 100 × 80 m. Further south opening onto the main thoroughfare, oriented northeast-southwest, a large enclosed complex of 65 × 120 m with a central pavilion could be identified as a macellum. The survey in the northwestern part of the city revealed two semicircular structures. The first one is orientated towards the southwest like the agora and has a circular orchestra with a diameter of 27 m and a cavea of 70 m diameter, while the second one is slightly smaller and orientated towards the southeast. The varying dimensions of the both structures led to an interpretation as a theatre and an odeion next to each other. Such an arrangement is well known in Roman cities, for example in Pompeii. In the northeastern part of Pompeiopolis the magnetogram revealed a structure which can be interpreted as a gymnasion (von Kienlin, 2011). On the eastern hill foot there are remains of a Roman villa. The fortifications themselves were detected in the eastern part of the plateau where remains of the enclosure wall and a watch tower are visible (von Kienlin, 2011). The last one has a high magnetic anomaly due to fire damage (Fassbinder *et al*., 2007; Fassbinder, 2011).

Figure 1: *Overview over the site of Pompeiopolis.*

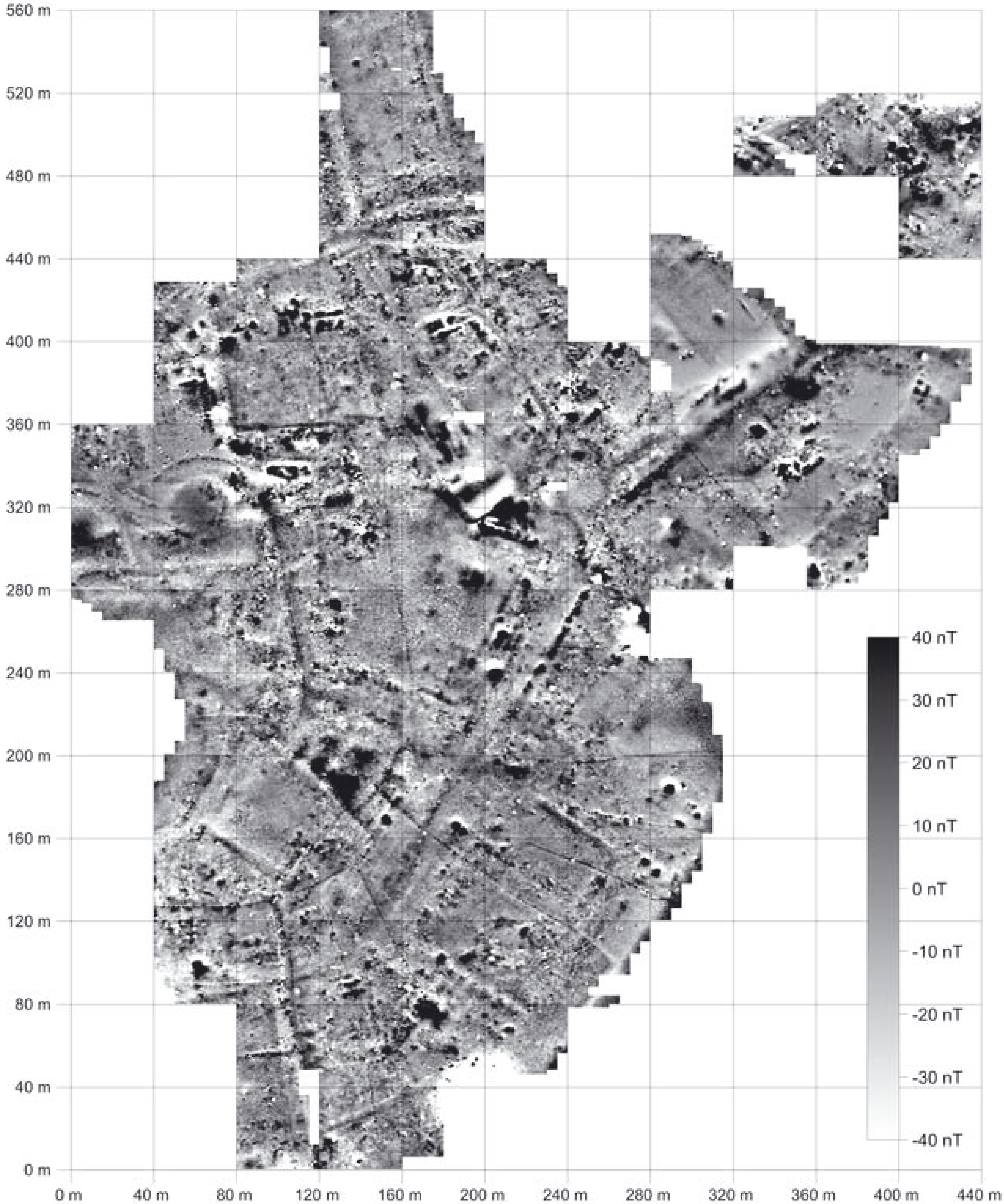

Figure 2: *Magnetogram of the Roman city of Pompeiopolis. Caesium magnetometer Scintrex Smartmag SM4G-Special, Duo-Sensor-configuration, Dynamics: ± 40 nT in 256 greyscales, Sensitivity: ±10 pT, Point density: 50 × 25 cm, interpolated to 25 × 25 cm, 40 m grids.*

2.2. Ground-penetrating radar

In order to obtain more detailed information on some of the buildings, a GPR survey was performed in 2012 in cooperation between the universities of Munich, Harvard, Rome, Istanbul and Kastamonu. Here, we present the radar results of two test areas. We used a GSSI SIR-3000 with a 400 MHz antenna for the survey. The sample interval was chosen as 2 cm inline and 50 cm crossline. Due to the rough surface, we could not achieve denser profile spacing. The soil of this region consists of Kastanozem, which has a topsoil rich with organic materials and with a high pH-value. The lower soil up to a depth of 100 cm is enriched with calcium-carbonate or gypsum. Kastanozem occurs mainly in the dry areas of steppe regions (European Soil Network Bureau, 2005). These soil conditions are ideal for both magnetometer and radar prospection. We determined the soil parameters during the measurements by time-domain reflectometry. The soil was very dry with a moisture level of around 6 Vol% and a conductivity of 0.6 – 1.8 dS/m, which provided almost perfect conditions for GPR. Yet, using the 400 MHz antenna, the penetration depth in August 2012 was limited to 1.2 m only, due to the compaction conditions of the soil, which either absorbed the signal or reflected it back to the surface.

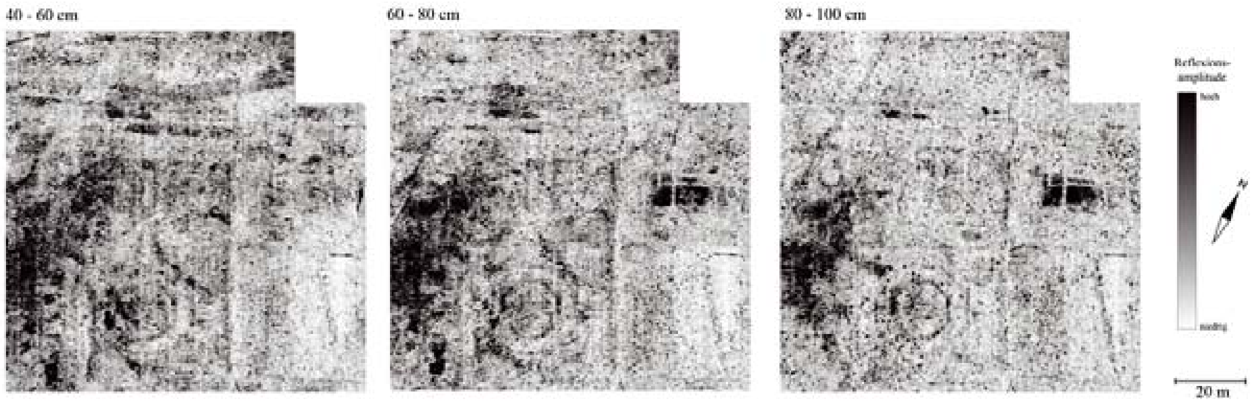

Figure 3: *Selection of depth slices in the area of the Macellum. GSSI SIR-3000 with 400 MHz antenna, Point density: 2 × 50 cm, Size of the grid: 100 × 100 m.*

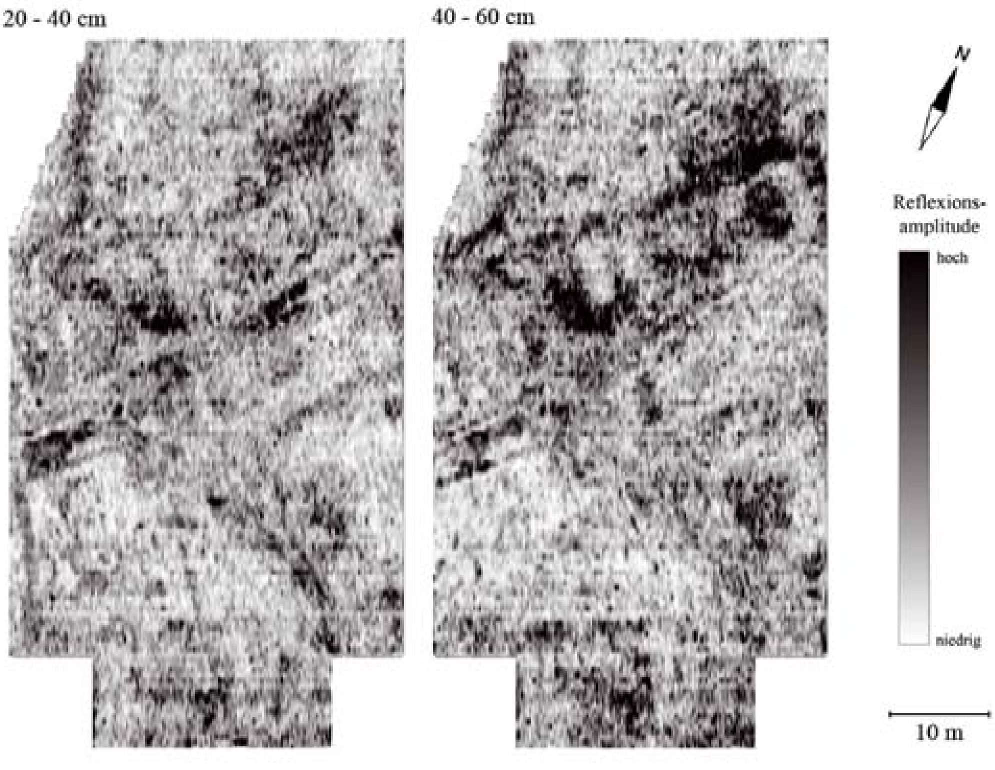

Figure 4: *Figure 4. Selection of depth slices in the area with the temple at the hilltop. GSSI SIR-3000 with 400 MHz antenna, Point density: 2 × 50 cm, Size of the grid: 38 × 69 m.*

One of the survey areas focused on the above-mentioned macellum. The ongoing excavation of the macellum is directed by Ruth Bielfeldt (Harvard University). Roman market places for delicacies and other luxuries were often monumental, sometimes pompous buildings of multifunctional use (Bielfeldt, 2011). The magnetometric survey had already mapped the architectural layout of a rectangular area enclosed by arcaded porticoes and surrounding a central pavilion. A series of test trenches conducted in 2008 and 2009 have confirmed the overall design of the complex; they also exposed part of the foundations of the large pavilion (tholos) revealing the unusual octagonal shape of the centralized building, the diameter of whose cella was about 20 meters. A second foundation running parallel to the cella wall presumably supported a surrounding peristasis.

The results of the radar survey show the archaeological remains in a depth of 35 – 120 cm (Figure 3). For the central pavilion, the depth slices confirm the results of excavation: they show clearly that the tholos does indeed feature two foundations of octagonal shape, the interior supporting the cella walls, the exterior supporting a colonnade which surrounded the building on all sides. In the southwestern part of the tholos interior, an area of high reflection amplitudes corresponds to the remains of an ancient mosaic floor, already excavated in 2008 (the trench was refilled). This is also the point at which the cella walls are best preserved. The exact purpose of the tholos remains to be determined in future excavations. It may have served as a fountain house, a mercantile kiosk or a ceremonial building. Similar polygonal constructions in the center of a macellum were found e.g. in Leptis Magna (Libya), Puetoli (Italy), Pompeii (Italy) and Cuicul (Algeria) (Bielfeldt, 2011). To the southwest of the tholos a series of point foundations are already known from the magnetogram (Figure 2); they were subsequently confirmed by test trenches. They also appear in the radargrams. This confirms the hypothesis that the macellum was framed by arcuated porticoes and adjacent rows of shops in the back. In this part of the grid a rectangular area of high reflectivity was detected which might indicate a preserved brick floor. In the same area the magnetometer data reveal very high magnetic anomalies. The northwestern precinct wall of the macellum also appears very clearly. It is flanked by several abutting walls belonging to small shops. Outside the macellum, the main street of Pompeiopolis is visible as a lower reflective anomaly, especially within the depth range of 40 to 60 cm. It has an approximate width of 10 m. Within the area covered by the street some further linear anomalies could indicate the presence of a canalization. To the northwest remains of another building complex was detected, but this extends beyond the grid of our survey. In the interior of the macellum courtyard further faint structures are discernible, though their purpose has not yet been determined. The circular anomaly in the center of the macellum cannot be interpreted by the radargrams alone. Here, an archaeological excavation will provide better insight.

Northeast of the macellum and adjacent to it a separate building can be identified by an excellent preserved floor. It contained several rooms, but it seems that little remains of the corresponding walls, which appear as areas of very low reflection amplitude. The precinct walls of this large annex, which were detected by our magnetometer prospection, were not covered by the radar survey as they seem to have been completely robbed out. This is evidenced by their appearance as positive anomalies in the magnetogram which indicates the sedimentation of the remaining ditch.

At the highest topographical area of the city, several large and irregular magnetic anomalies of nonspecific shape dominate the magnetogram. It was impossible to ascribe them to an exact building layout. Here, we tried to clarify the situation by GPR. The buried walls at a depth range of 25 – 70 cm belong to an east-west oriented construction with an entrance to the west facing towards the theater (Figure 4). Judging from its footprint and its exposed location the building might have been a temple of ca. 40×25 m size. It seems to be accessible by a staircase and a portico with visible column settings. In the eastern part of the building, a square shaped structure (25×25 m) is recognisable, which could be interpreted as the cella. Its interior is subdivided into several niches by thin walls. As in the case of the tholos of the macellum, the areas of high reflection amplitude indicate the points at which the ancient floor is preserved. The 4 m wide linear anomaly that runs across the building could be linked to the modern car tracks in this area or a channel and is possibly not of archaeological importance.

3. CONCLUSION

The GPR survey results presented here show that different geophysical methods are indispensable complements of one another. While magnetometry is best suited for a large-scale but nevertheless detailed survey of a Roman town, radar is the most appropriate technique to resolve more specific details of selected stone buildings. The radar surveys in the city of Pompeiopolis are an important contribution to the study of the urbanization of northern Anatolia. The GPR depth slices provide detailed maps of the surveyed buildings that will provide a welcome base for further archaeological investigations.

ACKNOWLEDGEMENT

We owe thanks to the director of the excavation Latife Summerer (LMU Munich, Institute for Classical Archaeology) for the invitation to carry out the radar prospection in Pompeiopolis and the review of a perliminary version of this paper.

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THE GEOPHYSICAL RESEARCH OF THE DOME OF ST. ELIZABETH AND THE CHAPEL OF ST. MICHAEL IN KOSICE

J. Tirpák, M. Bielich

In the years 2006-2007, the Archaeological Institution of the Slovak Academy of Sciences conducted rescue project in the surroundings of The Chapel of St. Michal in Kosice. The chapel is one of the oldest buildings in Kosice, built probably in the first half of the 14th century on a site of a cemetery that belongs to The Church of St. Elizabeth (Figure 1). During renovations in 1880s, all of the church's annexes were removed. The renovations ended in 1904. The chapel is representative of the 'Burgund' gothic in Slovakia.

The oldest written source mentioning the chapel comes from the year 1452, and it concerns the year 1428 (Wick, 1936). The south sacristy of the chapel was built around 1508. Around this time, Kosice-born Juraj Satmari, the bishop of Pat'kostolie, expanded the chapel by adding an annex in the south. The south wall was broken through, an already existing sacristy was demolished, and the work closed the oratorium of the presbyterium and the steps to chorus. In the place of the old sacristy, a new one was built next to the south entrance. In the year 1771, Bishop Karol Esterhazy prohibited burials at the cemetery around the chapel and the dome. The cemetery around The Chapel of St. Michal (caemeterium maius) and the cemetery around The Dome of St. Elizabeth (caemeterium minus) were enclosed with an iron fence from the 16th century, and later by a stone wall (Henszelman, 1996). In the year 1805, after an agreement with the city council, the bishop of Kosice Andrej Szabo took the wall down. The localization of the original stone wall is slightly different than the localization of walls built after 1904 (Ďurišová, 2003).

The first phase of the archaeological research was a geophysical survey using a Georadar RAMAC-X-3M (Geoscience Malaa, Sweden) with shielded antenna with frequency of 250 MHz. The goal of the research was to identify old and abolished building phases of the chapel, the stone walls, and to potentially detect unknown building structures. Georadar measurement were carried out with a point density of 0.2×0.5 m on the total area of 3,700 m^2. For data processing, GPR_SLICE software (Geophysical Archaeometry Laboratory, USA) was used. The data is presented as vertical and horizontal cross-sections, and 3D visualization of radarograms. The radar antenna was pulled on grass, asphalt and stone surfaces. Because the measurements were conducted on different surfaces, and to determine the penetration, to enter values with different depths of permittivity and resistance, conductivity for εr was measured for individual layers and surface inhomogeneities. In this case, the relative $\varepsilon r = 9$ permittivity and speed for vr = 0.1 m/ns on hard surfaces, and $\varepsilon r = 18$ and speed for vr = 0.07 m/ns on the grassy surface. The survey was conducted on 17 sections around the dome, and 11 sections inside.

The results of the measurements: The Dome of St. Elizabeth The whole extent of the geophysical measurements is depicted in Figure 2. We will present more detailed results from areas 1 and 17, and a summary of areas 1–17 in the form of georadar horizontal cross-sections for the layer 70–90 cm depth. In area no. 1, inhomogenities were discovered in the 0.3–2.3 m depth.

Figure 1: *The present view of the Cathedral of Saint Elisabeth and Chapel of Saint Michael.*

The horizontal cross-sections and 3D visualisation show that under the terrain of the area there are pronounced linear anomalies, and part of these indicate architectural structures. In area no. 17, the inhomogenities were found in the depth of ca. 0.3–2 m, and linear anomalies are pronounced here as well. These indicate architecture and the old stone wall, and part of them shows the progress of the infrastructure network – the tram track, sewer, etc.

The summary of the georadar measurements in the areas 1–28 (Figure 3) are shown in the form of horizontal cross-sections in the layer of 70–90 cm. Values with high amplitude (marked in black) indicate the presence of archaeological objects – the remains of architecture or objects filled in stone destruction and part of the course of infrastructure anomalies.

The goal of the research was to clarify the building phases of the stone wall around the cemetery, and other building activities in the vicinity of the chapel. Based on the data, archaeological excavations were conducted in the areas that showed anomalies (Figure 4). Archaeological test trenches were laid, and in trench

Figure 2: *The georadar plan of measuring of the areas No.1 to No.28.*

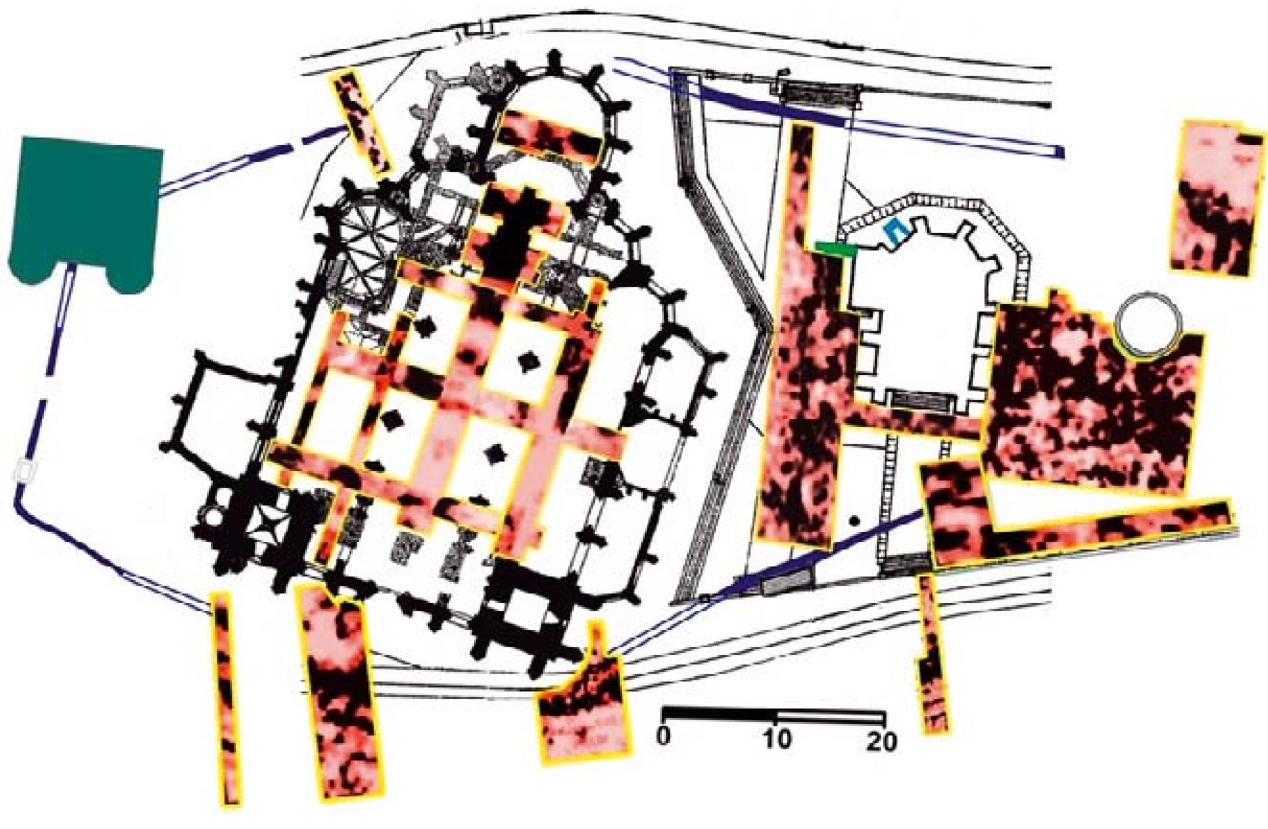

Figure 3: *Overall results of georadar measuring of the areas No.1 to No.28 in the form of horizontal slices of the layer with the depth of 70–90 cm.*

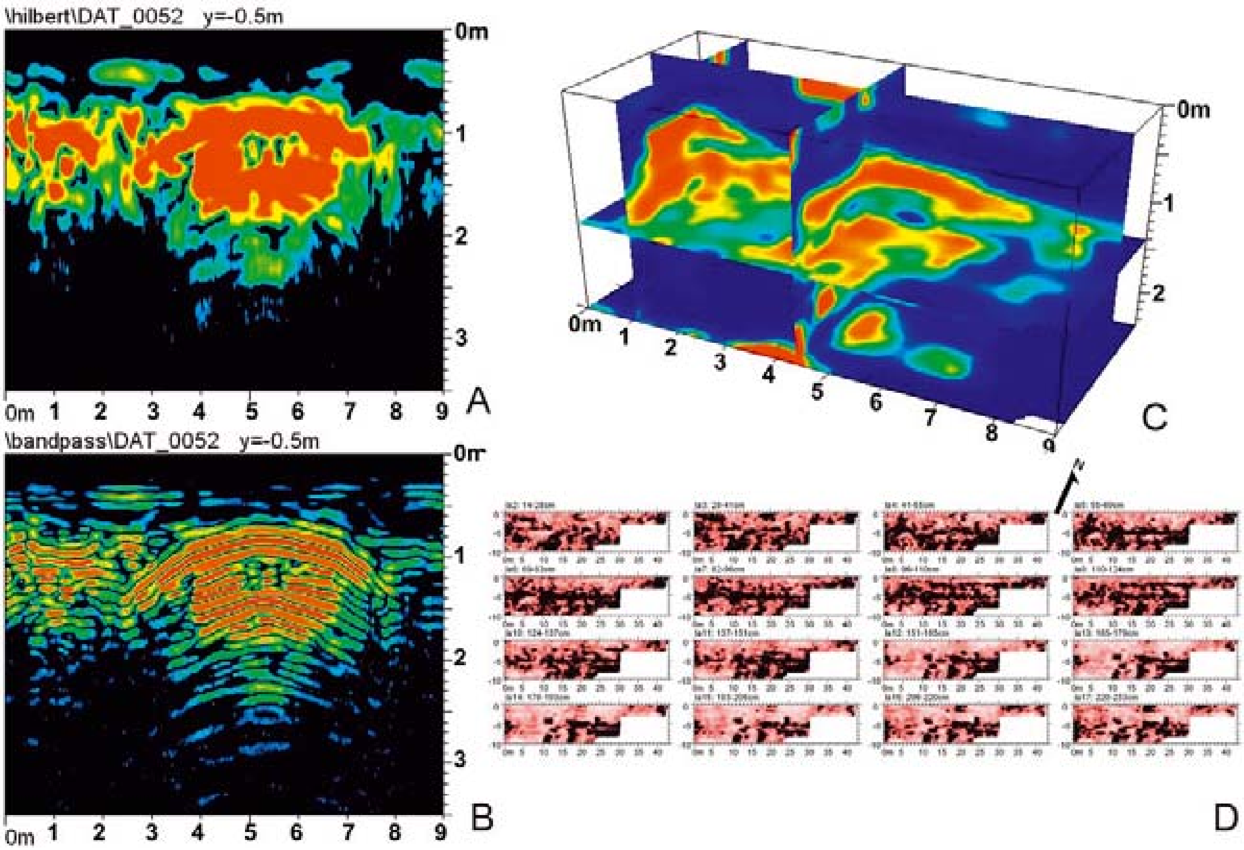

Figure 4: *GPR results: A & B) Area No 25 vertical cuts of crypt. C) Area No 25 vertical and horizontal cuts crypt 3D. D) Area No. 1 horizontal sections that capture the Satmáryovsku extension of the year 1508.*

B and C the stone wall was detected. In trench area No.2, the annex from the year 1508 was discovered (Figure 4,D). In area 3 we uncovered a house from 19–20th century that is related to reconstruction work conducted on the chapel and the dome in this period.

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KARABALGASUN: THE UIGURIAN CAPITAL IN THE ORCHON VALLEY, MONGOLIA. PRELIMINARY RESULTS AND FIRST TESTS WITH MAGNETOMETER PROSPECTION

J.W.E. Fassbinder, R. Linck, C. Franken

1. ARCHAEOLOGICAL BACKGROUND

In 742 AD, the Uigurs destroyed the East-Turkish Empire in Mongolia, and were accepted as Khan over the Steppe regions by the Chinese Emperor in 744. Thereafter, they started to construct and to build their capital named Karabalgasun. Cities of the Nomad Empire were necessary mainly for administrative purposes, as a storage yard for their loot and tributes, for cultic purposes, as market places and justice courts. The Uigurs chose the Orchon Valley for their settlement for strategic as well as for religious reasons. In 840 AD, the Jenissei Kirghiz conquered and partly destroyed Karabalgasun and the Uigurian Empire, thus ending the Uigurian Empire. Karabalgasun, with an extension of more than 32 square kilometres, was the largest medieval city in the eastern Central Asia (Hüttel and Erdenebat, 2009).

So far, there have still been only a few archaeological studies on the topic of the nomadic cities in the Central Asian steppe. Logistic and infrastructural problems during the cold war complicated large excavations in this region. The archaeological emphasis of former archaeologists focused on excavating kurgans and collecting their rich gold treasures.

Karabalgasun is located in the Orchon valley ca. 340 km west of Ulan Bator, the modern capital of Mongolia. W. Radloff of the Russian Orchon expedition drew the first topographical map of the deserted medieval city in the year 1891 (Radloff 1892). However, is was only in 2007, when the first archaeological survey by the Mongolian-German Orchon expedition (MONDOrEx) of the Archaeological Institute of the Mongolian Academy of Science (MAW) and the German Archaeological Institute (KAAK) Bonn, Germany was executed.

Before the first test excavations, Martin Schaich (Fa. Arctron GmbH, Germany) performed an Airborne-Laserscan and created a topographical map of the entire above-ground remains of the city. Many structures are only minor elevations in the topography, but there are also quite good visible upstanding monuments, such as the 360 × 404 m wide palace complex with upstanding adobe walls and 8 m high ramparts (Figure 1). The archaeological work concentrated at first on questions of the development of the city, as well as on the research on the internal division and the function of different urban districts. The main topic is, whether the quarters were divided functionally or according to the population's ethnicity or religion. So far, it is also unknown which city model – the Chinese or the Eastern Iranian – is dominant at Karabalgasun. Another interesting question is, how the nomadic way of life influenced the development of Karabalgasun (Hüttel and Erdenebat, 2009).

To answer some of these questions, a supplementary large-scale high-resolution magnetometer prospection was undertaken in addition to excavations, in the framework of a cooperation contract among the Department of Geophysics of the Ludwig-Maximilians-University Munich and the German Archaeological Institute (DAI) Berlin.

Figure 1: *Karabalgasun. Magnetic prospection with the handheld Caesium-magnetometer-system in the landscape of the deserted city. In the background are the remains of the Palace district with adobe bricks.*

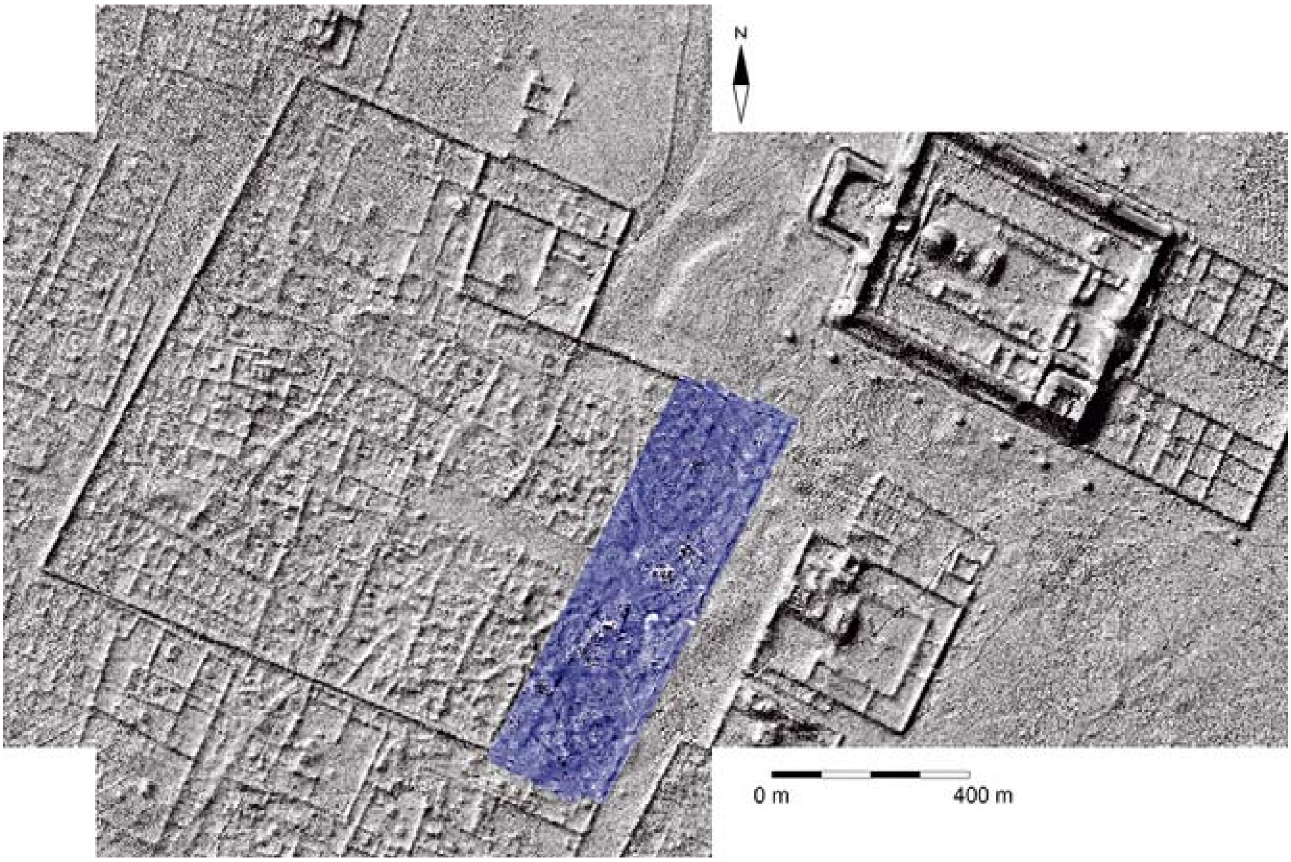

Figure 2: *Karabalgasun. Excerpt of the Airborne-Laserscan terrain model of the city overlaid by the magnetogram (blue) (Airborne-Laserscan by M. Schaich, Fa. Arctron GmbH, Germany).*

2. RESULTS OF MAGNETIC PROSPECTION

With respect to the 32 km^2 area of the Karabalgasun city, we choose a test area of ca. 200 $\times$ 800 m for a first magnetometer prospection. Near the centre of the city, a rectangular district of approximately 800 $\times$ 1400 m is enclosed and separated from the other districts by a wall that is still clearly visible in the steppe. The district is located in the west, adjacent to the huge palace district (Figure 2). For the magnetometer measurement, we used the Scintrex SM4G-Special Caesium magnetometer in a duo-sensor configuration. The total Earth's magnetic field in Karabalgasun was 58,840 $\pm$20 nT (7/2012), sampling rate 25 $\times$ 50 cm interpolated to 25 $\times$ 25 m, 40 m grid, sensitivity $\pm$10 pT, dynamics $\pm$8 nT in 256 greyscales.

The resulting magnetogram (Figure 3) revealed detailed structures and the layout of this city district. The enclosing wall exists of two adobe walls that run parallel to each other at a distance of about 4 meters. Some parts of the outer wall show up with a high magnetic anomaly, due to the remanent magnetization of burnt bricks, but large parts of the wall was simply made of sun dried adobe bricks. The inner part of this district displays a typical layout of a nomadic city. The whole area is predominantly littered with numerous irregular shaped anomalies that can hardly be ascribed to a ground map of buildings or residential houses. Beside this, a small number of house foundations can be magnetically traced by the high remanent magnetization of rocks, burnt bricks and roof tiles that can be found on the ground. The orientation and the layout of these foundations, however, are irregular with respect to the orientation of the outer wall. Moreover, they are neither related to each other, nor do they resemble each other. Every ground map of a building has its own orientation and size. On the corner of one building, we found clear evidence of a lightning strike with its typical star-shaped and very height remanent magnetic anomaly (Figure 4).

3. CONCLUSION

Karabalgasun is among the largest archaeological urban sites that remain undisturbed and are not overbuilt by modern constructions. This offers the unique opportunity to conduct archaeological research with large-scale magnetometer prospection, and hence with a non-invasive archaeological method. With respect to the size of the area, a fast, but nevertheless sensitive and detailed and magnetic mapping with a height spatial resolution is required.

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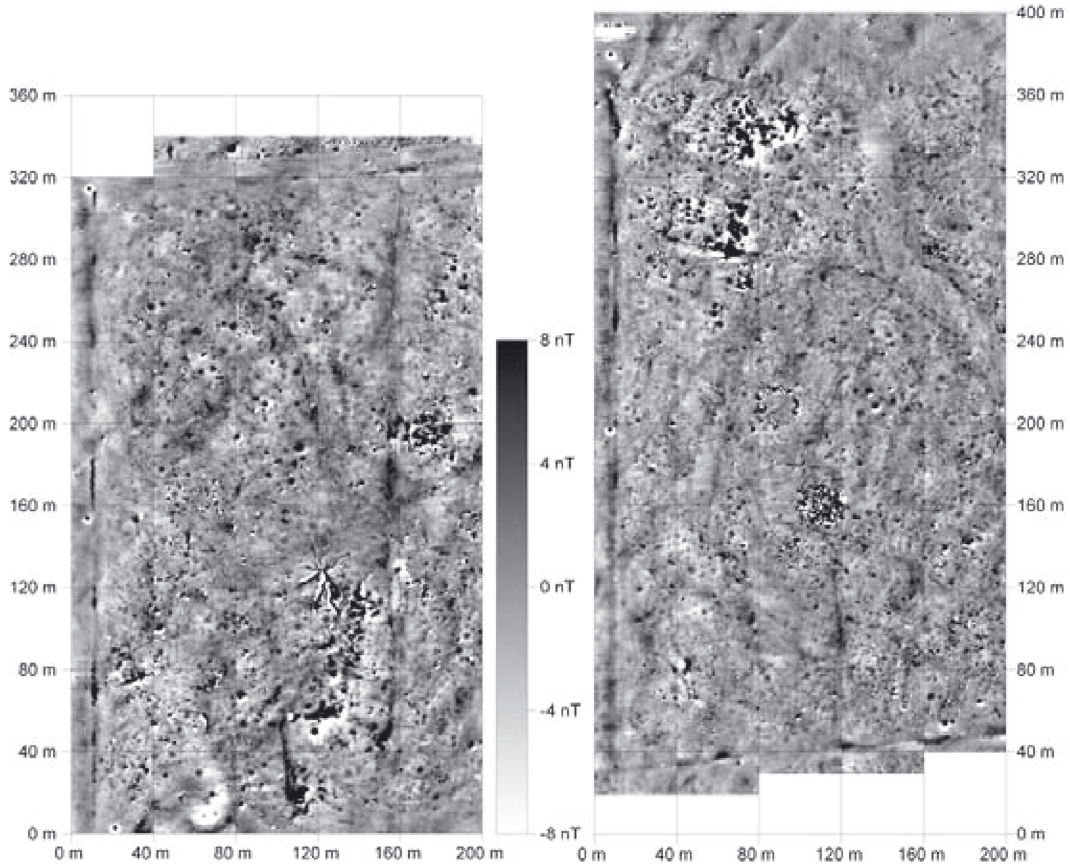

Figure 3: *Karabalgasun. Magnetogram of the survey area 2012. Caesium magnetometer SM4G-special in duo-sensor configuration, sensitivity ± 10 pT, sampling rate 25 × 50 cm interpolated to 25 × 25 cm, dynamics ± 8 nT in 256 greyscales, intensity of the total Earth's magnetic field 58,840 ± 20 nT.*

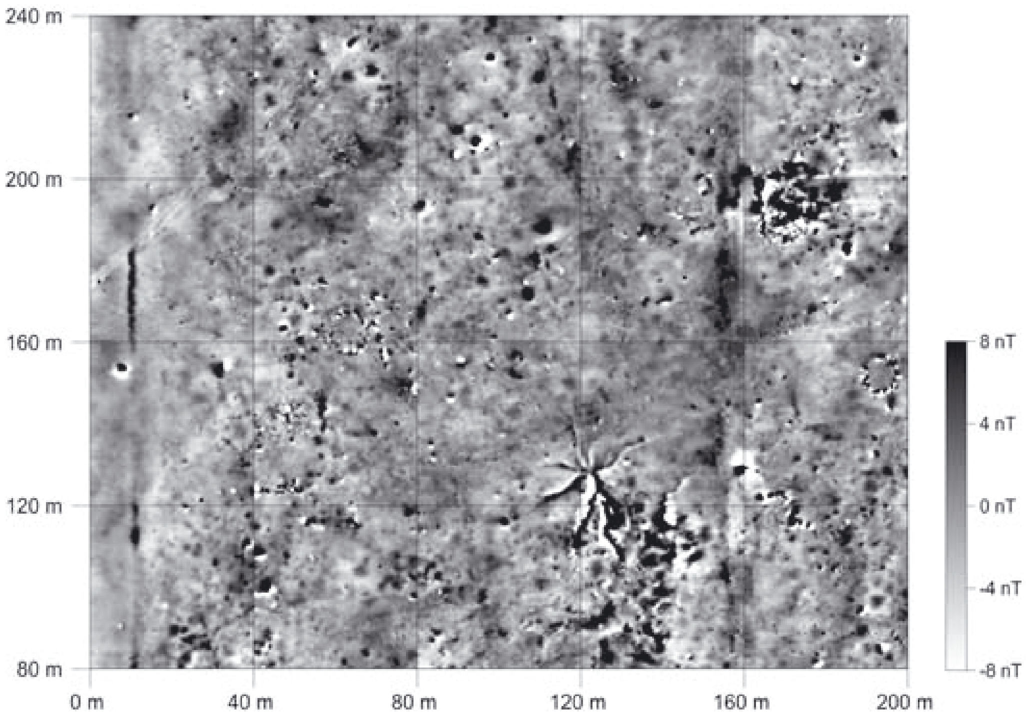

Figure 4: *Karabalgasun. Detail of the magnetogram revealing details of house fundaments and the star-shaped remanent magnetic anomaly of a lightning strike.*

PRELIMINARY RESULTS ON THE DEVELOPEMENT OF A COMPREHENSIVE INTERPRETATION WORK FLOW. THE CASE STUDY KLEINRÖTZ/AUSTRIA

K. Kastowsky-Priglinger

The interpretation of archaeological data sets within relevant literature varies from the presentation of visualized raw data (e.g. Bescoby *et al*., 2009), to oral descriptions (Campana *et al*., 2009b, Aspinall *et al*., 2008), visualizations of anomalies (e.g. Clerq *et al*., 2012; Leopold *et al*., 2011), to full visual and archaeological interpretations (e.g. Neubauer, 2001; Fassbinder, 2010) and its transformation into archaeological maps and detailed reports (Neubauer 2001). There have been calls for a comprehensive interpretation of archaeological prospection data, but as yet there are no specific directions given and what is missing has not been clearly articulated (e.g. Jordan, 2009; Aspinall *et al*., 2008; Neubauer, 2001, 2004; Campana and Piro, 2009).

At present, the team of the LBI ArchPro works to develop interpretive expertise based on the long-term experience of the ZAMG Archeo Prospections® team. The interpretation steps are based on a comprehensive workflow within a GIS environment that combines different stages within one project for later interrelation, combination and statistical evaluation. All anomalies are segmented, digitized and correlated to attributes and additional information within a geodatabase (ESRI®).

Based on the latest methodological developments and geodatabase design for magnetic interpretation of the LBI ArchPro[1], the Case Study Kleinrötz/Austria was re-interpreted within the dissertation project of the author. The aims were a first evaluation of and developmental suggestions for the geodatabase design, the development of a preliminary interpretation workflow for the visual interpretation of anomalies, and to assess enhanced interpretation possibilities of the archaeological landscape around Kleinrötz. The preliminary results are presented here.

The archaeological landscape around Kleinrötz was first documented with aerial photography in 1980, followed by geophysical survey in 1997 by Wolfgang Neubauer at the University of Vienna, using a caesium magnetometer system in a raster of 0.5 m $\times$ 0.25 m. The system used was a hand-held system with four sensors plus one reference sensor on a non-magnetic cart (Neubauer, 2001). Archeo Prospections® repeated and extended the measurements in 2003 and 2004 to cover an area of 118,261 m^2. Preliminary results have been presented revealing a multi-period archaeological landscape with high potential (Neubauer, 2001; Melichar and Neubauer, 2010). First analyses resulted in a description of the Middle Neolithic circular ring ditch overlaid by a Hallstatt period cemetery. Further Middle Neolithic settlement structures, including pits and building structures, have been identified in the southeast of the circular ring ditch. These preliminary results already show the high potential of the site. A first comparative analysis of the 1997 and 2003/2004 surveys of the Middle Neolithic circular ring ditch revealed the site to be in grave danger of destruction from intense agricultural use and erosion (Melichar and Neubauer, 2010).

The interpretation of the archaeological site Kleinrötz, based on the newly developed LBI geodatabase, followed several predefined steps. The magnetograms have been pre-processed with APmag, a software development by Archeo Prospections®. In Figure 1, the magnetogram is within a 256 greyscale range; anomalies are shown from white to black.

The first step was a verbal description of the magnetogram for a general overview as well as the definition of an interpretation strategy. In the case of Kleinrötz, the first description of Magnetograms 1 and 2 led to a predefinition of certain areas of interest like the double circular ring ditch (N), some smaller anomalies around the double circular ring ditch, the smaller circular ring ditches (SW), an empty area in the middle of the magnetogram and an area with various anomalies (E). In Magnetogram 2, southeast of Magnetogram 1, some further smaller circular ring ditches can be seen as well as some stronger anomalies. The next step was the visual interpretation of the detected contrasting anomalies within a GIS environment based on the new LBI ArchPro geodatabase design. Starting with the high-density anomaly area in the east of Magnetogram 1, followed by the ditch systems and remaining anomalies (Figure 2), the whole magnetogram was abstracted into lines, points and polygons for further analysis. The interpretation was performed on the greyscale visualization -8/+12 nT with reference visualizations within the range of -2/+3 nT, -4/+6 nT and -16/+24 nT. Pre-defined editing parameters within ArcGIS (e.g. streaming) were applied and enhanced.

So far, the anomalies have been described on a visual basis, derived from their magnetic anomaly type, morphological type, and respective probability and an archaeological type and probability. The geodatabase allowed quick application of attribution and a high performance. Although all features have been drawn by hand, the whole visual interpretation was completed within two full working days. The performance within ArcGIS by ESRI® full filled all needs for a geo-referenced accurate visual interpretation. The single steps as well as the workflow have been documented for further evaluation.

Initial results are a preliminary report on the verbal description, as well as thematic maps of the interpreted archaeological features.

To be able to compete with fast changing agricultural technologies, industries and urban development, large-scale archaeological prospection has developed as one of the most efficient tools to preserve cultural information. New interpretation approaches need to be considered and developed for new techniques, but until now there has been no comprehensive approach or workflow dealing with the latest techniques and methodological approaches within archaeological prospection. This workflow is needed for a comprehensive and integrated interpretation approach, the reproducibility of data sets and the interrelation of different case studies.

Rapid technical developments within archaeological prospection, new possibilities offered by ArcGIS software, as

[1] The LBI ArchPro geodatabase was designed by Wolfgang Neubauer and Matthias Kucera in collaboration with Karolin Kastowsky-Priglinger.

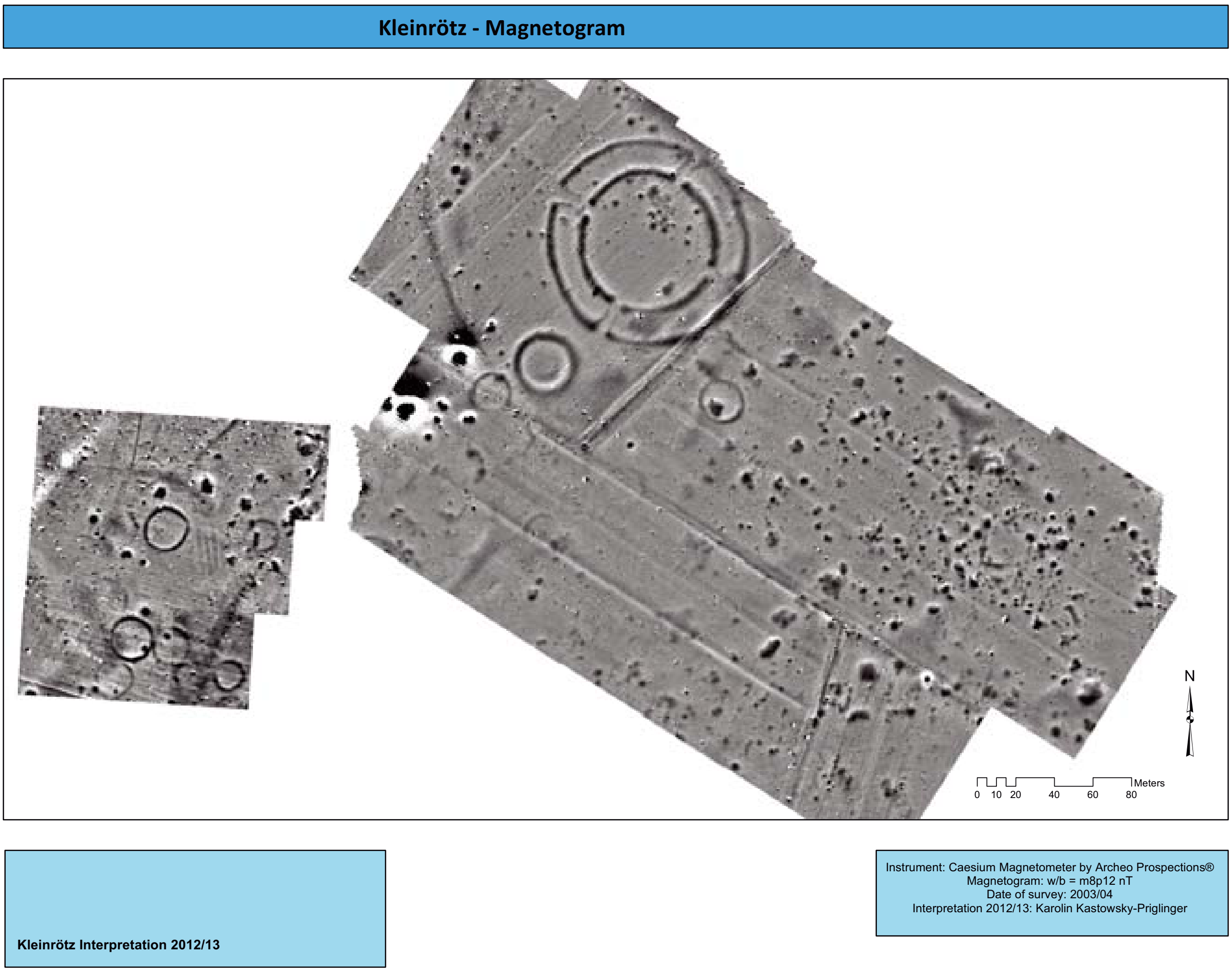

Figure 1: *Magnetogram 1 (large) & 2 (small) – (-8/+12 nT – white/black) campaign 2003/04 (© figures with courtesy of Archeo Prospections®).*

well as semi-automated interpretation steps need to be taken into consideration for new and advanced interpretation approaches of archaeological prospection data. A next step will be the application of the workflow within a large scale survey for further enhancements.

The interpretation of Kleinrötz, based on the newly designed LBI ArchPro geodatabase and the pre-defined workflow, showed clear enhancement compared to earlier and more commonly used interpretation approaches. Performance was faster and the visual interpretation was clearly enhanced.

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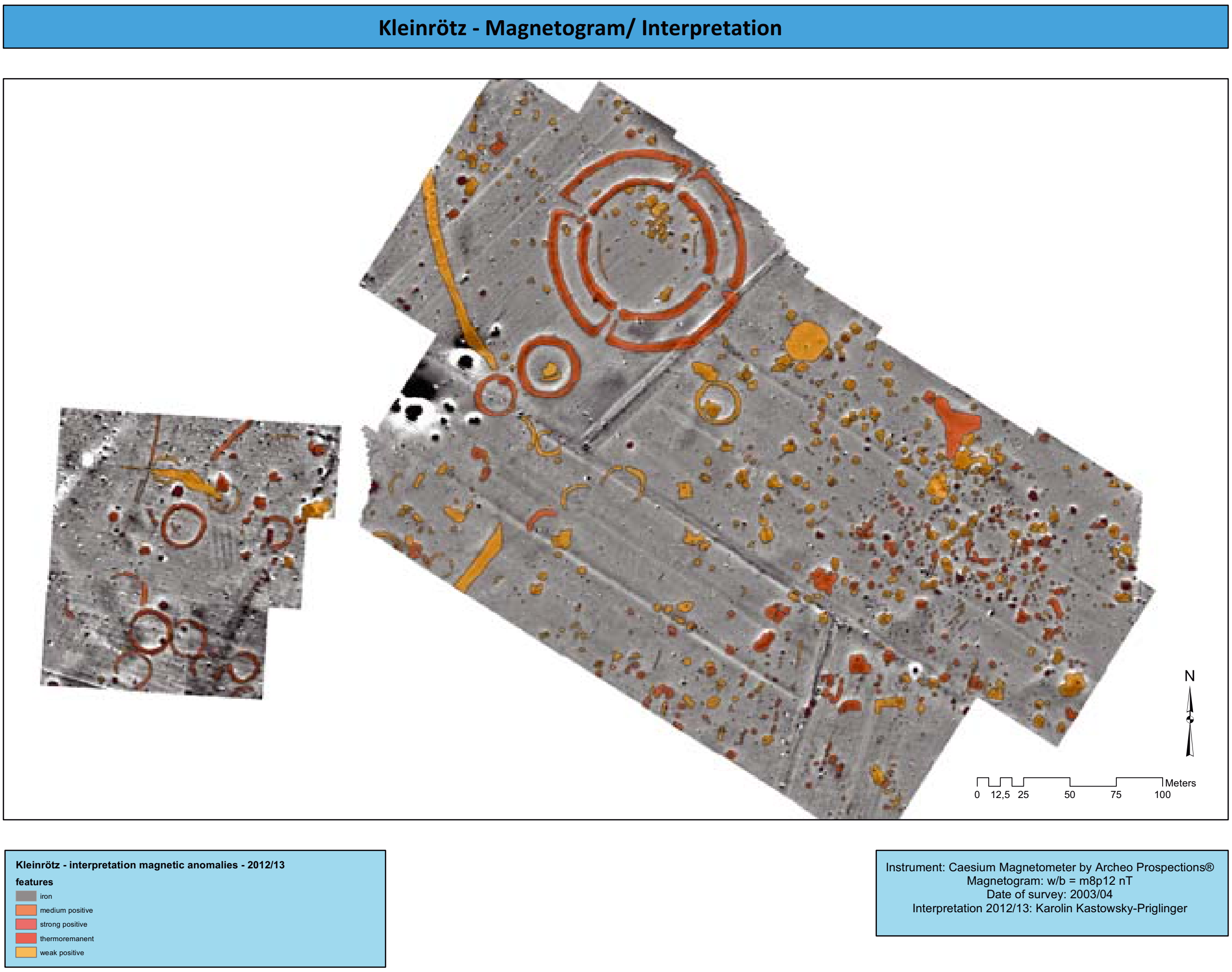

Figure 2: *Magnetogram 1 (large) & 2 (small) – (-8/+12 nT – white/black) with preliminary visual interpretation of contrasting anomalies (© figures with courtesy Archeo Prospections®).*

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HISTORIC LANDSCAPES IN RELIEF: DETECTION AND INTERPRETATION OF HISTORIC LANDSCAPE ELEMENTS USING GEOMORPHOMETRIC AND IMAGE ANALYSIS TECHNIQUES

C. Sevara

A shift in focus from the local to the regional is a hallmark of recent trends in the analysis and investigation of the present remains of the past. An integrated perspective, combining data from multiple sources in order to evaluate anthropogenic traces from a more holistic viewpoint, is another. Both of these trends are supported by advances in the collection and spatial resolution of non-invasive geospatial data, including the use of high-resolution, large-area remote sensing and geophysical prospection datasets. However, multi-component high-resolution datasets covering large areas tend to contain a large amount of information, which must be analyzed, classified and interpreted if it is to be of any use. It is becoming more and more difficult to classify these data, chiefly due to the time-consuming nature of manually searching through datasets coupled with the difficulty of recognizing subtle differences in topographic relief without the aid of computer visualization, e.g. through the use of artificial illumination techniques such as Sky View Factor (Zakšek *et al.*, 2011). A semi-automated approach can save time and help to detect features that may not be identified via traditional (manual) interpretation methods, and allows for rapid processing and classification of large datasets while still providing user control over elements of the process. Object Based Image Analysis (OBIA) and geomorphometry approaches present tools that may offer effective solutions to these issues. As it is by now well established that modern geospatial datasets, such as airborne laser scanning-derived elevation models, are capable of capturing the remains of relict field systems, enclosures and road alignments that are in many cases not visible to the naked eye (Sittler, 2004; Lasaponara and Masini, 2009; Stular and Keller, 2009), it stands to reason that geomorphometric and OBIA techniques, being driven in part by elevation differential, can be successful in the derivation of such feature boundaries as well as the determination, to some extent, of their superposition.

To that end, this presentation will show the preliminary results of the development of these techniques for the detection of the present remains of past land use as a part of landscape characterisation research in the Kreuttal region of Lower Austria (Figure 1). Using Historic Landscape Characterisation (HLC) as a basis, this study aims to broaden HLC approaches by utilizing new technologies and integrated datasets to examine elements of landscape character which may not be otherwise apparent (Rippon, 2012, p. 19,21). Combined with classified historic map, satellite and aerial photography data as structuring components, geomorphometric algorithms for terrain classification have been scaled so as to aid in the semi-automated identification of historic land-use elements in the region from high-resolution digital elevation models (DEMs) of the case study area. Techniques such as retrogressive analysis and landscape deconstruction (Cousins, 2000, p. 17; Oosthuizen, 2006, p. 77-79) are applied to the resulting datasets in an attempt to establish baseline time-depth for landscape elements, while the above-mentioned geomorphometry-based approaches developed specifically for the classification of historic landscape elements are applied in order to determine the extent and superposition of historic features. The results of this study are then compared to independent interpretations of the same datasets, which have been carried out using traditional methods and independently verified in the field, and provide a quantitative analysis of the effectiveness of geomorphometric approaches with regard to the detection of archaeological features of this nature.

Although geomorphometry has only recently come to the attention of the wider archaeological community as a potentially viable research tool, morphometric techniques for land surface and landform classification are not new (Pike *et al*., 2009, p. 12), though they have yet to be extensively applied in historic landscape characterisation studies. Recent examples of geomorphometric and OBIA-based techniques in archaeology include their use to delineate landforms as a basis for predictive modeling in the Netherlands (Verhagen and Drăguţ, 2012) and the extraction of archaeological features from high-resolution satellite images of Nisa and Babylon (Jajah and Ulivieri, 2010). What is new is the very high spatial resolution that modern DEMs can achieve as processed products of high-resolution remote sensing data collection campaigns. In addition to the wealth of historic cadastral and remote sensing data that have guided this study, the Kreuttal case study area has recently been overflown by full-waveform airborne laser scanning (ALS) campaigns, the results of which have allowed for the generation of filtered, very high-resolution DEMs of the case study land surface using the latest ALS technologies. A greater spatial resolution effectively translates to the ability to represent more detailed topographic elements, and by extension to detect and extract them using their differences in elevation as classificatory parameters (Drăguţ *et al*., 2011, p. 162) (Figure 2). Furthermore, the rural landscape in the Kreuttal case study area provides a suitable environment for the detection of historic landscape elements such as field systems, enclosure boundaries and road alignments, as the continuity of land-use from the medieval period has preserved much of the visible historic structure of the landscape. All of these factors have made the Kreuttal area the ideal location for research into the viability of terrain analytical and image analysis techniques as methods for the detection and interpretation of historic landscape components.

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Figure 1: *The Kreuttal case study area, Lower Austria. Satellite imagery source: ESRI/ArcGIS online.*

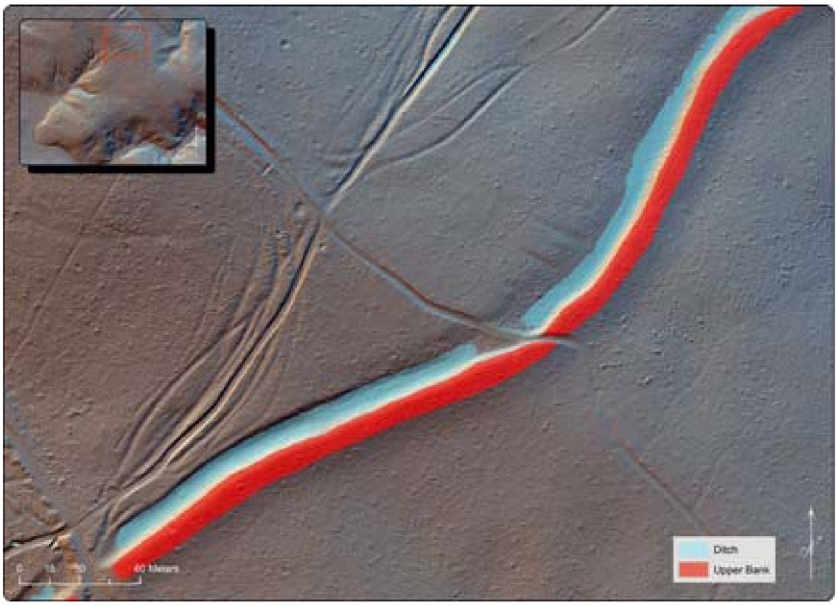

Figure 2: *Section of a presumed Iron Age hillfort, Kreuttal case study area, showing semiautomatic classification of some feature elements using morphometric approaches based on topographic position (Jenness 2006) as applied to a 30cm LiDAR derived DSM.*

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WHY? HOW? WHEN? – A CLOSER LOOK ON ARCHAEOLOGICAL PROSPECTION FOR KIDS AT THE KINDER-UNIVERSITIES IN RAABS AN DER THAYA 2011 AND VIENNA 2012

K. Kastowsky-Priglinger

Increasing public awareness for scientific research and results should be one of the main goals of any archaeological institution. An important and challenging audience to reach is children, from school age on. Summer schools, camps and so-called Kinder-Universities are one attractive way to reach them in an interesting and voluntary environment. The LBI ArchPro is promoting such initiatives, and the first engagements resulted in successful dissemination and awareness of Archaeological Prospection and very positive feedback from the recipients.

The multi-lingual and international Junge-University at Raabs an der Thaya/Lower Austria invited the LBI ArchPro to participate in 2011 with a lecture on archaeological prospection (http://www.jungeuni-waldviertel.at/). The auditorium had more than 70 children between 10 and 14 years old from Austria and the Czech Republic. The lecture was simultaneously translated into Czech. The aim of the lecture ("High-Tech Archaeology. Tracing the past with Computer, Laser and Radar") was to translate the often challenging and diverse matter of archaeological prospection in an interesting, understandable and enjoyable way, to arouse interest in the field and to convey the importance and appeal of archaeological prospection. The lecture was such a great success that the LBI ArchPro participated the following year, summer 2012, at the Kinder-University Vienna (http://www.kinderuni.at/).

The Kinder-University Vienna took place for the 10th time, and has growing visitor numbers every year, with more than 4,200 participants in 2012. More than 120 children attended the lecture "What do Computer, Magnetic and Radar have to do with Archaeology? Following Indiana Jones and Lara Croft with up-to-date technologies!" and participated in the open concept of the talk. The intense communication between lecturer and audience, the many questions and the storm of personal contact after the lecture also showed the broad acceptance and interest in the field.

Figure 1: *Using high-tech archaeology with computers, lasers and radar to engage children with archaeological heritage at the Jugenduni Waldviertel 2011. (Photo by Christoph Priglinger) ©LBI ArchPro.*

HOW TO CONSTRUCT A FORTIFICATION SYSTEM IN THE BORDERLAND OF A SWAMPY LOWLAND DURING THE 16TH/17TH CENTURY – A COMPREHENSIVE PROSPECTION STUDY OF THE DIELER SCHANZEN, EASTERN FRISIA, NW GERMANY

A. Hüser, C. Schweitzer

The *Ostfriesische Landschaft*, the regional association for culture, science and education in East Frisia, has been the project partner of the European Union-funded research project "Grenzland Festungsland" since 2010. Part of this project is the archaeological prospection of an early modern fortification system at the borderline of the Eastern Netherlands and northwest Germany.

In Germany, the archaeological study of early modern fortress construction is currently a desideratum. In East Frisia, fortification systems have now been investigated for the first time. A great opportunity arises in connection with the Dieler Schanzen near Weener in the district Leer (Figure 1). The site has not been built over after its demolition in 1672, and today it offers excellent conditions for a comprehensive prospection study. The following review of historical events supports the understanding of the development of this special place in the south of East Frisia (Table 1). The construction of a first earthwork in 1580 is related to the events of the so-called Eighty Years War in the Netherlands (1568-1648), which led to the independence of the Netherlands from the Spanish crown. Important access routes between Germany and what is now the Netherlands were closed by military fortresses during the siege of the city of Groningen, then under Spanish occupation. Large swamps and peatlands offered a natural borderline and the few paths through the moors could be blocked. The same applies to the situation on the Eastern Frisian peninsula, which was confined by a wide mud belt in the south. The protection of trading roads required the construction of fortifications.

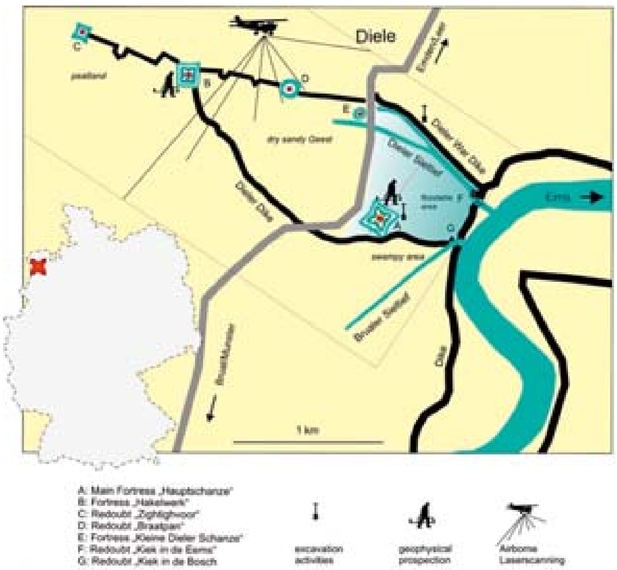

Figure 1: *Modified map of the defensive system "Dieler Schanzen" of 16th, 17th century on the basis of a historical map from the year 1755 (original drawing by H. Friesenborgh, Lower Saxony state archive Aurich). The map shows all elements of the fortification complex.*

The Dieler Schanzen enjoyed their "golden age" during the Thirty Years War (1618-1648). They had to protect the most important trade route between Emden and Munster at the borderline between the county of Eastern Frisia to the northwest and the area of the bishopric of Munster (North Rhine-Westphalia) to the southeast (Figure 1). A 2.5 km long defensive system of several small and larger fortresses and redoubts was built, which were connected by walls and ditches. This system started in the east on the banks of the river Ems with two redoubts ("Kiek in de Eems" and "Kiek in de Bosch") from where the water traffic was controlled and two important sluices were guarded. These sluices regulated the water drainage in the area around Diele and Brual. In peacetime, the collected water of the Dieler and Brualer Sieltief (depression) could be drained off into the Ems at low tide. In the event of war, controlled flooding transformed the landscape into morass which impeded the attack on the fortress.

The main fortress of Diele, the so-called "Jemgumer Zwinger" in the centre, and the fortress "Hakelwerk" to the west are the main components of the defensive system. Both show up in a characteristic early modern style with wide ditches, walls, and bastions projecting outward from the four corners. The western end of the fortification system is located near the border of today's Dielerheide, where the narrow dry sandy Geest area ends and passes into the peatland.

PROSPECTION ACTIVITY

The investigations of the Dieler Schanzen developed into a multi-disciplinary study, which covered archaeology, pedological observations, analysis of historical sources and of aerial photographs, geophysical prospection, and airborne laser scanning (Table 2). The integration of all results eventually led to a coherent picture of the development of the most important main fortress.

Geophysical Prospection

The prospection activities started with geophysical surveys focused on the investigation of the two main fortresses (Figure 1, A and B). The objective for the main fortress Dieler Hauptschanze was to define a ground plan of the central part, because adequate historical sources do not exist. In the case of the fortress Dieler Hauptschanze (Figure 1, A) caesium-magnetometry proved to be the successful method (Caesium-Magnetometer SM4G-Special, point density 25*25 cm, 40 m grids). The remains of the demol-

Figure 2: *Main fortress Dieler Hauptschanze – magnetogram on aerial photograph; the vegetation shows the quadratic outline of the outer walls and ditches; the remains of the demolished casern of 17th century are marked by highly magnetized bricks; ground plan of the casern: 65 m by 65 m, inner court of 35 m by 35 m; examples for anomalies of munitions of 16th, 17th century (cannonballs and bombs) marked by red circles, 2 excvated bombs at location B1, B2; outline of 4 archaeological trenches in blue; cesium-magnetometer SM4G-special, scale -5, 18 nT, point density 25 × 25 cm, 40 m grids.*

ished casern from the 17th century are marked by highly magnetized bricks, which reveal a quadratic ground plan of the casern (Figure 2). Four wings of the building are grouped around a central courtyard and form a 65 × 65 m square building complex. The outside areas with walls and ditches are full of small circularly shaped anomalies of 10 to 30 nT.

Many of them are caused by old munitions from the 16th and 17th centuries (cannonballs and bombs) (Figure 2). At the two locations B1 and B2, old bombs 60 to 70 kg in weight have been excavated. In order to calibrate the magnetic signature the anomaly of a 10 kg cannonball buried at a depth of 30 and 100 cm was measured. As anticipated from the beginning, magnetometry was suited to detect structures comprising remnants consisting of brick. However, in areas outside the central buildings, other imprints of human construction activities were not discovered due to the lack of magnetization contrasts.

The prospection objective for the other main fortress, the Hakelwerk, (Figure 1, B) was first to reconstruct its original shape and secondly to search for former buildings. Only the southern half of the fortress is recognizable, showing two bastions in aerial photographs, whereas the northern area is completely void of any structures. The magnetometer survey, which covered the entire site, failed to detect the previously identified southern ditch, but discovered some brick-related anomalies in the centre of the fortress. The resistivity method was tested successfully on the southern ditch, and will be applied next year to search for the northwestern bastion.

Archaeological Prospection

Due to time and financial constraints, the archaeological "hard" prospection (excavation) had to be limited to the central hill of the main fortress 'Dieler Hauptschanze' with its barracks. It has been the aim from the beginning of the project to affect the historical monument as little as possible. This was to be achieved by narrow trenches placed at the right locations, in order to characterise as broad an area as possible with minimal disturbance. The archaeological sections were planned following the geophysical interpretation, assuming brick remnants of a four-wing barrack and an inner courtyard with a large well. This

Figure 3: *Main fortress Dieler Hauptschanze – foundation trenches backfilled with rubble were excavated and no masonry as expected.*

was essentially confirmed by the north-south section No. 3 and 4 (Figure 2). However, remains of walls preserved to this day are missing. Instead, trenches filled with brick rubble were found, which are causing the spotted anomaly pattern of the wings in the geophysical image (Fig. 3).

The large anomaly in the courtyard area was correctly interpreted and confirmed by the archaeological sondage: A circular well shaft made of bricks, 3 m deep and 1.5 m wide, which served to supply drinking water for the soldiers, was excavated.

The main fortress Dieler Hauptschanze was most probably built on an elevated dry and sandy ground, beginning in about 1580. Tracks of a chariot in section No. 3 can be dated to the first building period of the fortress or before. A sandy layer of up to 30 cm covering the natural ground formed the substructure to stabilize the wall foundations. Buildings from this early building phase were grounded ca. 30 cm above the bedrock. The excavations have shown that they were protected by ramparts 3 to 4 m in height. The early buildings were destroyed and built over. The area inside the ramparts was continuously filled up with sandy soil and waste. The barracks with the courtyard prospected by magnetometry belongs to the last building phase on top of a hill surrounded by the flat lowland. The digital elevation model (Figure 4) shows that the building complex is still slightly embedded in the top area of the hill surrounded by the crest of the ramparts.

The entrance of the fortress from the East crossed the two water-filled ditches by wooden drawbridges and passed the wall through the main gate.

The excavations recovered large amounts of pottery, tobacco pipes, animal bones and, quite natural for a fortress, weapons. Lead bullets as ammunition for muskets, parts of rapiers and grenades made of iron are to be mentioned, with special attention drawn to two complete mortar bombs and numerous fragments of such bombs from the 17th century, which clarify the brutality of the siege battles for the Dieler Schanzen in the period between 1664 and 1672. These large 30 cm calibre bombs, 60 to 80 kg in weight, were filled with about 4 kg of gunpowder, which was an innovation of the artillery at that time.

Airborne Laser Scanning/Historical Maps

To get a first overview of the entire fortress complex, historical maps and aerial photographs were examined and evaluated, followed by the ground inspection of detected remnants. This study resulted in the outline of a highly complex defensive system. Due to its location in the cultivated and ploughed lowlands, some elements were difficult to recognize. Therefore in spring 2012 the entire Dieler Schanzen complex was covered by an airborne laser scanning survey (MILAN Geoservice GmbH, Germany, 4 km^2, density of about 10–13 measurements per square meter). The accurate mapping of surface features allowed documentation of elements of the fortification system that were known from historical maps, but not recognized in the landscape. The so-called Dieler military dike (Wehrdeich) serving to cause controlled flooding east of the main fortress Dieler Hauptschanze was captured perfectly by the LiDAR data (Figure 1). Likewise, the old access road to the fortress was perfectly imaged, emerging as a flat wall with ditches on both sides. Small pits and

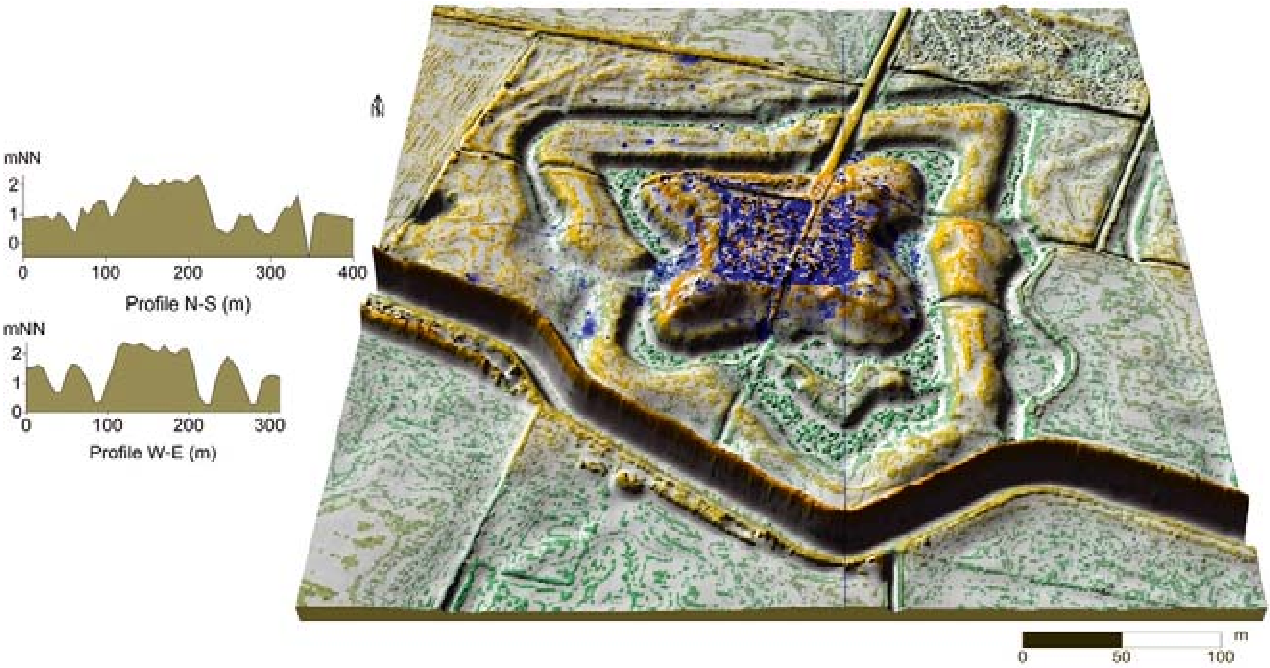

Figure 4: *Dieler Hauptschanze- digital terrain model from LiDAR data (MILAN Geoservice GmbH, 2012) with superposed magnetogram in blue; cesium-magnetometer SM4G-special, scale 0,10 nT, point density 25 × 25 cm, 40 m grids.*

mounds west of the Dieler Hauptschanze also could be mapped. These date back to the Dutch siege of the Schanze in 1664, when the besiegers were stationed here.

Today's appearance of the main fortress Dieler Hauptschanze can be illustrated in a 3D model from LiDAR data in combination with a magnetogram showing the central hill, the remains of the barracks, and the fortification walls and ditches (Figure 4).

SUMMARY

Its partnership with the European Union-funded research project "Grenzland Festungsland" has enabled the Ostfriesische Landschaft, the regional association for culture, science and education in Eastern Frisia, to investigate the fortification system of the Dieler Hauptschanzen. The 2.5 km long defensive system was built during the 16th and 17th centuries to protect the most important trade route between Emden and Munster at the borderline between the county of Eastern Frisia to the northwest and the area of the bishopric of Munster to the aoutheast. It consists of several small and larger fortresses and redoubts connected by walls and ditches. Due to time and financial constraints careful planning was requested to comprehensively explore the most important fortification complex in the region. The study of historical maps, aerial photographs and the airborne laser scanning survey provided the map of the Dieler Schanzen, showing individual fortification elements. Discussions with local people gave valuable hints at old landmarks and recent changes of the landscape. Geophysical prospection delivered a ground plan of the main fortress, which served as the basis for planning the archaeological trenches. Furthermore, magnetometry mapped the locations of old ammunition, cannonballs and bombs, two of which were excavated for scientific examination. Resistivity surveys could identify buried ditches, to identify the old shape of the fortress. The excavations, although carried out as small-scale trenches, were the only way to actually reconstruct what life used to be like in the fortresses. Numerous clay pipes, pottery, shoes, food waste, weapons and projectiles, etc. provide insights into the daily lives of soldiers, both in war and in peacetime. The excavations also revealed the building phases of the main fortress during its nearly 100-years history before its demolition in 1672.

MULTI DEPTH ELECTROMAGNETIC SURVEYS IN IRELAND: INCREASING OUR CHANCES OF DETECTING ARCHAEOLOGICAL FEATURES

J. Bonsall, C. Gaffney, T. Sparrow, I. Armit

Low frequency electromagnetic (EM) techniques using Slingram instruments have been used for archaeological prospecting since the 1960s. Traditionally in Europe, EM surveys have not enjoyed widespread use (Gaffney, 2008), and in Ireland even less so; this has been due to a number of factors, such as limited data collection ability, inherent issues of instrument drift, a lack of depth analysis, and partly due to an over-reliance on magnetometer, earth resistance and ground penetrating radar technologies. Despite this, EM surveys have previously offered a number of benefits over traditional magnetic and electrical methods, principally the simultaneous acquisition and co-location of quadrature and in-phase data to assess soil properties similar to those identified in earth resistance and magnetometer surveys. The measurement of quadrature and in-phase components allows the calculation of conductivity and magnetic susceptibility, respectively. Under certain practical conditions, EM surveys provide a very reasonable approximation of these properties and are therefore capable of identifying a broad range of archaeological features including cut features, masonry and areas of burning. However, previous studies have indicated the values are only estimates as the conductive and magnetic components are not entirely separated (Tite and Mullins, 1973; Tabbagh, 1986a, Linford, 1998).

Both commercial and academic prospecting strategies have recently been driven by a need to resolve all (or most) archaeological features, rather than those that exhibit exclusively magnetic properties, by the acquisition of high resolution data in an increasingly efficient manner (Gaffney *et al*., 2012) and by the investigation of archaeological features at depth using 3D or pseudo-3D methods. These drivers have previously been met by high-speed multi-method investigations employing magnetometer, earth resistance and/or GPR surveys (Dabas, 2009; Trinks *et al*., 2010; Campana and Dabas, 2011), although the development of a new generation of multi-depth instruments suggest that EM prospecting may have a role to play. In this presentation, we assess the abilities of a new electromagnetic system, the CMD Mini-Explorer, for the prospecting of archaeological features on Irish soils (Figure 1).

The Mini-Explorer EM probe is primarily aimed at the environmental / geological prospecting market for the detection of pipes and geology. It has long been evident from the use of other, more limited, EM devices that the CMD might be suitable for shallow soil studies and applicable for archaeological prospecting. Of particular interest for the archaeological surveyor is the fact that the Mini-Explorer simultaneously obtains both quadrature ('conductivity') and in-phase ('magnetic susceptibility') data from three depth levels. As the maximum depth range is probably about 1.5 m, a comprehensive analysis of the subsoil within that range is possible. As with all EM devices, the measurements require no contact with the ground thereby negating the problem of high contact resistance that often besets earth resistance data during dry spells.

In theory, the ability to measure two phenomena at three depths suggests that this type of instrument could reduce the number of poor outcomes that result from single measurement surveys. The high success rate reported here in the identification of buried archaeology using a multi-depth device that responds to the two most commonly mapped geophysical phenomena has implications for evaluation surveys.

Figure 1: *CMD Mini-Explorer, a new electromagnetic system.*

Like other modern EM devices, the simultaneous acquisition and co-location of quadrature and in-phase data means that the same volume of earth is investigated for any given sample point, something which magnetometer and earth resistance surveys are unable to do, no matter how accurately the data are collected. This gives the Mini-Explorer a significant advantage over conventional magnetometer and earth resistance surveys in terms of analysing the geometry and geophysical magnitude of responses from sub-surface archaeological features.

1. ASSESSMENTS FROM THE REPUBLIC OF IRELAND

A large number of assessments have been carried out in the Republic of Ireland, some of which are discussed below in relation to challenging variables that have traditionally limited the ability of conventional magnetometer and earth resistance surveys to identify archaeological features, such as very high and very low contrast magnetic geologies, dry and saturated soils and the ability to obtain depth or pseudo-depth information.

1.1. Slievemore, Achill Island, Co. Mayo

Excavations at Slievemore mountain (Rathbone *et al*., 2011) found that the morphology of pre-bog field walls were highly varied and far more substantial than surface indications suggested. Bog probing, traditionally a very successful method of identifying field walls elsewhere in County Mayo (Warren, 2008), is problematic at Slievemore as the mountainside is co-

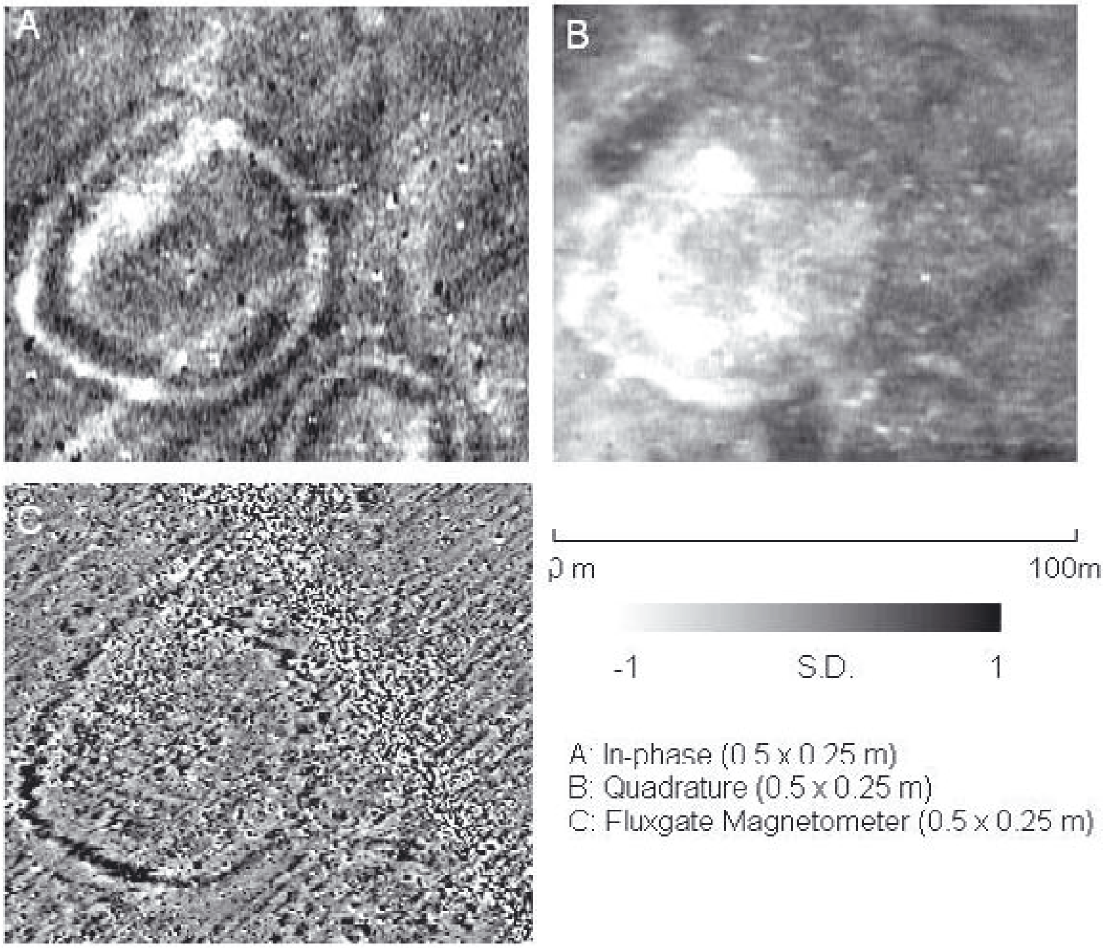

Figure 2: *Results of survey at Kilcloghans, Tuam, Co. Galway. 2a) in-phase and 2b) quadrature from the EM probe. 2c) results from a fluxgate magnetometer.*

vered by dense build-ups of stone within the mineral soil. A magnetometer survey was not viable due to the strong background magnetism of the psammites, marbles and schist geology; a Wenner array earth resistance survey did manage to identify the field walls, although progress was slow and impeded by the need to obtain probe contact upon the uneven surface. The EM survey was used to overcome these challenges. Both the apparent magnetic susceptibility and apparent conductivity data identified the pre-bog field walls, which corresponded well with excavation data and the earth resistance survey. Neither the magnetic susceptibility nor conductivity data were affected by the magnetic geological response. The Mini-Explorer could be operated reasonably well on the wet and boggy upland soils allowing data acquisition at both a faster rate and a higher resolution than the earth resistance survey.

1.2. Davidstown, Co. Kilkenny

During prolonged periods of hot weather and low rainfall, dry conditions caused by evapotranspiration can either prevent the identification of earth cut features in earth resistance data and/or hinder the insertion of probes within the compacted soil (Clark, 1996; Fry *et al*., 2011; Parkyn *et al*., 2011). An earth resistance survey of an enclosure ditch at Davidstown was abandoned due to seasonally dry soils. The EM methodology, which does not require ground contact, obtained high quality apparent conductivity data; the comparative earth resistance survey (attempted over the same area on the same day), failed to obtain satisfactory probe contact. Both the in-phase and conductivity data identified the enclosure ditch; the in-phase and conductivity data also identified the presence of a bank, an archaeological feature that usually fails to appear in magnetometer data due to weak magnetic contrasts. Banks are also notable by their rarity in earth resistance surveys.

1.3. Kilcloghans, Tuam, Co. Galway

Limestone, which covers most of Ireland, is a magnetically weak geology that often causes cut features to remain virtually indistinguishable from the background soils in magnetometer data (Bonsall *et al*., 2011). As a result, magnetometer surveys on the predominant limestone geology often fail to identify or characterise significant cut features, particularly enclosure ditches, such as those at Kilcloghans, which were mapped as very weak magnetic responses (Figure 2c). Both the in-phase (apparent magnetic susceptibility; Figure 2a) and quadrature (apparent conductivity; Figure 2b) data from Kilcloghans identified the ditched enclosures very well. The apparent magnetic susceptibility data mapped the enclosures as strongly contrasting coherent responses on the limestone soils. The use of detailed EM surveys lends itself as a suitable method of assessing cut archaeological features upon limestone soils.

1.4. Hughes-Lot East, Cashel, Co. Tipperary

The Mini-Explorer, when used in both the HCP and VCP dipole orientations, obtains data from 12 configurations at depths claimed to range between 0.25–1.8 m, at a reasonably fast rate of acquisition. The accuracy of depth data were assessed next to a partially excavated bi-vallate ringfort enclosure at Hughes-Lot East. The excavated components of the ringfort ditches were 1–1.3 m in depth (Ó Droma 2011). The EM survey clearly identified the unexcavated portion of the ringfort ditches and compared very well with magnetometer and earth resistance data. The ditches were visible in all 12 configurations of the EM data, although they were barely appreciable at the lower levels (in the 3-VCP-Q and 3-HCP-I configurations). This suggests that the depth data were accurate to within half a metre at the Hughes-Lot East enclosure. It is reasonable to regard the depth information as relative depth between the successive layers rather than true depth; the accuracy of the depth data are strongly influenced by physical properties of the underlying soil, which are often unknown (Tabbagh 1986a).

2. CONCLUSIONS

The CMD Mini-Explorer has demonstrated an ability to detect a wide range of archaeological features. Excavations and 2D geophysical data have confirmed that the conductivity and in-phase responses have identified ditches (including significant enclosed settlements), walls and banks. The instrument performed well within the variables assessed such as geology, soils, vegetation cover and climate. The instrument has for example successfully identified archaeology upon magnetically strong geologies; beneath layers of peat; on grazed, neglected and upland pasture and over very dry soils during particularly hot weather.

It has been shown that the CMD Mini-Explorer has the ability to determine the presence of a variety of discrete archaeological features across a range of site types and locations. The depth range is suited to shallow soils and, given the variables involved in the estimation of depth, is particularly useful for the investigation of complex stratigraphy such as those found on archaeological sites.

We conclude that the instrument is suitable for prospecting surveys of areas of unknown archaeological potential – if archaeological features are present, we have found that at least one of the datasets would indicate a measurable and understandable signal. This point is very important if one considers the use of a multi depth EM system in commercial or evaluation surveys. The use of a multi depth EM sensor appears to reduce the chances of incorrect technique choice, especially in areas of difficult geology or variable soil depth.

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NIESZAWA: A FORGOTTEN MEDIEVAL CITY IN POLAND DISCOVERED WITH THE USE OF REMOTE SENSING TECHNIQUES

M. Jaworski, M. Pisz, S. Rzeźnik, W. Stępień, P. Wroniecki

Nieszawa is a city that has been well known and well documented in historical sources. Founded in AD 1424, it played a crucial albeit short role in the history of Poland. Nieszawa, due to its highly advantageous location approximately 1 km from the Teutonic-controlled trade powerhouse that was the city of Toru (Thorn) and due to favourable tariffs, began to grow very rapidly. Thanks to the contemporary prosperous economic situation based on Polish grain export, Nieszawa began to successfully compete with Toru in mediating the trade between large trade centres of Kraków and Gdask.

Despite the city's growing prosperity, its political situation changed drastically during the Thirteen Years' War when Toru defected to the Polish King. One of the terms of Toru's defection was the destruction of Nieszawa. However, as the city had a very crucial role during the war as a supply centre for the Polish army, the Polish King decided to move the city over 30 km south along the Vistula River in order to appease both sides of the conflict. Nieszawa was finally abandoned in AD 1462 and transferred to its new, less favourable location. Over time, it was marginalized and to this day exists as a small township of about 2,000 persons.

Currently, old Nieszawa is administratively a part of modern Toru, though fortunately its location on a fluvial terrace of the Vistula left the terrain mostly undeveloped and undisturbed, and after 550 years it is still used as plough land. This series of fortunate coincidences allowed for the remnants of the medieval city to remain mostly untouched since its abandonment.

Even though historical sources mention that old Nieszawa was located near the Dybów Castle, ruins of which exist to this day, the precise location, shape or size of the city was unknown. In 1999–2001, an archaeological excavation project co-funded by the city of Toru attempted to locate old Nieszawa with the use of test trenches. This project unfortunately failed to definitively answer the abovementioned questions regarding the location of the city, although archaeological features and one house from the same chronological period were found.

A breakthrough was achieved after many years of aerial prospection carried out by Wiesaw Stępień from 2001-2011 (a two seater aircraft was used). Aerial images registered crop marks similar to the shapes of houses from the late-medieval period. These occur in a regular pattern, resembling the frontages of a city square (Figure 1). Images taken during the excavation project showed that the test trenches unluckily missed most of the municipal features.

The aerial discoveries were presented by Stępień during the 2011 AARG meeting in Poznan. Because of the significance and potential of such a discovery, a non-invasive survey project financed by the Ministry of Culture and National Heritage was commissioned in 2012 to conduct geophysical prospection, mainly magnetic, in order to identify the extent and nature of the discovered crop marks. Some smaller scale electrical resistivity survey was also commissioned.

The aim of the new project is the non-invasive discovery and documentation of the probable location of medieval Nieszawa, and in particular to define such characteristics as scope, shape and distribution of municipal buildings (e.g. Figure 2). In addition, the project seeks to determine the nature of the city's surroundings, such as the course of the nearby roads, passages within buildings or even parcel spread. A very important aspect of the research is to document the current state of preservation of all archaeological remains in response to direct threats such as the negative impact of the Vistula River, agriculture and treasure hunters.

In order to capture the city and its background, field prospection encompassed 15 ha of magnetic and 0.5 ha of electrical resistivity survey. It has revealed that the city extended further than the 6 ha initially observed from cropmark distribution. The area detected through aerial photography turned out to be only one of three town districts, as the features associated with buildings spread further west. The city consisted of two quadrants and a city square, with visible buildings that could signal plans for further expansion to the south.

Through post-processing of acquired geophysical data, aerial photographs, orthophotography and historical data as well with 3D reconstructions, it will be possible to produce outcomes that will not only give a unique, scientific view into subsurface deposits but will also be presented in an approachable form to the local community. The results of this project will also have an impact at the decisions concerning preservation and further treatment of the site in order to protect this remarkable remnant of history.

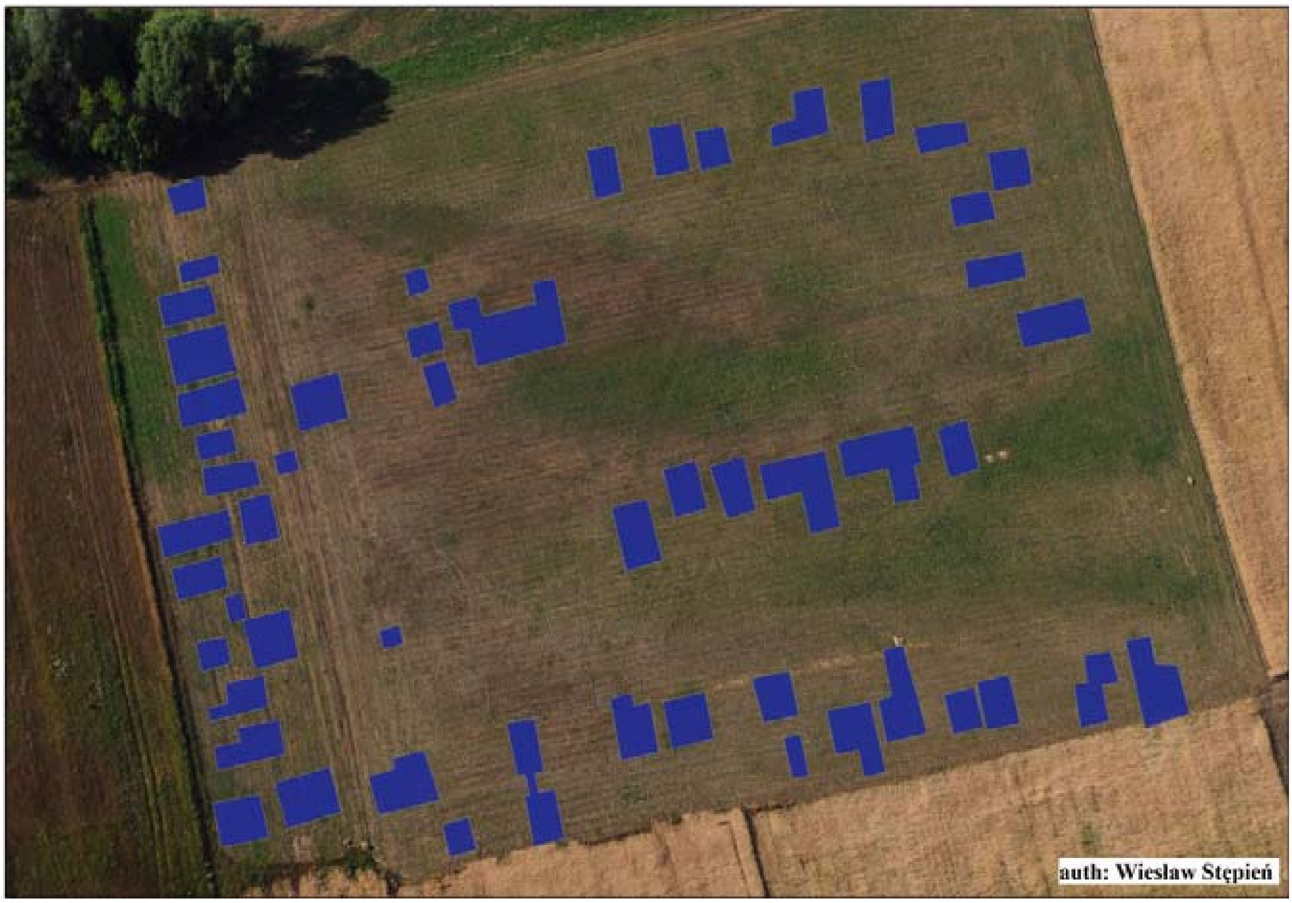

Figure 1: *Interpretation of aerial imagery from the 2008 survey (auth. W. Stępień)*

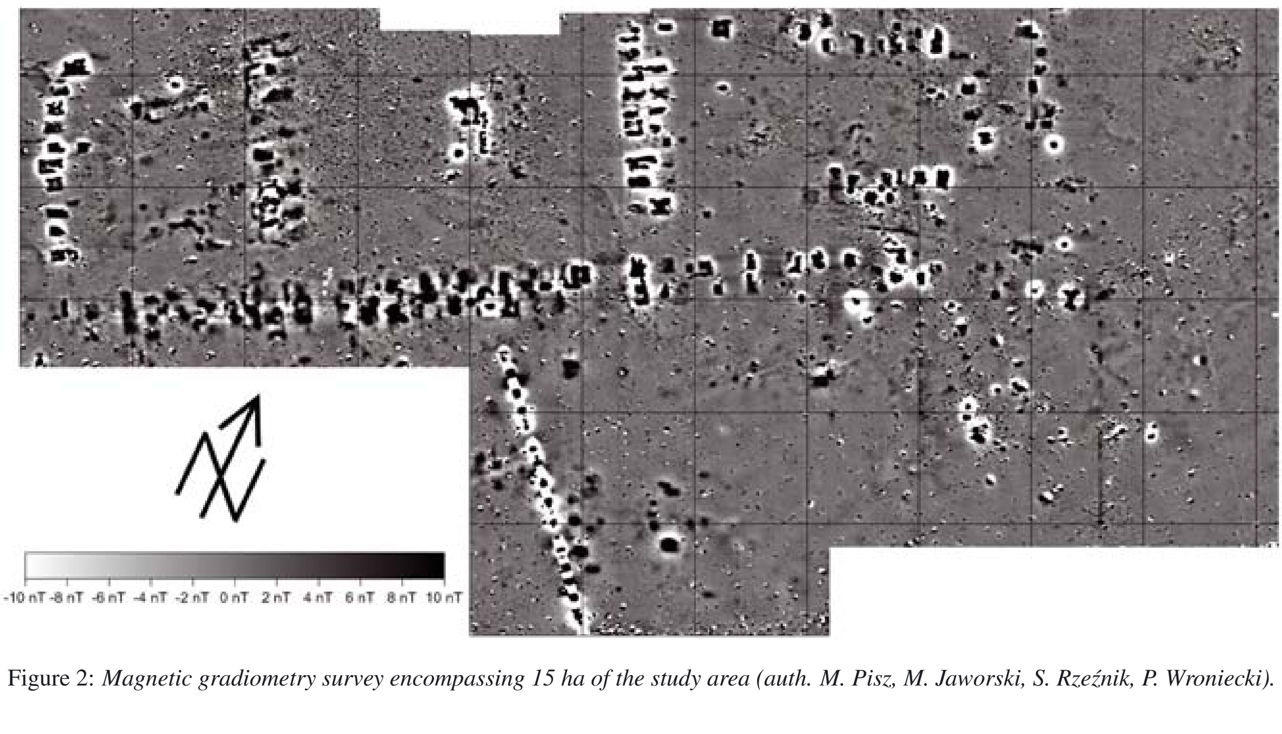

Figure 2: *Magnetic gradiometry survey encompassing 15 ha of the study area (auth. M. Pisz, M. Jaworski, S. Rzeźnik, P. Wroniecki).*

ELEMENTS OF THE BRONZE AGE LANDSCAPE OF "CIKOLA WATER SYSTEM" PRELIMINARY RESULTS

L. Reményi

The general goal of the archaeological survey of the "Cikola water system" (more than 300 km^2) is the reconstruction of the past landscape, changes in settlement patterns and land use, as well as the general history of the landscape changes. The methodology of the project is as follows: First stage: General survey of the area, by data collection (official site database, data of repositories, archaeological literature and local history), topographical analyses (e.g. historical and archival, hydrological and other maps, DDM reconstructions, aerial photos, and remote sensing data), and by intensive field survey. Second stage: Systematic and complex survey (systematic field survey, geophysical survey and other remote sensing, geoarchaeological investigations) of the representative sites of the pattern. Third stage: The results of the surveys, processing of archaeological and GIS data and general reconstruction of the landscape changes.

The first intensive period of settlement in the area is during the Bronze Age, Reinecke phase A2-B (ca. 1900–1450 BC), as well as the period of the Vatya culture. One of the best known Bronze Age tell cultures in the Carpathian Basin is the Vatya culture, which developed in the centre of the Carpathian Basin at the beginning of the second millennium BC. Life on most of the tell settlements started in the previous (Nagyrév) period, and there is no evidence for a break in the settlement structure and pattern. New theoretical research suggests that the tell system is a complex economical and social system.

The fortified (defensive) settlements of the Vatya culture spread during the later phase of the culture into the Budai and Velencei Mountains, and to the valley of the Vál and to the northern part of the Sárvíz River. Earlier research named these fortified settlements pseudo-tells, and emphasized their defensive role. Based on the evaluation of maps dealing with the spread of the Vatya fortified settlements, these defensive Vatya settlements were interpreted as a network of fortress system that surrounded the Vatya territory (Kovács, 1969; Bóna, 1975, 57-59).

We found three known Bronze Age fortified settlements in the study area by preliminary data collections: Perkáta, Faluhelyi-dűlő (Hatházi, 1996, 14, site 3), Perkáta, Forrás-dűlő I (Czajlik, 2004) and Perkáta, Forrás-dűlő II (Terei et al., 2011), and ca. 20 sites identified by intensive field survey of the area. We can interpret nine sites as Bronze Age fortified settlements – by the data of field survey and aerial photos and by the relief of the site – and another 4-5 sites as settlements (without evidence for defensive systems). We cannot interpret clearly the

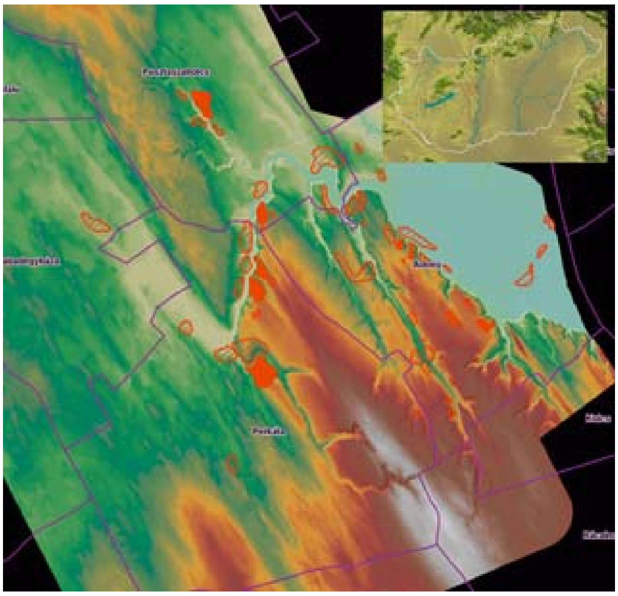

Figure 1: *Bronze Age sites, and Bronze age fortified settlements of Cikola water system.*

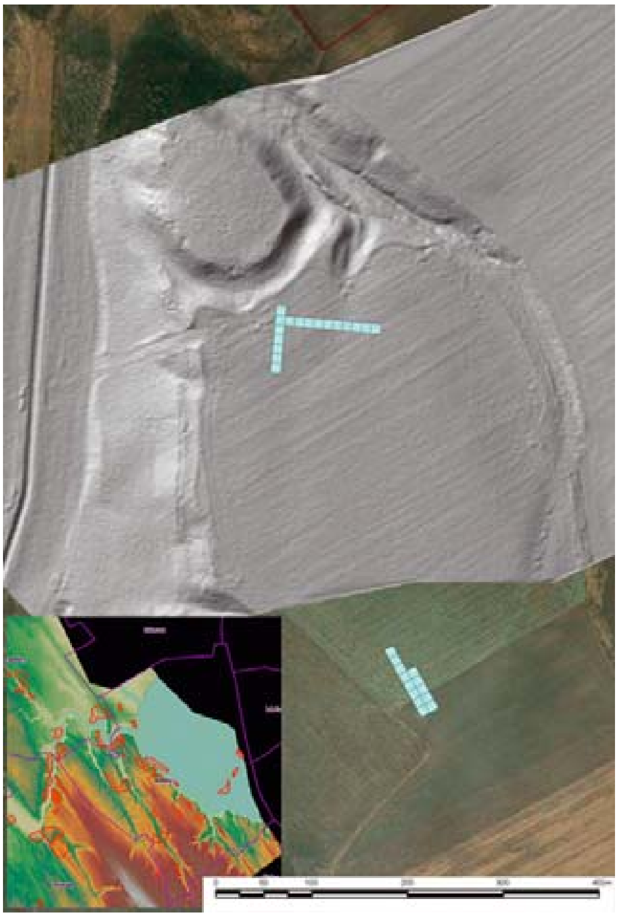

Figure 2: *Structure of Perkáta, Forrás-dűlő I. site, and the location of systematic field surveys.*

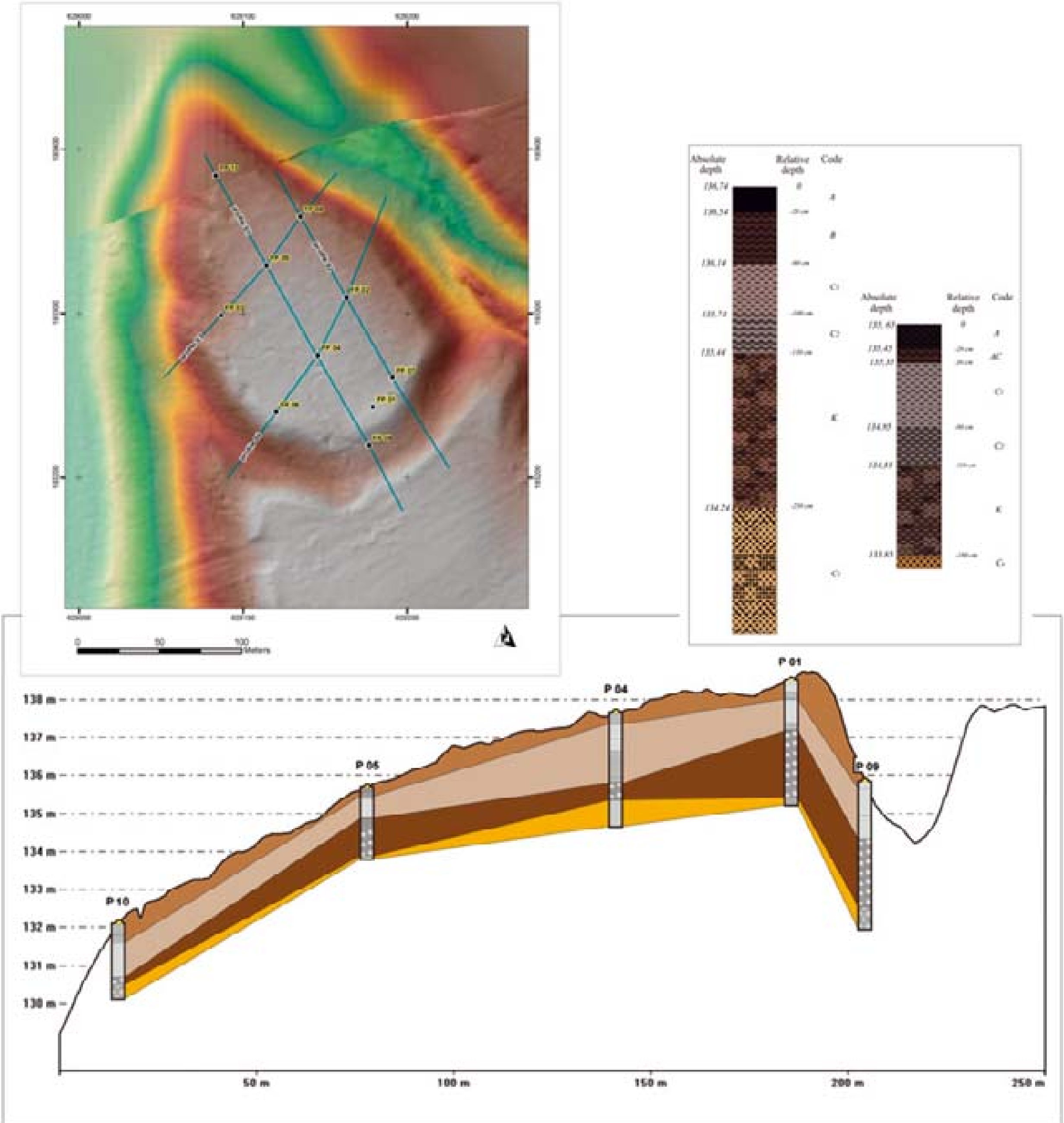

Figure 3: *Shallow geological drillings and the formal cross-section of the settlement part.*

other sites, but one of these sites can be identified as cemetery. The Bronze Age sites are concentrated on the edges and in the valleys of the NW-SE direction loess-plateau (Figure 1).

The selected site for the complex survey is Perkáta, Forrásdűlő I, selected for its good conditions for the surveys. The most important question was to reveal the stratigraphy, chronology and the inner structure of the fortified settlement. Based on systematic approaches (intensive and systematic field surveys, geophysical survey, analysis of aerial photo data and LiDAR survey) we can reconstruct the size, inner structure and the chronological framework of the site. Based on geophysical survey data, analysis of aerial photos and DDM generated by the LiDAR survey, the site is separated into two main parts: an inner part, called "small castle" and separated by concentric wide ditches on the edge of the hill (ca. 250 × 120 m), and the "external" settlement part (ca. 470 × 290 m) surrounded by a thinner ditch. Finds of the Vatya culture (Reinecke BA2-BB) were identified over the entire area by intensive and systematic field surveys. Sherds of the Urnfield culture (Reinecke Bronze Age D – Hallstatt AB; 1250–800 BC) concentrated on the inner part of the sites and around the inner ditches (Figure 2). Therefore, the total settlement area was first populated by Bronze Age "Vatya" inhabitants, and the total structure was built in this period (ca. 1900 BC).

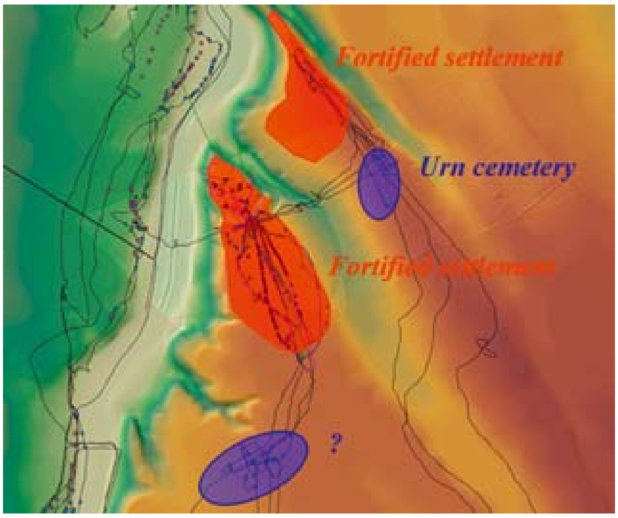

Figure 4: *The base units of Bronze Age settlement pattern and Landscape.*

The stratigraphy and C14 based absolute chronology of the site is most important for the theoretical analyses (pseudo-tell or tell problem). We tried to reconstruct the vertical structure of the inner part ("small castle") by geoarchaeological investigation (Reményi *et al.*, 2012). Shallow geological drillings were carried out on the smaller, distinctive part of the fortified settlement. The drillings were conducted in three parallel lines along the axis of the settlement. Each drilling was continued until it reached the typical geological parent material of the area. On-site description of the core material – sampled in 10 cm intervals – was carried out according to standard soil description methods. Determination of the stratigraphy of the settlement was refined based on the laboratory analysis of two representative cores. Laboratory measurements included soil scientific analyses (pH, CaCO3%, TOC, texture identification), radiocarbon measurements of six samples, and archaeobotanical analysis of the culturally influenced layers.

Based on the preliminary results we may state that the separated inner part of the Bronze Age defensive settlement is a multilayered settlement, which – at some locations – bear a 1.50 to almost 2.0 m thick cultural layer (Figure 3). The absolute chronological framework of the inner part was determined by radiocarbon measurements of six samples from the drillings: the cultural layers dated to between 1730 and 1530 BC. The site is parallel with the Koszider phase of the Vatya culture – and other Bronze Age tell cultures – and the early phase of the Tumulus culture (Reinecke Bronze Age B period).

So the fortified settlements of the Vatya culture are the centres of a complex economical and social system, just like "classic" tell settlements, and the role of classic tell settlements and "pseudo-tells" was probably the same (see Gogâltan, 2002; Fischl and Reményi, 2007). The preliminary results of the investigations of the stratigraphy and chronology at Perkáta, Forrás-dűlő I site confirmed the new theoretical approaches.

Perkáta, Forrás-dűlő II is another fortified settlement located at the next hilltop, 500 meters away from Forrásdűlő I (Terei *et al.*, 2011). A Bronze Age urn cemetery was identified by sporadic surface finds near the external settlement. Similar features are found near most of identified fortified settlements within the Cikola water system.

The hilltop fortified settlements and connected urn cemeteries are the base units of the Bronze Age settlement pattern and landscape of Cikola water system (Figure 4). The Bronze Age network of fortified settlements was built following similar microregional patterns.

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NON-INVASIVE SURVEYS OF THE ROMAN FORT APSAROS (GONIO) IN GEORGIA

K. Misiewicz, W. Małkowski, M. Bogacki

Non-invasive survey carried out in June 2012 of the site Gonio in Georgia (Figure 1) was aimed at providing supplementary data to enable the rational continuation of excavations on this site planned by the Warsaw University Institute of Archaeology. Aerial photographs from a kite, topographical measurements and geophysical magnetic prospection were included in the survey.

The site of Apsaros, already well-known from written sources (e.g. Strabo- Starb 11.2.18 among others), was correctly identified at the beginning of the 20th century (Miller, 1916), and was mentioned in the scientific literature in 1938 (El'nickij, 1938). Regular archaeological excavations were being conducted here from the beginning of 1960s (Lekvianidze, 1961). In the course of one of the final acts undertaken by the German-Georgian expedition, a magnetic survey with a Overhauser proton magnetometer was carried out over the stronghold and in its immediate surroundings during 2000-2003 (Geyer, 2002). Conducting new measurements, over ten years after the German investigations, not only expedited excavation planning but also provided the opportunity to compare the effectiveness of the applied magnetic method with that of other equipment and updated measurement techniques.

Thorough descriptions of the Apsaros stronghold and surviving remains appear repeatedly in the literature (Plotke-Lüning, 2003). Plans of the fortification, as well as of remains revealed in the course of excavations, have been published many times (Mamuladze, 2003; Kahidze, 2004). Unfortunately, these reports are not always free from mistakes concerning not only sizes of fortifications, but also the number of towers, or the internal area of the fort itself. Therefore, we decided that the first phase of the new survey should be a vetting of current arrangements using correct photogrammetric documentation based on aerial photographs and topographical measurements.

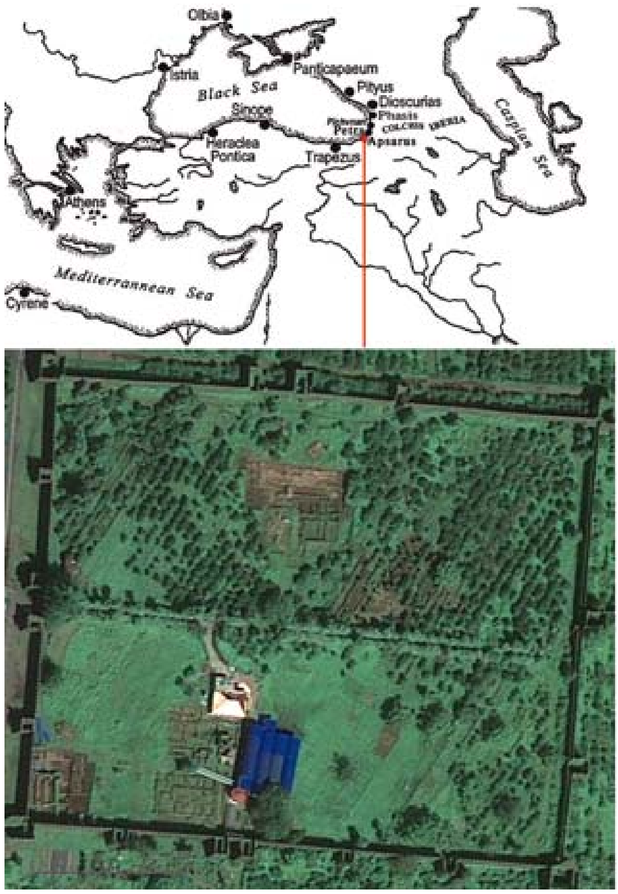

Figure 1: *Location of the site Apsaros (Gonio) in Georgia.*

KITE AIR PHOTOGRAMMETRY AND TOPOGRAPHICAL MEASUREMENTS

Visual documentation of areas on which geophysical measurements were planned was the purpose of the kite aerial photographs. One photographic session was enough to photograph nearly the entire fort. Altogether, over 900 vertical and oblique photographs were made, from which best 100 were chosen for further analyses. A Canon EOS 5D with 24 mm- 2.8 fixed-focal lens was hung on a radio-controlled frame, which could be turned around in any direction. A foil-type kite with dimensions of about 3.5 × 4 m was allowed to rise to a height of approximately 100-150 m. Before the photo session, almost 50 photo-points, localized with a RTK-GPS device with the accuracy up to 3 cm, were laid out in the area of the fort. This allowed for locating collected 2 and 3-D data in the same system of coordinates as the grid of geophysical survey using photogrammetric software. Vertical photographs were processed in the photogrammetric software together with geodetic measurements, resulting in a Digital Surface Model (Figure 2a) and Ortophotomaps (Figure 2b) of surveyed area that are compatible with most GIS software and programs for processing 3D models. Topographical measurements essential for preparing 3D models of the relief of the ground surface were performed with the application of the Topcon Hyper Pro RTK GPS system. GPS receivers communicated over radio modems. The mobile receiver obtained referential correction data from the base station receiver over the UHF radio working in a range 410-470 MHz (the power of 0.5–1 W). This enabled work in an open area with a radius exceeding 1 km. In the course of measurements, corrections were passed in the format to the CMR (Compact Measurement Record). Information concerning the L1 GPS and L2 GLONASS signals was sent with location information (coordinates) and the parameters of the base station aerial. In such a configuration, the measurements had a horizontal GPS accuracy H: ± of 10 mm + 1 ppm and vertical accuracy V: ± of 15 mm + 1 ppm. Topographical measurements were performed in three stages. First, accurate measurements for location and altitude of preserved walls were taken. Second, measurements were collected automatically in the course of recording changes in the intensity of the magnetic

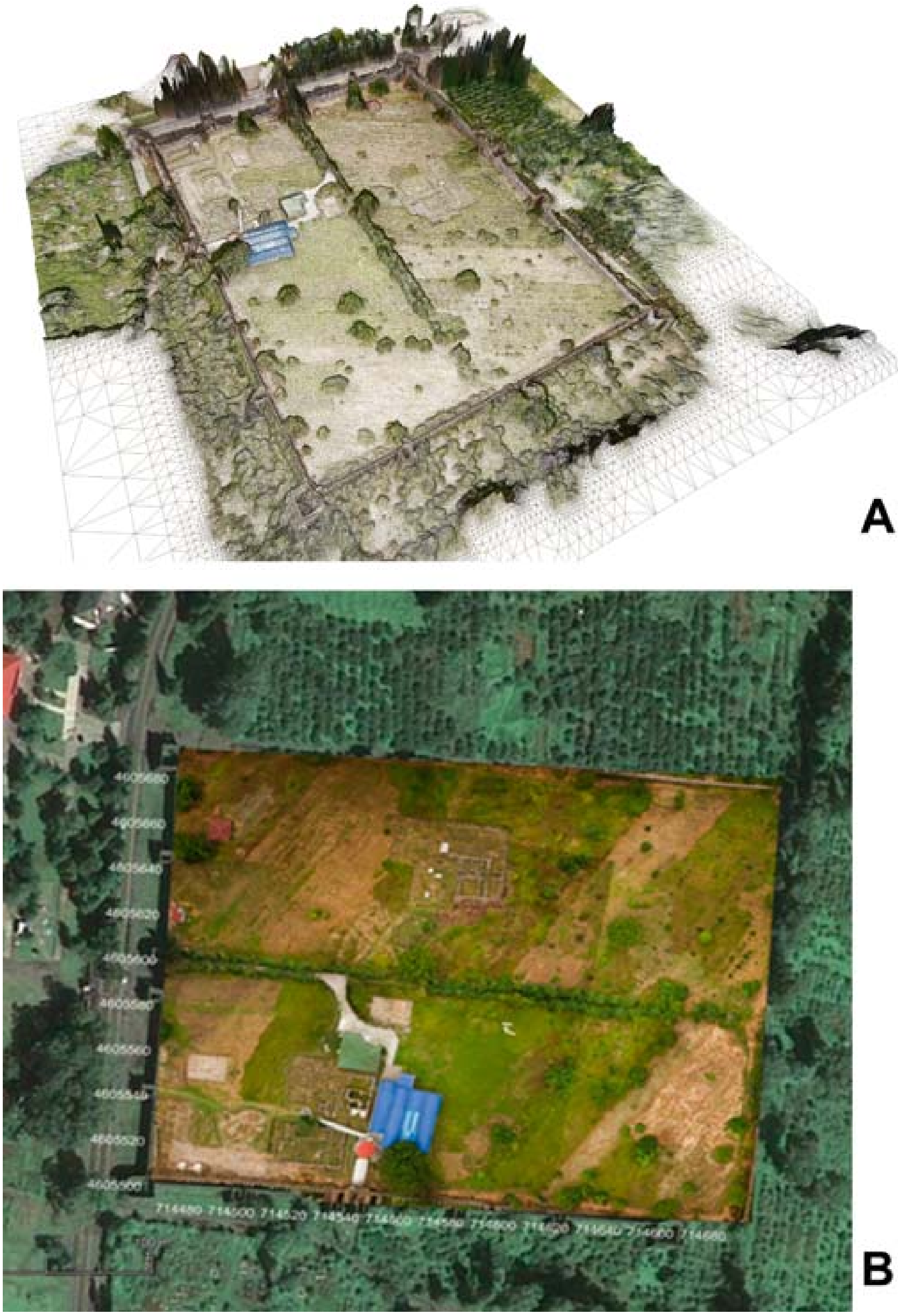

Figure 2: *Gonio2012. 2a) digital surface model (DSM); 2b) Ortophotomaps from Apsaros.*

field. Third, precise coordinates were taken for photo-points, which are essential to prepare 3D models of the surveyed area with photogrammetric software.

GEOPHYSICAL SURVEY

Geophysical measurements were conducted using the Geometrics G858 Magmapper caesium magnetometer, with two horizontally adjusted probes. In this way, measurements of the value the total vector of the magnetic field intensity were performed. The applied horizontal system of probes allowed simultaneous calculations of the pseudo-gradient values of the horizontal component (horizontal gradient) on the basis of observations of the difference of recorded values of the intensity of magnetic field, measured by probes located 0.5 m apart and using a measurement cycle of 0.1 seconds. Altitude measurements, using the RTK GPS system, were conducted at the same time as the mag-

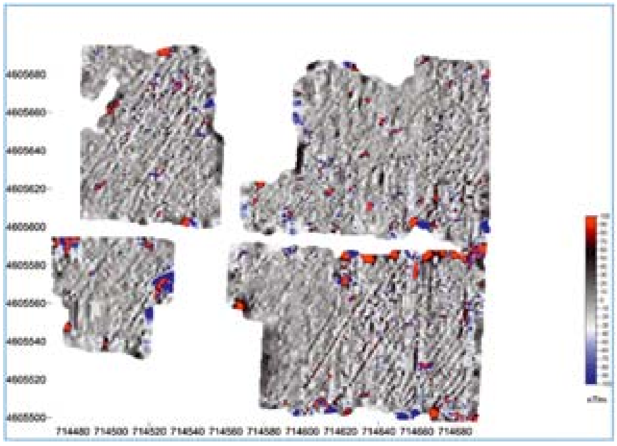

Figure 3: *Gonio 2012. Map of the disposition of values of the pseudo-gradient of horizontal component of total vector of intensity of magnetic field of the Earth.*

Figure 4: *Gonio 2102. Orthophotomaps with location of archaeological trenches and a map of the disposition of values of total vector of intensity of magnetic field of the Earth.*

netic survey, thereby connecting in one system a magnetometer and GPS to get the exact location of observed changes of the intensity of magnetic field in three dimensions. This allowed the fieldwork to move in an efficient manner, without requiring other location systems, e.g. marking out of orthogonal grids in the field or stretching measuring tapes. The registered data set was transferred to the computer by the MagMap2000 program, which allowed the transformation of the geographic coordinates in grades (BLH Breite Länge Höhe) to the metric system (UTM – Universal Transverse Mercator), according to parameters assumed for the position (moving on N-S and E-W axes, determining the central meridian and the scale factor). Ultimately, by applying the procedure described above, the transformation from the global system of coordinates to local systems for archaeological work on specific sites is possible.

As a result, collected measurements were calculated for pseudo-gradient values of the horizontal component of the vector of the total magnetic field strength in the range from - 100 to + 100 nT/m (Figure 3). Most of the changes detected are from contemporary metal constructions supporting plant-lanes raised on the site as elements of museum exhibition. The presence of such construction caused strong dipole-dipole anomalies, which cause quite significant changes in the intensity of the magnetic field. However, similar dipole-dipole anomalies could been caused by heavy burned objects lying in archaeological layers. Among these are terracotta pipes carrying water into the baths, structures of kilns and fireplaces in kitchens within Roman and Byzantine buildings, as well as in structures built during the Ottoman and later periods. In the resultant image of the disintegration of the horizontal pseudo-gradient values, narrow linear anomalies are also visible. They appear on the north-south axis, but mainly are located obliquely towards the applied measuring grid. These last anomalies were caused by irregularities on the ground surface, which facilitated water retention in the period when the area inside the stronghold was used as a citrus orchard. So possible changes in the disposition of the value of the pseudo-gradient of the horizontal component caused by potential archaeological remains are being effectively masked by anomalies resulting from contemporary changes in local relief, and do not permit exact localization of the archaeological remains inside the stronghold.

A more distinct picture of the arrangement of anomalies relating to archaeological remains was obtained by recording the disposition of values of the total vector of the magnetic field intensity (Figure 4). Here, linear structures caused by irregularities of the ground surface are also visible, but far more clear are the narrow linear anomalies indicating the foundations of ancient buildings inside the stronghold.

Registered anomalies were interpreted, allowing them to be connected with specific archaeological features, the presence of which could be the sources of observed changes of the intensity of the magnetic field. An analysis of the shape, size and dynamics of individual anomalies was used in an attempt to obtain data concerning not only the precise location of archaeological objects, but also to determine presumable depth of deposition and to assess the state of preservation.

A map linking all data, including precise locations of previously excavated remains, orthophotos and aerial photographs, 3-D digital elevation models of the surveyed field, and results of geophysical measurements, was presented as the final stage of the non-invasive surveys. The map (Figure 4b) allows for further planning activity on this site and will enable rational planning for necessary large-scale excavations.

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HIGH-RESOLUTION MULTI-CHANNEL GPR SURVEY OF THE ROMAN TOWN FLAVIA SOLVA IN AUSTRIA

W. Neubauer, S. Flöry, I. Trinks, A. Hinterleitner, K. Löcker, S. Seren

The Roman town Flavia Solva, located in the Roman province Noricum (Styria, Austria) and founded in the early first century AD, has been investigated by geophysical prospection since 1998 through the ZAMG Archeo Prospections® team. Aerial archaeology and excavations have revealed the rectangular street system of the town. The municipal area of the ancient town is located at the western bank of the river Mur and covers an extent of some 39 ha, partially destroyed by the modern town, roads and industrial zones. Over the past ten years, the Archeo Prospections® team has conducted systematic geophysical prospection surveys at Flavia Solva, combining magnetic and GPR measurements in order to explore the extent and inner structure of this Roman town. As of 2009, an area of 5.43 ha has been surveyed with GPR and 13.84 ha with magnetometry.

With the establishment of the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro), the Roman town of Flavia Solva was selected as one of the case study areas for developing and testing a new large-scale integrated prospection approach. In the meantime, the initial large-scale prospection approach has been copied by a group of amateur prospectors, covering the same area previously surveyed with high-resolution Caesium magnetometers, with dual sensor fluxgate magnetometers, proving that today comparable results can be achieved with commercially available instrumentation in a fraction of the time required in earlier years. As large-scale prospection projects can be very delicate to conduct in regard to the understanding and support of the generally numerous land owners involved, as well as regarding other stakeholders and public awareness, such duplicate activities are not at all helpful in pursuing the objective of integrating non-invasive prospection methods further into the archaeological process. However, despite such interventions, which may also be questioned from an ethical point of view, the main goal is to develop new techniques and methodology by empirically applying them to suitable archaeological sites and landscapes, and to investigate the limitations of the respective hardware, software and logistics for their further improvement.

The initial Earth resistance surveys conducted in 1998 located the forum and confirmed high resistivity contrasts, indicated favourable conditions for GPR measurements for the prospection of further details of the town structure. From 2000 onwards, GPR surveys have been carried out in Flavia Solva (Neubauer *et al.*, 2001; Neubauer 2008). The primary objective of the prospection work was a detailed survey of the north-eastern part of the municipal area. At the time, an area covering more than 4 ha has been recorded three-dimensionally, in detail, over the course of ten days of fieldwork. At that time, the survey was conducted using a PulseEKKO 1000 GPR system with 450 and 900 MHz antennae in a raster of 0.5×0.05 m, covering the greater parts of 10 *insulae* (domestic structures). The early GPR surveys from the year 2000 were repeated manually in 2007 and 2008 using the latest instrumentation (PulseEKKO Pro and Noggin Plus systems from Sensors & Software) and higher spatial resolution (0.25×0.05 m) . These repeated measurements documented the progress made in the field of archaeological GPR applications (Neubauer 2008; Neubauer *et al.*, 2009) and were presented at the 8th International Conference on Archaeological Prospection held in Paris in 2009.

In winter 2012, the same area was investigated again using a motorized multichannel MALÅ Imaging Radar Array (MIRA) in collaboration with the system manufacturer MALÅ Geoscience (Figure 1). The 16 channel 400 MHz antenna array using real-time kinematic GPS positioning was able to cover an area of 9 ha within 20 working hours at a resolution of 0.08×0.08 m. The objectives of this reinvestigation were the documentation of the development in comparison with former prospection approaches and the more detailed imaging of the mapped structures. The MIRA system covers a 128 cm wide swath for each driven track. In-line GPR trace sampling was set to 8 cm with a trace stacking factor of 4. The antenna array was placed in a front-mounted box on the hydraulic system of a small tractor. Power-supply and a field computer for data collection were installed on the vehicle. Accurate positioning of the GPR measurements is crucial and was implemented using real-time kinematic GPS. The position information is transferred via radio link to the measurement vehicle, where the information is recorded together with the GPR data. The GPR and positioning data stream is processed using an adapted version of the APradar software. This software, which was also used for the previous surveys, allows the pre-processing, interpolation, coordinate system transformation and three-dimensional migration of the enormous amount of data within short time. The processing results are exported as geo-referenced TIFF images, specific raster formats, or animations representing the generated 3D data volumes. For further data analysis and interpretation, the visualisations are imported into a GIS environment.

On basis of these first GPR surveys, an archaeological and historical interpretation of the north-eastern part of the municipal area of Flavia Solva has been published (Groh *et al.*, 2002) as an extension of the archaeological interpretation report by Archeo Prospections®. With the new-high resolution GPR results, many of the interpretations can be refined and open questions can be addressed. The new survey reveals unprecedented details of the Roman buildings detected earlier.

A vast Villa Urbana with a central peristyle court including water basins has earlier been postulated to be located in the north-eastern part of the municipal area, despite concerns derived from the high magnetic response of the "courtyard". Based on the combined interpretation of the magnetic and GPR survey data, several rooms with hypocausts were distinguished with a high probability. Now these interpretations have been verified by the results of the MIRA measurements, as the hypocausts became clearly visible in great detail in the GPR depth-slices generated from the high-definition data volumes (Figure 2). As the "peristyle court" is hypocausted, it has to be interpreted as a large hall providing access to several rooms with further hypocausts

Figure 1: *The navigation in case of the high-resolution GPR measurements with the 16-channel MALÅ Imaging Radar Array in Feburary 2012 were facilitated by the clearly visible tracks in the snow.*

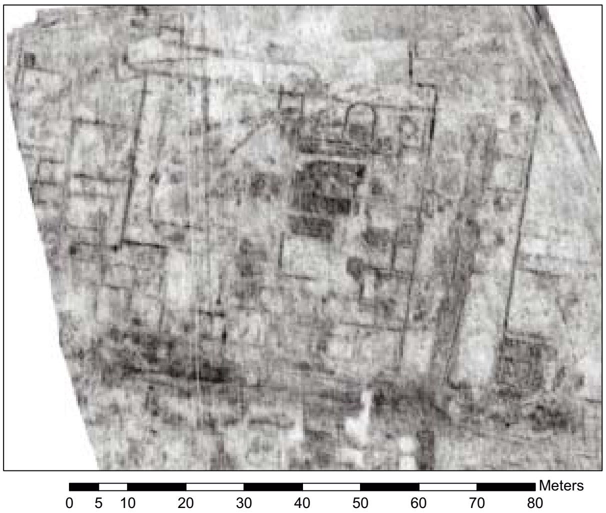

Figure 2: *GPR depth-slice (ca. 50-150 cm depth) surveyed in February 2012 in Flavia Solva with the MIRA system showing hypocausted rooms of an extensive Roman building.*

and additional basins. Therefore, the new data confirmed the initial interpretation of the complex as a central bath of the Roman town. The integrated prospection approach as started with the LBI ArchPro case study will lead to a more complete understanding of the layout and function of the Roman town of Flavia Solva.

To this end, large-scale applications of non-invasive archaeological prospection methods (e.g. aerial archaeology, airborne laser scanning and all kind of near-surface geophysics) will be applied to take advantage of the great potential offered by these methods. This approach presents the most appropriate solution in order to provide both archaeologists and planning authorities with the necessary spatial information at multiple scales, ranging from the individual archaeological site to a complete archaeological landscape. However, scientific archaeological prospection requires the implementation and adherence to the highest technical standards concerning instrumentation, spatial sampling intervals, positioning accuracy, data processing and visualization, as well as appropriate novel methodological concepts for the archaeological interpretation of the prospected individual sites and archaeological landscapes. This requirement demands coordinated fundamental research aimed at the development and improvement of new ways to acquire the basic data sets, and to extract their archaeologically relevant information by means of well-thought-out, integrative interpretation tools.

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DAMPING CORRECTION FOR GPR SIGNALS BY USING BELIEF PROPAGATION

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1. INTRODUCTION

Ground Penetrating Radar (GPR) is often used to explore archaeological ruins and remains. Radio waves transmitted from the GPR are reflected at the boundaries of electrical properties in the ground, and the reflected wave is received. However, various physical factors within the ground can have a sharp damping effect on the radio wave, and the damping rate becomes larger as the measurement depth from which the wave is reflected increases. For detecting the target signals from a received waveform of GPR, it is necessary to remove the damping from the received waveform. In a conventional method for damping removal, a received waveform is simply multiplied by an amplification factor, which is the inverse of a damping rate by medium derived from assuming a homogeneous subsurface. As noise is always included in a received waveform, the signals and noise are uniformly amplified together without distinction in the conventional method. In addition, in order to determine the damping rate, a damping coefficient is required, which is estimated from the approximate values of the relative permittivity and the conductivity of soil.

In this paper, we proposed a damping correction method for a received waveform of GPR by using probabilistic models. This method can selectively amplify the target signals in the waveform, and does not need to know in advance a damping constant or the other physical properties of soil that are required in the conventional method.

2. THE PROPOSED METHOD

2.1. Bayes' estimation and Belief Propagation

Let $\boldsymbol{g}$ denote an observed waveform of GPR and let $\boldsymbol{f}$ be an unknown ideal waveform that is not damped and has no added noise. Both $\boldsymbol{f}$ and $\boldsymbol{g}$ are vectors composed of N time series data set as follows.

$$\boldsymbol{g} = (g_1, g_2, \ldots, g_N)\boldsymbol{f} = (f_1, f_2, \ldots, f_N)$$

It is also assumed that $\boldsymbol{g}$ is generated as a result of adding noise to damped $\boldsymbol{f}$ as follows.
$g_i = A_i f_i + n_i$ where, A_i is the damping rate, and n_i is noise.

Our purpose is to estimate $\boldsymbol{f}$ from given $\boldsymbol{g}$, and we carry it out probabilistically based on a posterior probability distribution $P(\boldsymbol{f}|\boldsymbol{g})$, which shows occurrence probability of various patterns of $\boldsymbol{f}$ on the condition that $\boldsymbol{g}$ is given. According to Bayes' formula (equation (1) in Appendix A), $P(\boldsymbol{f}|\boldsymbol{g})$ is derived by two probability distributions $P(\boldsymbol{f})$ and $P(\boldsymbol{g}|\boldsymbol{f})$. $P(\boldsymbol{f})$ is called a prior probability distribution and shows the occurrence probability of various patterns of $\boldsymbol{f}$, and this is modelled by considering prior knowledge for $\boldsymbol{f}$. $P(\boldsymbol{g}|\boldsymbol{f})$ is called a likelihood and shows an assumed conversion process from $\boldsymbol{f}$ to $\boldsymbol{g}$.

Meanwhile, in general, there are two ways of estimating $\boldsymbol{f}$ by use of $P(\boldsymbol{f}|\boldsymbol{g})$. One is MAP (maximum a posteriori, equation (2) in Appendix A) and the other is MPM (Maximum posteriori marginal, equation (3) in Appendix A). MAP requires evaluating $P(\boldsymbol{f}|\boldsymbol{g})$ in all patterns that $\boldsymbol{f}$ can take. MPM requires some multiple summation to calculate a marginal probability distribution $P(f_i|\boldsymbol{g})$ from $P(\boldsymbol{f}|\boldsymbol{g})$. Thus, the computational complexities for both methods increase exponentially with the sample number of $\boldsymbol{f}$. If the number is too large, it becomes difficult in practice to execute MAP and MPM due to the enormous amount of necessary calculations. However, in the case of assuming a correlation between each element in $\boldsymbol{f}$ which should be estimated, a calculation technique called Belief Propagation (BP) enables one to effectively derive $P(f_i|\boldsymbol{g})$ by reducing some multiple summation for marginalization. Therefore, we can execute MPM. Equation (4) in Appendix A shows the expression of $P(f_i|\boldsymbol{g})$ by BP in the simple case of assuming that each element in $\boldsymbol{f}$ correlates only with the both sides of itself.

2.2. Modelling

$P(\boldsymbol{g}|\boldsymbol{f})$ and $P(\boldsymbol{f})$ which we modelled for our purpose are shown by equation (5) and (6) in Appendix A, respectively, and $P(\boldsymbol{f}|\boldsymbol{g})$ which was derived by substituting those two equations into Bayes formula is shown by equation (7) in Appendix A. In $P(\boldsymbol{g}|\boldsymbol{f})$, the differences between g_i and damped f_i , which are considered as the added noise, belong to normal distribution based on the assumption of the generation process from $\boldsymbol{f}$ to $\boldsymbol{g}$ as described earlier. Although various damping processes exist in the ground, we set only one damping rate A_i, which decreases exponentially for the sampling time t_i, because no matter what the process of damping in the ground is, the degree of damping for the received wave usually becomes larger with an increase in t_i, or an equivalent increase in depth. For modelling $P(\boldsymbol{f})$ we assumed in this paper that the differences between one element f_i and its sides belong to normal distribution. This $P(\boldsymbol{f})$ indicates the correlations between an element of $\boldsymbol{f}$. Therefore, the BP algorithm is applicable.

The hyperparameters in a probability distribution, such as α, σ and γ in our model shown in equation (5), (6) and (7), can be estimated by the maximum likelihood method (MLM), as is common in the statistical sciences. EM (expectation maximization) method is one of the numerical computations used to execute MLM. By combining BP and EM methods, we built a damping correction algorithm with automatic estimation of the hyperparameters in our models. Hence, it allows a correction without pre-setting a damping constant γ.

3. EXPERIMENT

We verified the effectiveness of the proposed method by applying it to a synthetic radargram (Figure 1b). That was generated by adding Gaussian noise ($\mu = 0, \sigma^2 = 5^2$, SN ratio:11.98[dB]) to the result of the simulation with FDTD method for an underground model (Figure 1a). Figure 1c and 1d show the resultant radargram corrected for damping by the proposed method and the conventional method, respectively. In Figure 1d, the reflected wave from the deeper object is somewhat buried in the noise. On the other hand, In Figure 1c, the contrast between

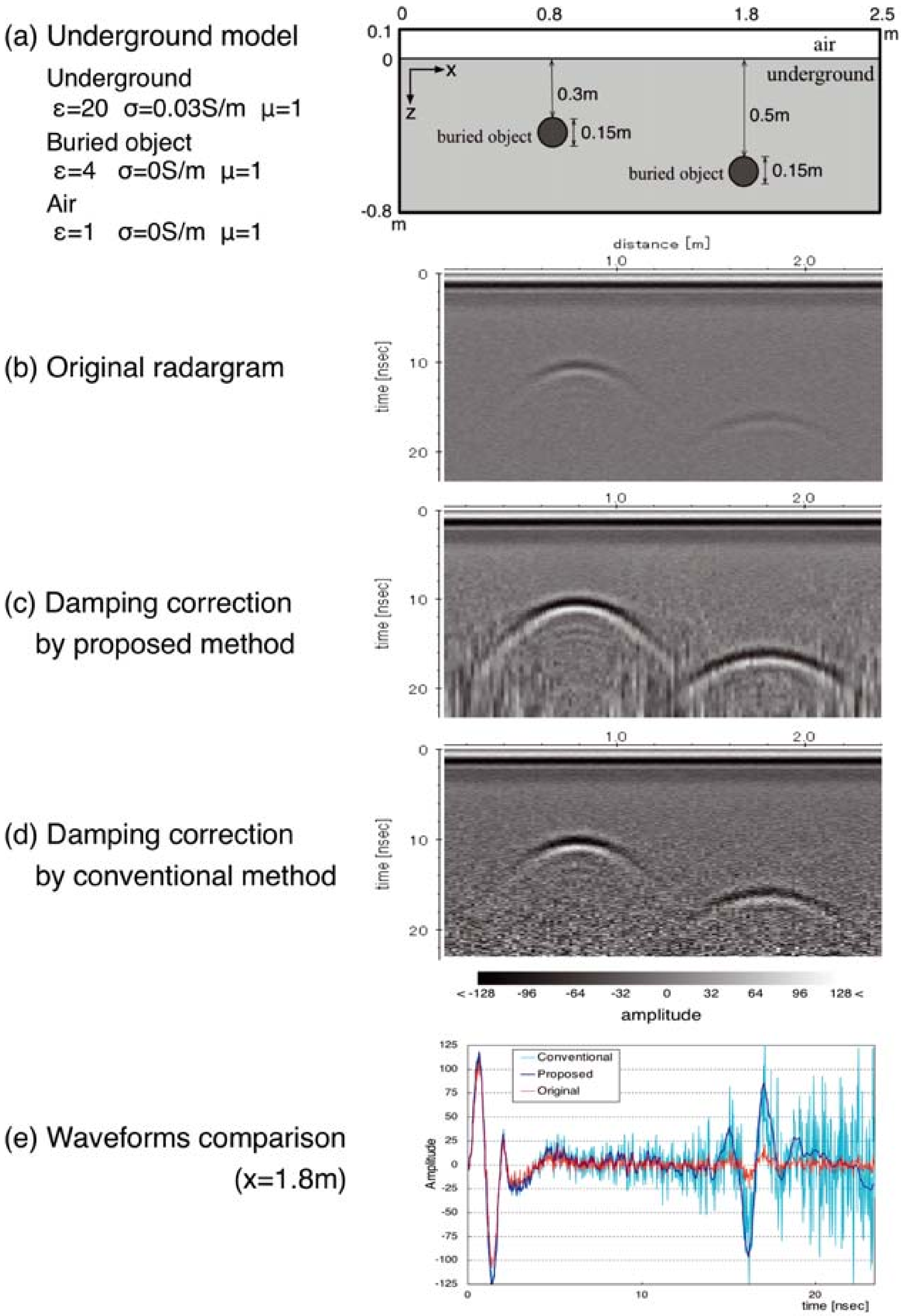

Figure 1: *Experimental results of applying the proposed method to a radargram.*

the reflected waves and the background became higher, and the peak amplitude of the reflected wave from the deeper object was amplified to a value close to that of the reflected wave from the shallower object. In addition, the standard deviation of added Gaussian noise was estimated as approximately 5 by the proposed method. Figure 1e shows an original waveform of a trace, a corrected waveform by proposed method, and a corrected one by conventional method. This demonstrates that the signals from the object were sufficiently amplified by suppressing amplification of the noise through the proposed method.

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$$P(\boldsymbol{f}|\boldsymbol{g}) = \frac{P(\boldsymbol{g}|\boldsymbol{f})P(\boldsymbol{f})}{P(\boldsymbol{g})} = \frac{P(\boldsymbol{g}|\boldsymbol{f})P(\boldsymbol{f})}{\sum_{\boldsymbol{f}} P(\boldsymbol{g}|\boldsymbol{f})P(\boldsymbol{f})}$$

(1)Bayes formula

$$\hat{\boldsymbol{f}} = \arg\max_{\boldsymbol{f}} P(\boldsymbol{f}|\boldsymbol{g})$$

(2) MAP (maximum a posteriori) estimation

$$\hat{f}_i = \arg\max_{f_i} P_i(f_i|\boldsymbol{g}) \quad (i=1,2,\cdots,N)$$

$$P_i(f_i|\boldsymbol{g}) \equiv \sum_{f_1}\cdots\sum_{f_{i-1}}\sum_{f_{i+1}}\cdots\sum_{f_N} P(\boldsymbol{f}|\boldsymbol{g})$$

$$\hat{\boldsymbol{f}} = (\hat{f}_1, \hat{f}_2, \cdots, \hat{f}_N)$$

(3) MPM (maximum posteriori marginal) estimation

$$P_i(f_i|\boldsymbol{g}) = \frac{\mathcal{L}_i(f_i)\mathcal{R}_i(f_i)}{\sum_{f_i}\mathcal{L}_i(f_i)\mathcal{R}_i(f_i)}$$

$\mathcal{L}_i(f_i)$ and $\mathcal{R}_i(f_i)$ satisfy the following recurrence equation function W_i is given by a posterior probability disribution

$$\mathcal{L}_1(f_1) = 1 \qquad \mathcal{R}_N(f_N) = 1$$

$$\mathcal{L}_{i+1}(f_{i+1}) = \sum_{f_i} W_i(f_i, f_{i+1})\mathcal{L}_i(f_i) \quad (i=1,2,\cdots,N-1)$$

$$\mathcal{R}_{i-1}(f_{i-1}) = \sum_{f_i} W_{i-1}(f_{i-1}, f_i)\mathcal{R}_i(f_i) \quad (i=N, N-1, \cdots, 2)$$

(4) Expression of posteriori marginal distribution by Belief Propagation assuming the correlation between f_i and f_{i+1}

$$P(\boldsymbol{g}|\boldsymbol{f}, \sigma, \gamma) = \prod_{i=1}^{N} \frac{\exp(-\frac{1}{2\sigma^2}(g_i - A_i f_i)^2)}{\sqrt{2\pi\sigma^2}}$$

damping rate $A_i = e^{-\gamma t_i}$

f_i, g_i : amplitude value of the i-th element in $\boldsymbol{f}, \boldsymbol{g}$

t_i : sampling time of the i-th element in $\boldsymbol{f}, \boldsymbol{g}$

γ : damping coefficient

σ : standard deviation of noise

(5) Liklihood

$$P(\boldsymbol{f}|\alpha) = \frac{1}{Z_{pri}}\prod_{i=1}^{N}\exp(-\alpha(f_i - f_{i+1})^2)$$

$$Z_{pri} \equiv \sum_{\boldsymbol{f}}\prod_{i=1}^{N}\exp\left(-\alpha(f_i - f_{i+1})^2\right)$$

α : degree of correlation between f_i and f_{i+1}

(6) Prior probability distribution

$$P(\boldsymbol{f}|\boldsymbol{g}, \alpha, \sigma, \gamma) = \frac{\prod_{i=1}^{N} W_i(f_i, f_{i+1})}{\sum_{\boldsymbol{f}}\prod_{i=1}^{N} W_i(f_i, f_{i+1})}$$

$$W_i = \exp\left(-\frac{1}{2\sigma^2}(g_i - A_i f_i)^2 - \alpha(f_i - f_{i+1})^2\right)$$

(7) Posterior probability distribution

Appendix A

RAPID PROCESSING OF GPR TIME SLICES FOR DATA VISUALISATION DURING FIELD ACQUISITION

N. Linford

Recent developments in multi-channel instrumentation now allow unprecedented levels of high sample-density GPR to be collected over very large areas. The volume of data created by such surveys can present a significant challenge for data processing, and is often only undertaken after the fieldwork has been completed. This paper describes the development of software tools to allow the rapid processing of continuous wave stepped frequency GPR data in the field, with each swath of multi-channel measurements processed immediately following completion of the line, whilst the system continues data acquisition. The data are processed to a full series of geo-referenced amplitude time slices allowing in-field quality assurance of both the GPR signal and positioning information (e.g. GPS coordinates). This immediate analysis also allows both the density of survey coverage to be confirmed, so that large gaps between instrument swaths can be avoided, and the extent of the survey to be adjusted in relation to the detected anomalies. The instant display of processed results has also proved useful when demonstrating the GPR technique to surveyors who have not used this technique before.

1. INTRODUCTION

The recent introduction of multi-channel GPR instrumentation has allowed high-density data sets to be collected over increasingly large areas using vehicle towed antenna arrays (Linford *et al.*, 2010; Trinks *et al.*, 2010; Novo *et al.*, 2012). Such data sets present a significant challenge for subsequent processing and visualisation, often requiring the use of considerable computing power to obtain optimum results. However, obtaining georeferenced results in the field, preferably during data acquisition, is also valuable to allow quality assurance and determine the location of further survey coverage. Whilst this can be conducted using existing software tools, these require the periodic manual transfer of data, often following the completion of data acquisition at the end of the day, and may take some time before the collected data are processed into time slices.

This paper describes the development of software tools to allow the rapid processing of continuous wave stepped frequency GPR data in the field immediately following acquisition. As it is difficult to continuously monitor the output of each channel of a multi channel system during acquisition, the presentation of the completed instrument swath as a time slice in the field allows and immediate assessment of the data quality across the array to be obtained. Defective channels can therefore be identified and any hardware faults either rectified, or the sampling regime altered to account for this during further acquisition. In addition, producing geo-rectified time slices from the positional data allows any gaps between instrument swaths to be identified and repeated together as necessary. This is particularly important for high density sample intervals where the goal of the survey is to produce a data set approaching the Nyquist sampling limit. The quality of the positional data may also be assured, allowing an alternative positioning method to be used should this prove necessary, for example due to a compromised GPS signal under tree cover.

2. METHOD

Data was collected in the field with a 3D-radar GeoScope continuous wave stepped frequency GPR system together with a 21 channel multi element air-coupled V1821 array (Figure 1). Operating over a typical bandwidth between 50 and 1250 MHz recording the amplitude and phase in 2 MHz steps across this range at a sample interval of 0.075m $\times$ 0.075m results in an HDF format file of approximately 150 MB for a 100 m long instrument swath, including positional data. During data acquisition, the GeoScope provides a continuous display of a single channel chosen from the array via a 10 MBPS LAN for display as a time domain profile on the control PC. Following completion of the swath the GeoScope formats the acquired data to an HDF file on an internal solid-state disk drive within the system unit. Acquisition would then continue until the resulting files are manually transferred from the GeoScope disk for data processing, usually at the end of the day when the file transfer may take several minutes to complete.

The new software tools described here have been developed for the GeoScope system and run in parallel with the 3D-radar data acquisition client software. Once acquisition of each instrument swath is completed and the GeoScope has formatted the HDF file this is automatically transferred to the PC for commencement of data processing and display. Typical initial data

Figure 1: *Photograph of the 3d-radar Geoscope system utilising a 21 channel V1821 antenna array towed by a light weight All Terrain Vehicle. This survey, at the Fishbourne Roman Palace, West Sussex, UK, allowed a local volunteer geophysics team to take part in the GPR survey and see the results of each data swath added to the time sliced image of the results immediately after acquisition.*

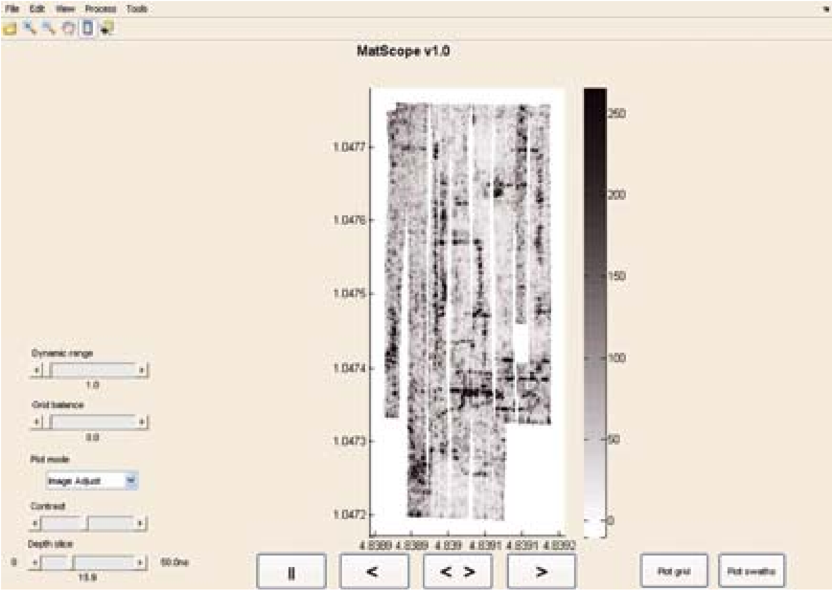

Figure 2: *Screenshot of the GPR data collected at Fishbourne Roman Palace displayed as georeferenced swath plots, allowing any large gaps between lines in the coverage to be identified during field acquisition.*

Figure 3: *(a) extract of the data from Wrest Park showing compromised positional data due to tree cover obscuring the GPS signal. Analysis of time slices during acquisition allows the degradation of data quality to be rectified (b) by suitable means in the field.*

processing for field display would include the conversion of the frequency domain data to the time domain time, background removal, dewow and gain. A series of frequency windows may be applied during conversion and appropriate suppression of the surface wave multiples can be applied, using either a PCA based algorithm in the frequency domain or an adaptive Savitzky-Golay filter once converted to the time domain (Sala and Linford, 2012). For rapid processing in the field a single frequency window will generally suffice. Further data processing can include: bandstop frequency filter, automatic gain, predictive deconvolution, topographic shift/tilt corrections and 3D migration using an adaptive velocity field. A Hilbert transform can then be applied to produce the final data cube for display.

The resulting time domain data is then displayed as an amplitude time slice together with previously collected instrument swaths. Using a Panasonic CF-30 Toughbook laptop PC with a 1.6 GHz Intel dual core processor and 1GB of RAM a typical 21 channel, 100 m long instrument swath can be fully processed and displayed in less than 2 minutes. The software also allows steps of the GPR data processing to be conducted on the GPU(s) on the graphics card (e.g. inverse FFT algorithm). Given the highly efficient pre-processing to produce the raw HDF data files by the GeoScope, the automated file transfer and processing will usually be completed in the time taken to turn the vehicle-towed array around at the end of the line. This allows the operator to monitor the data quality before commencement of the next instrument swath.

Positional data is produced from NMEA format GPS strings converted to Ordnance Survey NGR coordinates, corrected with a probabilistic filter to remove erroneous data points and interpolated to each recorded GPR trace, taking account of the orientation and position of each antenna element in the array. The resulting geo-referenced time slice data is then displayed as a greyscale image either directly without any interpolation across the combined data set (swath plot), or following the application of a bidirectional gridding algorithm (grid plot) to produce a continuous plot. For very large data sets, where the bidirectional gridding algorithm may require more processing time, a decimated data set may be processed with a reduced number of traces or in-line samples to improve the speed of display.

The "tape recorder" style buttons included on the GUI allow for the automated production of an animation built from individual frames calculated from the gridded data set through a user defined range. Data animation can often provide a useful means of analysing complex 3-dimensional GPR data sets and may reveal subtle anomalies that only become apparent in comparison to other, vertically adjacent, responses.

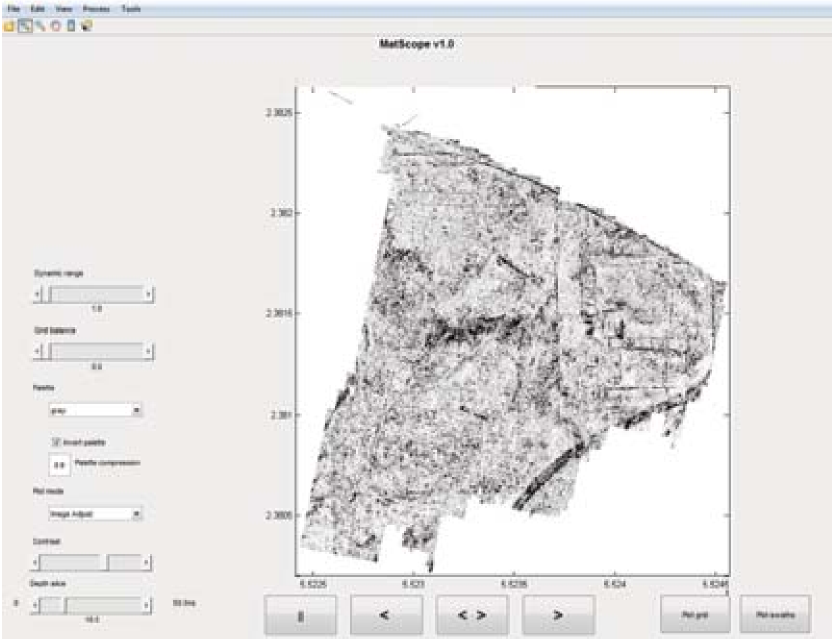

Figure 4: *Screenshot of the large area GPR survey at Audley End House, Essex, UK shown as an interpolated time slice image.*

3. RESULTS

Figure 2 shows a screen shot from the software showing the currently acquired data as a swath plot. In this case, part of a survey over the remains of the west wing of the Fishbourne Roman Palace (Linford, 2012), each line of data is plotted as an individual swath indicating the exact area covered by the antenna as recorded by the GPS. A problem with the navigation of the lines to the East of the survey has resulted in an unacceptable gap between adjacent swaths in this area. This was recognised immediately in the field allowing the survey lines to be repeated to produce a more appropriately sampled data set suitable for the final interpolation and gridding.

Whilst the quality of positional data can also be assessed through a direct vector plot of the recorded GPS coordinates, producing a full georeferenced time slice of the data may sometimes reveal more subtle defects within this data. For example, Figure 3(a) shows a portion of the GPR survey conducted at Wrest Park, Bedfordshire, (Linford, 2011) where mature tree cover to each side of the formal garden at Wrest Park resulted in a degraded GPS signal, clearly visible in the towards the edge of the coverage. Identifying such degradation of the GPS data in the field allows either an alternative means of positional control to be used, for example using a robotic total station, or the quality of the GPS data to be immediately tested through more rigorous GPS processing (Figure 3(b)).

The software has also been optimised to allow the efficient display of large area data sets at high sample density that may now be acquired rapidly in the field. Efficient memory handling, through windowing the input data, allows the display of multiple instrument swaths at an appropriate screen resolution. At Audley End House the GPR survey was initially targeted over an area of interest identified from previous earth resistance coverage (Linford and Payne, 2011). However, in-field analysis of the amplitude time slices confirmed both the quality of the GPR data and the benefit of extending the survey beyond the initial target area, including metalled road surfaces, to more fully complement the existing resistance results (Figure 3).

4. CONCLUSION

The ability to visualise large scale GPR data sets from array based antenna during field acquisition provides an important means of quality control and the ability to provide an initial assessment of the results. Whilst this does not replace the need for more considered, post-acquisition processing the ability to achieve useful, geo-referenced results during the field survey can still be of considerable benefit.

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IMPROVEMENTS IN THE IDENTIFICATION OF ARCHAEOLOGICAL BURIED FEATURES IN QUICKBIRD IMAGERY AND IN GROUND MAGNETIC DATA

M. Ciminale, M. Noviello, L. Amoruso, V. De Pasquale

The launch of Very High Resolution (VHR) satellite sensors meant a significant evolution for Remote Sensing archaeological applications, since data with high spatial resolution may be used to identify signals related to buried archaeological remains (e.g. cropmarks, soilmarks, dampmarks) in very extended territories. On the basis of this consideration, we developed a suitable image processing workflow to improve the cropmarks visibility in the VHR satellite imagery.

In the framework of this study, magnetic data have been used as ground truth references. To achieve this most effectively, an algorithm allowing minimization of the plough effects in the magnetogram was implemented, and the high-quality results illustrated.

Satellite images have been used for archaeological applications since the 1970s when they started to be available for civil purposes. In particular, terrestrial and ocean monitoring from space started with the launch of Landsat satellites (1972-1999). Since they acquired data with a spatial resolution of 30 m and 15 m (MultiSpectral and PANchromatic images, respectively), only large archaeological feature detections were possible. Over the years, other satellites with increasing spectral and spatial resolutions have been launched: for instance, French SPOT5 (2002) improved pixel dimensions to 10 and 5 m respectively for MS and PAN images. However, the usefulness of satellite data for archaeological studies increased markedly when VHR satellites were launched starting from the end of '90s. In fact, their advanced sensors are able to locate and recognize small landscape features thanks to their very high PAN-spatial resolution.

As a consequence, VHR satellites can produce very useful results when detecting signals (cropmarks, soilmarks, etc.) related to buried archaeological remains (e.g. De Laet *et al.*, 2007; Gron *et al.*, 2011). Up to now, there are no standard and unambiguous procedures to process satellite data for the detection of these signals (Lasaponara and Masini, 2011). This is due mainly to two reasons: 1) the use of the Remote Sensing in this field is a still developing; and 2) signals generated in vegetation and soil depend on the typical environmental characteristics of the site being studied.

The main purpose of this study was to improve the visibility and recognition of cropmarks appearing in VHR satellite images in order to better identify the buried structures that generated them. In this light, the following steps were carried out:

- application of several pansharpening algorithms
- application of one spatial enhancement filter

All methods were evaluated on QuickBird (QB) imagery acquired in the Tavoliere plain (Apulia, Southern Italy) on May 27th, 2006, a period of the year generally characterized by the best cropmark visibility. It covers an area of about 37 km^2 and is composed of two types of images: a multispectral and a panchromatic one. The spatial resolution is 2.69 m and 0.67 m at nadir for MS and PAN respectively.

Characterized by a long-term human presence since the Neolithic, Tavoliere plain is one of the most important archaeological areas in Southern Italy (Volpe, 2002). Today this territory is marked by an intensive cultivation of cereals in which both negative and positive cropmarks are often considerably and clearly visible (e.g. Ciminale *et al.*, 2007). In particular, cropmarks generated by a buried ancient settlement were taken into consideration. This site has a wide extension (more than 10 ha) and shows several archaeological marks related to buried remains which date back to different ages (Figure 1).

The obtained results demonstrate that Pansharpening is a suitable operation to increase the spatial resolution. Specifically, the best output for the examined satellite data is given by the Principal Component Resolution Merge algorithm (PCRM).

In addition, the application of the Wallis Adaptive-case C (WAC) spatial filter to the pansharpened output makes the image still sharper, guaranteeing a good local contrast and improved edge enhancement. Therefore, archaeological signals are better defined and more distinct (Figure 2).

To supplement this study, a high-resolution ground magnetic survey was also carried out (Figure 3a). Data were processed (Mather, 1999; Ciminale and Loddo, 2001; Lilesand *et al.*, 2008) in order to minimize undesired contributions (commonly spikes, stripes, zigzag effects) which very often affect measurements and reduce the readability of archaeological signals. In general, after these steps, the results obtained are of very good quality (Figure 3b). Nevertheless, a further improvement was achieved by implementing a new filtering algorithm in Matlab, based on the computation of a composite amplitude spectrum, which allows reduction in the noise generated by modern ploughing. This noise manifests itself as repetitive, nearly regular, linear patterns. The process was carried out in the frequency domain, the inverse Fourier transform then yielded the final image without the noise component. Results were really successful (Figure 3 c,d); the final magnetogram displayed a more detailed reconstruction of the buried presences and was taken as a reference in order to better verify the quantity and significance of the information extracted from the proposed satellite data processing (Figure 4).

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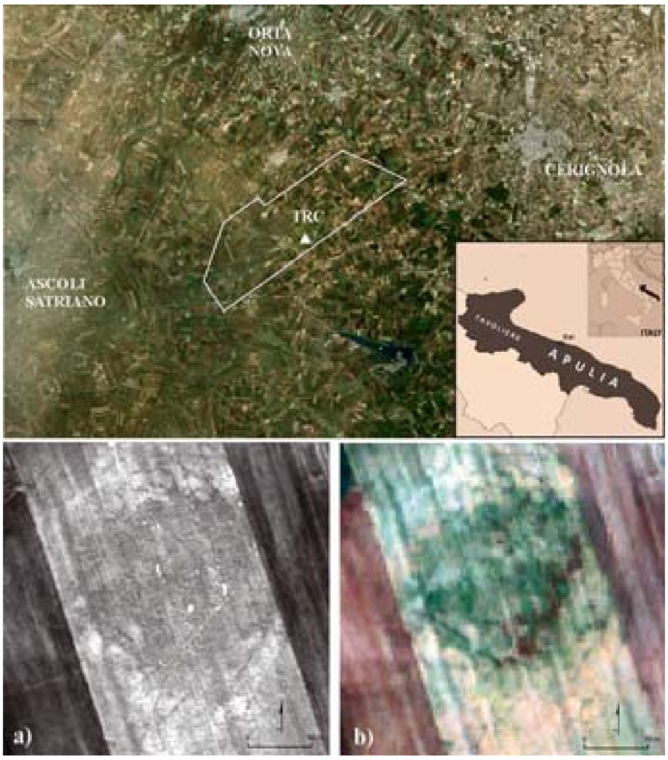

Figure 1: *Study area. Top: QB image, the polygon limits the area of about 37 km^2 covered by the acquired dataset. The TRC triangle indicates the location of the test site. Below: the enlarged details show the TRC site both on panchromatic and multispectral data. a) TRC site on PAN; b) TRC site on MS. Please note that all Figures appearing in this extended abstract are displayed at the best contrast stretching.*

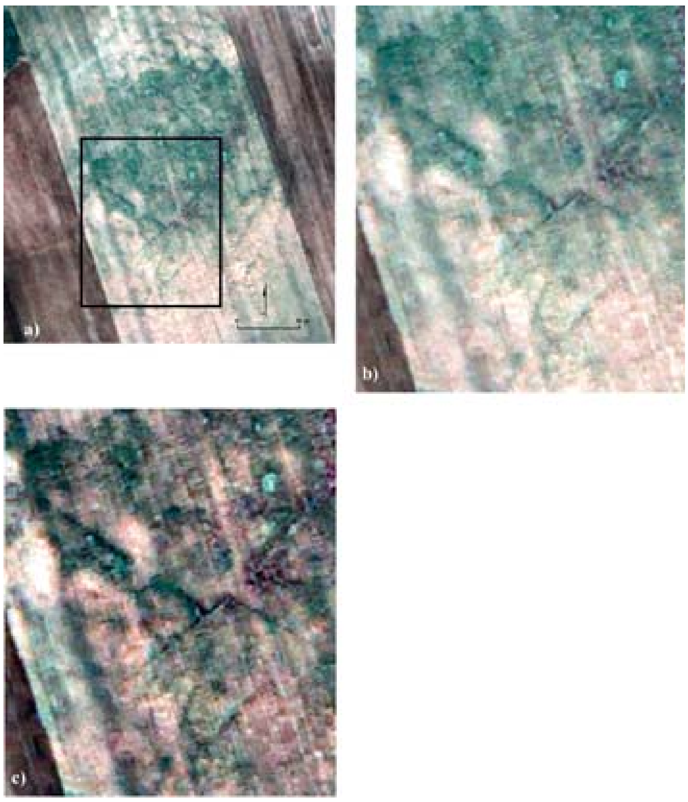

Figure 2: *TRC site. Application of WAC: a) input data (PCRM); b) zoom in on PCRM data in the area limited by the rectangle; c) output from WAC filter.*

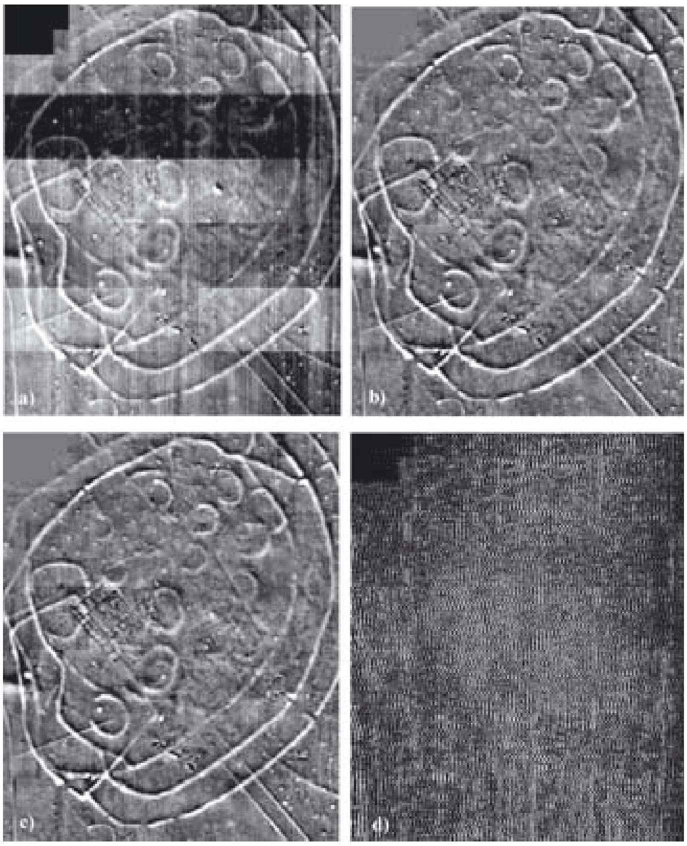

Figure 3: *TRC site. High resolution magnetic survey; a) raw data; b) processed data without plough effect reduction; c) processed data after plough effect reduction, final magnetogram ; d) difference between b) and c). b) and c) are stretched in the range [-11, 17] nT black/white, d) in the interval [0,1] nT b/w.*

Figure 4: *TRC site. a) final magnetogram stretched in the range [-11, 17] nT b/w; b) input data (PCRM): only a part of the buried remains are outlined (some sections of the external ditches and of the road as well as undefined linear features); c) output after the filtering operation: a rise in the number and quality of the archaeological signals can be easily observed.*

UNDERSTANDING HYPERSPECTRAL DETECTION DYNAMICS: ANALYSIS AND CHARACTERISATION OF ARCHAEOLOGICAL VEGETATION MARKS USING CONTINUUM REMOVED REFLECTANCE SPECTROSCOPY

D. Stott, A.R. Beck, D. Boyd, A.G. Cohn

We demonstrate how hyperspectral remote sensing can be used to investigate the phenotypic response of vegetation canopies to sub-surface archaeological features, and how this changes over time in response to changing environmental and agricultural conditions. This is accomplished using continuum removal for the characterisation of archaeological vegetation marks. This technique, novel in its application to archaeology, enables the resolution and separation of foliar biochemical content from the structure and density of the vegetation canopy.

Archaeological features are the result of anthropogenic interference with the natural soil matrix. This causes differences in the composition and structure of the soil. These influence the development and health of the vegetation on the surface. Under certain conditions this influence is detectable as variations in the vegetation canopy that can be recorded and mapped using airborne imaging spectroscopy. These sensors vary in their ability to discriminate between different phenomena, dictated by the spatial, spectral and radiometric resolution of the sensor.

Presently, the vast majority of this work is undertaken using visible-wavelength photography, which is both cheap and readily available. Hyperspectral sensors, on the other hand, have yet to be widely utilised for archaeological detection. This is partially due to their scarcity and expense, but the complexity, breadth and depth of these data also present many difficulties. Previous studies have often attempted to resolve these challenges by using brute-force computation to segment and classify imagery to identify those parts of the spectrum useful for the detection of archaeology, exploiting the properties inherent in the structure of the data itself. This approach is problematic, as most vegetation-mark archaeology is detected by subtle relative variation from the background, and as such has no unique spectral signature usable for classification. This is compounded by changes in soil, land management, weather and the variable nature of the archaeology itself.

Deploying these sensors successfully requires a fine-grained understanding of the interactions between the archaeology, environmental processes and the vegetation canopy. This is worthwhile, as hyperspectral sensors can discriminate far more subtle variations in the properties of the earth's surface than conventional imaging techniques. This means that there is the potential to both detect more subtly expressed features and to extend the temporal window for the detection of vegetation marks. The Detection of Archaeological Residues using Remote sensing Techniques (DART) project seeks to address this by repeated ground-based and aerial measurement of hyperspectral reflectance over different soils and crops in conjunction with continuous monitoring of changing environmental conditions to determine the optimal deployment of these sensors for detecting archaeology.

Using these multi-temporal measurements, we explore how the contrast between the background and the archaeological feature can be detected and how it changes over time. This is examined in the structure of the vegetation canopy and the relative content of specific foliar biochemicals and pigments. This enables the determination of the extent to which contrast is based on qualitative stress and vigour variations expressed as differences in the photosynthetic mechanism of the plants as opposed to quantitative developmental and structural differences expressed as changes in biomass such as Leaf Area Index (LAI).

This distinction is made using continuum removed reflectance, a technique that uses the size, shape and position of absorption features related to known foliar constituents to examine their properties. This can be normalised employing the relative area or depth of the feature, enabling the effects of variations in biomass to be negated. The absorption features that can be investigated using this technique are correlated with the content of:

- Chlorophyll a+b
- Lignin
- Nitrogen
- Cellulose
- Water
- Phosphorous
- Protein
- Amino acids
- Sugar
- Starch

The following example explains this approach using ground data collected along a RTK GNSS located transect 15 m long, centred over a known archaeological feature identified by fluxgate gradiometer survey at Diddington in the south-east of England. This transect is located on deposits mapped as Quaternary sands and gravels of the lowest two (undifferentiated) terraces of the River Ouse. The feature is part of an enclosure complex dating to the Iron Age. Excavations undertaken in part of the same complex for the installation of monitoring equipment in the adjacent field showed that the soil profile away from the archaeological features comprised a 0.15 m-thick humic A horizon overlying a 0.20 m-thick silt/clay B horizon. The C horizon consisted of ca. 0.20 m of homogeneous yellow-brown silt/clays, i.e. a flood-plain deposit, while the terrace gravels outcropped at >0.55 m below ground surface. In other words, the present soil in the sampled field has developed in overbank alluvium rather than terrace gravels.

Spectroradiometry readings were acquired with an ASD FieldSpec Pro at sub-metre intervals on the following dates: 14/06/11; 29/06/11 and 15/07/11. The field was under winter wheat while these measurements were recorded. There was no rainfall in the area during this period, resulting in obvious vegetation marks visible as height variations in the maturing crop. The continuum removed reflectance plots presented here focus on three absorption features related to chlorophyll (670 nm), water (1200 nm) and lignin (1730 nm). These plots are normalised by depth at band centre.

Figure 1 shows how the reflectance of the crop and the contrast between the vegetation marks changes over time in the data from the spectroradiometry transect. On the 14th of June, the

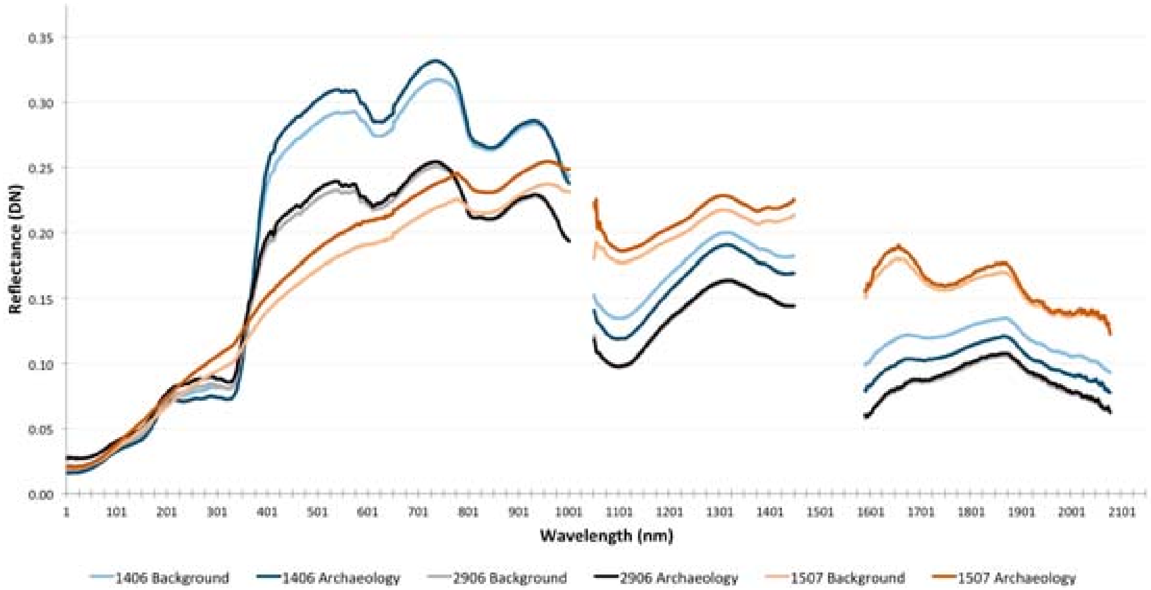

Figure 1: *Raw spectro-radiometry reflectance spectra from June and July 2011.*

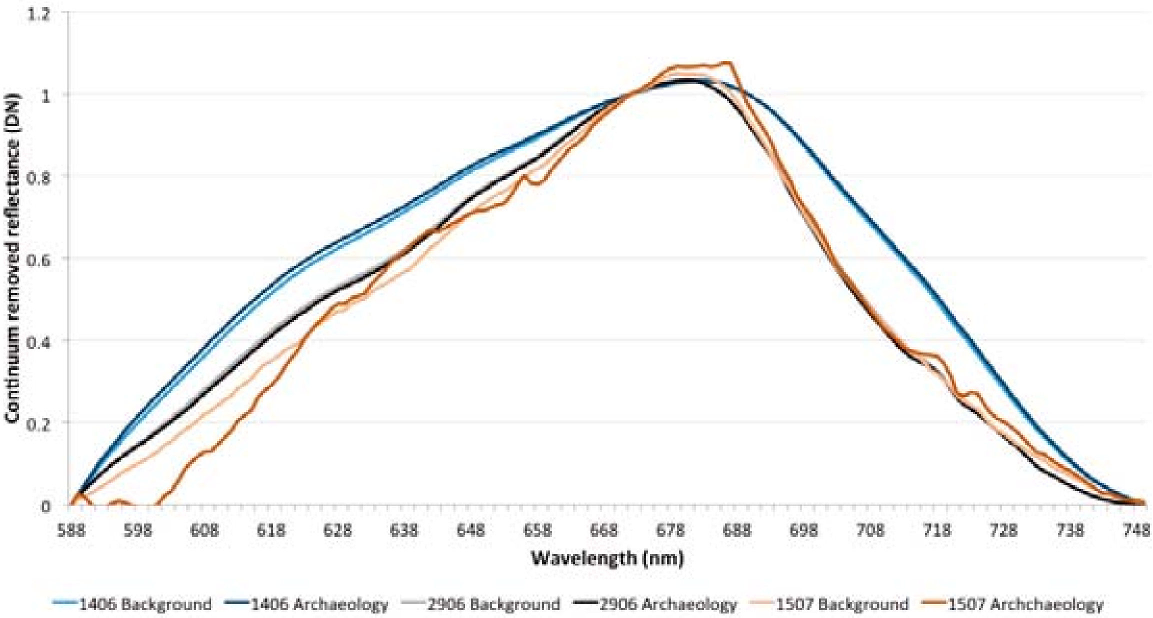

Figure 2: *Continuum removed spectra for the 670 nm absorption feature.*

crop over the archaeology showed greater absorption in the visible spectrum and greater reflectance in the NIR when compared to the background. This is consistent with variations in the density and health of photosynthetic vegetation. On the 29th of June, this relationship changed, with the crop over the archaeology showing greater reflectance in the visible spectrum compared to the background. This may indicate that the crop over the archaeology had reached maturity and started to senesce sooner than the background. On the 15th of July, the crop had senesced and ripened, with the archaeology demonstrating greater reflectance over most of the visible and NIR portions of the spectrum. This contrast is indicative of the greater mass of senesced vegetation over the archaeology compared to the background.

The band-normalised continuum removed spectra from the 670 nm (chlorophyll a+b) absorption feature show little contrast between the archaeology and the background (see Figure 2) on the 14th and 29th of June 2011. This indicates that on these dates there was comparatively little difference in the photosynthetic pigments in the foliage, and that the contrasts visible in the raw spectra are more likely the result of variations in biomass. The data from the 15th of July shows greater contrast, but given that the senesced vegetation was no longer photosynthesising, these data are less reliable.

In the 1200 nm absorption feature (foliar water), there is again little contrast between the archaeology and the background (Figure 3). There is a greater contrast on the 29th of June than on the 14th of June, but this remains subtle. The data from the 15th of July shows greater contrast, but the depth and breadth of the

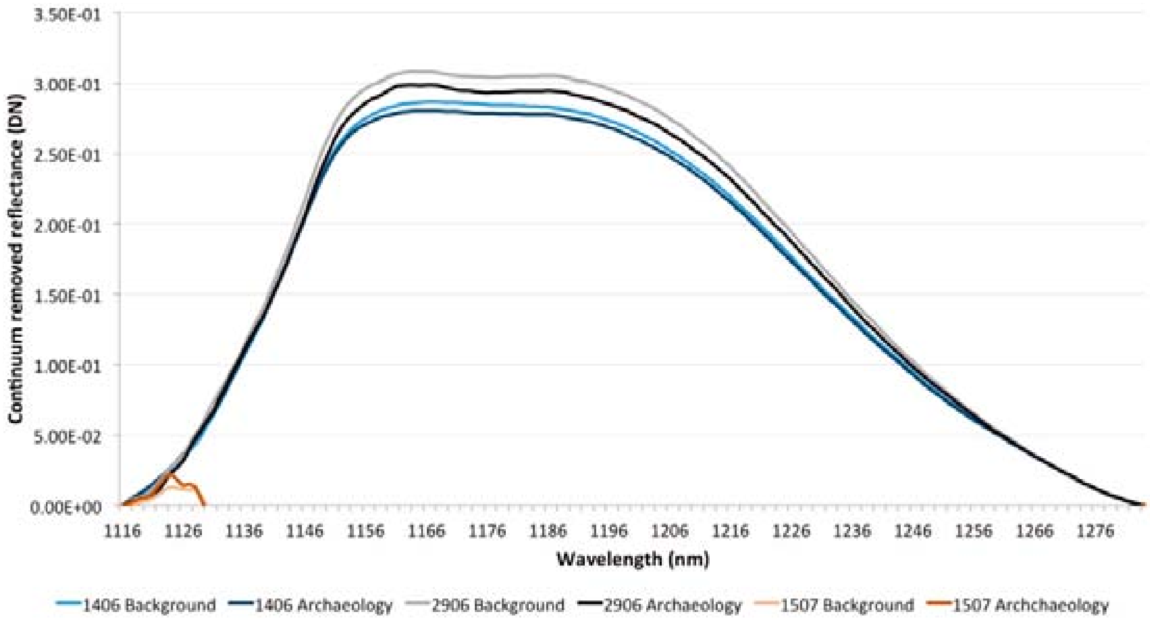

Figure 3: *Continuum removed spectra for the 1200 nm absorption feature.*

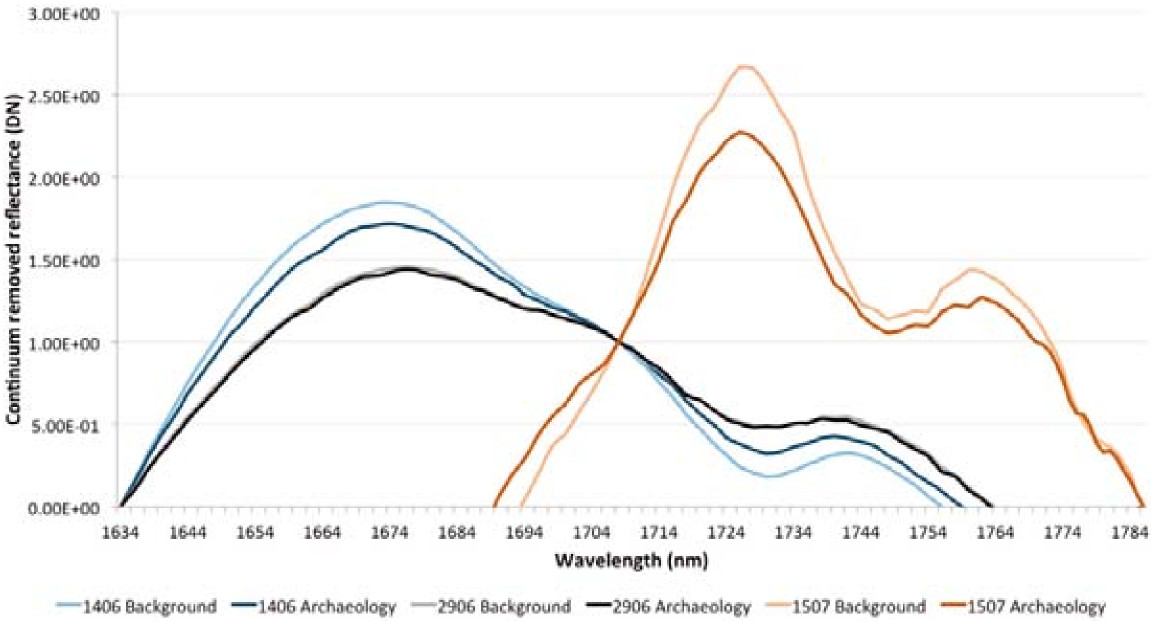

Figure 4: *Continuum removed spectra for the 1730 nm absorption feature.*

absorption feature is much narrower compared to the data from June. This is a result of the dry, senesced vegetation retaining almost no water.

The 1730 nm absorption feature (lignin) shows significant variation for the 14^{th} of June (Figure 4). This is probably a result of the lower LAI for the crop growing on the background compared to the archaeology, meaning that there is a greater return from the dry mass of the plant. The data from the 29^{th} of June shows little contrast and a change in the shape of the absorption feature, indicative of ripening and senescence. The data from the 15^{th} of July shows a significant lateral shift compared to the previous dates, resulting from the difference between active and senesced vegetation.

It is evident from these results that the location (in the electromagnetic spectrum) and nature of contrast changes over time, and that the most effective use of any sensor for archaeological prospection is contingent on understanding the nature of this contrast. The methodology presented here will enable the definition of detailed metrics for the investigation of contrast in vegetation marks, and these can be used to better understand the physiological responses of plant communities to underlying archaeological features. It is hoped that this, in turn, given increased understanding, will enable the derivation of information about the nature and composition of the archaeological features themselves.

EDGE MAPPERS APPLIED TO RESISTANCE AND MAGNETIC MAPPING DATA

A. Stampolidis, G.N. Tsokas

ABSTRACT

We apply certain edge mappers to magnetic and resistivity data from the archaeological site of Mitrou, Central Greece. These kinds of filters could be very helpful in the archaeological interpretation of such data sets. They are capable of locating the lateral limits of most of the subsurface targets.

The application of edge mappers on magnetic data is a common practice in aeromagnetic data interpretation, while their application on the various types of magnetic archaeological prospection data was recently tested. In this work, we consider the resistivity mapping data measured with the twin-probe array analogous to magnetic data reduced to pole and we apply edge mappers on them. We discuss the merits and drawbacks of those edge mappers as applied to archaeological prospection data.

1. INTRODUCTION

Magnetic and resistivity prospecting are tools for detecting and mapping buried antiquities, because in general they have different properties than the soil in which the antiquities are buried.

Magnetic survey provides a mapping of the subsurface distribution of magnetization. Differences in magnetization of buried antiquities come from differences in their magnetic susceptibility and remnant magnetization. Presuming that the antiquities have magnetization that can be distinguished from that of the subsurface, mapping the distribution of magnetization reveals the buried antiquities.

Magnetic anomalies are asymmetrical because of the dipolar nature of the Earth's magnetic field. A common method to transform the dipolar shape of the magnetic signal into a monopolar one is the reduction to the north magnetic pole (Blakely, 1995, 441). Afterwards, techniques that sharpen the edges of the anomalies, like the "Wallis filter" (Scollar *et. al*., 1986) can be used to enhance the signal from the subsurface targets.

A similar concept applies to resistance mapping, but to a lesser extent. This is because the electrode arrays most commonly used in archaeological prospection (twin probe or pole – pole) produce monopolar signals centred above the subsurface targets that create them. Resistance mapping with the twin probe array is considered analogous to the magnetic signal that has been transformed with the reduction to the pole filter.

Enhancing the interpretation of archaeological prospection data through better visualization and edge delineating techniques has always been the main concern of researchers (Cheyney *et al*., 2010, 2011; Stampolidis *et al*., 2012 and references therein). This work intends to exhibit the usefulness of certain edge delineating techniques with respect to their performance in archaeological prospection. The criteria for the success of those filters are their efficiency in locating the edges, their behaviour in the presence of noise and their spatial resolving ability.

2. DATA USED

Resistivity and magnetic surveys were carried out at the prehistoric site of Mitrou islet in 2003 and 2005, respectively, in order to guide and inform the 2004–2008 excavations (Tsokas *et al*., 2012). Resistance mapping was carried out in the abandoned open fields of the site, and magnetic gradiometry in the olive groves that cover the remainder of the islet. The resistance method was deemed more likely to produce measurable anomalies from architectural remains buried in a clayey environment. On the other hand, it is well known that electrochemical activity in tree roots creates resistance anomalies, and thus the olive groves were surveyed using the magnetic method, which is insensitive to this phenomenon. The data used in this work are from the north part of the islet.

The edge mappers that were applied to the data are shown in Table 1. The gradiometer data is the background of Figure 1. The calculated maxima after applying the PSG-hgm, TF-hgm, TH and TDXAS mappers have been superimposed on the background. The resistance mapping data is the background of Figure 2. The calculated maxima after applying the TF-hgm, TH, TDXAS and THDR mappers have been superimposed on the background.

Method	Formula	Reference
Pseudogravity horizontal gradient magnitude, **PSG-hgm**	$[(dPSG/dx)^2 + (dPSG/dy)^2]^{1/2}$	Cordell and Grauch, 1985
Total field horizontal gradient magnitude, **TF-hgm**	$[(df/dx)^2 + (df/dy)^2]^{1/2}$	Grauch *et al*., 2001
Theta Map, **TH**	$[(df/dx)^2 + (df/dy)^2]^{1/2}/AS$	Wijns *et al*., 2005
Tilt angle horizontal gradient magnitude, **THDR**	$[(dTI/dx)^2 + (dTI/dy)^2]^{1/2}$	Verduzzo *et al*., 2004
Balanced horizontal gradient magnitude multiplied by the Analytic signal, **TDXAS**	$[tan^{-1}[(df/dx)^2 + (df/dy)^2]^{1/2}/\|(df/dz)\|] \cdot AS$	Stampolidis *et al*., 2012

AS is the abbreviation for Analytic Signal. f is the measured field, that is ΔZ for the gradiometer data and ΔR for the resistivity data.

Table 1: List of Edge Mapping Methods Considered in this Study.

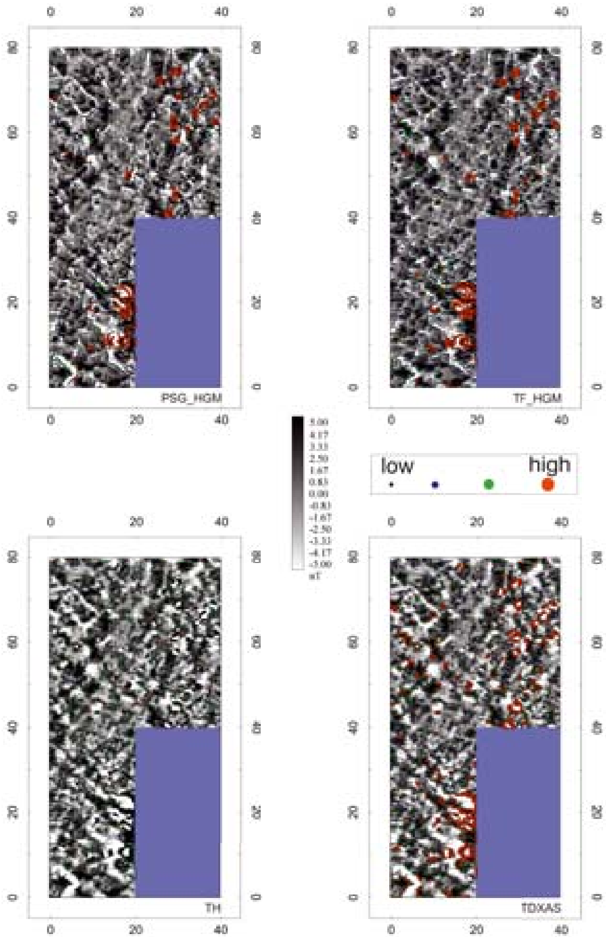

Figure 1: *The background is the measured gradiometer field. The maxima inferred after applying various edge mappers are superimposed on each drawing. Each mapper is referred by its acronym.*

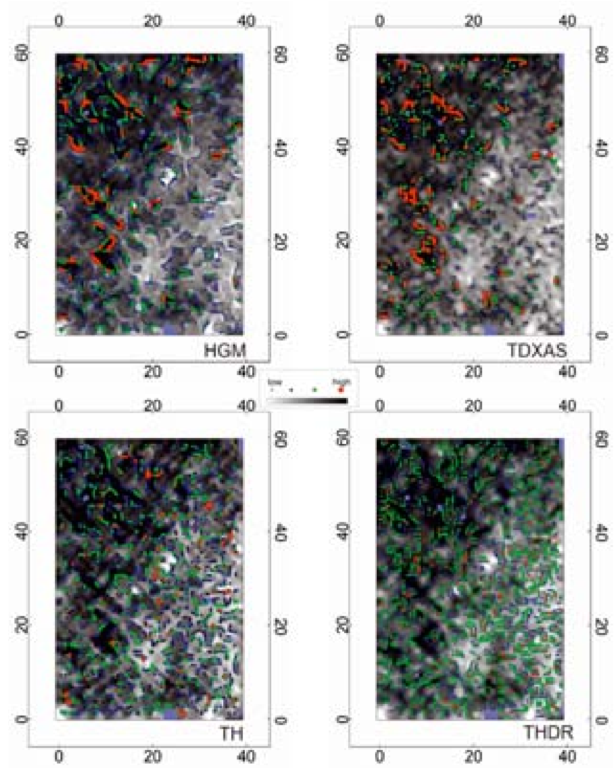

Figure 2: *The background is the measured resistivity field. The maxima inferred after applying various edge mappers are superimposed on each drawing. Each mapper is referred by its acronym.*

3. CONCLUSIONS

Edge mapping methods can definitely improve the interpretation of archaeological prospection data, because they can delineate the locations of the edges of subsurface structures. The edge mappers worked well on both data sets. They can assist the interpreter to locate linear features that are not easily visible on the data.

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UPDATE ON THE SIMULATION OF ASTRONOMICAL ASPECTS OF MIDDLE NEOLITHIC CIRCULAR DITCH SYSTEMS

G. Zotti, W. Neubauer

1. INTRODUCTION

Since the 1980s, a large number of prehistoric circular ditch systems (Kreisgrabenanlagen, KGA) have been found in a large region of Central Europe. They were built by several contemporary culture groups in a relatively short epoch of the Neolithic (about 4850-4500 BC). The purpose of these huge monuments, which are always found close to a settlement, is still unclear, but a cultic function of some form (meeting or ceremonial place) seems most likely (Melichar and Neubauer, 2010).

The large diameters and distinct shape, usually with two or four well-defined entrances, also invite an interpretation that some form of ritual celestial observation may have played a role in their construction and use. For instance, entrances appear to be oriented towards sunrise or sunset at the solstices, as has been suggested by Becker (1996) for KGA in Bavaria, or towards the extreme lunar risings and settings known as lunistices for the KGA in Slovakia and Austria, as suggested by Pavúk and Karlovský (2004).

A preliminary archaeoastronomical investigation of 28 Austrian KGA in 2003/04, based only on interpretation sketches of the geomagnetic prospection results and a few horizon profiles created from a digital terrain model in a GIS, found a suggestive connection with a few solar dates (solstices and cross-quarter days, which are just between solstices and equinoxes, like our All-Saints day), as well as with a few conspicuous stellar objects. The stellar alignment in one KGA was presented confirmatively with a panorama image for a desktop planetarium program created from a virtual model built based on the magnetogram by an external company (Zotti and Neubauer, 2010). A presentation test in a planetarium, which seemed the natural choice for a possible demonstration to the public, proved problematic because the planetarium is only constructed to show the upper hemisphere, while our archaeological scenery should naturally also include the ground with a simulation of the prehistoric architecture (Zotti *et al.*, 2006). Therefore, desktop virtual reality seems better suited as a method for such presentations. The lack of properly surveyed horizon data called for a much more detailed study, which was performed during the ASTROSIM project (2008-2012) supported by the Austrian Science Fund (FWF) under grant number P21208-G19. Preliminary results were presented at AP2009 (Zotti *et al.*, 2009), and it is now appropriate here to present an update on the results.

2. SURVEYS AND DIGITAL MODEL BUILDING

New surveys of the horizon line have been taken in the field with a total station at all 31 magnetically prospected KGA in Lower Austria. The azimuth and altitude data were plotted into a diagram that showed solar, lunar and stellar diurnal tracks for the KGA epoch, and a panorama photograph was accurately fitted onto this measured horizon line, so that also the approximate distance to the horizon can be estimated. These horizons can be directly evaluated in a panoramic viewer, or can be imported into a desktop planetarium like Stellarium[1], which has been selected for astronomical visualization. This program offers a nice visualization of the night sky with exchangeable constellations, exchangeable horizons and ultra-wide projections, is free and open-source and therefore can be verified by studying the source code, and if necessary bugs can be fixed and extensions can be programmed as plugins.

For all KGAs, a piece of digital terrain model textured with a modern map, the magnetogram, and the outlines of the interpreted features were exported from ArcGIS 9.3 into accurately georeferenced models for the 3D modelling program Google SketchUp, where ditches were cut into the terrain and palisades were erected. SketchUp (meanwhile acquired by Trimble) can be extended with self-written Ruby plugins, and several plugins have been developed to aid in the development of virtual models for archaeoastronomical purposes. One of those directly allows the loading of a horizon panorama in the format used by Stellarium. SketchUp does not have a translation invariant skybox background node, so the panorama is applied to a spherical ring, which is linked to always surround the view camera in order to avoid parallax artefacts when the scene is viewed from different viewpoints. Looking along architectural features in the model in SketchUp, therefore, immediately shows whether an entrance as seen from another important point, like the centre or the opposing entrance, would lie in the direction of a rising or setting point of one of the celestial objects suspected to having had the attention of the builders, or to some distant conspicuous landscape feature, which also seemed to be a possibility of ritual orientation worth studying (Zotti and Neubauer, 2011). The georeferencing property could also be used for the correct simulation of solar shadows, but the Neolithic solstice positions are slightly different from those observed today and cannot be reached.

In addition, a panorama export plugin was developed, so that views from static viewpoints from any georeferenced SketchUp model can be presented in Stellarium. For a more accurate simulation of celestial positions, the atmospheric effects of refraction and extinction were also implemented and contributed to the main program (Zotti and Neubauer, 2012a). However, in the times of almost ubiquitous interactive 3D graphics, the ability of desktop planetaria to utilize only static viewpoints seemed a bit limited, and the project called for a more direct way of investigation and demonstration of the results relating to stars expected from the previous investigation. We therefore created a plugin for Stellarium that provides a 3D simulation of a foreground model, which is combined with the presentation of the night sky provided by the program. The accuracy of the simulation has been confirmed with a model of a modern astronomically oriented and motivated architecture created in Sketchup (Zotti and Neubauer, 2012b).

[1] Stellarium website: `http://www.stellarium.org` (visited 2012-10-29)

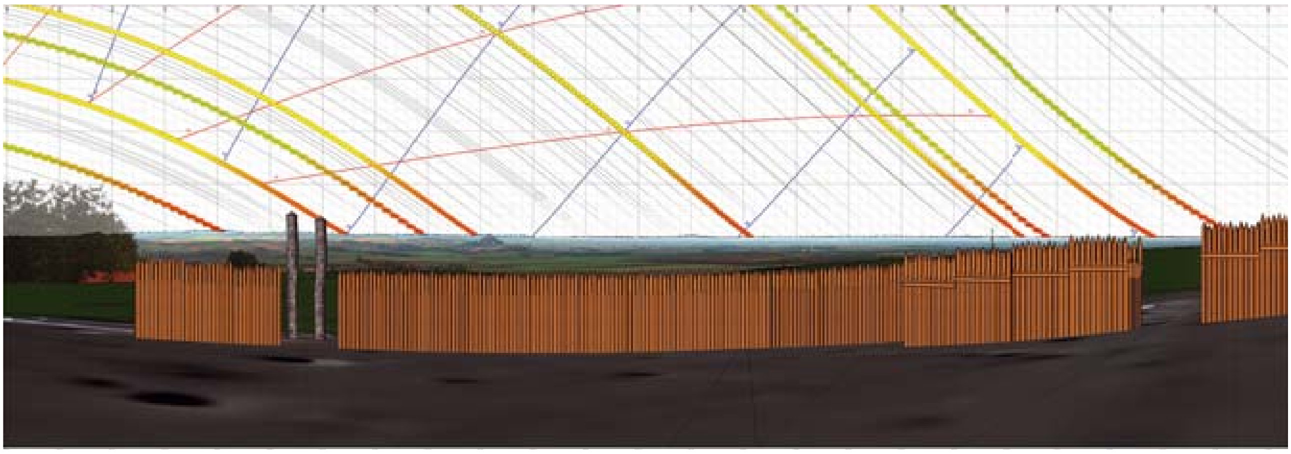

Figure 1: *A view from the center of KGA Altruppersdorf. The sloped terrain most likely allowed a view over the palisade. While the north-west entrance (right) coincides with the summer solstice sunset in this view from the KGA centre, the south-west entrance does not coincide in a similar way for the winter solstice.*

3. RESULTS

The modelling with panoramic photographs taken in the field during site visits and with a larger digital terrain model allowed the creation and investigation of KGA in their respective landscape. It also achieved a much clearer understanding of the KGA environments than was previously gained from virtual models, which only showed the earthwork itself, or of the static panoramas available previously for the desktop planetarium.

The first survey results seemed to confirm solar and stellar observations, although we also noted that the terrain may have been important as well, because often there was one entrance on the highest and one on the lowest point in the terrain. In KGA Steinabrunn, a mismatch was detected between the surveyed horizon and the digital terrain model used for the previous virtual reconstruction panorama, which erroneously had shown a nearby hill, invalidating one of the previously identified solar orientations. KGA Gauderndorf entirely failed to show the stellar pattern suggested previously, but was clearly identified as having been slope oriented, and ultimately slope orientation, and not astronomical orientation, turned out to be prevalent on almost all KGAs, with the confirmed stellar orientation in Steinabrunn likewise explicable as being a top entrance. Only in late 2011, when LiDAR based digital elevation data became available, were we able to confirm the slope orientation with even more certainty. In several cases, a slope line analysis in the LiDAR-based DEM, smoothed to get rid of the smallest visible furrows, convincingly showed slope lines connecting two entrances in the modern surface, while the very homogeneous image of the magnetogram gave no indication of asymmetric erosion which would have tilted the terrain, so the same slope should have been prevalent in the original terrain (Figure 2). There seems to be only one KGA, Pranhartsberg 2, where one entrance, maybe even emphasized by two postholes, can be shown to be perfectly in line with the summer solstice sunset, while the opposing entrance appears to be disturbed but may well have been directed towards winter solstice sunrise, and where the entrance axis neither follows nor is perpendicular to the slope line. In a few other sites, a solar connection is still suggested but coincides with the slope pattern.

While most of the 3D analysis was done directly in SketchUp, the Stellarium plugin developed in parallel clearly showed an error in the stellar orientation of the previously generated static panorama mentioned above, and when other suggested stellar orientations were ruled out by the surveyed horizon elevations it became clear that the stellar hypothesis had to be abandoned entirely. However, the summer solstice sunset entrance orientation for KGA Pranhartsberg 2 can be simulated very convincingly (Figure 3).

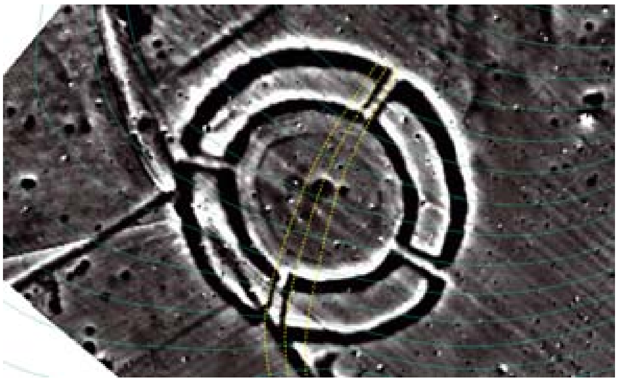

Figure 2: *A slope line analysis of a LiDAR based DEM in KGA Steinabrunn shows a very simple explanation for the layout of two entrances. The terrain slopes from the northeast down to the south-west entrance (Zotti and Neubauer, forthcoming).*

4. CONCLUSION AND PERSPECTIVE

This result, totally inverting the previous assumptions, certainly appears disappointing for supporters of widespread systematic ritual sky observation, but shows clearly the necessity of combining results from geophysical or other archaeological prospection or excavation, which is traditionally only published in flat maps, with an analysis of a reasonably large piece of high-quality digital terrain model surrounding the monument in question in order to gain a better understanding of the topographical situation.

For presentation of stellar results we had expected to confirm to a wider audience, we had envisioned the use of the Stellarium plugin with a series of SketchUp models. However, without need

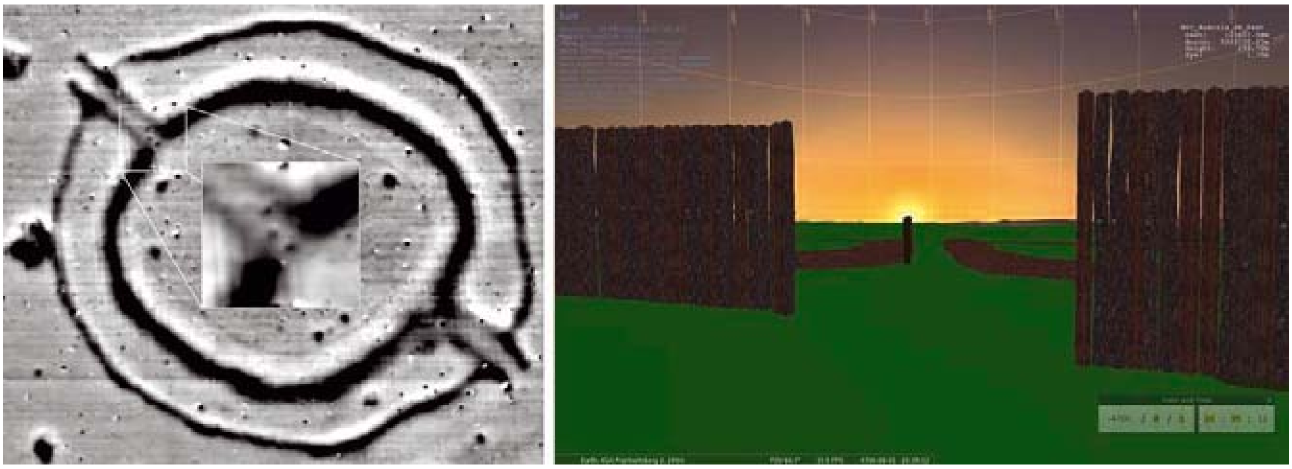

Figure 3: *Magnetogram with possible postholes in the northwest entrance, and Stellarium simulation of the summer solstice sunset in a virtual model of KGA Pranhartsberg 2.*

to simulate the night sky, we now intend to use the Unity3D[2] game engine to develop a high-quality interactive model of a considerably larger area surrounding KGAs Pranhartsberg 1 and 2, which should be based on the currently available archaeological knowledge of the terrain. Also this model will be capable of demonstrating archaeoastronomical circumstances.

ACKNOWLEDGMENTS

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AERIAL IMAGERY AND INTERPRETATION OF ROMAN VIMINACIUM

N. Mrđić, M. Korać, S. Golubović

The Roman city and legionary camp Viminacium is located in fields in the vicinity of villages Stari Kostolac and Drmno, Braničevo District, Serbia (Figure 1). The advantage of this location, compared to other sites, is that there is no modern settlement above the ancient remains. This enables us to apply multidisciplinary methods in systematic research of the all segments of ancient urbanism. The combined city, legionary fort, cemeteries and further suburban zones (protected core and buffer zone) cover 450 hectares. This is an enormous area to cover in order to define the topography and organization of ancient Viminacium. Analyses of satellite and aerial imagery was the fastest way to establish a rough plan of the area.

Systematic study of aerial imagery collected from 1967 onwards shows stunning differences in features that were visible on only some individual images. These features were combined in GIS in order to create a comprehensive plan. Topographic plans (1:2500) were also combined with the aerial images. Test trenches and geophysical methods were then used to confirm the acquired results.

Old plans of Viminacium, from 19th and early 20th century researchers, were incorporated into the GIS database and superimposed over the aerial images. This allowed defining the exact locations of buildings and features once observed while they were still visible above ground. Combining old plans with geophysical surveys shows that many buildings that were still visible in the 19th century, or excavated in 1882 (Figure 2) and 1902, still exist underground.

The entire 3,800 m length of the defensive walls is defined, together with several gates and all the gates of the legionary fort. Preliminary phases of city development are also suggested. The existence and lack of fossae in front of some defence sectors are accordingly explained.

Roads and aqueducts are mapped in sectors where no rescue excavations were previously conducted. Some of the major buildings are visible on aerial images, including the existence of two large buildings around a central forum and amphitheatre.

Results of this comprehensive analysis are constantly being updated through geophysical surveys of the urban zone. A digital terrain model is also being prepared to help in visual impression of the area.

Figure 1: *Aerial image of Viminacium (1996).*

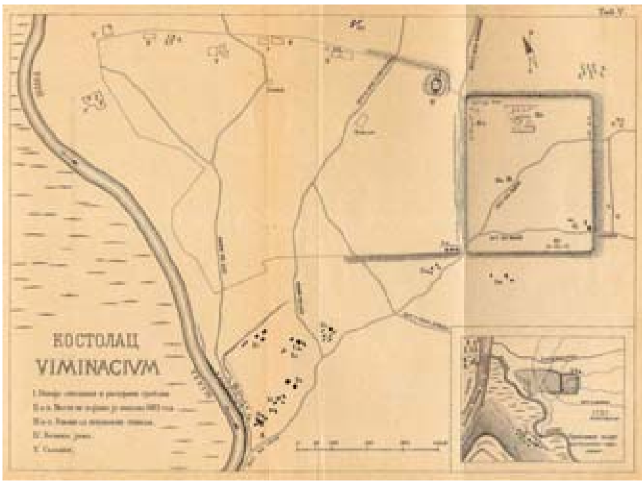

Figure 2: *Plan of Viminacium by Mihailo Valtrović (1884).*

WADI ABU DOM ITINERARY (W.A.D.I.) – AN ARCHAEOLOGICAL ROAD SURVEY PROJECT IN SUDAN

T. Karberg

The aim of this paper is to present some preliminary results of a survey project in Sudan. The project was inaugurated in 2009 by Angelika Lohwasser at the Freie Universität Berlin, and from 2010 on transferred to Westfälische Wilhelms-Universität Münster. From 2009 till 2011, three preliminary campaigns supported by small-scale funding were carried out; from 2012 on, the project was fully financed and expanded to regular 3-month-campaigns (at the moment granted for 3 years).

The project was set in the Wadi Abu Dom in the Bayuda desert in northern Sudan, which is thought to have been a major communication route between the political capital of the late Kushite Empire, Meroe near the modern village of Begrawija, and the main religious center of Napata, located close to Gebel Barkal at the outskirts of the modern town of Karima. The lower Wadi Howar leads directly towards the Gebel Barkal from the other bank of the Nile. This communication route was sometimes labeled as the 'Kushite Kings's Road'.

Alongside this main aim, the project's concept is to document all pre-modern human remains within the whole Wadi and its banks. The survey campaigns were prepared by satellite image analysis, and during the field research the survey was carried out by teams equipped with field computers with a mobile GIS application especially adjusted to the projects needs in collaboration with the Institute of Geo-informatics of Münster University.

The GIS software used by the project in the field is based on the ArcPad mobile platform, running on a Trimble Juno PDA as field computer (Figure 1). The data acquisition of ArcPad was augmented by some pre-defined categories at three levels of data organization, to ease the later analysis of the data in a database. Even a person not trained in GIS applications can use the program after a short introduction.

To document an archaeological spot, a button 'site' can be activated (automatically generating a consecutively numbered polygon shape), and a category from a pre-defined drop-down menu (like cemeteries, settlement structures, campsites etc.). Afterwards, single 'features' can be attached to the site (automatically generating point shapes numbered according to the site number), with defined categories and sub-categories (like 'tumulus' and 'tumulus type NN') already pre-selected by the program according to the site category. Pictures from an integrated or external camera can be attached to any site or feature (also generating point shapes).

All polygon or point shape information is automatically georeferenced by the internal GPS receiver of the Trimble Juno.

For storage, visualization and analysis, the data acquired via ArcPad is regularly checked in into a Geodatabase run by an ArcGIS desktop application, augmented to contain all relevant data (including photos and drawings) of the project.

A simple (non-differential) GPS receiver is used to generate the topographical reference of the data collected, regularly integrated into the Trimble Juno PDA. The precision of the data has been sufficient, but an improvement would be a useful task for the near future.

Figure 1: *The ArcPad mobile platform, running on a Trimble Juno PDA as field computer.*

Around 2000 archaeological sites have been discovered and documented thus far, including different categories like cemeteries, settlement structures, and rock art (Figure 2). Due to the main aims of the project, special attention was paid to indications of traffic and road installations, like ancient donkey tracks, alamat, campsites or road installations.

Interestingly, many remains of traffic installations were found so far, but most of them can be attributed to short- or middle ranged traffic based on local and regional movement patterns, most likely caused by semi-nomadic mobile lifestyle. A dominant type of archaeological sites, so far, is the so called campsite, an area where traces of mobile huts and camp fires (under ideal circumstances associated with datable finds like ceramics) can be found. Surprisingly, it turned out that aside from the artefacts recovered, ancient and relatively recent campsites look almost the same in the archaeological record. Other important features to reconstruct the ancient traffic history of the area are tracks left by donkeys – these are difficult to date, but in some cases, concentrations of broken ceramics beside those tracks indicate their age. In one case, sherds of an almost complete ancient vessel were found next to an obstacle at the ground, making it quite

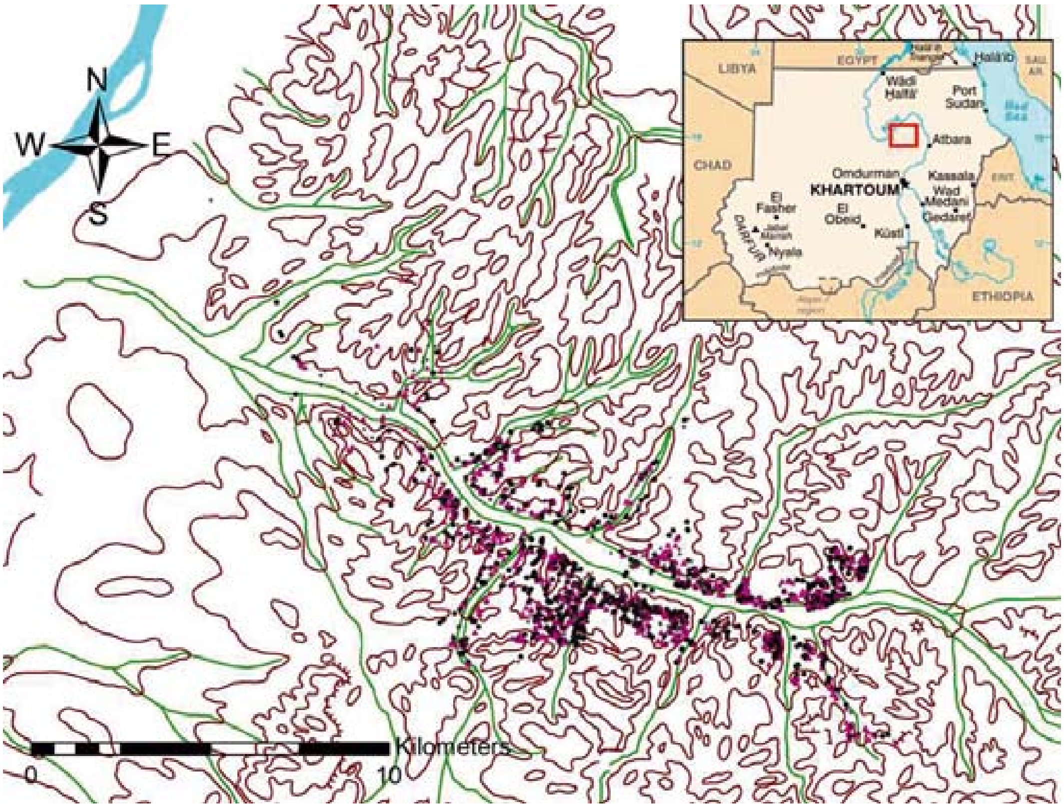

Figure 2: *2000 archaeological sites discovered and documented so far, including cemeteries, settlement structures, and rock art.*

likely that the vessel fell off the donkey because it stumbled over it. The specific conditions of the rubble plateaus of that stony desert terrain show almost no abrasion by surface water, plants or agricultural activities (only wind affects the soil surface), so that single incidents like the stumbling of that ancient donkey have indeed a chance to be conserved over centuries on the ground.

Most interestingly, a quite distinctive differentiation between 'land to settle' and 'land to move' proved to be possible. On the other hand, installations attributed by earlier authors to more centrally organized long-ranged traffic proved to be of different nature.

For example, the ruin of Umm Ruweim (which was investigated to some detail in 2011), compared by other authors to the Hydreumata of the Egyptian Eastern Desert (and thus, as those, interpreted as road installations), turned out to be a central complex with settlement and ritual elements, most probably associated with a local elite and not with a central administration organizing over-land traffic to and from an administrative centre like Meroe or Napata.

Additionally, the complexes of Umm Ruweim 2 and Umm Khafour, sometimes interpreted as a kind of corral for overnight stops of caravans, turned out to be of a completely different layout than estimated before. Investigations in 2012 show that the structures originally contained some parts made of mud brick architecture, making a role as settlement and/or storage building more likely.

Further development of the data acquisition technology is planned, for the near future focusing on the improvement of the positioning precision by integrating differential GPS measuring into the mobile GIS platform. An idea for later improvements of the work would be the integration of an octocopter or another comparable low-altitude remote sensing platform, since it turns out that a pedestrian-survey on the ground cannot cover the whole length of the Wadi banks in the same detail as has been done thus far and in an appropriate amount of time. A complementary deployment of remote sensing methods could deliver the data to fill the gaps in the pedestrian field survey.

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WALK THE LINE. IMPLEMENTATION OF REGIONAL-SCALE GIS-BASED FIELD SURVEY METHOD FOR AGRICULTURAL AREAS IN HUNGARY

M. Stibrányi, G. Mesterházy

1. INTRODUCTION

Archaeological field survey is one of the easiest and most obvious site reconnaissance methods in intensively ploughed agricultural areas, such as those covering most of Hungary. The fertile loess soils of the Carpathian Basin provided very rich potential for colonisation by agricultural communities since the Neolithic. This potential has resulted in a very high density of human land-use and associated archaeological remains. There is no great difference today; according to CORINE, more than 55% of the territory of Hungary is arable agricultural area. Considering the quantity and richness of archaeological sites and the high percentage of arable fields, there are huge amounts of archaeological data literally lying on the ground.

Naturally, Hungarian archaeology has used these opportunities from the beginning. Even the term field survey usually refers to plough-walking in the Hungarian terminology. Most of our knowledge about sites comes from plough-walking; the first and only, yet regrettably cancelled, country-wide undertaking to identify sites in Hungary, called Hungarian Archaeological Topography, operated from the 1960s to the 1990s and identified about 10,000 sites on 11.7% of Hungary, based on extensive field survey (Laszlovszky, 2004; Wollák, 2009).

Despite the abundance of information – or maybe partly due to it – research in Hungary has rarely explored the full range of potential data collection methods. The usual extensive field survey results with drawn circles on maps are not useful for examining site intensity or distinctions between periods on a multi-temporal site, not to mention research using geostatistical approaches or network analysis. However, the abundance of data seems to allow such approaches as well (recently e.g. De Haas, 2011). An even larger problem is the lack of regional-scale intensive surveys. Site reconnaissance usually targets areas where one can expect archaeological occupation (e.g. near water-courses), but testing the validity of this approach is vital for understanding human occupation on a regional scale (Kowalewski, 2008). The well-known intensive field survey using grids for collecting finds offers much more accurate data; however, this approach is very time-consuming and is usually used only for intra-site surveys.

2. MOTIVES AND AIMS

In recent years, when we started to research archaeological network analysis and predictive modelling based on the site registers in Hungary, we regularly faced problems caused by inaccurate archaeological data. Later we realised that if we want to create data or even verify it, we need to establish a method which allows us to compare and set up a resolution in which our data collection is valid. We are led to believe that the data available by utilizing a field survey approach has a much greater potential for archaeology than the current implementations would suggest.

In order to explore this potential, we required an intensive field surveying method, which:

- is time and cost efficient
- is based on former field survey techniques and useful in Hungarian landscape conditions
- allows us to identify archaeological sites on a large scale with the same resolution
- creates comparable and easily repeatable data
- allows to differentiate ages and periods within one site
- is based within a GIS environment
- uses handheld GPS devices

Naturally, most of these requirements have been the focus of research since the 1970's (e.g. Bintliff, 2011; Gojda, 2004; De Haas, 2011), so it was obvious to base our research on these approaches. In some cases, we needed to adjust the methodological framework to our expectations and aims; therefore, we inserted new elements. The usual problem with field survey is that the collection of precise data is too slow to be efficient at a larger scale. In our view, there are two fundamental reasons for this: (1) setting up a grid for the survey, and (2) the more accurate the data collection and documentation, the slower the process. We find the latter a bigger problem, high density collecting could make large-scale survey very slow.

However, there can be a compromise in that regard, by setting up a large 100 by 100 m grid and making it "virtual" using the GPS not only for collecting the finds, but also as grid markers. Collection of finds will be still according to a grid but this only exists on each surveyor's GPS unit. Of course, the downside using this method is that we will only be able to obtain exact information about densities and periods, depending on the number of swaths within one grid, in a 25-100 $\times$ 100 m resolution. The upside, however, is that it allows us to cover large areas quickly and effectively. Testing suggests that a team of four surveyors can cover 1 km^2 daily. Most importantly, this method enables us able to create easily quantifiable and comparable data on a large scale.

3. EXTENSIVE FIELD SURVEY METHOD

By using the framework of the Hungarian national mapping (EOTR) and projection system (EOV), a 100$\times$100 m north-oriented virtual grid system was defined. A unique identification number, as the basic unit of the field survey, was connected to every grid. This digital data were uploaded into the handheld GPS devices, and therefore it was not necessary to mark the grid's corner points on the field. In every 100$\times$100 m grid, four people spaced 20-25 mm apart collected and marked every artefact's spatial position with handheld GPS, parallel with the north-south or east-west axis of national mapping, thereby surveying approximately 10% of every grid. At the edge of every grid, the field surveyors packed the artefacts simultaneously,

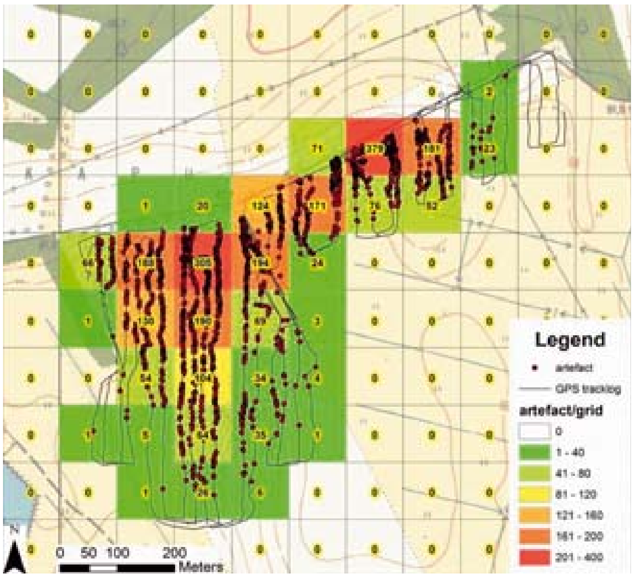

Figure 1: *Field survey result in the Sárvíz River valley, central Hungary.*

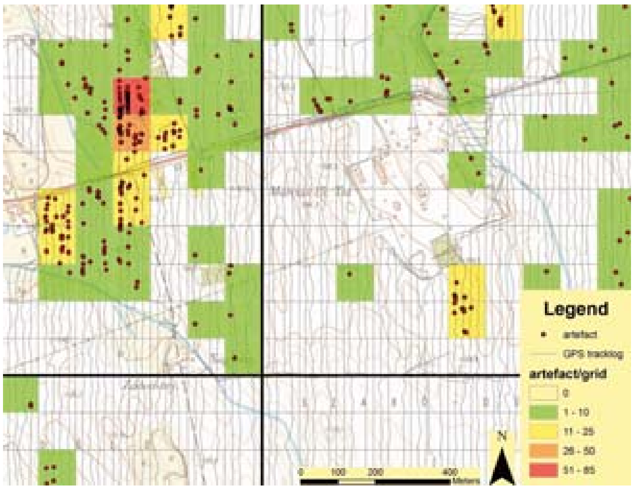

Figure 2: *Field survey results in the Polgár region, northeast Hungary.*

providing the proper resolution of the field survey. Spatial location of visible features (e.g. mound, artificial cuttings) was also marked, along with the stone density points, if those referred to human construction (e.g. roads, buildings). Visibility condition on a 0-7 scale was defined on the field for each agricultural parcel, through the mutual consensus of field survey team members.

The use of this grid system expanded the available possibilities during post-processing and data analyis. The method transforms the traces of human occupation in the surveyed area into an intensity map. Through the GIS, we are also able to deal with in-site distribution and intensity of archaeological ages and periods, as well as with site and off-site distribution (Bintliff, 2000). Moreover, the definition of every parcel's visibility condition allows working with biases, such as how different land cover modifies the recognition of surface artefact conditions (Figure 1).

4. TESTING AND RESULTS

The method was first tested in the Polgár region (north-eastern Hungary) in two weeks during September 2012. We used the method to surveying both known and unknown archaeological sites, to verify the potential to separate densities and periods within sites. Although the issues of dating the artefacts slightly narrowed our testing opportunities, it was possible to differentiate different densities for diverse archaeological ages and periods within single sites (Figure 2).

During October 2012, another campaign was held in collaboration with Czech, Polish and Slovakian researchers to survey a continuous 20 km^2 in the Sárvíz valley (central Hungary) as part of the Workshop for Reading Past and Present Landscapes project, funded by the International Visegrad Fund. In this paper, we would like to show the method in detail and the test results as well (Figure 1).

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USING BARCODE, TABLET PC AND SMARTPHONE TECHNOLOGY FOR ARCHAEOLOGICAL FIELD SURVEYS

J. Coolen, M. Fera, M. Doneus, E. Grillmayer

In the past decade, handheld computers and personal digital assistants (PDA) have become an integrated part of the archaeologist's toolkit (Ryan and van Leusen, 2002; Campana, 2005). Being designed for mobile applications, personal digital assistants (PDA) have proven especially useful for archaeological field surveys, where portability and ease-of-use are given priority over screen size, computing power and mapping accuracy. Mobile devices allow for fast, paperless recording and display of relevant data and substantially ease the integration of field recordings in the subsequent analysis and reporting process. Numerous archaeological survey projects now employ dedicated PDAs with satellite navigation receivers and light GIS software to record field data, position survey transects and navigate to survey targets (Tripcevich, 2004; Wagtendonk and de Jeu, 2007) (Figure 1). This paper aims to show how the documentation process can be further optimised by the use of barcode tags and explores the potential of modern consumer tablet PCs and smartphones as an alternative to dedicated PDAs.

Figure 1: *GPS receivers and PDAs are now commonly used in large-scale field survey projects.*

Systematic archaeological field surveys often involve the identification and collection of large numbers of artefacts. In order to relate the finds to a discrete location and to the collection parameters that have been recorded for this location, they need to be tagged. This is usually done with an individual number, which is either assigned progressively in the field or defined in advance, referring to the survey unit (transect, grid square, parcel etc.) or a single find. The manual writing of find tags is time consuming and prone to errors. Pre-printed barcode labels present a simple alternative, and allow for better control both in the field and in subsequent processing phases (cf. Dibble *et al.*, 2007).

Our workflow involves the following steps. In the field, survey finds are put in find bags with barcode labels applied to them. The barcodes represent discrete alphanumerical codes and serve as find identification numbers. The codes can be randomly chosen from a previously defined set and can include additional information on the survey collection. For example, each collector can have barcodes starting with their initials, or different codes can be used for separate survey areas. The barcodes are scanned using a barcode reader connected to a mobile computer via Bluetooth (Figure 2). Alternatively, a smartphone or tablet PC can directly function as a scanner using the internal camera and a barcode reading application. Either way, the decoded barcode is written directly into a specified field of the survey database and linked to a spatial feature. During each of the subsequent processing stages (washing, restoring, analysing, storing) the barcodes are scanned, which allows for better control and monitoring of the find processing procedure. As the finds are analysed by specialists, the barcode serves to link the specialist's database entry to the field survey database, and thus to integrate the archaeological evidence into a GIS.

Tablet PCs and smartphones have only recently become widely available and affordable, and their use in archaeology is still in a testing phase. Several pilot projects such as the Pompeii Archaeological Research Project: Porta Stabia (Porta Stabia, 2012) and the Sangro Valley project (Motz and Carrier, forthcoming) have shown that consumer tablet PCs and smartphones present an interesting alternative to more expensive, dedicated handhelds for archaeological fieldwork. However, given the fact that many archaeologists use smartphones and tablets in their private lives, it is surprising that only few seem to exploit the potential of these devices for archaeological field data recording so far. Interestingly, smartphones and tablet PCs appear to be used more frequently to disseminate rather than to carry out archaeological research.

The main advantages of smartphones and tablets are the low costs, the wide range of available applications, and the fact that they present an all-in-one solution, combining the functions of a handheld computer, digital camera, GPS receiver, various inertial meters, barcode and RFID scanner, voice recorder, mobile phone etc. All mobile platforms that are currently being released support WiFi and Bluetooth connections, which allows for cloud computing and the connection of external devices. Whereas most survey projects cannot afford more than one dedicated PDA per crew, it is possible to equip each surveyor with a tablet or smartphone even when project resources are limited. Similarly, mobile consumer devices present an ideal tool for community archaeology projects integrating non-professional archaeologists

Figure 2: *In the Kreuttal survey, find bags were labelled with barcodes and scanned using a bluetooth barcode scanner connected to a PDA.*

for the contribution of survey data.

Current consumer tablet PCs and smartphones also have some weaknesses, however, when compared to dedicated handhelds. First, they are not designed for rough outdoor work, and hence are sensitive to dust, moisture, shocks and scratching. Other issues include battery life, GPS accuracy and status control, readability in bright sunlight and the compatibility of various apps running simultaneously.

The paper will present the first results and experiences with barcode technology and mobile consumer devices within intensive and extensive field surveys in the Kreuttal area in Lower Austria, which are part of the PhD project of the presenting author.

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FROM POINT TO POLYGON – INVESTIGATING A ROMAN RURAL LANDSCAPE

N. Doneus

ABSTRACT

The Roman site at Halbturn, Austria has been the subject of different interdisciplinary archaeological research projects in the past. An area of 2 km^2, including a Roman villa rustica, several graveyards and related agricultural areas has so far been documented and investigated by large-scale prospection and targeted excavations. The term '*villa rustica*' implies a complex spatial model, consisting of settlement, workshops, graveyards, cultic sites and agriculturally productive land. Dealing with such a model requires adequate methods, such as the combination of large-scale prospection, GIS and spatial analysis. They can allow a better understanding of the Roman rural landscape, provided that archaeological features are mapped correctly. The purpose of this paper is to demonstrate how mapping and interpretation of Roman settlements, and in a broader sense, working with spatial analysis, can be affected by research strategies and selected archaeological methods.

1. INTRODUCTION

Distribution maps, as a tool for visualisation of archaeological spatial information, are an integrative part of archaeological research. They include background information such as the number of sites, their size, chronology and accurate spatial location. Based on these or similar classifications, distribution maps can visualise a representative sample for a certain archaeological period. The representativeness of a sample is of main importance for archaeological research, not just because of the generally fragmented nature of the archaeological record. The choice of suitable methods and their application to specific archaeological problems has a strong impact on the perception and evaluation of archaeological features. Consequently, the mapping of sites or structures does not automatically lead to the visualisation of a representative sample but to the distribution of single settlement features. Roman settlements represent a large part of the Austrian archaeological record. Excepting its small northern parts, Austria was completely Romanised during the 1st century AD. The river Danube, as the Limes border, was a barrier for people but not for goods – for that reason, many daily goods were the same south and north of the river Danube. However, there is one important difference between the Romanised and non-Romanised parts of Austria remains – stone buildings were generally not built north of the Danube in Roman times. In fact, all stone buildings in Austria between prehistory and the 11th century were of Roman origin. This fact had a strong influence on archaeological research in Austria, as stone buildings are easy to recognise as Roman settlement features. Much of the archaeological work has therefore focused on small-scale excavations, on typology or classifications of buildings contained in urban and rural Roman sites (Cencic, 2004; Biró, 1974). Consequently, other kinds of settlement features were rarely recognised, documented or evaluated. Furthermore, the main Roman settlement form (villa rustica) is defined as an area inside a typical square enclosure, with stone buildings of different size and orientation concentrated inside this area (Thomas, 1964). Therefore, any settlement activities were expected to have taken place only inside the enclosures. The same logic is applied to archaeological finds.

The results of single excavations together with unsystematic field surveys are frequently used as basis for distribution maps (Gabler, 1994, Vol. 2, 137–140), or for the interpretation of Roman settlement structures (Zabehlicky, 1999). Since such maps are based on the assumption that the corresponding villa rustica fits into an enclosure, they actually reflect nothing more than the distribution of a single settlement feature – a stone building.

2. THE CASE STUDY OF HALBTURN

Behind the term villa rustica, which is usually a synonym for Roman rural settlement, we should understand much more than just a few buildings of a working farm. In fact, the term villa rustica describes a complex spatial model, consisting of settlement area and zones of working activity, farm buildings and agricultural areas (fields, pasture and forest), graveyards and cult sites. To realize this spatial model requires research on a larger spatial scale and a change in research perspective, with a focus on documenting the entire landscape. The case study of the Roman settlement of Halbturn tries to elaborate on these aspects: after mapping the first finds or structures in the landscape (Figure 1 left) we will try to render the entire archaeological site visible, which can be achieved with methods such as large-scale prospection (Figure 1 right). Through the mapping of structures on a large scale, we have the opportunity to localise the entire site appropriately – in the form of points on a map as well as in the form of polygons. This approach allows improved research strategies and the modification of distribution maps (distance to water, distance from main road to the main living area or to the graveyard, etc.).

The case study area is located near the village of Halbturn in eastern Austria, about 60 kilometres to the east of Vienna. In Roman times, the settlement was part of the province of Pannonia, with the capital city of Carnuntum situated approximately 30 kilometres north of the site. From the late 1980s, archaeological prospection has been successfully applied on the site (Daim and Doneus, 2004; Doneus, in press), resulting in the discovery of a small-scale archaeological landscape covering some 2 km^2, which was surveyed by remote sensing techniques, geophysical prospection and systematic field walking surveys. A large settlement area consists of one or two farms and several activity zones, including stone buildings, hundreds of pits, sunken huts and a complex network of ditches (Figure 2). Four (?) contemporary graveyards seem to belong to the settlement, which has been dated to the 2nd – 5th centuries AD. The site is surrounded by six contemporaneous Roman settlements. The location analysis based on environmental variables, the relationship of the site to the surrounding landscape and its setting in relation to the other contemporaneous settlements in the vicinity suggests that the subdivision of the land was strongly influenced by environmental conditions. Therefore, the distances between Halbturn

Figure 1: *General site location by point mapping (left), and specific location by use of a polygon (right).*

and neighbouring settlements vary between two and seven kilometres. From information about the neighbouring settlements, the available land for the villa at Halbturn can be roughly estimated to some 130 ha. The settlement occupies an almost central position within the surrounding land, and is situated on the border between two different local environments. Such a choice of location can be seen as an indication of the equal significance accorded to agriculture and animal husbandry in Roman times. Evaluation of animal bones and botanic samples, combined with soil maps and the spatial location of the fields, support this interpretation of the available data. Stockbreeding played an important role; especially the breeding of horses, which were born and trained in the villa and then sold on large markets in the cities.

3. CONCLUSION

Distribution maps of Roman settlements in Austria have so far been based on small-scale excavations and field surveys, providing us with information in the form of sparse dots on the map. Using the case study of Halbturn it can be shown that through the application of a systematic and integrated prospection approach this point information can be enriched by mapping various activity areas – settlement activities were recognised and documented several hundred meters away from main dwelling houses. As a consequence, the site can be mapped in form of numerous more precise polygons. Even if we want to use point presentations for a large-scaled analysis of settlement patterns, deriving the point from the well-investigated polygon information will result in a far better and more accurate location: if we compare the original official site-location with prospection results, we can notice a considerable difference in regard to soils, slope and distance to water. Using the original point based information from unsystematic field surveys, we would obtain an incorrect impression of the spatial parameters of the Roman Villa of Halbturn.

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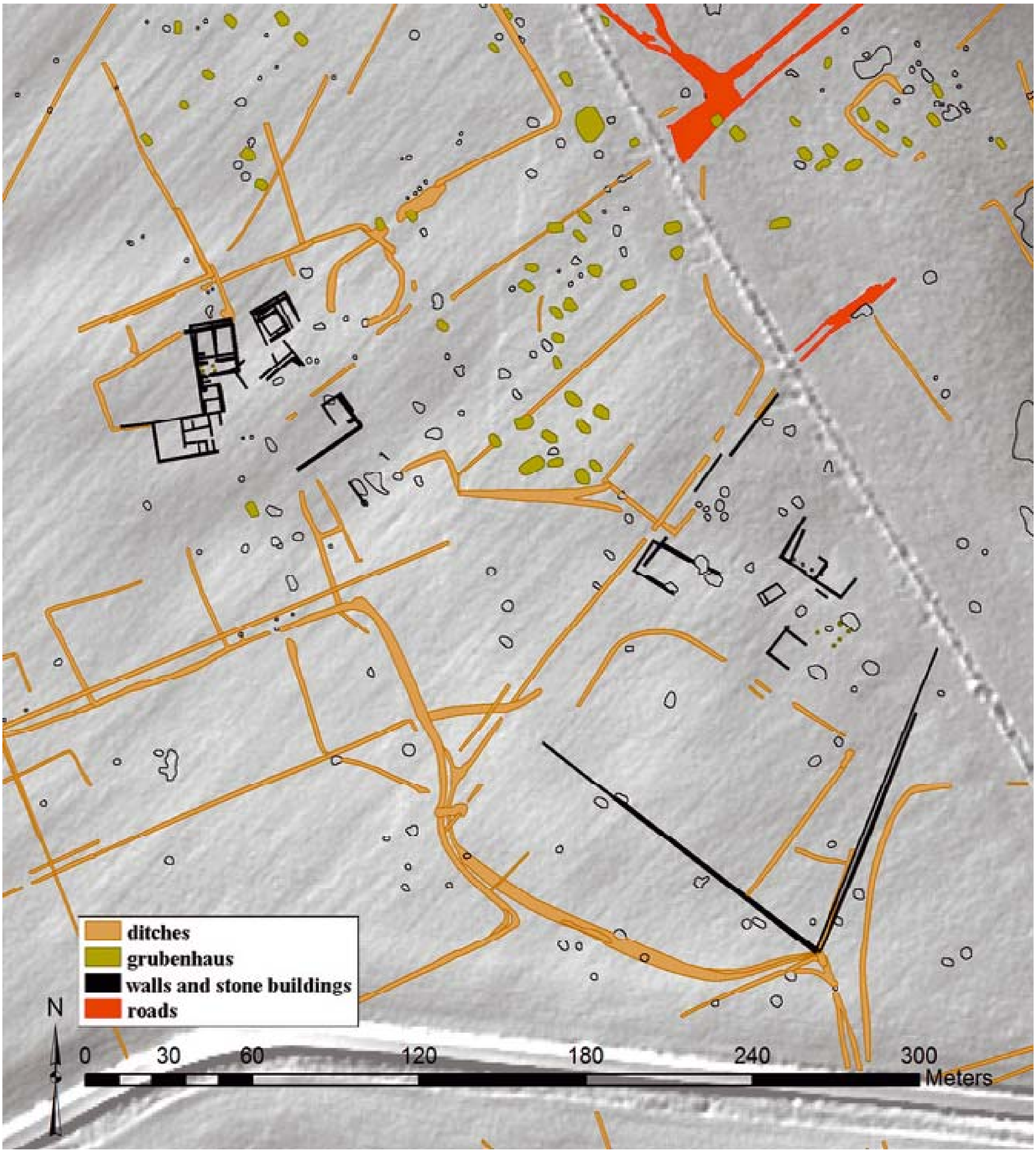

Figure 2: *A detailed view of the main settlement area of the rural Roman site of Halbturn.*

OBJECT VERSUS PIXEL – CLASSIFICATION TECHNIQUES FOR HIGH RESOLUTION AIRBORNE REMOTE SENSING DATA

M. Pregesbauer

ABSTRACT

Aerial remote sensing is commonly used in archaeology for the non-invasive detection, mapping and investigation of buried prehistoric sites. The recorded data can contain numerous crop marks and crop features caused by archaeological structures in the ground. Mapping these archeological features can become a time consuming procedure, especially when huge archaeological landscapes are covered by high-resolution remote sensing data. Automated and Semi-Automated Classification methods before the actual archaeological interpretation can enhance the productivity of the archaeological interpretation process for aerial remote sensing data. The two main classification approaches are investigated to determine their suitability for mapping archaeological features regarding high resolution aerial remote sensing data.

1. INTRODUCTION

Aerial remote sensing is widely used to document crop marks that might indicate buried archaeological and palaeoenvironmental features (Scollar, 1990). To maximize the potential of the acquired data, an integrated workflow, ranging from the data acquisition to the final Interpretation Map was defined and is shown in the following chart in Figure 1.

To prove the usability of two automatic classification approaches, a LiDAR (Light Detection and Ranging) data set from the prominent UNSECO World Heritage Site Birka–Hovgården, Sweden, a Viking-Age settlement, was used. The data acquisition was carried out on 28–29 November 2012, with a mean point density of approximately 6 points per square meter. A digital terrain model (DTM) was generated by applying the filtering algorithm as described in Doneus *et al*. (2008) and shown in Figure 2.

As a preliminary step, and to retrieve the maximum information from the original data, the positive and negative openness has been calculated and was subsequently used as input data for the classification. The positive and negative openness is an angular measure denoting the aperture angle of a cone centred at a grid point and constrained by the neighbouring elevations within a specified radial distance (Yokoyama *et al.*, 2002).

2. MOTIVATION AND AIM

The correct discrimination and automatic identification of archaeological features in remote sensing data requires, in addition to the spectral and measured values, the knowledge of the archaeologist who is mapping the landscape. In archaeological context, an adequate method has to be developed to isolate archaeological features and to separate them from features of non-interest.

Techniques and concepts derived from the research field of Geoinformation and Earth Observation Science have led to the emerging field of Pattern Recognition. Adapted to the archaeological application, classification concepts from the field of Pattern Recognition can be utilized for the analysis of high-resolution remote sensing data sets. Therefore the concepts of pixel based classifiers and object based image classification are used to demonstrate the capabilities of Pattern Recognition techniques.

3. PIXEL BASED CLASSIFICATION APPROACH

Starting with the concept of Pixel Based Classification, the methodology offers a wide range of different approaches (Tso and Mather, 2009). The Pixel Based Classification can be subdivided into three basic categories :

- Type of learning
  - collecting training samples for the characterization of target classes (supervised classification)
  - automatically detecting the number of classes by the classifier (unsupervised classification)
- Assumption on data distribution
  - Parametric Classifiers
  - Non-Parametric Classifiers
- Number of outputs for each spatial unit
  - each pixel is forced to show membership to a single class
  - each pixel may belong to multiple and partial classes

For the use of archaeological classification, at first supervised methods have been implemented and tested on the LiDAR data set of Birka–Hovgården. The main steps of a supervised classification approach is (1) the definition of the number of information classes and the collection of representative training data, (2) the estimation of the required statistical parameters from the training data and (3) the application of an appropriate rule.

As an example for supervised classifiers, a Minimum Distance and a Mahalanobis classifier have been tested and the results are shown in Figure 3.

For the archaeological application, the Mahalanobis classifier is more suitable because features which are coming from filter fragments of the DTM are not classified as it is with the Minimum Distance Classifier. The advantage of this type of classifier is mainly that it is using a distance function in the feature space which easy mathematically simple and computationally efficient.

The main limitation on supervised pixel based classifiers is that the object semantic of an image object is not taken into account, which means that only spectral features and/or measurement values are used to discriminate the pixel into object classes.

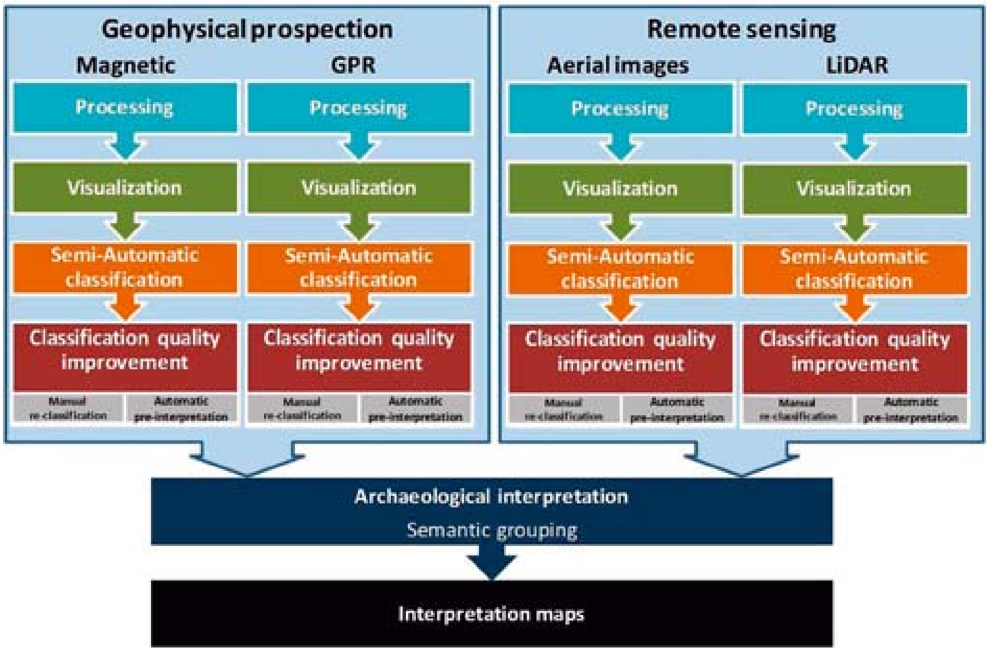

Figure 1: *Integration of the Image Classification into the Archaeological Data Processing Workflow.*

4. OBJECT ORIENTED CLASSIFICATION APPROACH

Instead of using individual pixels, the basic processing units of the object oriented classification are segments, or in other terms, image objects. Segmentation is always the first step to generate processing units (image objects) by applying a segmentation rule. The number of possible segmentation algorithms suitable for generating image objects is enormous: for the present case study a quadtree segmentation with a following image object fusion has been used (Baatz and Schäpe, 2000).

After segmentation, a classification procedure is executed at the image object level. All image objects meeting the predefined class criteria are assigned to the target class.

The resulting classified image object represents the burial mounds as well as the elongated feature on the left side of the left image in Figure 4. Compared to the manual mapping and interpretation done by Prof. Michael Doneus, around 93% of the manually interpreted features have also been classified by the algorithm. Comparing the shape of the burial mounds, it turns out that the automated classified polygons are tendencially too small in relation to the manual mapped ones. Applying a region grow algorithm enlarges the classified objects.

5. DISCUSSION AND OUTLOOK

As demonstrated in this case study, automatic classification approaches are able to enhance the productivity of the archaeological interpretation workflow. Based on the experience and knowledge of an archaeologist, the formalization of this knowledge into an appropriate rule will be the focus for future methodological developments. The capability to formalize not only measurement values and spectral properties but also the semantic relationships between neighbouring objects, as well as multi source data, enables great possibilities for future enhancements in the field of archaeological pattern recognition. Special focus will also be on the integrated classification of geophysical and remote sensing prospection data.

ACKNOWLEDGEMENTS

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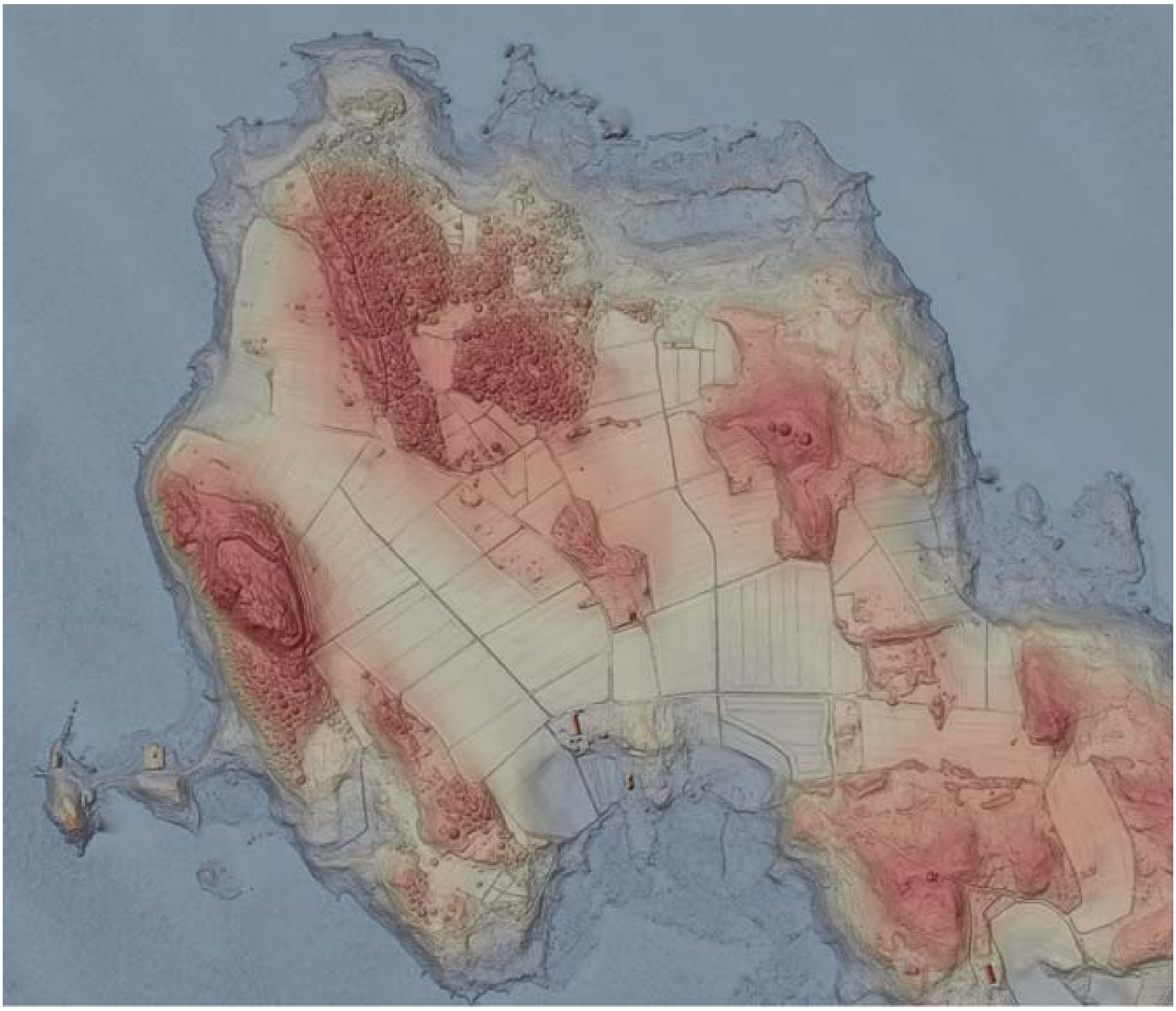

Figure 2: *Filtered Digital Terrain Model of a part of the Case Study Area Birka-Hovgården, Sweden (© LBI Archpro).*

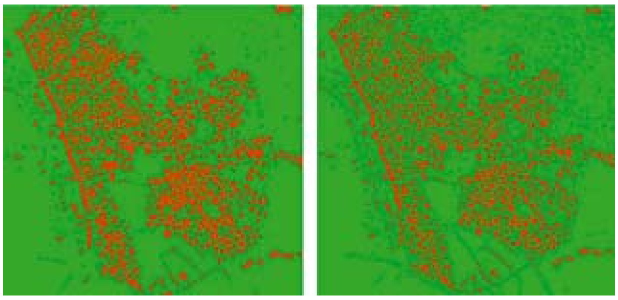

Figure 3: *The left image shows the results of the Mahalanobis classifier whereas the right image represents the results of the Minimum Distance Classifier.*

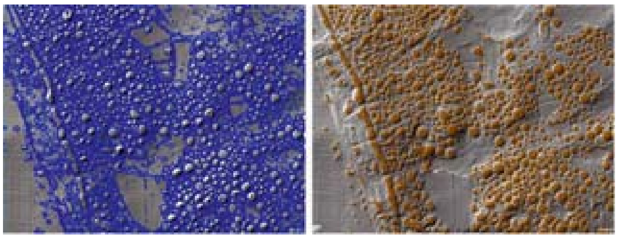

Figure 4: *Based on the initial segmentation (left image) the subsequent classification assigns the image objects to corresponding classes (right image).*

INTEGRATED ARCHAEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS TO STUDY THE AREA OF S. GIOVANNI IN LATERANO BASILICA (ROME, ITALY)

I. Haynes, P. Liverani, S. Piro, D. Zamuner

ABSTRACT

The Basilica of S. Giovanni in Laterano (St. John Lateran) is the Pope's Cathedral and the first public building constructed for Christian worship. Alongside it lays the first Baptistery in western Christendom. The complex has been the focus of sundry excavations since the 1730s. These have revealed traces of the earliest phases of both buildings, along with parts of the Castra Nova of the Imperial Horseguard, a bath complex and palatial housing. Interpretation of these excavations is difficult, however, as most are either undocumented or only partially recorded. The Lateran project is investigating the entire complex to integrate information from standing buildings, excavated structures and sub-surface features. It seeks to understand the stratigraphic, spatial and functional relationships of the different elements underlying the modern complex. GPR surveys provide information on the spatial context and identification of phasing of subsurface features, while laser scanning provides a spatially accurate, detailed representation of the many materials, textures and structures of the Lateran and archaeological remains.

During January and July 2012, a series of GPR surveys were conducted below the basilica, inside the archaeological area, and outside the basilica, to demonstrate the potential of this method for this analysis and to locate the expected archaeological structures.

1. INTRODUCTION - THE SAN GIOVANNI IN LATERANO COMPLEX

An exceptional building in its own right, the Constantinian basilica of S. Giovanni in Laterano holds the title of caput et mater of the churches of Catholic Christendom. The basilica is the Pope's own church, a pioneering structure and a site of remarkable archaeological importance. Extensive excavations beneath the complex have revealed not only the remains of the first powerfully influential basilica and baptistery, but also structures from still earlier periods. Chief among these are the barracks of the imperial horse guards, substantial palatial buildings, a bathhouse, and a street with houses. These areas are remarkably well preserved, and a substantial number of frescoes and mosaics survive *in situ*.

Extensive research by Prof. Paolo Liverani (Florence University) has enriched our understanding of the complex, but a major collaborative project is required to interpret the remains unearthed by previous excavators. The earliest recorded excavations took place in 1730, the deepest lie 5.5 m below ground level.

This project is undertaking an intensive scientific survey of the entire structure to integrate information from standing buildings, excavated structures and sub-surface features through the collaboration of Newcastle University (UK), Florence University (Italy) and Institute for Technologies Applied to Cultural Heritage (ITABC-CNR, Italy).

Figure 1: *San Giovanni in Laterano, Rome.*

2. RESEARCH DESIGN

The Lateran project aims to undertake a fully integrated 3D survey of the excavations under San Giovanni in Laterano. A particular concern is to find an approach that will not only allow collaboration between researchers using a range of established and innovative methods, but also a method that allows an integrated approach to the three-levels of structural data that form the complex (Gaffney, Haynes *et al*., 2008). There are the standing features on the modern city surface, as seen in Figure 1. These can only be fully understood in relation to subsurface features and vice versa.

There are also the extensive and inter-cut structures that form the opened area of excavations. Finally, there are the unexcavated deposits that lay either beyond the immediate confines of the site or beneath the area opened to date.

The aim of the GPR survey is to identify Roman and high-medieval age remains that could enhance understanding of the ancient topography and the evolving urban development of the study area. The main goals of this survey are the following:

- To determine the full plan of the Santa Croce oratory, built by Pope Ilaro (5^{th} century AD) and destroyed by Sixtus the Fifth; part of this building has been identified by Olof Brandt within the excavated area adjacent to the Baptistery.
- To determine the full extent of the palatial housing found below the western part of the Basilica.
- To determine the limits of *Castra Nova Equitum Singularium*, the barracks of the imperial horse guards established by the emperor Septimius Severus.
- To locate the remains of the buildings of the Lateran Patriarchy. These are known from renaissance plans, but up until now, it has not proven possible to locate them all on the ground.

Figure 2: *Archaeological map of the St. John Laterano Basilica (Rome). Green areas are those investigated with GPR; the numbers are related to the goals of the survey (Courtesy of Prof. Liverani).*

3. GROUND PENETRATING RADAR

3.1. Data acquisition

A GPR SIR3000 (GSSI), equipped with a 400 MHz bistatic antenna (GSSI) with constant offset and a 70 MHz monostatic antenna (Subecho Radar) were employed to survey the selected areas outside the Basilica in the S. Giovanni in Laterano square and in front of the Basilica. Some signal processing and representation techniques have been used for data elaboration and interpretation (Figure 2).

The horizontal spacing between parallel profiles at the site was 0.50 m,employing the two antennas. Radar reflections along the transepts were recorded continuously, with different length, across the ground at 40 scan s^{-1}; horizontal stacking was set to three scans.

In the area outside the Basilica, a total of 777 adjacent profiles across the site were collected alternatively in forward and reverse directions employing the GSSI cart system equipped with odometer. All radar reflections within the 90 ns for 400 MHz antenna and 195 ns for 70 MHz antenna (two-way-travel) time window were recorded digitally in the field as 16-bit data and 512 samples per radar scan.

A nominal microwave velocity of about 8 cm/ns was determined from fitting hyperbolas to the raw field data. This was used in estimating penetration depth from the GPR survey.

3.2. Data processing and Presentation

All the GPR data were processed in GPR-SLICE v6.0 Ground Penetrating Radar Imaging Software (Goodman, 2009). The basic radargram signal processing steps included: (i) post processing pulse regaining; (ii) DC drift removal; (iii) data resampling, (iv) band pass filtering, (v) migration and (vi) background filter.

With the aim of obtaining a planimetric view of all possible anomalous bodies, the time-slice representation technique was applied using all processed profiles (Goodman, Piro, 2008; Goodman *et al*., 2008; Leckebusch, 2008; Piro *et al*., 2008, 2012; Utsi, 2006). Time-slices are calculated by creating 2-D horizontal contour maps of the averaged absolute value of the wave amplitude from a specified time value across parallel profiles.

Time slice data sets were generated by spatially averaging the squared wave amplitudes of radar reflections in the horizontal as well as the vertical. The squared amplitudes were averaged horizontally every 0.25 m along the reflection profiles 3 ns (for 400 MHz antenna) and 6 ns (for 70 MHz antenna) time windows (with a 10% overlapping of each slice). The resampled amplitudes were gridded using the inverse distance algorithm with a search radius of 0.75 m. In addition, pseudo three-dimensional volumes of the reflections were generated to produce isosurface images.

Figure 3 shows the time-slices (in the time windows from 58 to 61 ns twt for 400 MHz antenna) for the investigated area. On this map, the individuated anomalies are visible and in particular the reflections obtained in the area N-E to the basilica can be related to the remains of the early Christian bishop's palace (high medieval period).

Figure 4 shows the time-slices at the time-window 112–118 ns (for the 70 MHz antenna) obtained in the same area.

Ground Penetrating Radar (GPR) survey at the Lateran has produced significant and fruitful results. The use of two different antennae has enabled to reach depths of up to 6–7 m.

All the obtained results are presented in 3D animation using real time Open GL graphic displays in which isosurface rendering, 3D time slice fence diagram are mixed with the filtered radargrams.

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The Authors are very grateful to Maria Ida Moretti and Daniele Verrecchia for their fruitful collaboration during the survey, the team of Newcastle University for the topographic support and Authorities of San Giovanni in Laterano Basilica, the Vatican Museums and the Soprintendenza Speciale per i Beni Archeologici di Roma for their help during the survey. The support of the British School at Rome is gratefully acknowledged.

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Figure 3: *S. Giovanni in Laterano square. GPR time slices in the time window 58-61 ns twt (estimated depth 2.4 m) for the 400 MHz antenna.*

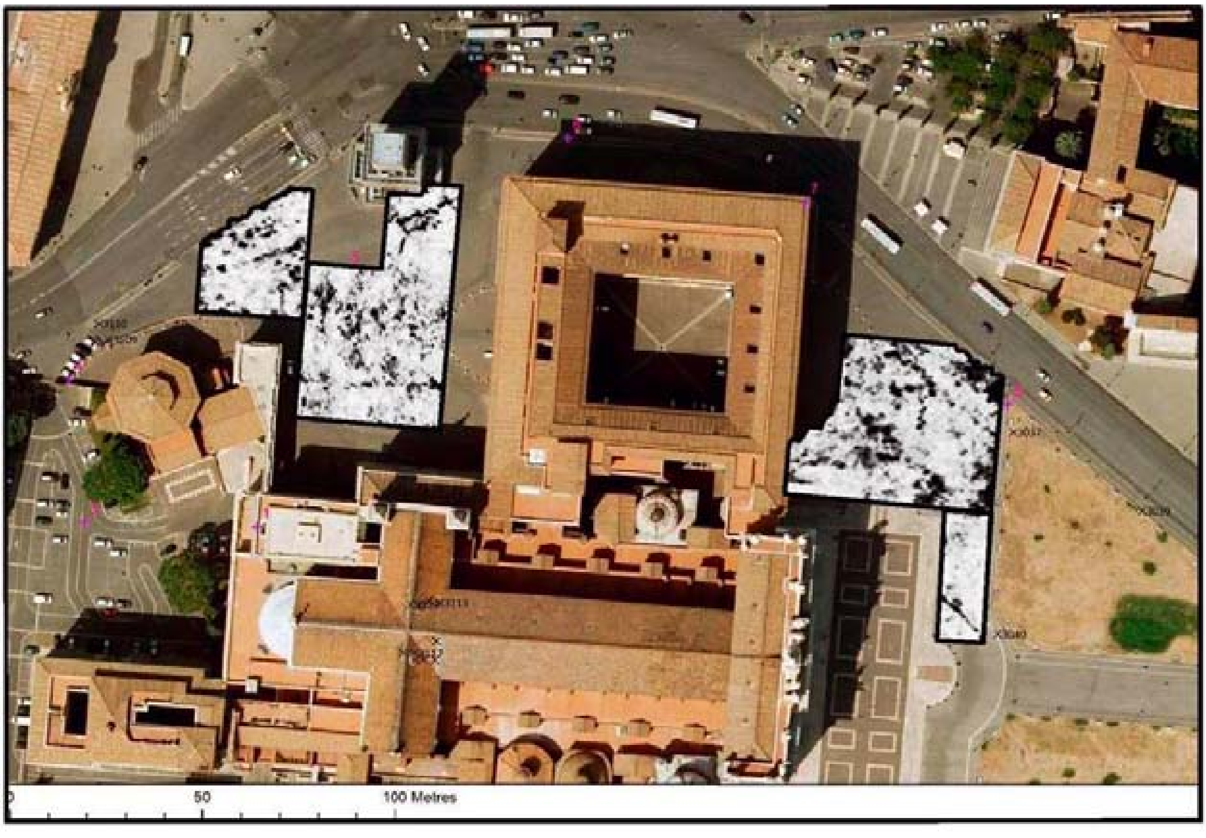

Figure 4: *S. Giovanni in Laterano square. GPR time slices in the time window 112-118 ns (estimated depth 2.6 m) for 70 MHz antenna.*

ASSESSING THE CONDITION OF THE ROCK MASS OVER THE EUPALINIAN TUNNEL IN SAMOS (GREECE) BY THE USE OF MULTIPLE GEOPHYSICAL TECHNIQUES

G.N. Tsokas, P.I. Tsourlos, C.B. Papazachos, J.-H. Kim, G. Vargemezis

1. THE TUNNEL OF EUPALINOS – PROBLEM SETTING

The surviving tunnel of Eupalinos (Greek: Efpalinos) comprises one of the greatest engineering achievements of the ancient Greeks. The tunnel itself was carved through solid rock (limestone) by digging from both ends and advancing to the central meeting position.

This way of digging was revolutionary at the time of the construction (6^{th} century BC), and the method used for maintaining the course of the two tunnels and achieving their meeting is still unclear. The ancient Greeks had no magnetic compass and no surveying instruments. Further, no tools like topographic contour maps (or any other kind of terrain depiction) existed, which in our day are considered obvious and absolute necessities for such a technical achievement. Further, as far as we know, the level of mathematical knowledge at that era was not adequate to support the construction. The "Elements" of Euclid appeared at least two centuries later, while a practical method for advancing from both ends of a tunnel is described by Hero of Alexandria only after three additional centuries (Apostol, 2004).

In order for the two sections of the tunnel to meet under a 160 m thick solid rock (Figure 1), Efpalinos would have needed a geometry-based method (Van der Waerden, 1968; Burns, 1971). This method is still unknown, because no convincing explanation exists. In fact, Goodfield and Toulmin (1965) and Apostol (2004) strongly question the applicability of Hero's method on the particular terrain of Samos.

The Eupalinos construction consists of three individual units: the 1,036 m long tunnel through the limestone, and two sections of duct (Figure 1). The northern duct section is about 895 m long and was used to bring water from the spring of "Agiades" to the northern entrance of the tunnel. Another 620 m of subterranean duct connects the southern entrance with the fountains of the ancient city. Note that the wall of the ancient city of Samos runs on top of the "Ampelos" hill. Therefore, the ensemble of the constructions associated with the tunnel comprise a well-designed water supply system.

The tunnel itself consists of two parallel shafts. The main one, which is 2 m wide and 2 m tall, and a trench cut in one side of the floor. The trench comprises the second shaft, and is 0.60 m wide and exactly 3.8 m deep at the north exit and 8.9 m at the southern exit. Therefore, the trench has a slope of 0.36%, which is adequate for water to flow freely.

Archaeological evidence shows that the whole system was used for about a thousand years. After some limited excavation and a survey in the 19^{th} century, the systematic study and cleaning was done by Kienast (1995) at the end of the 20^{th} century. The beauty of the ancient construction can be seen in Figure 2.

There has been damage to the ancient lining, visible manifestations of the existing failures of the stability of rock mass due to tectonic action. Therefore measures have to be undertaken which will heal the damages and preserve the monument

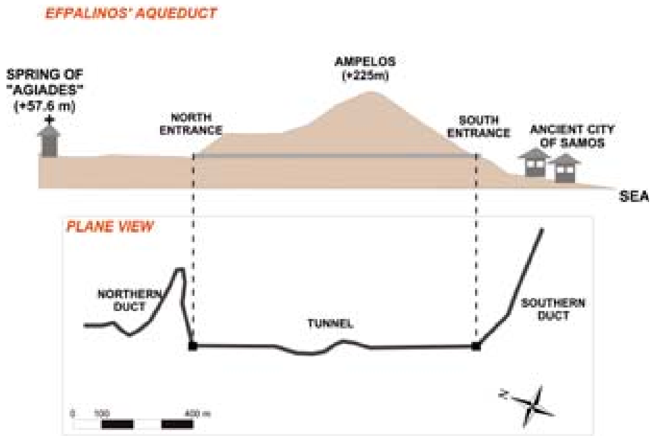

Figure 1: *Schematic representation of the constructions which compose the water supplying system of the ancient city of Samos. Both the design and supervision of the workings was done during the 6^{th} century B.C. by the engineer Eupalinos (Efpalinos in Greek) son of Nafstrophos from Megara (near Athens) as reported by Herodotus in his Histories (3.60) (http://en.wikipedia.org/wiki/Herodotus). The tunnel through the massive Limestone rock is named after him. Two buried ducts are associated with the tunnel, the northern one to bring the water of "Agiades" to the main tunnel and the second one to feed the fountains of the city.*

Figure 2: *View of the main tunnel. The metal grillwork is a modern safety construction to cover the trench of the lower tunnel.*

while securing the safety of the visitors.

A much needed geotechnical study was carried out with the aid of the geophysical survey described in these pages. The aim of the geophysical survey was to image the subsurface from the ground surface to the ceiling of the tunnel.

Conventional methods (VLF, SP, seismic refraction and Electrical Resistivity Tomography-ERTs) were employed, along with a relatively novel measuring approach. The latter consisted in laying out geophones and electrodes in a "tunnel to surface" mode and attempting tomographic imaging of the rock mass over the tunnel. Finally, the results of all the methods were integrated.

2. GEOPHYSICAL SURVEY FROM THE GROUND SURFACE

A number of VLF profiles were carried out on the slopes of the hill above the northern end of the tunnel. They were aimed at detecting the exact location of fractures and shear zones of the limestone. The goal was to detect fractures along the N-S and EW directions. Further, a 50 m wide shear zone was detected, which corresponds with observed instabilities along the tunnel.

Electrical resistivity tomography (ERT) surveys were carried out above the northern and southern end of the tunnel. The inversion technique of Tsourlos (1995), as modified by Athanasiou (2007a), was employed. The distribution of the resistivity for the northern ERT supports the VLF data interpretation. In fact, fractures are inferred by both methods. The ERT provided good images of the low resistivity areas (shear zones) formed by the action of the fractures. In turn, these zones are the cause of instability in the rock mass, and the observed failure of the tunnel lining. The southern ERT revealed that the tunnel crosses a shear zone.

Seismic lines were shot over the projection of the tunnel at the northern and southern edges. Both P and S waves were produced using a sledgehammer. The general reciprocal method (Parker, 1986) was applied first. Then, the outcome was considered as initial model for the inversion of the data, which was performed using the scheme of Soupios *et al*. (2001).

Since only one geological unit exists in the area, any variation of the seismic velocities reflects the condition of the Limestone rock mass. For the northern part, this was found to be healthy wherever the velocity of the P waves (Vp) is more than 2.0 km/sec. Further, the lateral distribution of velocities showed strong variations due to the intense tectonics.

The simultaneous measuring of both the P and S wave velocities enabled the assessment of the mechanical properties of the rock mass. In general, the subsurface models yielded using the seismic method are in agreement with the results of the ERT and VLF surveys.

3. NON-CONVENTIONAL GEOPHYSICAL SURVEY – SURFACE-TO-TUNNEL MEASUREMENTS

It is well known that the conventional surface ERT measurements show reduced sensitivity with depth. In our case, the Efpalinos tunnel is situated at about 50 m below ground surface, a fact that implies the low resolution of the surface ERT at the depth of the tunnel. Therefore, we decided to place electrodes in the tunnel and carry out ERT measurements in a "surface-to-tunnel" mode (Sasaki and Matsuo, 1993).

The electrodes were spaced 5 m apart, both on the ground surface and in the tunnel. The positions of the electrodes on the surface were identical to the positions used for the surface ERT. Further, the electrode locations in the tunnel are at the orthogonal projections of the respective surface electrodes.

Bentonite mud with some salt added was used as electrodes. This kind of electrical coupling has been proved to be functionally excellent (Tsokas *et al*., 2006; Tsokas and Tsourlos, 2007a; Athanassiou, 2007b; Tsourlos and Tsokas, 2007; Tsourlos and Tsokas, 2011).

Before attempting the "surface-to-tunnel" survey, we constructed several computer simulations of the tunnel and produced synthetic data in order to assess the effect of the tunnel on our measurements. The results suggested that the tunnel effect is generally limited and can be ignored.

Measurements were performed using the pole-dipole array. The entire dataset involved measurements including electrodes only on the surface, electrodes only in the tunnel, and electrodes both on surface and in tunnel. The inverted geoelectrical image is shown in Figure 3. The outcome of the "surface-to-tunnel" tomography produced a higher resolution image of the subsurface, which is compatible with the results of the standard surface geophysical methods. The space between 60 m up to the 80 m is better imaged than in the result of the ground surface array. In this area, a fractured zone was detected by the conventional tomography.

Next, a "surface-to-tunnel" seismic survey was conducted. Geophones were placed at the same places where the electrodes had been previously placed. The array of the geophones was shot from various points on the ground surface. Thus, seismic arrivals were recorded both at the geophones on the ground surface and at those which were placed in the tunnel. Inversion of the seismic data was performed by custom software. Figure 4 shows a preliminary inversion result (tomography) where the fractures and the shear zones inferred by the surface data have been drawn with black colour.

4. CONCLUSIONS

The combined and integrated use of conventional and relatively innovative geophysical methods assessed the tectonic regime above the Eupalinean tunnel in Samos. Fractures and shear zones were detected and imaged. Therefore, the geotechnical survey has been aided in proposing the correct measures for restoring and securing the construction. The increased resolution of the "surface to tunnel" imaging demonstrates the significant advantage of including these methods.

ACKNOWLEDGEMENT

The authors are greatly indebted to George Aggistalis, Constantinos Zambas and Mrs Maria Viglaki, director of the 21st Ephorate for Prehistoric and Classical Antiquities, who supported our study in various ways.

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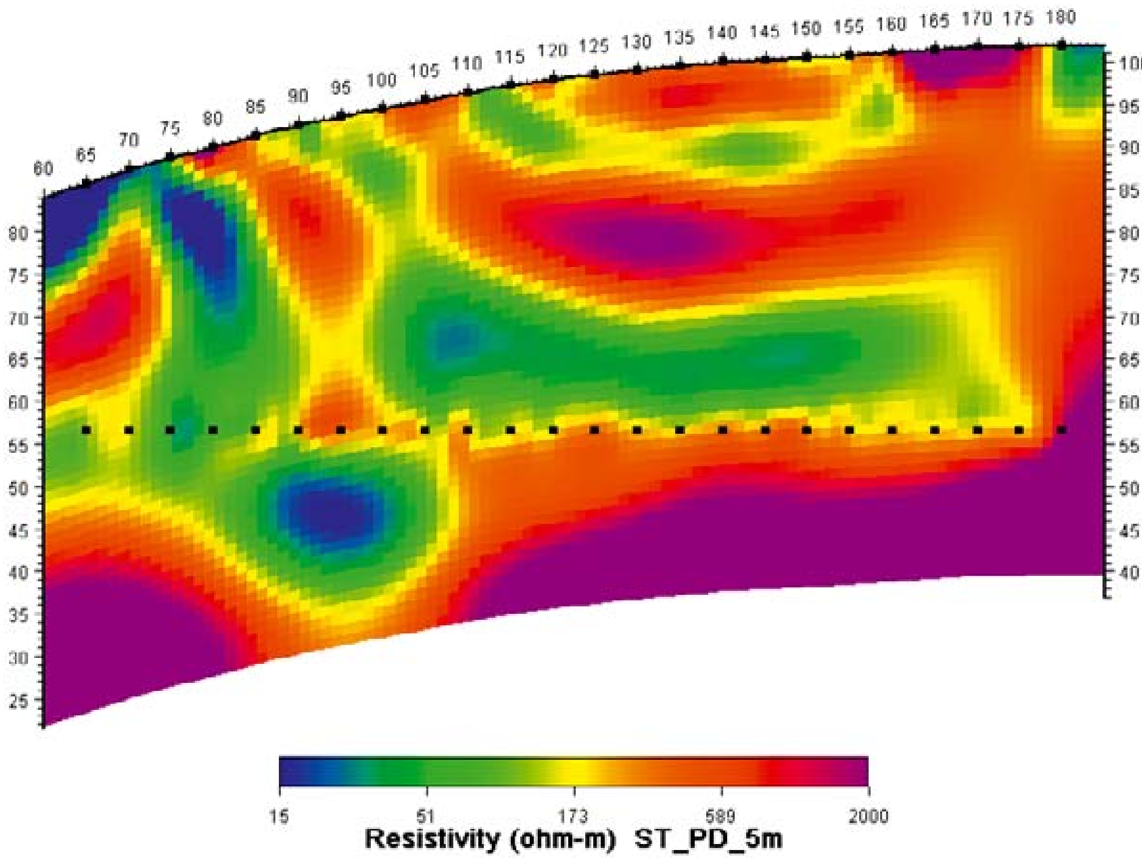

Figure 3: *Inverted ERT image of the "surface-to-tunnel" data-set.*

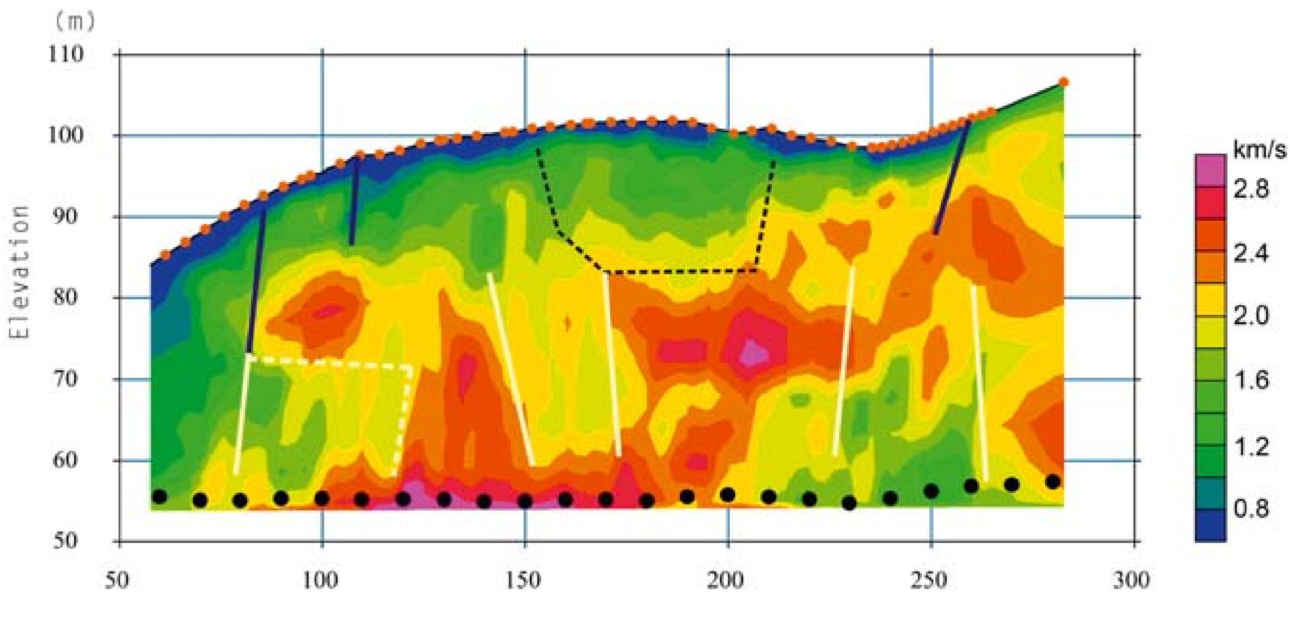

Figure 4: *The velocity structure of the northern part of the tunnel as inferred by the inversion of the "surface-to-tunnel" data. The black solid lines depict the fractures yielded by the conventional geophysical methods while the white ones comprise those resulted from the interpretation of this image. The dotted lines enclose shear zones.*

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AERIAL PHOTOGRAPHY AND GEOPHYSICAL PROSPECTION IN NORTHERN CAUCASUS – NEW RESULTS FROM THE KISLOVODSK BASIN

D.S. Korobov, V.Y. Malashev, J.W.E. Fassbinder

1. REGION AND MAIN STAGES OF PREVIOUS INVESTIGATION

The Kislovodsk basin is part of the unique Caucasian Mineral Waters area the North Caucasus region of Russia. It includes the town of Kislovodsk and its environs up to the hills of the Borgustan Range in the north, the upper reaches of the Podkumok River in the west, the Malij Dzhinal mountain in the east, and the Kich-Malka River in the south. This gives a study area with an extent of about 40 km east-west, 25 km north-south, 135 km along the perimeter, and covering over 835 km^2 (Figure 1).

A preliminary analysis of the archaeological evidence in the Kislovodsk basin, the earliest of which dates to the Aeneolithic, reveals several population peaks, as well as several gaps in settlement, which are so far difficult to explain. The most recent gap is in the 14th – 18th centuries when the region was practically uninhabited until 1803, the year the Russian fortress of Kislovodsk was founded (Afanas'ev *et al*., 2004, 69). That is why the local archaeological sites sustained little damage from anthropogenic activity and are in such good condition. However, the new town used a lot of stone from the nearby fortified sites, and the numerous kurgan (barrow) groups suffered badly from robberies, especially during the past fifteen years. The settlements which are further away from modern building sites, and the terraced fields and agricultural land plots with stone walls for boundaries (which look like the 'Celtic fields' of north-western Europe), have suffered no damage and now constitute a kind of 'archaeological reservation' where we can still discover new types of structures (Reinhold *et al*., 2007).

Since the mid 1990s, a large-scale project for the creation of the Kislovodsk Archaeological GIS, headed by Afanas'ev, has been in progress in the region. As part of the project, field surveys in 1996 – 2000 described about 800 archaeological sites from various periods, including many early medieval settlements and strongholds, and mapped those using GPS. The wide-scale survey doubled the number of archaeological sites known in the area.

Since 2000, we have been studying in more detail the early medieval fortified settlements in the basin and their economic zones, using multidisciplinary approaches (Afanas'ev *et al*., 2004, 71-77; Reinhold and Korobov, 2007, 197-200; Korobov, 2012, 44). Spatial analysis of the sites in GIS is conducted with the help of aerial photography and satellite imagery, and field research is supported by geophysical prospection.

2. TRACES OF EARLY ALANIC OCCUPATION IN THE REGION.

There can be no doubt that the early Middle Ages were the time of the greatest population density in the Kislovodsk basin (Korobov, 2012, 42-54). A preliminary survey and exploration of some defended settlements in the area led to the discovery of several early medieval artefacts from the 4th / first half of 5th centuries to the 7th – 8th centuries AD. Radiocarbon dates provide supporting evidence that defended settlements were in use for long periods of time that correspond to the dating of some pottery finds from the settlements and of grave goods from catacomb burials, excavated near some of them and generally considered to be of Alanic origin. The defended settlements on the top of the Borgustan Range are earlier, as shown by both radiocarbon dates and pottery finds datable to the 2nd – 5th centuries. Here, another type of defended site on natural elevations or promontories with artificially accentuated slopes ('escarpments') was discovered, most of which are situated on top of the Borgustan Range (Figure 1). Taking into account the earlier dates for some of these sites and their analogies among the so-called 'earthen fort hills' of the Early Alanic culture of the 2nd – 4th centuries AD (Arzhantseva *et al*., 2000), it is possible to suggest that the middle reaches of the Podkumok were a defended border between the Alanic population to the north, and local Caucasian peoples to the south in the time before the Hun invasion of the North Caucasus.

3. AERIAL PHOTOGRAPHY AND GEOPHYSICAL PROSPECTION OF NEW EARLY ALANIC SITES.

According to the assumptions described above, aerial photos from the early 1970s were investigated. The structures typical for Early Alanic defensive and burial sites were recognized on one photo made in September 1970. The hillfort with accentuated slopes ('escarpments') (Figure 2, 1) accompanied by a number of small burial mounds are readily recognizable on the image. Some of the mounds are surrounded by linear structures of square form recognizable on the photo because of white colour that could be interpreted as square ditches. In the centre of the cemetery, a huge barrow ('kurgan No 1') partly destroyed by ancient plundering is found (Figure 2, 2); the shape and dimensions of this burial structure is typical for the Early Bronze Age. Two plots for geophysical prospection were chosen in May 2012. The smaller (plot 1), 80 × 80 m and located to the west of the 'kurgan No 1', includes the largest square structure recognizable on the photo (Figure 2, 3). The larger (plot 2) has an area of 120 × 160 m, is located to the east of the 'kurgan', and has the most dense concentration of traces of small burial mounds (Figure 2, 4). The modern surface of the areas of investigation is very flat and does not contain any traces of burial mounds, which were destroyed by ploughing activity in the Soviet era.

4. RESULTS OF MAGNETOMETER PROSPECTION.

For the magnetometer measurements, we used the Cesium Smartmag SM4G-Special magnetometer in a duo-sensor configuration. This total field magnetometer enables us to detect magnetic anomalies with the highest possible resolution of ±10 Picotesla combined with a comparatively high spatial resolution of 25 × 25 cm. The diurnal variations of the Earth's magnetic

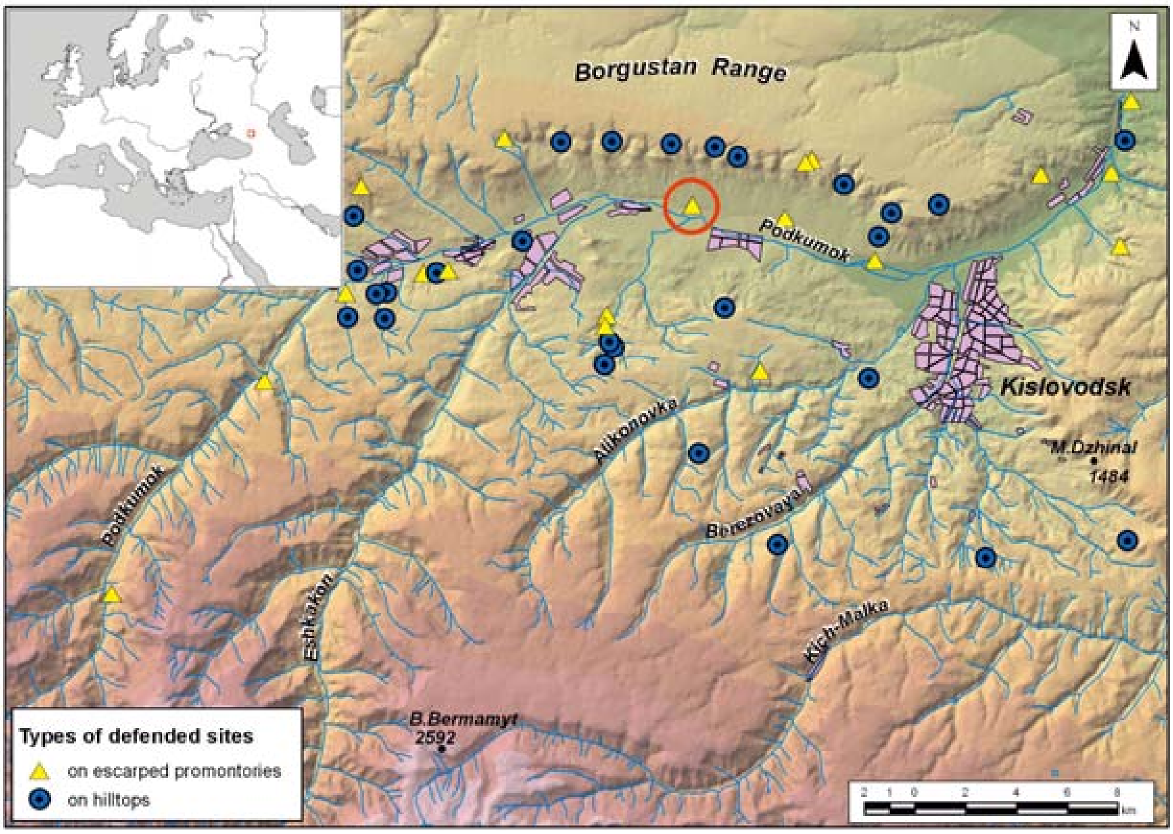

Figure 1: *Topographical map of the Kislovodsk basin with the distribution of defended sites of Early Alanic culture and place of integrated investigations (marked by red circle).*

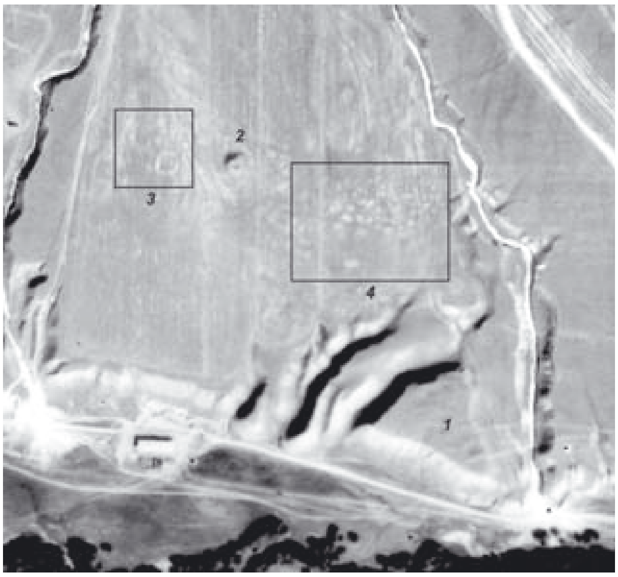

Figure 2: *Aerial photo of the site with geophysical prospection plots: 1 – fort hill; 2 – 'kurgan No 1'; 3 – plot 1; 4 – plot 2.*

field were reduced to the mean value of all data of each 40 × 40 m square and later matched to the data of the whole area. The configuration allows the detection of archaeological structures with the highest possible sensitivity of the instrument and the highest signal to noise ratio with respect to the archaeological anomalies. On the other hand, this configuration is also very susceptible to artificial and technical disturbances and rapid variations of the Earth's magnetic field. However, the application of the magnetometer in an uncompensated configuration was possible here because these sites are far from any technical installation.

The geology consists mainly of sand and small limestone gravels (diameter 0.1 - 5 cm) that is overlaid by a few centimetres (10-30 cm) of dark topsoil. This results in a high contrast of the magnetic susceptibility of ca. 500×10^{-6} [SI] units to ca. 30×10^{-6} [SI] units. The whole area was intensively used as farmland during the Soviet period. The resulting magnetogram of the two selected areas in the burial field are therefore in the first sight dominated by large erosion furrows that were carved in the slope of the hill as well as by the linear traces of the ploughshare. Nevertheless, all archaeological features can be detected very sharply by the magnetometer measurements. The first area (Figure 3a) contains traces of two Alanic burials that consist of a square shaped ditch ca 40-50 cm wide and a dark spot that marks the entrance to the catacomb. The largest structure (Figure 3a, 1) is associated with the white rectangular ditch recognized from the aerial image (Figure 2, 3). The traces of the old erosion furrows that were backfilled by topsoil reveals a positive (black) anomaly, the modern erosion canals show up by a negative (white) anomaly. The second area (Figure 3b) covered 120 × 160 m and revealed more than 20 square shaped enclosures in sizes from ca 5 × 5 m to 18 × 18 m, as well as numerous catacombs. In addition, three large rectangular and square

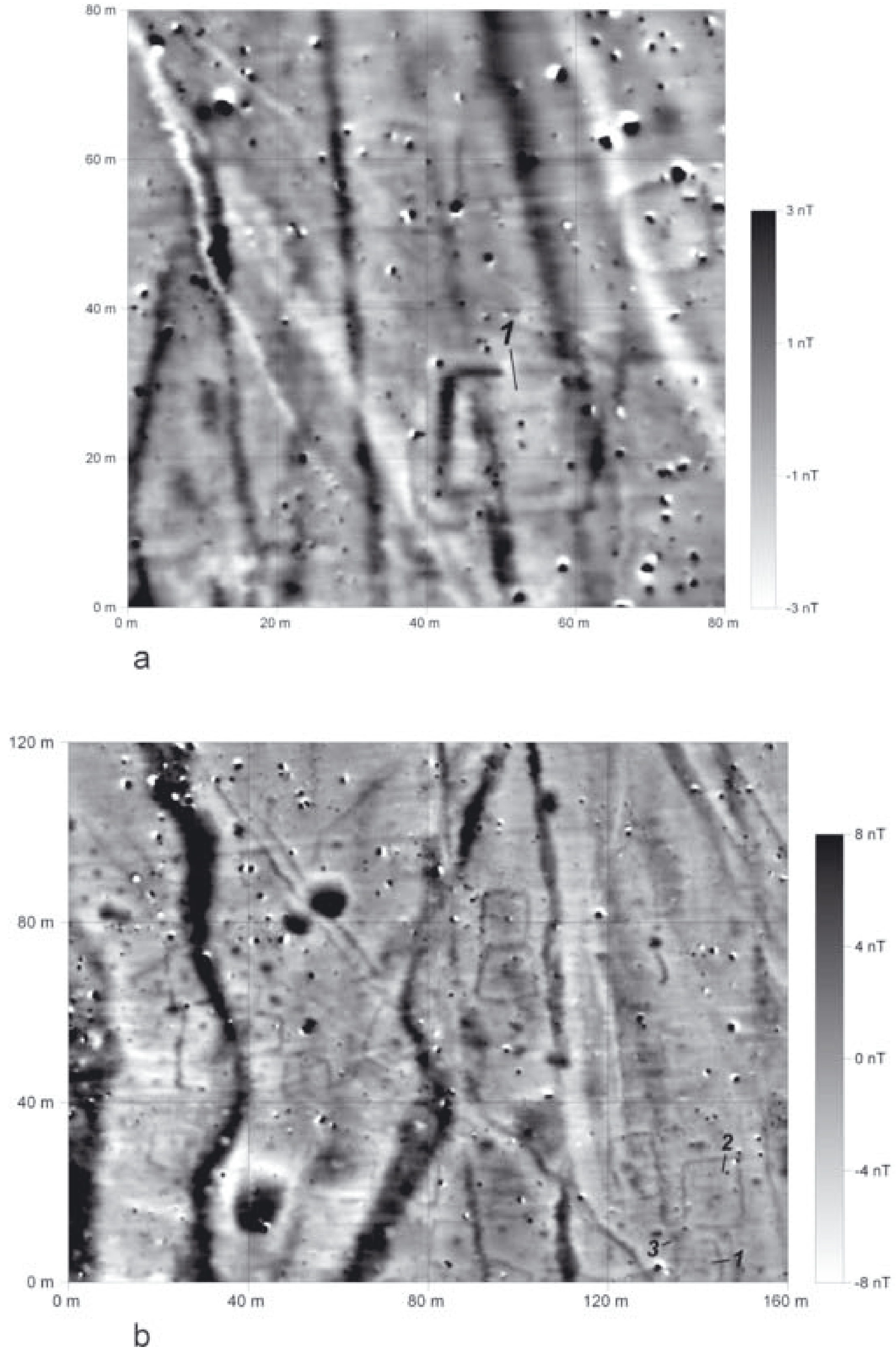

Figure 3: *Results: a) plot 1; b) plot 2 of the magnetogram of the Alanic kurgan field. CS-magnetometer in duo-sensor configuration, sensitivity 10 Picotesla (pT), intensity of the total Earth's magnetic field: 49.770 ±20 nT, dynamics (a) ±3 nT and (b) ±8 nT in 256 grayscales, grid size (a) 20 × 20 m and (b) 40 × 40 m, sampling rate 0.1 sec, sampling space 12,5 × 50 cm, interpolated to 25 × 25 cm.*

Figure 4: *View to the process of excavations of burial mounds 1 and 2 with rectangular ditches surrounded main chamber graves with round shape entrance pit of two-chamber grave in between.*

shaped pits of unknown function were located, along with erosion furrows. The irregular spiky sharp black/white anomalies can be ascribed to large gravel stones (diameter 20-40 cm) of basaltic origin with a high remnant magnetization and magnetic susceptibility values of up to 40 000 $\times$ 10^{-6} [SI] units.

5. RESULTS OF ARCHAEOLOGICAL EXCAVATIONS.

The conclusions obtained from interpretation of aerial images and magnetometry were checked in the field in September 2012. Two structures situated in the southeast corner of plot 2 were chosen for excavations as burial mounds situated in the closest distance to the hillfort. The excavations confirmed the interpretation of both structures as burial mounds surrounded by ditches of square forms (Figure 4). Burial mound 1 was limited by a ditch of 12 $\times$ 12 m with the entrance passage from the south; it was left out of the magnetometry plot (Figure 3b, 1). Burial mound 2 was surrounded by a ditch of 14 $\times$ 14 m with two entrance passages made in the south-west and south-east corners (unique case in the Northern Caucasus) (Figure 3b, 2). Both mounds were erected around the chamber ('catacomb') graves with the entrance pits of west-east orientation and underground chambers plundered in ancient time. Even the burial structures were heavily damaged and partly destroyed by robbers, although some human and animal remains were found accompanied by several grave goods characteristic for the first half of the 4th century AD.

Besides two burial mounds, another structure of round shape recognizable in magnetic plan was excavated (Figure 3b, 3). The structure opened here was a two-chamber catacomb grave from the middle of the 4th century AD, which was completely destroyed by plundering in the Middle Ages. Small test excavations were made on the western part of the hill where the traces of settlement area of the 3rd – 4th centuries AD were found. These indications of the occupation period of the hillfort could be connected with the burial structures found on the aerial photos and by magnetometry.

The integrated approach used by the authors seems to be the most effective way to discover and investigate the traces of the Early Alanic culture in the Northern Caucasus. The multidisciplinary research of the sites of these periods found in the Kislovodsk basin will continue. The project was supported by grants of Russian Foundation for Basic Research (No 12-06-00072 and 12-06-10007).

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ARCHAEOLOGICAL ANALYSIS OF THE RIJCKHOLT NEOLITHIC FLINT MINES SURFACE AREA

J. Orbons, J.W. de Kort, J. Deeben

Over a six year period, the Cultural Heritage Agency of the Netherlands (RCE) has conducted a large scale prospection around the Neolithic flint mines in the Rijckholt area in the south of the Netherlands. The prospection was aimed at trying to gain more archaeological information of the area around the well-studied flint mines. Specifically, the project seeks to find the Neolithic settlement of the flint miners, to try to delimit the extent of the flint mining area, to analyze the landscape and to gain insight into erosion processes and related threats to the archaeology.

The prospection consisted of field-surveys, interviewing local archaeologist and mapping their collections, augerings, geophysical surveys, trial trenches and excavations. The presentation will give an overview of the area studied and present some of the prospection results, but will mainly focus on the geophysical results in relation to the other archaeological studies. Several areas were surveyed, mainly with resistivity.

The area around the known flint mines was surveyed with resistivity to find shafts. Parts of that area had been excavated in 1964, but the location was not well documented. The survey traced the shafts and gave a good indication of the limit of the Neolithic shafts. Selected areas were surveyed with resistivity and magnetics to try to locate the Neolithic settlement. The areas were chosen based on surface finds and LIDAR analyses. Some linear structures were detected, although they were very obscure. Trial trenches proved they had no Neolithic origin.

An area with surface finds relating to flint-knapping rough flint was surveyed with resistivity. Nearly a hundred point like anomalies were found. The size and spatial distribution of these finds were very similar to the known flint mines. Augerings proved they were shaft-like structures. A trial trench proved it was a shaft filled with Neolithic material. There is still a discussion going on about the actual process of the filling of the shaft as it looks like there is a combination of anthropogenic activity and natural processes.

Figure 1: *Filled in shaft-like structure as detected with resistivity measurements.*

INTEGRATING GEOPHYSICS AND GEOARCHAEOLOGY FOR A HERITAGE MANAGEMENT TOOLKIT IN WETLANDS: SHAPWICK HEATH CASE STUDY

C.J. Bunting, N.P. Branch, S. Robinson, P. Johnes, L. Jones

Wetlands are a non-renewable resource of high potential for organic archaeological deposits and palaeoenvironmental reconstruction. This resource is at threat both through anthropogenic factors such as peat milling, and natural decay associated with global warming. Only a small percentage of the identified wetlands in North West Europe have been studied with regard to their depth, stratigraphic architecture and the heritage assets they contain. Understanding the heritage resource potential of lowland wetlands is critically important for the future management of cultural remains. Ground Penetrating Radar (GPR) is the primary non-destructive investigative technique suited to use in a wetland environment (Utsi, 2007). Although it has been shown to work well in some situations (most noticeably ombrotrophic bogs), it is still considered to be of very little use in other wetland situations particularly where the sediments are saline or contain clay. To enhance our understanding of the application of GPR to wetlands, data has been collected from five carefully selected wetland sites known to be associated with archaeological remains. Each of the sites is representative of different wetland environments and, more specifically, different sedimentary facies that are often found to contain important archaeological deposits, including ombrotrophic bog, fen bog, fresh water clays and silts, brackish-saline clays, and silts and sands. These different types of sediment present different challenges to GPR because of the physical and chemical properties of the sediments, and therefore they permit us to establish the limitations of GPR in wetlands.

The research will also explore the relationship between data from GPR surveys and the information required by geoarchaeologists. The focus is upon the implementation of a new methodology of ground validation to assess how dielectric permittivity and the strength of reflections relate to important geoarchaeological properties such as organic content, particle size distribution, magnetic susceptibility and the presence of a range of major and trace chemical elements. Links between each of these properties and ones known to affect the electromagnetic wave such as water content, porosity and electrical conductivity will be investigated through collection and laboratory analyses of sediment samples both at the surface and at depth in the survey area.

This paper presents the results of a GPR survey carried out at a site of international importance, the Sweet Track at Shapwick Heath (Bunting, 2012). The site-specific aim was to detect the Sweet Track north of the Shapwick Burtle, where its position is known from previous excavations, and determine if it is feasible to use this technique in an exploratory capacity to investigate if the trackway continues south of the Burtle, linking it to the Polden Hills. The results of the survey indicate that many anomalies can be identified including local stratigraphic units important for placing the previously excavated archaeological features in a more detailed landscape and environmental context. The location and nature of some smaller reflections suggest they may be archaeological remains but the failure of the higher frequency antenna to give higher resolution results makes it difficult to interpret these anomalies any further.

The area investigated is situated north and south of the eastern tip of the Shapwick Burtle (NGR: ST 4220 4020) in the Brue Valley, Somerset (Figure 1). The Sweet Track (monument no. 1014438) and Post Track are known to extend to the north of this feature and have been excavated in several sections. The most relevant to this study is that of the terminal site of the Shapwick Burtle excavation (Coles *et al*., 1973) and the Droveway (Coles and Orme, 1979) and Factory excavations (Coles *et al*., 1973), slightly further north.

This site has proved to be particularly beneficial for this research as a wide range of wetland sediments are encountered. The local geology of the area is a Lias (clay with limestone), of which the Westhay 'island' is composed. The Burtles in the area, including Shapwick Burtle, consist of sands and gravels (British Geological Survey, 1973). The majority of the Brue Valley is overlain by estuarine alluvium, alluvium and peat (Coles *et al*., 1973). Much of the Shapwick Nature Reserve is wooded with areas of wetter land colonised by reeds, although the area investigated in this study (Figure 1) is relatively flat land with a vegetation of short grass, and is currently used for cattle grazing.

Since this area of land has passed into the ownership of Natural England, attempts have been made to prevent it drying out to allow the archaeology to be preserved in-situ. Additionally, recent studies have involved the monitoring of water levels and chemistry to assess how well the trackway is being preserved using sediment cores and water samples collected from piezometers at locations along a north-south transect offset from the trackway to the east by 5 metres (Jones, 2009). The N-S GPR transect follows this line and has been compared to the core descriptions to aid interpretation of the stratigraphy (Figure 2). Previous geophysical surveys at this site include two GPR grids where the trackway is being preserved in a bounded area to the north of the area of study. Here the trackway was successfully imaged (Utsi, 2001; Armstrong, 2010). A grid surveyed in the Burtle area failed to identify the trackway and other techniques including ERT and magnetic methods were considered less reliable (Armstrong, 2010).

GSSI SIR20 equipment was used to conduct the survey with a survey wheel to accurately measure distances from points along and at the ends of transects located using a Leica RTKGPS. Fourteen standalone transects were collected using a 200 MHz centre frequency antenna (Figure 1), the first running approximately north-south 270 m along the monitoring transect described above. The other thirteen transects were collected perpendicular to and starting on this transect (in an approximately east-west orientation). The real time observation of these transects was used to select the location of a 15×15 m grid area for more detailed survey south of the Burtle on east-west transect 11 (Figure 1). This grid was surveyed with a 200 MHz centre frequency antenna at 0.5×0.02 m sample interval and a 400 MHz centre frequency antenna at a 0.25×0.02 m sample interval. Pro-

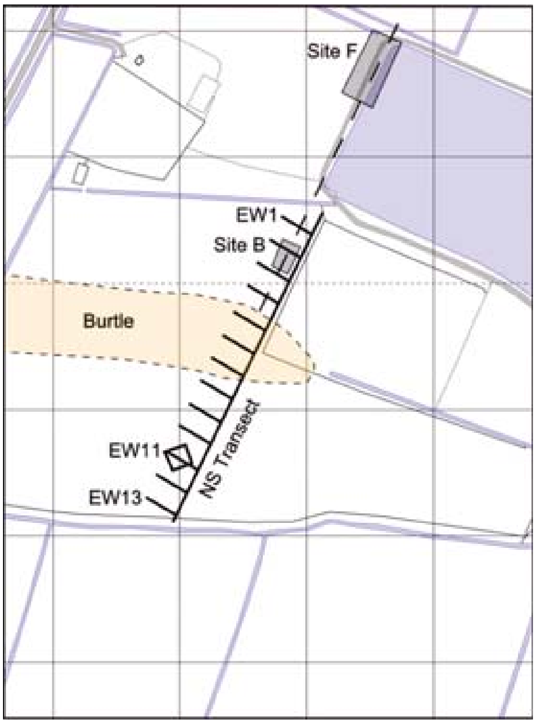

Figure 1: *Map showing the locations of excavations at site B (Burtle) and site F (Factory) (Coles et al., 1973), the north-south GPR transect (also the transect used by Jones (2009)), the 13 east-west GPR transects and the grid from the GPR survey. Grid lines are at 100 m and north is at top of page.*

cessing steps applied on data collection include a background removal, time-zero correction, a gain using eight points and a band pass filter. Post-acquisition processing using Radan 7 software included horizontal stacking of the north-south transect, additional time-zero correction and subtraction of mean trace. As the north-south transect went over the Burtle, incurring a large topographic variation, the data were imported into Reflex for topographic correction using GPS data collected at 5 m spacing. The data used to construct the 3D grid was also migrated using an average sub-surface velocity of 0.06 ns and had a Hilbert transform of magnitude applied.

The main features successfully imaged by the GPR work carried out at this site include the subsurface outline of the sandy burtle the transect crosses, a possible channel of clay or reed peat and wood peat layers (Figure 3). The overall velocity used for time depth conversions of the data has been estimated as 0.06-0.07 m/ns calculated using the depth to a redox probe (at a known depth of 1.5 m) imaged in the profile and checked with analysis of point source reflection hyperbolas. The material the redox probe is sitting in is humified Sphagnum peat, which is therefore given a velocity of 0.06-0.07 m/ns. Velocities for other materials in this transect have been estimated using reflection hyperbolas as;

- clay/reed peat; 0.046 m/ns
- sand burtle; 0.143 m/ns
- wood peat; 0.059 m/ns

The nature of the reflections is also observed to vary depending on the type of material encountered.

In addition to these important stratigraphic units, the area of previous excavation has also been identified. Many smaller reflectors are interpreted as isolated pieces of wood, some of which are potentially archaeological material. A patch of strong reflection on the south side of the Burtle is interpreted as a clay layer. These results have shown that GPR does work in this type of wetland environment and has a great potential identifying main stratigraphic units and potential archaeological targets. The units picked up by the GPR broadly agree with the stratigraphy shown by Jones (2009) and Coles *et al*. (1973).

The 200 MHz centre frequency antenna has generally been very responsive to the underlying deposits with a depth of c. 80 ns (2.5 m) imaged clearly; below which the noise levels increase suddenly and dramatically (Figure 3). This is likely to be due to the clay layer at this depth (Jones, 2009 and Figure 2). The results from the 400 MHz centre frequency antenna were expected to better resolve those features identified in the 200 MHz grid nearer the surface, but they are generally very poor. This is thought to be due to poor coupling of this lighter weight antenna with the uneven ground surface. The signal for this frequency also became attenuated at a much shallower depth of 39.99 ns (1.2 m).

There are two main outcomes of this research. First, we now have a greater understanding of the limitations to GPR in different types of wetlands. This has important implications for the future management of wetlands by identifying areas where wetland sediments have good potential for GPR survey, and those areas where it will be less effective and other methods need to be used. Secondly, the results from this project will improve the interpretation of GPR surveys carried out at wetland sites. This includes the identification of archaeological monuments and structures, but also identification and mapping of local stratigraphic units important for setting archaeological sites in a landscape and sedimentary context. This will not only improve interpretations of wetland sites, but also act as a guide for targeting future excavations.

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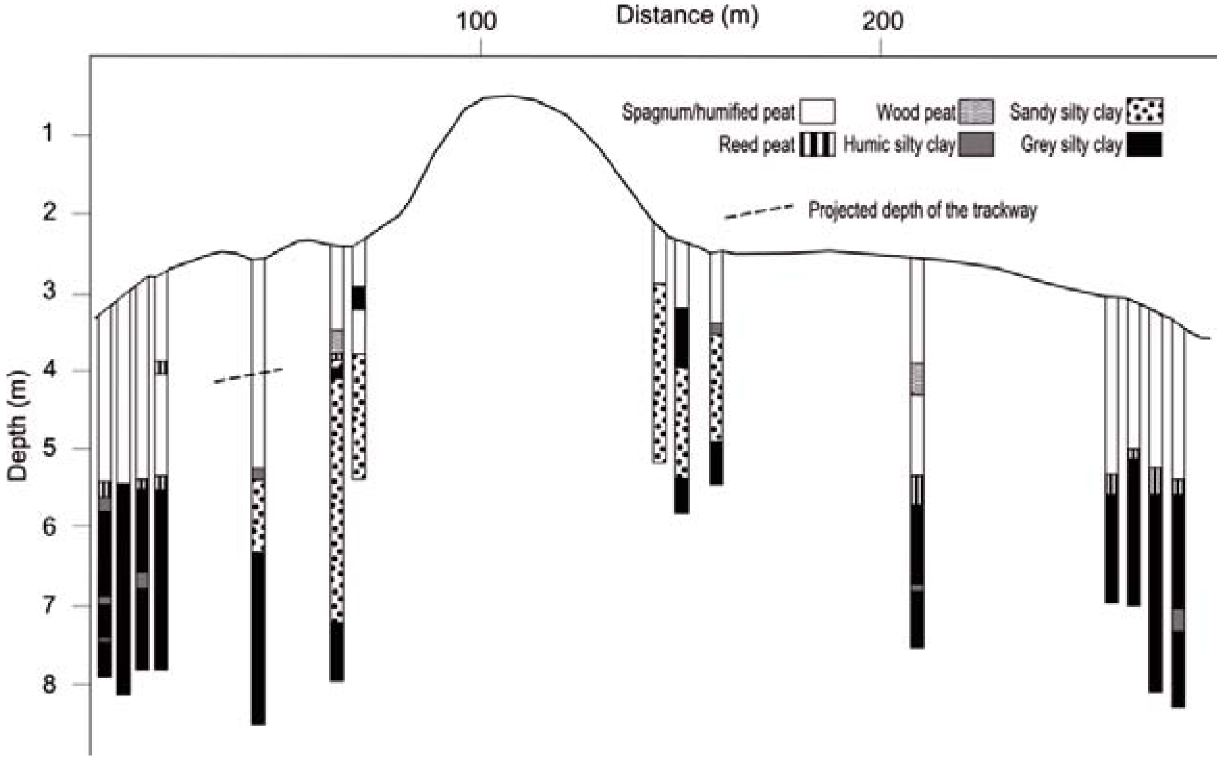


Figure 2: *Sediment logs from the north-south transect adapted from Jones (2009).*

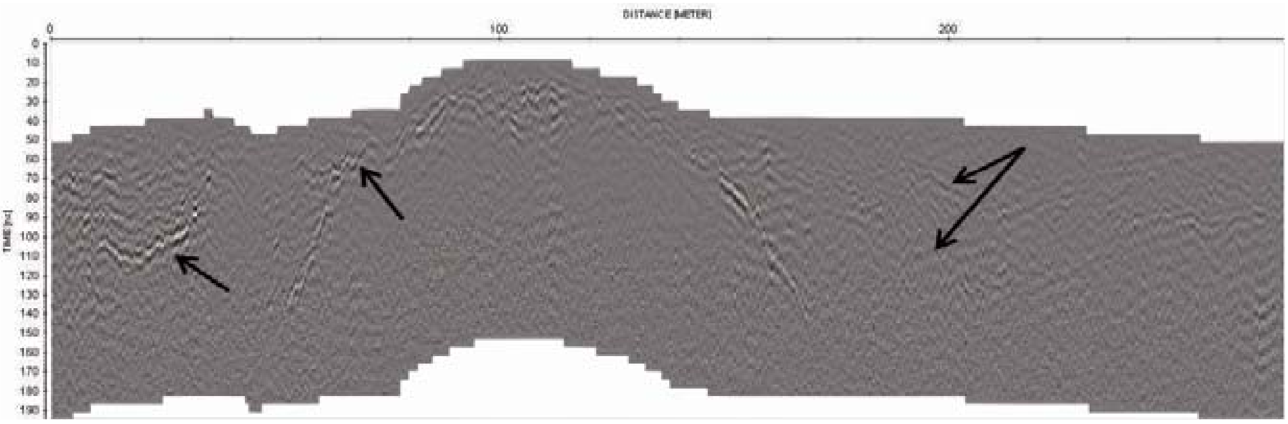


Figure 3: *200 MHz north-south transect topographically corrected, arrows indicate features referred to in the text.*

LARGE SCALE ARCHAEOLOGICAL PROSPECTION: CASE STUDIES FROM THREE YEARS OF FIELDWORK IN NORWAY

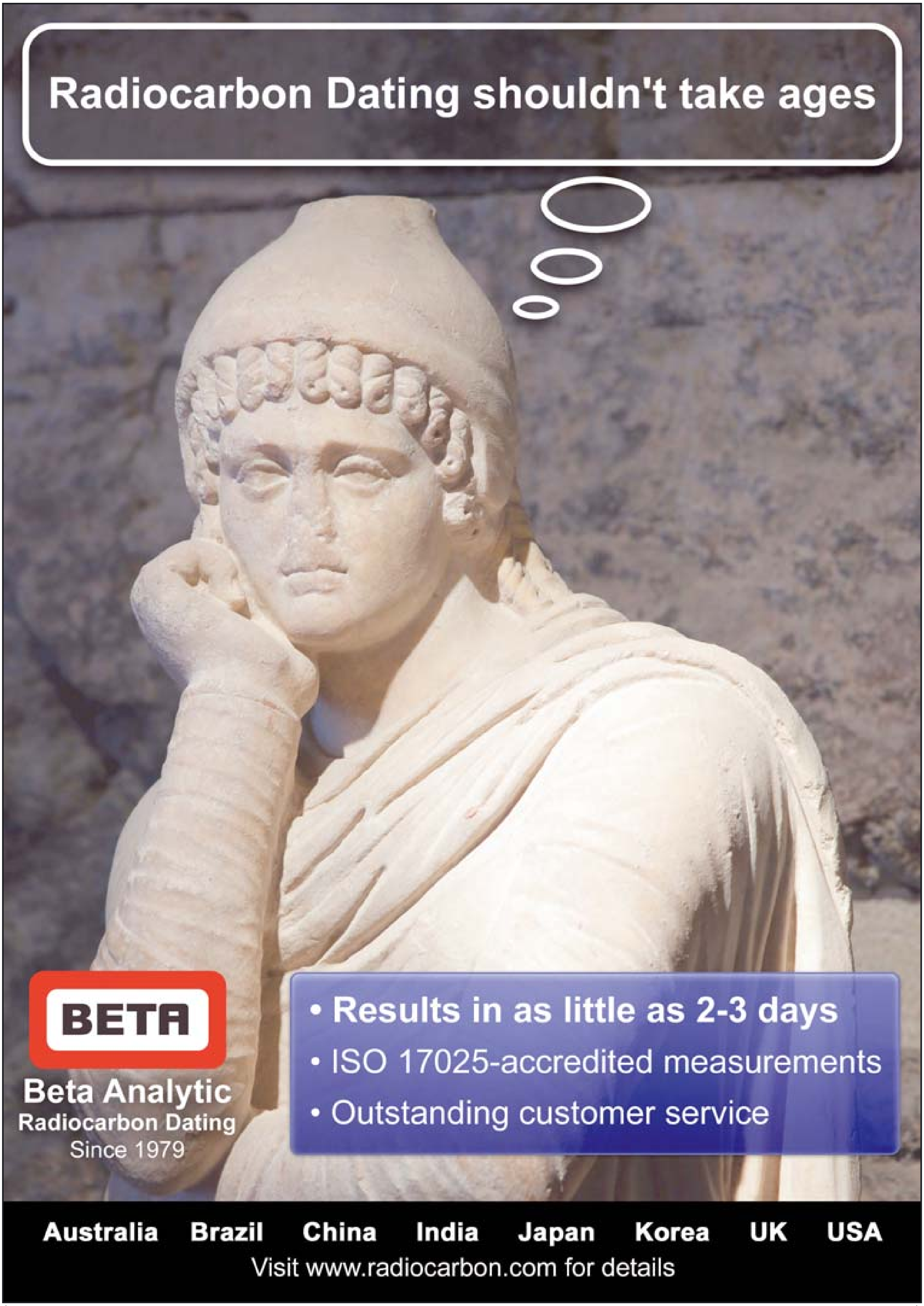
L. Gustavsen, C. Tonning, V. Lia, E. Nau, K. Paasche, T. Gansum, R. Filzwieser

In the last three years, a lot has changed for archaeologists in Norway concerning the use of digital archaeological data, and since joining the LBI ArchPro as a case study area in 2010, the possibilities of developing new and efficient non-intrusive methods has altered the way we explore and manage the cultural landscape. The combination of all available data sources makes it possible to construct and reconstruct the archaeology of past landscapes, and from a cultural heritage management perspective, the use of these sources facilitate informed decision-making and increased predictability.

The main approach for archaeologists working in the Norwegian counties the past 20-30 years has focussed on systematic test trenching in arable land. Although test trenching has the potential to uncover a wide variety of archaeological features and sites, little or no new methodology has been applied to this method concerning where the trenches should be placed in the landscape. In the planning process we have access to a variety of sources, including aerial photos, archives and usually historical maps. When none of these offer any indications of possible cultural heritage sites, however, we are forced to employ intrusive methods which may or may not prove successful in quantifying and assessing the state of the archaeology. Although test trenching undoubtedly has resulted in many remarkable finds and sites, the critique towards the use of these traditional methods is that they are time consuming and costly, in addition to being potentially damaging to the archaeological sites. Furthermore, where systematic trenching is employed one cannot be sure of the amount of archaeology in the areas between the trenches.

Some counties regularly conduct field walking surveys as well as systematic or random metal detector surveys. Furthermore, a few counties have also employed soil sampling techniques such as phosphate analyses. Archaeologists who are desperately searching for some vague elevation differences in ploughed fields that may indicate previous settlement traces or grave mounds are not uncommon in the Norwegian counties. The usefulness of these methods in terms of efficiency and results, however, can be questioned. Although there has been some sporadic use of geophysical surveys, these have largely been carried out on sites that are already known, and only a few results have been tested by excavation.

Large-scale archaeological prospection using high-resolution magnetometry and georadar in Vestfold County within the LBI ArchPro project has offered archaeologists in Norway new possibilities for detecting palaeolandscape and archaeological sites. Intertwined with the geophysical method of looking at past landscapes that are now arable land, the use of LIDAR is increasing in Norwegian cultural heritage management. Where the arable land ends, the non-arable and forested areas begin. While the use of geophysical methods can unveil archaeology beneath the plough soil, remote sensing by LIDAR unveils the complexity of the now forested and "invisible" archaeological landscapes. By combining remote sensing by LIDAR and large-scale geophysics, we now have unique possibilities to look beyond the modern landscape and create more comprehensive models of the past landscapes. In this presentation, we will discuss some possible scenarios for applying these methods on a large scale using Vestfold County as an example.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AN INTEGRATED GEOPHYSICAL APPROACH TO STONEHENGE

C. Gaffney, V. Gaffney, W. Neubauer, E. Baldwin, K. Löcker

The extent of previous geophysical prospection within the Stonehenge World Heritage Site up to 2001 has been estimated at 3.1602 km^2 (David, 2005, 14). Since that time, additional geophysical survey in the area probably amounts to about 0.8 km^2. The nature, spatial locations and extent of previous geophysical prospection work within the study area are broadly driven either by reactive evaluation strategies determined by the planning process and mitigation of proposed development, or by monument-focused research agenda, resulting in discontinuous, fragmentary, relatively small-scale and often linear rather than spatially-extensive survey areas (Payne, 1995, 2006; David and Payne, 1997; David, 2005; Darvill, 2005). These surveys have developed what we may regard as traditional monument/site-focused approach to field investigation. This has been a valid approach to answer specific project objectives. However, prior to the Stonehenge Hidden Landscape Project (SHLP), less than 4.0 km^2 of the landscape have been subject to geophysical survey of diverse types, with variable data resolution and uneven and fragmented spatial coverage. In contrast, the SHLP is producing a coherent high-intensity geophysical survey encompassing much of the World Heritage Site, providing high-resolution, contiguous extensive mapping of geophysical data.

As has been described in related articles and presentations (Gaffney *et al.*, 2012; Gaffney *et al.*, 2013) the intention of the SHLP is to explore landscape as undivided three-dimensional space and to understand ancient built environments and associated practices at extensive scales within that spatial framework. The results of this work form the basis of a highly detailed archaeological map of the 'invisible' landscape, providing the basis for a full interpretative synthesis of all existing remote sensing and geophysical data from the study area, as well as comparative evaluation of the results of archaeological excavation data in relation to geophysical results. The creation of total digital models of the Stonehenge landscape at a true 'landscape scale' that will not only transcend the immediate surrounds of individual monuments within the study area, but will also tie them together within a seamless map of sub-surface and surface archaeological features and structures. The massive scale and comprehensive nature of this dataset will allow for posing new questions about the past not possible using only information from surface remains or limited excavations. At the centre of the project philosophy is that the invisible landscape around the highly visible monument of Stonehenge remains key to the understanding of the monument itself.

In order to fulfil the objectives identified in Gaffney *et al.* (2013) there has been a requirement to take a significantly different approach to non-invasive work in the Stonehenge 'envelope' (defined by Cleal and Allen, 1995). There is a need to produce extensive but detailed data sets, which provide archaeological, pedological and geological information at differing depths. Geologically much of the survey area is said to lie above Late Cretaceous Chalk (Calcium Carbonate) approximately 85 million years old; the top layer is degraded by periglacial weathering during the last glaciation, which produced the underlying fracture patterns. The land has mostly been used for agricultural, but modern use, including 'festivals' and military activities, is well documented. The rolling landscape includes areas of both thin and deep soil cover, and mapping using a single technique, no matter how embedded in previous work, was not a supportable position.

As a result, the SHLP has developed a strategy for ground-based survey that is both extensive and flexible in the approach to a large landscape. Table 1 summarises the range of geophysical and other remote sensing data collection systems currently being used by the project team. The data rich environment that has been produced clearly relates to the primary objective of the project, which is to produce an uninterrupted dataset of above and below ground remains for archaeological analysis and reinterpretation within the context of the wider Stonehenge landscape.

In this presentation, the integration of differing techniques within the strategy will be illustrated, especially with respect to the objectives of the project. It will evident, even in a well provisioned project such as SHLP, that the key to success is deployment of appropriate techniques.

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Technique	Option	Feature	Landscape
Earth Resistance	Twin	X	
	Square	X	
Electrical Imaging	FlashRES64	X	X
Magnetometer	FF Motorised	X	X
	CV Cart	X	
	FF Cart	X	
	Bartington HH	X	
GPR	Mala Motorised	X	X
	S& S Motorised	X	X
	Single	X	
EM	Dualem	X	X
	CMD Mini-Explorer	X	
Laserscan	Leica/Riegl	X	X

Table 1: *Summary of Geophysical and other Remote Sensing Data Collection Systems Currently Used by the SHLP Project.*

SEARCHING FOR THE UNKNOWN UNKNOWNS. ALS DATA FOR ARCHAEOLOGICAL FEATURE DETECTION IN FORESTED AREAS OF SOPRON MOUNTAINS – A WORK IN PROGRESS

M. Stibrányi, G. Padányi-Gulyás

There are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns – the ones we don't know we don't know.

Donald Rumsfeld 2002.

Systematic archaeological topographic survey of forested areas has always been a difficult and uncertain task, and airborne laser scanning (ALS) technology was a remarkable leap forward in this field. More than a decade's worth of publications bear evidence that digital terrain models (DTM) derived from ALS hold significant archaeological potential, and different countries have explored that potential differently, according to their landscapes. In Hungary, research has mostly been limited to examination of some individual archaeological structures with ALS. In one case, it was also used for acquiring high-resolution DTM for archaeological prediction in low-lying wetland areas (Padányi-Gulyás and Stibrányi, 2011).

Large-scale ALS-based archaeological surveys of forested areas in neighbouring countries have already driven attention to the benefits of such approach (e.g. Doneus and Briese, 2011; Štular, 2011). However, no such initiative has been made in Hungary so far, partly due to financial reasons. As the preparation of a national ALS survey in Hungary is only a matter of time, it is urgent to explore the archaeological potential of such method in a Hungarian case study to raise the attention of stakeholders to this topic. It has become quite clear to the authors during our former experiences with ALS, that familiarity with the data collection process is essential in order to fully explore its archaeological potential. A DTM derived from ALS data is "not a given, 'objective' description of an existing relief. It is rather one possible representation, which more or less fits for the desired purpose" (Doneus and Briese, 2011).

According to a data transfer agreement between the Institute of Photogrammetry and Remote Sensing of the Vienna University of Technology and the Hungarian National Museum's National Heritage Protection Centre, we were authorised to use the dataset of an ALS survey of Sopron Mountains (Győr-Moson-Sopron County, NW Hungary) for archaeological purposes. The ALS survey was originally a part of an environmental monitoring project called ChangeHabitats2 (CH2), an environmental project aiming to develop cost- and time-efficient habitat assessment strategies by supporting fieldwork with modern airborne remote sensing techniques, i.e. hyperspectral imagery and laser scanning (LIDAR). Habitat indicators from airborne data will be used to preselect field sites of interest, to focus the fieldwork and to reduce fieldwork time. The project runs from 1/2011 to 12/2014 and is funded by the European Union, FP7 Marie-Curie Actions: Industry Academia Partnership Pathways (FP7-MC-IAPP).

During the project, a full wave-form ALS survey has been made in March of 2012 over 80 km^2 of the Sopron Mountains, with more than 12 ppm^2 density, which is ideal for archaeological purposes. The Sopron Mountains are considered one of the most researched forested areas in Hungary: four hillforts and barrows had been surveyed here (Nováki, 1997). In one case, a smaller area was surveyed with ALS technology (Czajlik *et al.*, 2012). It is important to see that these surveys only focused on places where surveyors expected to find archaeological features. However, one of the greatest benefits of large-scale ALS is the fact that the prospection is not narrowed down to these areas. Accordingly, we focus our research to the areas where no archaeological information is known to be present. Using the site reconnaissance potential of ALS survey, we mean to explore the opportunities of the method for the investigation of Hungarian landscape.

During the research, we process DTMs from the aforementioned ALS survey through our own resources using OPALS software, and evaluate the archaeological data. After that, we verify the results with field survey. In this paper we will discuss our experiences and initial results of research in progress.

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INTEGRATED PROSPECTION APPROACHES FOR ARCHAEOLOGICAL SITES IN THE ALLUVIAL PLAIN OF "CILICIA PEDIAS"

R. Rosenbauer, S. Erasmi, M. Novak, S. Rutishauser

This paper focuses on the added value created by combining different methods and illuminates the interaction of different prospection methods using the sites of Sirkeli and Margarsos as examples. An emphasis will be put not only on the question of how optical and radar data can complement each other, but also on the possibilities of “ground truthing” spaceborne technologies by the additional use of geophysical prospection. The potential of future sensors for the archaeological research of settlement clusters will be outlined, and propositions for hitherto undeveloped methods will be presented.

For several thousand years, the alluvial plain of Cilicia Pedias constituted an important settlement cluster at the juncture of Anatolia and the Levant. This extremely fertile and strategically important landscape is characterized by the sharp contrast between a vast plain and the steep, enclosing mountains of the middle Taurus or Amanus. Historically, this unique situation led to a constant change between historical phases with independent power structures in Cilicia and the integration of the plain into different foreign empires. Though the Cilician Plain spans the same area as Cyprus and is half the size of Sicily, only a few archaeological excavations have been established in this area to date. As a result, several questions of historical geography remain unanswered. In particular, important sites that have frequently been cited in literary sources, like the Hittite places of worship Kummanni and Lawazantiya, and the important city of Mallos, have yet to be located. The detection of these important sanctuaries and settlements is inseparably linked with the reconstruction of the natural environment of this area, so that the research of ancient riverbeds and coastlines will play a key role.

Since 2005, the Institute of Archaeological Sciences at the University of Bern, in co-operation with the Istanbul Üniversitesi and the Onsekiz Mart Üniversitesi (Çanakkale), has participated in research in this fascinating region. A particular focus is the combination of large-scale remote sensing and exploratory investigations of selected sites that are located along the Pyramos (Hittite: Puruna, today: Ceyhan River). The selected test sites differ in their temporal context as well as their location and function. Among these are a sanctuary from the imperial period residing on the foothills of the Taurus Mountains (Uzunoğlan Tepesi), a Bronze and Iron Age settlement mound proximate to the shore of the Pyramus (Sirkeli Höyük), and a heavily fortified Hellenistic harbour site located at Cape Karataş (ancient: Magarsos). The comprehensive research of these sites will comprise of a broad range of modern fieldwork and remote sensing methodologies.

Apart from the classic techniques of excavations and archaeological surface surveys, extensive geophysical prospection work (geomagnetism, geoelectrics and ground-penetrating radar) has been included. The mapping of the sites was conducted by geodetic surveys using tachymetric surveying and RTK-GPS, including the creation of small-scale reference DEMs (Digital Elevation Models). Remote sensing methods were integrated by means of geospatial products of different scales: large-scale analysis was conducted using mostly Landsat (specifically Global Land Survey), multispectral-data and SRTM-C, in particular ASTER-DEM data, that were complemented in some cases by SRTM-X data. Furthermore, the “historic” satellite images of the Corona missions (KH4-A, KH4-B) have played a crucial role in locating possible sites. These depict the landscape prior to the 1980s population explosion and related intensification in agriculture and urban development. For clarification purposes and the prospection of buried cultural monuments, high-resolution and very high-resolution satellite images were used as well. These comprise of scenes from the IKONOS, Quickbird, OrbView, GeoEye, WorldView-1 and WorldView-2 sensors. Additional high-resolution X-Band radar data (TanDEM-X StripMap, Spotlight and high-resolution Spotlight) has been incorporated since 2010 in collaboration with the University of Göttingen, Germany. These have been utilized for the creation of interferometric elevation models as well as the exploration of fluvial systems (dead channel mapping).

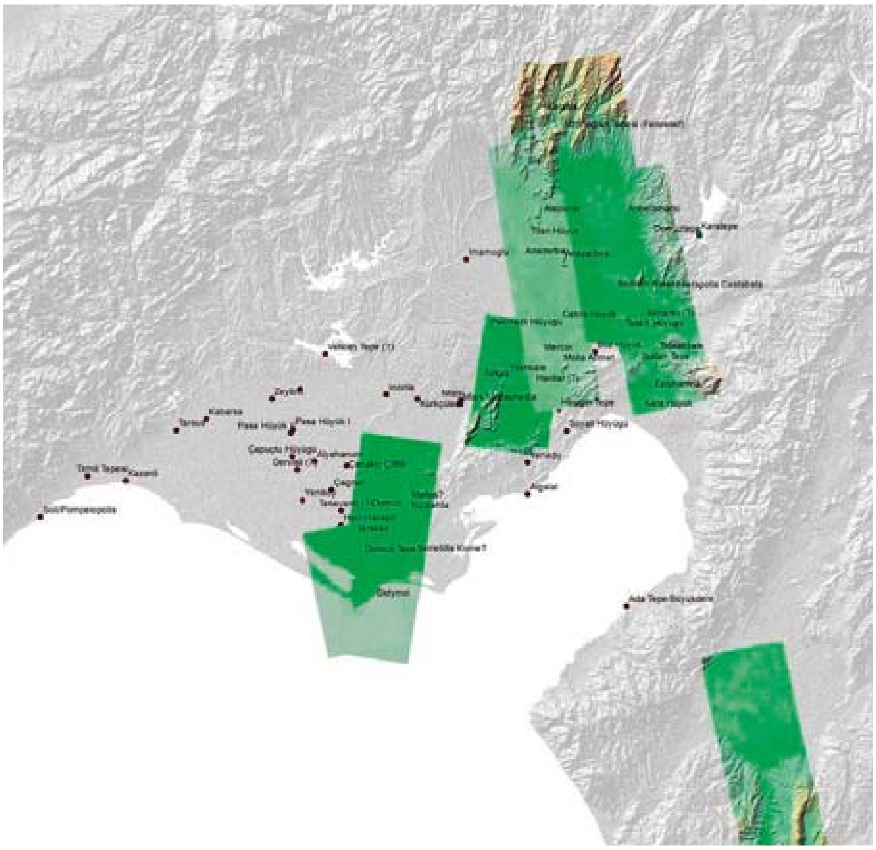

Figure 1: *Cilicia Pedias: Coverage of high-resolution elevation models created from TanDEM-X single pass interferometry (as of end of 2012).*

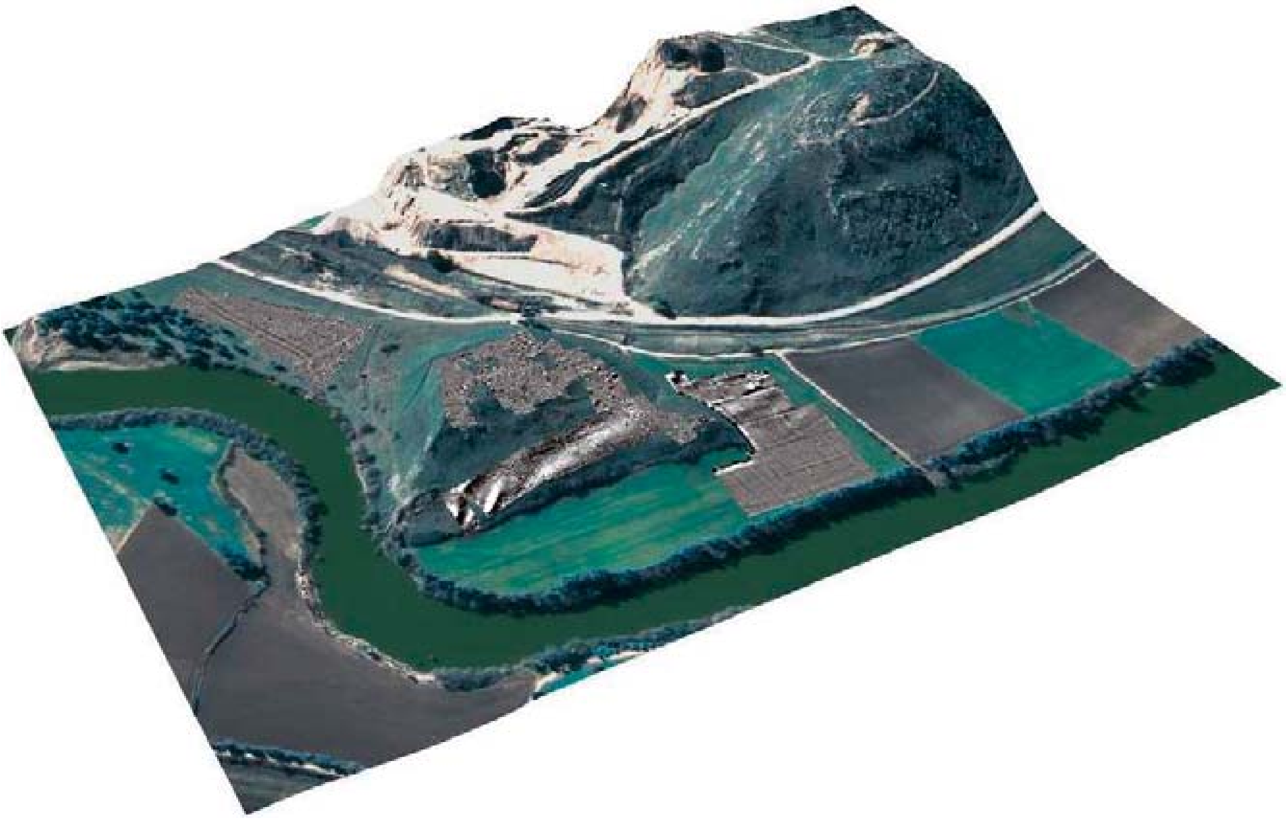

Figure 2: *Sirkeli Höyük: Results of geomagnetic survey at Sirkeli Höyük, superimposed on a perspective view of the Bronze and Iron Age mound (textured with World-View-2 satellite imagery).*

COMBINED NON-INVASIVE SURVEY OF THE GDANSK BAY WITH THE USE OF SONAR SCANNING AND MAGNETIC MEASUREMENTS

W. Małkowski, K. Misiewicz, W. Ossowski

At the first stage of survey (carried out since 2008), a multi-beam sonar system (Reson 8125 Seabat), supported by an inertial system Ixsea Hydrins with a dGPS / RTK Trimble MS 750 positional receiver, was used to scan the bottom of Gdansk Bay, located in the Baltic Sea near the port city of Gdańsk in Poland. The system was supported by towed CM2 EDF C-max sonar. In water depths not exceeding 20 metres, the multi-beam echo sounder was used as the main survey tool, and the towed sonar was used for complementary bathymetric measurement of selected objects.

Measurement profiles were prepared in an east-west direction. Initial measurements were done on profiles 20 metres apart in the course of works the distance between profile were reduced to 15 m and finally to 10 m. For a depth of less than 7 m, the intermediate supporting profiles were carried out to cover 100% of selected areas. The shallow coastal zone, where the depth was less than 3 m, was surveyed by an echo single-beam sounder Reson Navisound 515 towed from the pontoon. Maps and cross-sections of registered objects were created using QLOUD software to decide whether it is worthwhile to conduct sonar towed measurements. Data acquisition with the latter device was carried out using a frequency of 780 kHz in a grid 2 $\times$ 12.5 meters (where the acoustic beam runs at a frequency of 20 Hz). In this way, all shallow coastal zones with depths of less than 7 m were surveyed. The sonar scanning revealed many valuable archaeological objects. The most interesting were shipwrecks – “Copper wreck", “Ore carrier” and "Falburt" – dated from 14th to 17th centuries (Figure 1).

In June 2012, non-invasive surveys of the Gdansk Bay were continued in order to verify the location of selected objects with the use of a caesium magnetometer (Geometrics G-858 Magmapper) adapted to the conditions of marine survey. The applied magnetometer with a horizontal system of probes (put in tight-waterproof containers) allowed for simultaneously registering values of total intensity of the Earth’s Magnetic Field and calculating the pseudo-gradient of its horizontal component. The latter have been carried out by observations of differences of values registered in 0.1 second measuring cycle by probes located 1 m apart. The magnetometer was connected with the RTK GPS system, thus providing the exact location of registered anomalies. Mode RTK determined the position very precisely, both vertically and horizontally, and in combination with the survey footpath GPS visualization, provided the full quality check of conducted measuring works. The measurement system was installed on an aluminium punt driven with an internal-combustion engine (Figure 2). Probes put on the non-magnetic frame were fastened in front of the bow of the boat, 3 m from the GPS receiver (installed over the centre of deck) and about 5 m from the engine, thereby eliminating the influence of the frame of the boat and the instrumentation on the magnetic measurements.

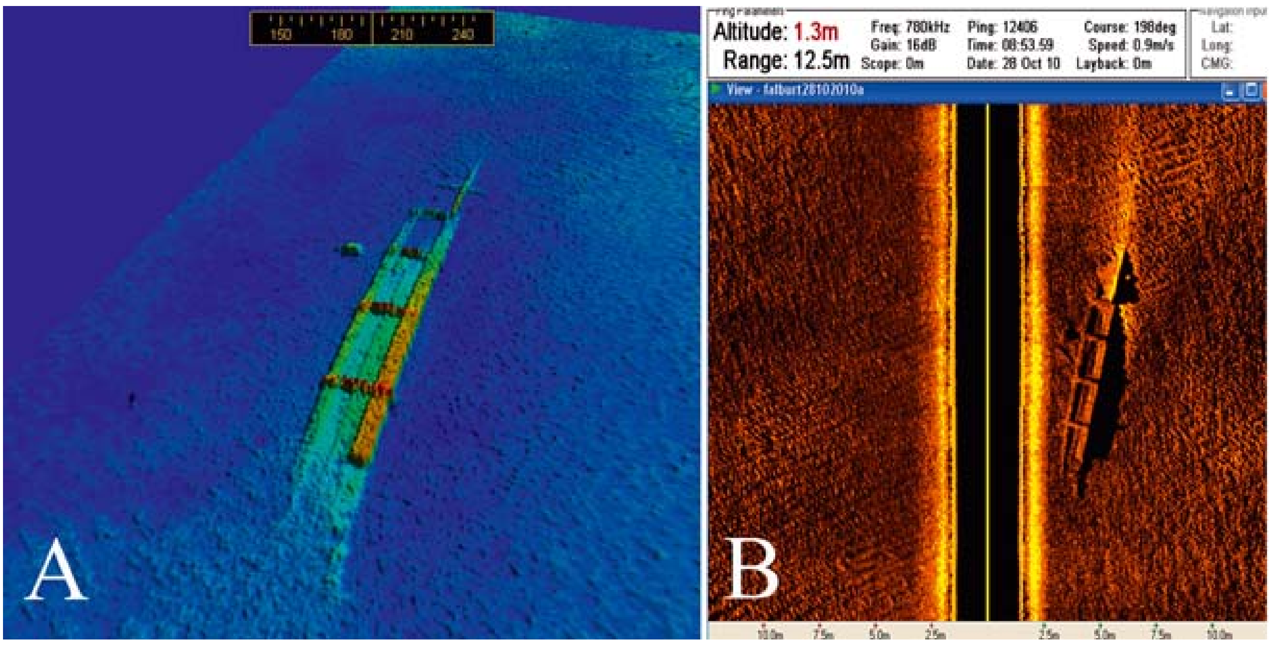

Figure 1: *3-D model A, and sonogram B of the detected shipwreck “Falburt”.*

RESULTS OF MAGNETIC SURVEY

Shipwrecks of ships in the study area lie at depths from 3.5 into 6.5 m. The cargo of these ships, which included iron elements, as well as burnt features or objects subjected to thermal processes, could trigger changes in the magnetic field intensity, depending on the state of preservation and the depth of the shipwrecks. Registered anomalies should have mostly dipole-dipole character, with decreases and increases of the value of the intensity of magnetic field depending on location of the object causing anomalies.

We assumed that anomalies of this type could be detected by the equipment used for prospection from the water surface, without any need to immerse probes, and this was confirmed by the results of survey.

In the magnetic measurement results, changes in magnetic field values in the range from 49940 - 50839 nT have been registered. Calculated values of horizontal pseudo-gradient did not exceed the limits between – 98 + 55 nT/m. It is possible to frame the data (the entire dataset contains 16,440 records) in terms of the following clusters of percentage values (in nT/m): 2.61 % above 10 and below -10; 2.12 % in the range from 5 to 10 and from -5 to -10; 22.65 % from 3 to 5 and from -3 to -5; 72.62 % in the range from -3 to 3. Recorded anomalies appeared in different degrees of strength depending on the character of the objects causing the anomaly – from isolated amendments of the magnetic field intensity to large zones with rows of successive maxima and minima. Cargo of the "Ore carrier" consisted mainly of a large quantity of iron, causing much stronger changes, even above $\pm$ 40 nT/m (1 in Figure 3, anomaly A-A'). Remains of the wreck "Falburt" in the form of timber structures, visible at the bottom of the bay (Figure 4), was registered as a low amplitude anomaly of the row from 0 to - 3 nT/m (3 in Figure 3, anomaly B-B'). Two other anomalies, which can be associated with "Falburt" or possibly with another wreck nearby, were still registered in surveyed area (2, 4 in Figure 3). In the case of anomaly 2, values of horizontal pseudo-gradient from -2 to -5 nT/m indicate iron or heavy burnt objects as the source of the anomaly. It lies about 13 m northwest from the visible remains of the wreck. The second anomaly, nr. 4 in Figure 3, forms only slight changes in intensity of magnetic field with values from 0 to -2 nT/m. Timber structures similar to the remains of the wreck "Falburt" could be the source of this anomaly. Further support for this hypothesis comes from the similar arrangement of poles of the anomaly.

Survey on the area of the Gdansk Bay allowed for testing the application of a boat as the mobile system for magnetic prospection. The magnetometer G858 turned out to be the effective tool for detecting remains laying at depths to 6.5 m. This device would probably also be effective at slightly greater depths. Juxtaposing results with the seafloor relief allows for marking out the specific places determined by the specific depth.

After non-invasive surveys, some of the allocated sites have been tested by diving combined with photograph documentation. In the case of shipwrecks, diving surveys were carried out by underwater archaeologists from the Polish Maritime Museum in Gdansk, who also collected wood samples for dating. After these studies, the bay and shore near the port of Gdańsk could become a "Mecca" of Polish underwater archaeology for the next decade of the twenty-first century.

Figure 2: *Boat with the measurement system.*

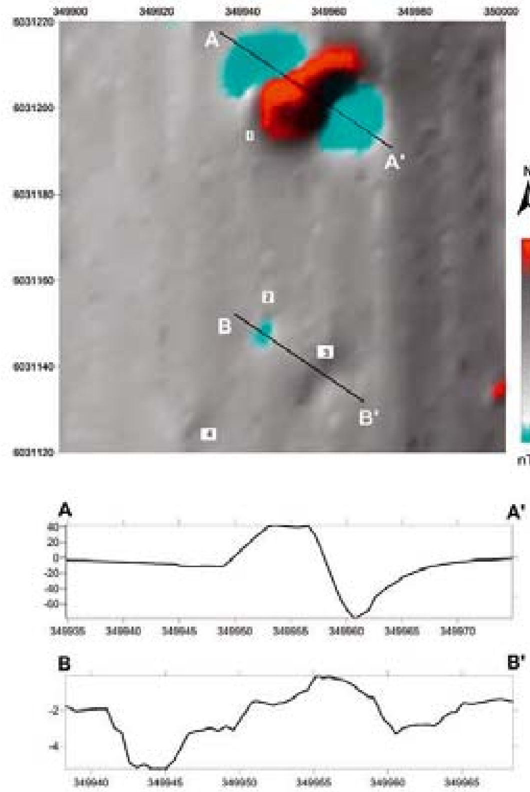

Figure 3: *Map of the disposition of values of pseudo-gradient of horizontal component of full vector the intensity of the Earth's magnetic field and diagrams of magnetic anomalies caused by possible presence of shipwrecks A-A' "Ore carrier" B_B "Falburt".*

Figure 4: *Remains of the wreck "Falburt during excavation.*

THE MANY SCALES OF RURAL LIFE IN PROTOHISTORIC ITALY

K.L. Armstrong, M. van Leusen, W. de Neef

The Rural Life in Protohistoric Italy project is a 5 year NWO (Netherlands Foundation for Scientific Research) funded project examining a series of small rural protohistoric (Bronze and Early Iron Age) sites discovered in about six months of systematic fieldwalking over a ten-year period in the basin of the Raganello river in northern Calabria, Italy. The archaeological distribution map produced by this previous research contains 155 'sites' – mostly small scatters of pottery – of protohistoric date, an impressive record but one we know is influenced by various discovery and research biases. The protohistoric material is harder to identify than that of more recent periods due to the types and degree of fragmentation of the ceramics, and can only be discovered where archaeological deposits are being exposed at the surface by agriculture or other erosional processes. The Rural Life project has two main research aims: firstly, to interpret the scatters in terms of patterns of settlement and land use, and secondly to study the research and discovery biases and develop methods to mitigate them. Geophysics plays a role in both of these: we can prospect for sites in areas where ceramic surveys are not possible, and we can use geophysics to understand more about the buried archaeology associated with the known pottery scatters.

In our region, however, and for protohistory in Italy more generally, geophysics is rarely used, and we therefore lack basic knowledge about the geophysical expression of protohistoric sites. Moreover, little or no studies of soil properties and environmental magnetism have been conducted by archaeologists,

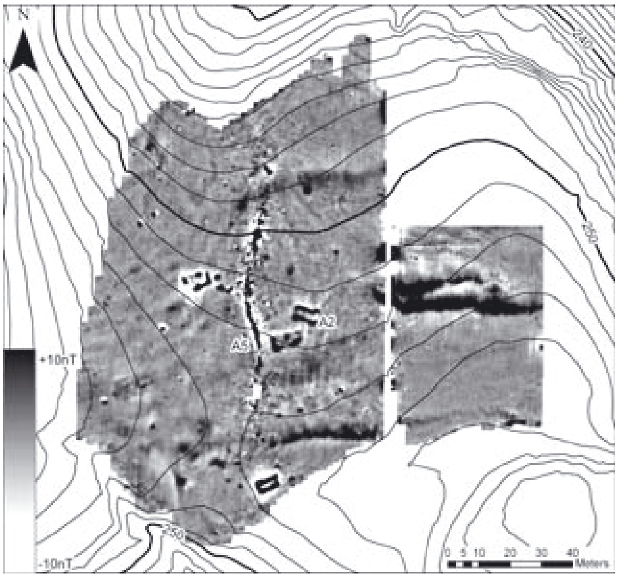

Figure 1: *Processed (interpolated and smoothed) gradiometer data produced by Eastern Atlas GmbH over Portieri, displayed at ±10 nT with 1 m topographic contour lines, derived from a LiDAR based DEM. Anomalies A2 and A5 are labelled.*

so we must conduct additional methodological research. In addition, there are a number of challenges to conducting and interpreting archaeological geophysics. The soil moisture and stoniness mean that, so far, GPR and resistivity have not provided useful results, though we hope that prospecting in different seasons will yield better data. Accessibility in a mountainous landscape is a large problem, as are the often steep slopes. The landscape is also highly fragmented, which means that to survey a reasonable area, we often have to set up local measurement grids, make repeat visits at different times to catch fields without crops, and survey partial grids. The physical characteristics of the research area also cause interpretational problems: the terraces, slopes and slope processes affect the data in a variety of ways, often interact with each other, so unravelling the exact mechanisms at work can be very complicated. The study region also has a variety of soils with very different magnetic characteristics, from the ferruginous soils of the Pleistocene marine terraces to the younger and thinner soils formed on limestone, schists and marls. These units can occur in complex mixtures and within a short distance of each other.

These factors have led us to use a variety of magnetic approaches, alongside geoarchaeological studies. Our site-scale investigations are conducted with either hand-held or cart-based gradiometer systems, but we also employ magnetic susceptibility (MS) studies on a wide range of spatial scales, from laboratory studies of samples and materials to landscape-scale walkover surveys. We have spoken at various conferences about other aspects of this project: at CAA 2012 in Southampton we spoke about the technical and intellectual challenges of integrating legacy data and working in multidisciplinary international teams. At EAA 2012 in Helsinki we spoke more generally about the aims of the project and the way we are using a variety of types of data to answer our archaeological questions, and at the 2012 Landscape Archaeology Conference in Berlin we presented a poster exploring the different scales of data we collect. The current paper will go into more detail about how we use geophysical and archaeological data from different scales to make synthetic interpretations of the settlement and land use history and the post-depositional processes that affect it. The key data we integrate are geophysical, archaeological, pedological, geomorphological and ethnographical. In this paper, we will not address the mathematical integration of geophysical data, and we will only briefly touch on the technical aspects of integrating diverse datasets.

Throughout the following discussion, we will use one of the sites we have investigated over the last two years, called Portieri, as an example. The site was discovered in 2010 after pottery scatters were observed in the field and in a section along a hollow road that runs to the south of the site. This is part of the landscape scale-package of data that makes up our archaeological distribution map. Eastern Atlas GmbH of Berlin conducted gradiometer surveys on the whole of the area that was available at the time, resulting in the following geomagnetic map (Figure 1).

The presence of four rectangular anomalies – probably buildings – in the data made this site a priority for more de-

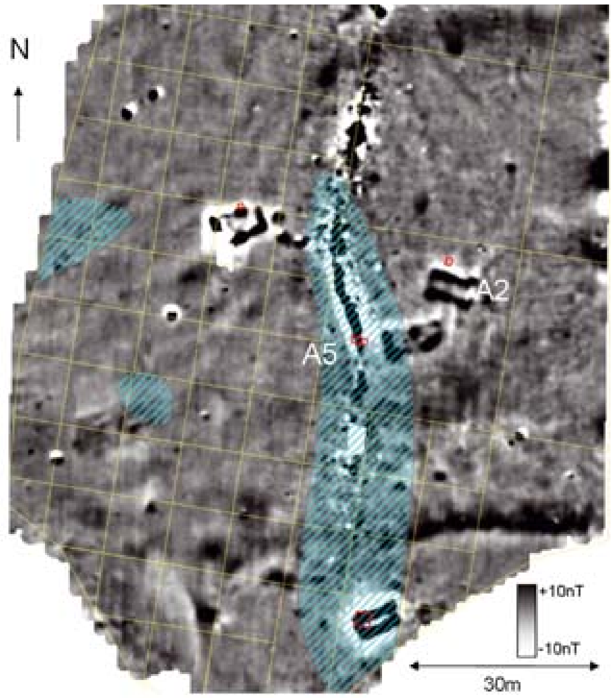

Figure 2: *Extract of Gradiometer data from Portieri (see Figure 1 for details), with 2011 test trenches marked in red, the detailed ceramic survey grid in yellow and surface concentrations of ceramics shown by blue hatching.*

tailed investigation in 2011, when the geomagnetic survey was partially repeated and extended to neighbouring fields. We also excavated a series of test pits to test our interpretation of the geophysics and to obtain dating evidence. The field was also resurveyed intensively for ceramics and other archaeological materials to see how any surface scatters might be related to the geophysical data (Figure 2).

As you can see in Figure 2, the finds data do not exactly match what we see in the gradiometer data, and we need to investigate this at various scales in order to understand why this should be so. Portieri lies on a saddle with a complex series of geomorphological processes operating at small scales; there are both colluvial inputs and erosional outputs. Depositional and post-depositional processes play a role in the disassociation between the ‘structures’ and the pottery scatters. A surface MS survey was able to give some evidence about the relative depths of the bodies of earth responsible for the anomalies: the sinuous anomaly marked ‘A5’ in Figure 1 has an MS surface signal, but the rectangular anomalies do not. This difference in burial depth might partially explain why little pottery is found directly over the rectangular anomalies.

The test pits shown in Figure 2 were designed to examine some of the gradiometer anomalies in detail, and to establish exactly what was causing them. To help achieve this, we took a series of MS profiles on trench sections and sampled contexts for laboratory analysis. We also examined typical archaeological materials and local stones using an MS3 with an F sensor. In archaeological terms, we were able to confirm that the structures date to the Final Bronze Age. In most cases, the trench data show that the gradiometer anomalies are being caused by burned building materials.

To be able to integrate geophysical and archaeological interpretations, we needed to be able to accurately co-locate the diverse datasets produced by different disciplinary teams working in the field at different times (hence under different seasonal conditions) and often with very different technologies. There is also a logistical challenge in ensuring the right work is done at the right time; for example that topsoil spectra are obtained before the field is walked across or otherwise altered, and that geophysical surveys are conducted both before and after the ceramic surveys remove any surface finds. This latter point is particularly important in the light of our goal of developing a prospection method that does not rely on the presence of visible surface ceramics. Sherds will strongly affect MS data obtained with the MS2D loop, and they need to be removed prior to the MS survey to see if the associated soils have an elevated MS on their own.

The detailed MS studies at Portieri have raised some questions as well. In anomaly A2 (see Figure 1), a limestone wall was discovered running in the same position as the gradiometer anomaly. However, the limestone blocks themselves have a very low MS (see Figure 3).

The material between them does have some magnetic susceptibility, but this is not really strong enough to produce the anomaly seen. The section measurements also show no sign that a high MS fill within the wall trench might be responsible. The test trench dug in A5 was expected to find a clear cut or gully feature filled with a discrete body of enhanced MS material related to the occupation or destruction of the site, but we in fact found – and this was borne out by measurements on sections – that there is a diffuse area of enhanced soil that extends beyond the width of the test pits, and that is somehow producing a discrete and strong gradiometer anomaly.

We needed all of the diverse types of evidence, at multiple scales, in order to be secure in our interpretation of the site at Portieri, and by extension, of the other rectangular anomalies discovered in the surrounding landscape. The site level data could not be securely interpreted without understanding both the landscape context and the origins of the individual anomalies themselves. Covering wider areas is also important because we want to understand the gaps in the archaeological record: are the places without ceramics at the surface also devoid of geophysical anomalies? What is happening in the places where we do have ceramics but no anomalies? We already know that limestone walls do not always produce anomalies. Given the problems experienced in our experimental resistivity and GPR surveys, we do not currently have a solution to this.

Interpreting a geophysical plot when you already have an idea of what you expect to see is relatively straightforward. For our region and period, we do not have any studies of comparable rural sites. Few of them have been investigated by excavation and, to our knowledge, geophysics has never been employed. This means we examine our gradiometer data with very critical eyes: we need to know the nature and origin of all of the anomalies we see before we can decide what significance they have. We also have to collect detailed oral histories from local farmers to establish which anomalies might be modern interventions in the landscape. It is our contention that the problems we have had in locating, explaining and understanding some of our anomalies shows there are basic challenges in interpretation that the discipline of archaeological geophysics as a whole needs to step up to.

To try to move forward with these issues, we are working with teams from Leuven University, the Flemish Institute of Technological Development VITO, and the Max Planck Institute and Johannes Gutenberg University in Mainz, looking at the associations between hyperspectral soil signatures, archaeo-

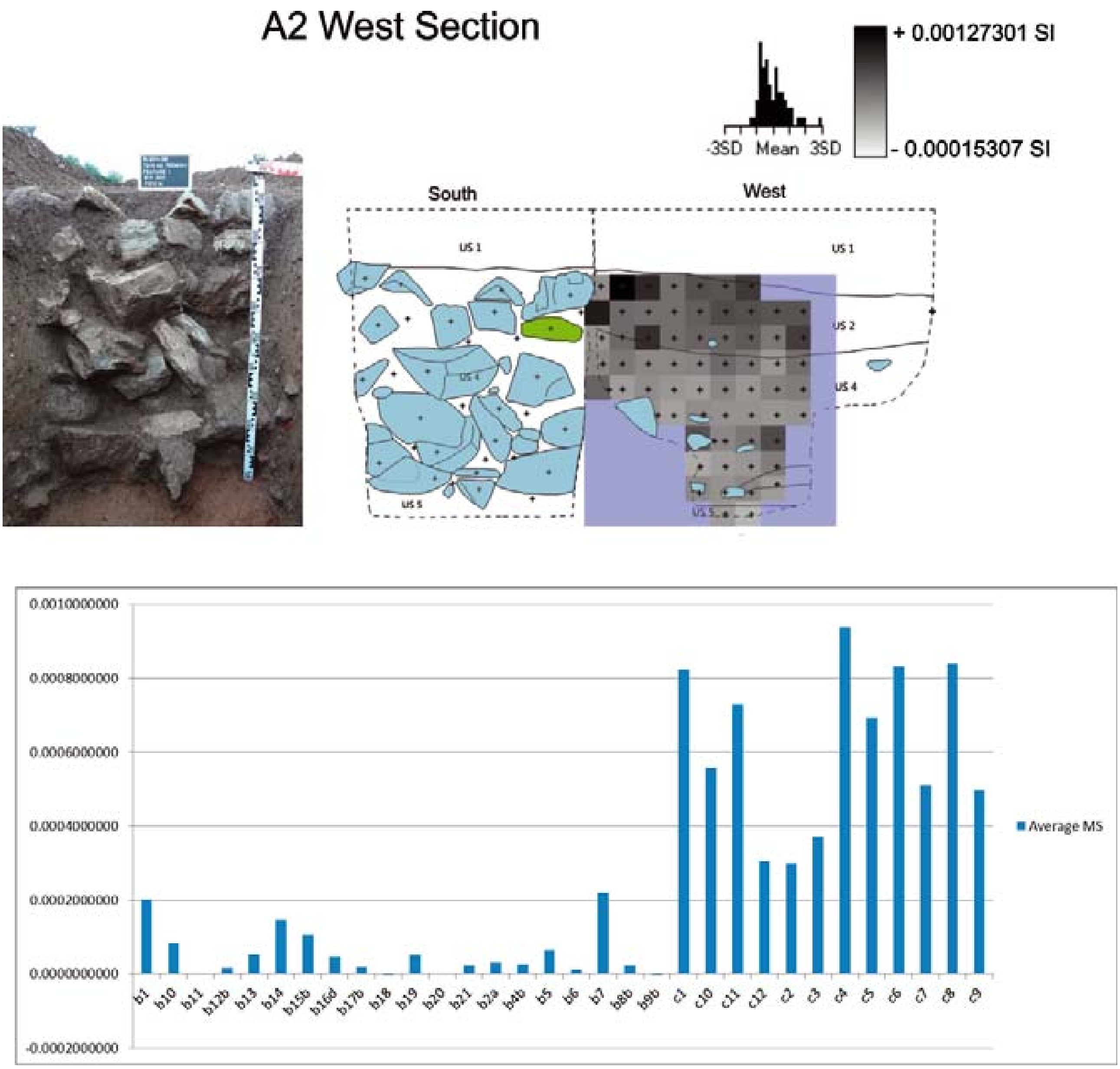

Figure 3: *Data from the sections of the trench opened to investigate anomaly A2 in 2011. Top: the limestone wall (photograph) and section drawings with rectified plot of MS measurements using a Bartington MS3 with F sensor taken on 10 cm grid. Bottom: MS measurements from the stones (b#) and soil between them (c#) taken using a Bartington MS3 with an F sensor.*

logical / human altered soils and their chemistry and magnetic properties. We will also be using the data from the trenches and laboratory work to conduct forward modelling of the structures excavated at Portieri to see if we can reproduce or explain the anomalous gradiometer responses mentioned.

WITHIN THE ROUND BARROWS OF STONEHENGE LANDSCAPE: SURVEYING TOPOGRAPHICALLY COMPLEX MONUMENTS WITH GPR

E. Baldwin

1. RATIONALE

The structure of the British round barrow has long been accepted as being characterized by distinct and recurring forms that are the result of deliberate intent on the part of their builders (Field, 2010). Deviation from these forms and characteristics are therefore intentional and important. Identifying and understanding deviations from the accepted pattern of structures has become increasing difficult. Intrusive investigations of extant round barrows have practically ceased and, as David Field points out, recent barrow investigations are now restricted to ploughed out examples where the mound has failed to survive (Field, 2010). Consequently, archaeologists are now reliant on the records of 200 years of excavations of varying standards for information relating to prominent superstructure of the round barrow monument class. What reliable records exist from 20th century excavations demonstrate complex sequences of reuse over time; nonetheless, little is understood of the domed superstructure itself, and of its design and construction, as the majority of investigations have targeted the funerary nature of these monuments (i.e. burials and grave goods). Not every round barrow contained burials, and some may have functioned in a ceremonial, rather than a funerary, capacity. In many documented instances, the mound structure masks preceding monuments of equal importance which now remain hidden beneath. It would therefore seem appropriate, at this point in time, to turn to the non-invasive techniques of remote sensing (e.g. geophysical survey) for assistance in furthering our knowledge of earthen round barrows by the systematic investigations of this monument class within a landscape setting.

2. BACKGROUND

This work forms an important component of the research the University of Vienna is currently undertaking as part of the Stonehenge Hidden Landscapes Project in collaboration with the University of Birmingham as principle partners in the Ludwig Boltzmann Institute of Archaeological Prospection and Virtual Archaeology (LBI ArchPro). The project aspires to survey 8 km^2 of the landscape centred on Stonehenge 'envelope' using motorized magnetic and GPR systems. The survey area contains various sizable upstanding monuments, including numerous round barrows (mounds). Most round barrows are too large to be driven over with wide multi-probe arrays, and need to be surveyed with conventional hand-held systems.

Geophysical survey of various sized mounds, however, is not without difficulty – the complex topographical nature of these monuments introduce (a) the element of depth to the intended target, and (b) errors due to topography and tilt. It is important first to understand the complex nature (both structurally and archaeologically) of the intended survey target – the earthen round barrow.

3. ARCHAEOLOGICAL PROBLEM

3.1. The earthen round barrow – definition

The earthen round barrow is a round or elongated mound, predominately of earth often but not always raised over at least one burial (either internment or cremation). Usually, it is surrounded by a continuous ditch, which provided the material for the mound and occasionally may be interrupted by a causeway. The form of the earthen round barrow in Britain can be generally classified into five types as defined by their profile: bowl, bell, saucer, disc and pond, the first being considered 'standard' and the latter four thought of as 'fancy'. Architectural features such as kerbing of stone or timber or the inclusions of timber or stone uprights sometimes assisted in the original definition of the hemispherical mound structure.

3.2. Funerary nature

Barrows which contain burials (traditionally referred to as tumuli) may also be associated with complex structures such as cists, mortuary enclosures, mortuary houses or even chambered tombs. It should be noted, though, that these associated funerary details may vary greatly in time and space, and may have been later additions. Because of their funerary associations, round barrows clusters are generally grouped into round barrow 'cemeteries'.

4. DISTRIBUTION

Over 20,000 earthen round barrow have been documented throughout Britain, and previously unrecorded examples are discovered each year. Bell, bowl, saucer and pond types are prevalent throughout the Wessex landscape of south-west England, within which Stonehenge lies. The area immediately surrounding Stonehenge is known as the most densely populated area of barrow concentrations anywhere in Britain. The principle barrow clusters around Stonehenge are the: Cursus Ridge Group, Normanton Gorse group, New and Old King Barrow groups and Winterborne Stoke group. Even today, these barrow groups dominate the landscape immediately visible from the Stonehenge stone circle (referred to as the Stonehenge envelope).

4.1. Dating

Most British round barrows are thought of as originating in the Bronze Age. However, round borrow construction and burial (in some cases, reuse) were common throughout the Roman, Anglo-Saxon and Viking periods. Notable earlier examples such as Duggleby Howe have been also dated to the Neolithic through excavation. The numerous round barrows populating the Stonehenge landscape are traditionally dated to between ca. 2000 – 1500 BC. The dating of the Stonehenge round barrows is based mainly on the results of 200 years of archaeological excavations on many of the mounds.

4.2. Historical investigations

The ubiquitous and accessible nature of earthen round barrows throughout Britain ensured that they received much attention, and they have suffered a long history of invasive intrusion, beginning as early as in the Roman and Viking periods, as well as during the Middle Ages (as summarized by Crawford, 1960). Intrusions intensified with the treasure hunting of the 16th and 17th centuries, and only began to gain scientific respectability in the early 19th century with the widespread antiquarian investigations led by Colt-Hoare (in Wiltshire), among others. The documentation and recording of these 'scientific excavations' are of varying standards. In many instances, the extent of intrusion is unknown and can vary from wholesale excavation or sectioning to randomly located explorations; most usually, some form of shaft was sunk swiftly into the centre or side of a barrow, typically in search of burials.

The result is an inconsistent record and incomplete picture of the true nature of the earthen round barrow, and in particular of those around Stonehenge.

4.3. The importance of the earthen round barrow

Paul Ashbee (1960) stated that, in his view, the study of round barrow was of the primary importance, particularly in light of (a) their association (noted above) with [earlier] henges and circles, and (b) the distinctive absence of settlement evidence that characterizes the British Bronze Age. He advocated for the ordered study of their problems, structure and contents, as imperative to understanding the builders of these monuments.

4.4. Monument at risk

Interestingly, when writing in the early 1960s, Ashbee already highlighted the destructive nature of invasive archaeological investigation (namely excavation) and warned of the detrimental consequence for the preservation of this class of monument. His warning seems to have been heeded, and the invasive investigations of round barows has declined to the point that only ploughed-out examples are being excavated (Field, 2010). Today the main threat to the preservation of the British round barrow is fourfold:

1. Agriculture (and failure of scheduling in some cases)
2. Land management (or absence of, but should include historic planting of trees)
3. Tourism (path erosion, collapse, fire, memento collection)
4. Rabbits (borrowing; also badgers)

4.5. Gap in knowledge

Consequently, the aversion to intrusive investigations, such as excavation of extant round barrows, in an effort to preserve them for prosperity has resulted a direct gap in our knowledge regarding the exact nature of the superstructure of the earthen round barrow and any associated features (Field, 2010). However, while intrusive excavation of these notable monuments is restricted, non-invasive remote sensing techniques, and in particular geophysical prospection, is allowed and has the potential to fill in noticeable gaps in the archaeological record of the earthen round barrow.

5. METHODOLOGICAL APPROACH

Magnetometry, ground penetrating radar (GPR), earth resistance, electrical imaging and low frequency EM surveys represent the major prospecting tools available to the archaeological community. All of these could be employed in the survey of a round barrow, but only two of the above techniques (GPR and electrical imaging) produce the volumetric datasets that are the most suitable for the survey of topographically complex mounds; of the two, GPR permits faster collection of higher resolution data.

5.1. GPR survey

Ground-penetrating radar is normally chosen because of its ability to detect subsoil anomalies (features) in both rural and urban environments, as well as its ability to estimate the approximate depth of a buried feature by collecting data along 3-dimensional profiles through the earth.

GPR survey is an active geophysical technique involving the transmission of electromagnetic (radio) pulses from a transmitter antenna moved across the ground surface. When the pulse reaches an interface between different materials, some of the energy is reflected back to a receiving antenna whilst some travels further into the ground and is reflected from a deeper subsurface discontinuity. The amplitude of the returned pulse is dependent on the velocity of the radar wave as it passes through a material. The relative dielectric permittivity (RDP) is a measure of the ability of a material to conduct the radar wave and will vary depending on the composition, porosity and moisture content of the material. The travel times of each pulse are recorded and allow an approximate depth measurement to be made by assuming a dielectric constant value, although these depths should only be considered as estimations unless accompanied by ground-truthing.

5.2. Surveying complex topography

The problematic nature of the geophysical survey of mounds is well documented (Goodman *et al.*, 2007; Leckebusch and Rychener, 2007; Goodman and Conyers, 1998, 122-123). Over 'Topographically complex' survey areas, the paths of radar waves behave in a very complex manner when tilted and/or rolled. It is clear that certain criteria must be fulfilled to successfully detect subsurface anomalies within or under a mound:

- All radargram profiles have to be topographically corrected in-line.
- All radargram profiles have to be tilt-corrected for pitch and rolled.
- The velocity of the radar wave needs to be accurately calculated locally by direct-wave analysis methods utilising two antennae and/or calculating the Relative Diaelectric Permittivity of the local soil in a laboratory.

Recent advances in processing and imaging techniques (Goodman *et al.*, 2007; Leckebusch and Rychener, 2007) have succeeded in making significant progress in compensating for both topographic and antenna tilt (roll and pitch) corrections over difficult topography. Best practice, however, always aims to collect the best data in the field and avoid (or at least minimize) post-processing, which usually results in dramatic manipulation of the original raw data.

6. CHALLENGE

This work concentrates on a methodological study for improving the collection of GPR data over a topographically complex form such as a round barrows, as an improved first step in the process of imaging features buried within mounds. Traverse lines for data collection are usually orientated in parallel lines along either the X or Y axis with a view to cutting any known or expected features at an angle and avoid the inadvertent removal of features along lines of data during post-processing. A similar approach is applied in the first instance to target mounds in an effort to compensate for the unpredictable behaviour of the GPR wave and reflection within or throughout the topographically complex form of the mound. However, better coverage will not necessarily equate with better results, and a more novel approach for collection of data is proposed: collecting data in 'radials' originating from (or pivoting through) the crown of the mound (top and centre) The radial survey of mounds would be a first step in avoiding or at least minimizing tilt errors from antenna roll and pitch.

A novel approach to data collection would have to be combined with high-resolution topographic mapping of each mound surveyed with a combination of 3D laser scanners which would result in highly accurate terrain model to be used for topographic correction and for fusing the above-ground (extant barrow mound) and below-ground features (burials, architectural features) into one visualization.

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SPATIAL ORGANISATION OF PERSEPOLIS (FARS, IRAN): PRELIMINARY RESULTS FROM A LARGE GRID STUDY CARRIED OUT WITH A CS60 CONDUCTIVITY AND SUSCEPTIBILITY METER

S. Gondet, J. Thiesson

The SELOPerse project, in which the study presented here takes place, is funded by the European Union through a Marie Curie intra-European fellowship and is hosted by the Department of Heritage Studies (DISMEC) of the University of Bologna, in Ravenna (Italy). The fieldwork is carried out within the joint Iranian-Italian archaeological mission of studies in Persepolis/Parseh (Askari Chaverdi and Callieri, 2012) directed by Dr. A. Askari-Chaverdi (University of Shiraz - Iran) and Prof. P. Callieri (University of Bologna) and supported by the Iranian Centre For Archaeological Research (ICAR) and the Parsa-Pasargadae Research Foundation (PPRF).

The project aims to study the ancient Achaemenid settlements in the vicinity of Persepolis, one of the sumptuous royal residences built by King Darius I (520-486 BC) and located in the centre of his Empire. Its most famous feature is the Terrace of Persepolis, a stone platform 12 ha across and 12 m high (at its maximum), carved and built at the foot of a limestone mountain range. A complex of monumental gates, audience halls, royal pavilions and administrative buildings, some of them abundantly decorated with bas-reliefs, was erected on it, and some erected at its foot in the plain towards the south. Because the works on this Royal precinct have taken up most of the attention of scholars, its vicinity has been neglected. Nevertheless, in the early 1930's the discovery of administrative archives brought to light information about the daily activities in the city of Persepolis (i.e. Parsa) and illustrate the fact that its vicinity had been settled and exploited. Some survey fieldwork (Sumner, 1986) have tried to tackle this, but our archaeological knowledge of Persepolis is still strictly limited to the royal architecture.

In order to get a better image of the spatial organisation of Persepolis, between 2005 and 2008 we carried out several systematic and extensive multidisciplinary surveys in the cultivated fields around the site (Gondet *et al*., 2009; Boucharlat *et al*., 2012). This was the only way to acquire archaeological information in a present day landscape where the remains of the Achaemenid period disappear gradually due to modern human pressure and intensive cultivation. These works have revealed a landscape organisation around the Royal Precinct as well as an intense exploitation of the natural resources. They lead us to suggest a new vision of the site organisation scheme as a kind of "garden city" and that we have called the Persepolis Settled Zone. This zone comprised widespread settlement blocks extending over several km^2; some sheltering the numerous inhabitants and ensuring the administrative and economic functions, others corresponding to more isolated luxurious buildings for the elite. These blocks were probably located within a landscaped area of gardens, parks, fields and orchards.

The most illustrative results have been obtained in the Persepolis West sector and between there and the Terrace located 1 km further west. Here the magnetic maps show long ditches dividing the zone into large plots of several hectares (Figure 1). Some of them were certainly densely built and others corresponded to unbuilt but landscaped areas, probably some parks, orchards or cultivated fields. The first are characterized by higher gradient dynamic areas combined with sherds concentrations on the surface. Nevertheless, due to the succession of deep ploughing, the shallow Achaemenid remains have been quite fully levelled and it is very difficult to get the accurate plan of the buildings in these places.

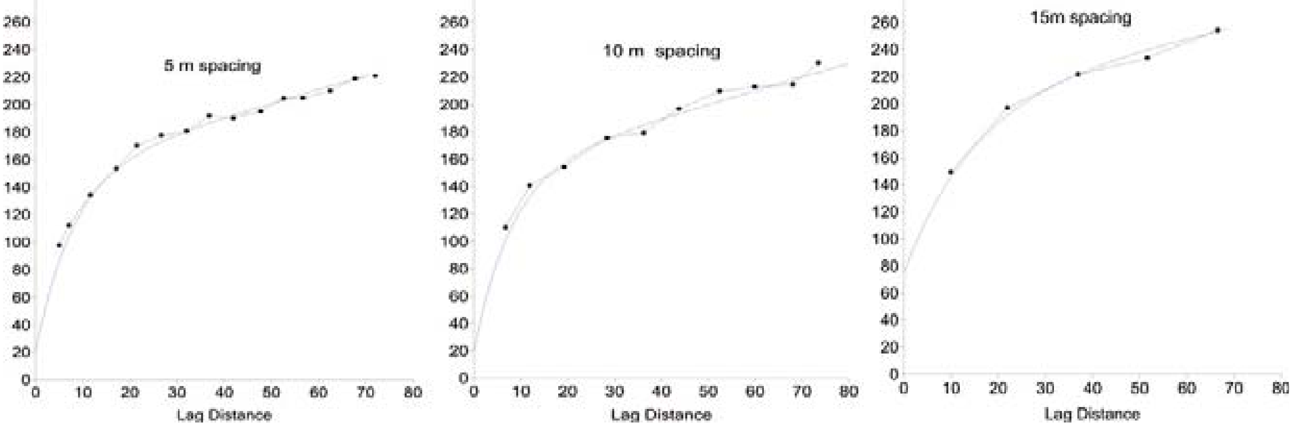

Figure 1: *Reconstruction of the Achaemenid landscape orientation north west of the Persepolis Terrace and examples of the magnetic gradient maps on which is based the interpretation.*

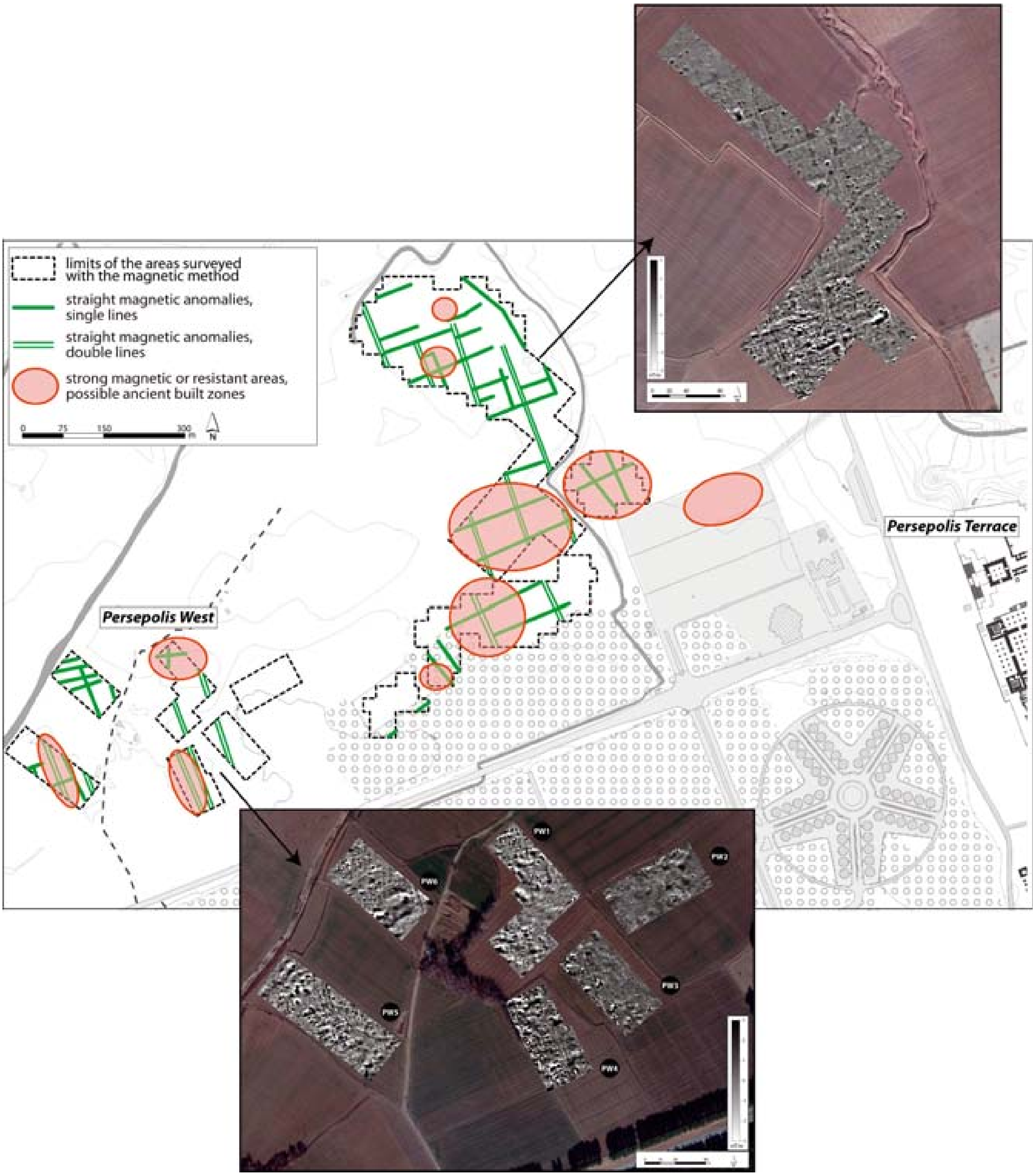

Figure 2: *Magnetic gradient map obtained on the two test fields in the Persepolis west area.*

As a conclusion of the surveys, we were only able to map and to delineate the ancient built areas spread widely over several dozen of hectares. To cover the entire surface of the Persepolis Settled Zone by mean of fine magnetic surveys with profiles every meter is not feasible without the use of devices towed by vehicles. This strategy seemed also non-relevant due to the fact that we can only map some areas of ancient occupation and not their accurate plan. Considering that the magnetic properties of the subsoil layers show slight differences between built and unbuilt sectors, we intend to carry out geophysical surveys by using appropriate electromagnetic devices with a larger grid sampling strategy. The goal of this approach is to demonstrate the dotted organisation as well as to estimate the built surface that together could be the "city" within the overall landscaped zone. This large scale mapping work could also serve to further studies, for example finer grid surveys to get more detailed map.

The device used is the CS60, a prototype developed at the UMR 7619 Sisyphe lab (Université Pierre et Marie Curie – Paris). It is an electromagnetic induction (EMI) slingram device with coplanar coils (Job *et al.*, 1996; Thiesson *et al.*, 2009; Thiesson *et al.*, 2011). The transmitter and receiver are spaced by 0.6 m. Its working frequency is 27960 Hz and the device measures the in-phase and quadrature out of phase of the secondary electromagnetic field. After calibration, the maps are given in apparent magnetic susceptibility and apparent electrical conductivity.

In the first stage of the project, during autumn 2012 we carried out test surveys on a field previously surveyed with a G858 caesium Geometrics gradiometer, where we had detected some sharp magnetic contrasts. We chose to focus the test onto two fields of the Persepolis West area (PW3 and PW4 fields on Figure1). The maps show clearly two distinct zones (Figure 2): a higher magnetic one corresponding to the west field and to the western border of the east field; a less magnetic one towards east. To describe these results in a general way, we can say that magnetic dynamism decreases from west to east in this area. Taking into account the actual topography, deeply transformed by modern agriculture, we suppose that this result could be linked to the levelling works undertaken within the east field to make irrigation easier. These earthworks would have destroyed the shallow archaeological layers. Nevertheless, this clear contrast encouraged us to carry out the test with the CS60 on these fields in order to see how close the results obtained with both methods could be. A second goal was to compare the general shapes of the magnetic zones at several grid steps and to determine the best sampling space to map ancient occupation areas in order to choose the better strategy to adopt for the forthcoming surveys. Measurements were taken on a 5 m grid and resampled at 10 and 15 m.

The map presented here (Figure 3) must be considered as a preliminary result as it shows variations of raw in-phase measures. The data need additional processing to obtain an apparent magnetic susceptibility map. However, some first remarks based on the comparison of both maps can be drawn up. Overall, the map obtained with the CS60 reveals results similar to those obtained with the gradiometer at a finer grid. The subsoil layers of the entire western field show high in-phase (i.e. magnetic susceptibility) values. The response of the north-eastern part of the second field is also quite comparable to the results of the earth magnetic gradient survey. Nonetheless, at this place the dynamics are slightly different; the in-phase values are the highest obtained on this sector while the gradient measures are quite similar than those obtained further west. The same observation can be made for the north corner of the surveyed area, although one major difference can be pinpointed. In about the middle of the western limit of the map, the in-phase results show an area, rather a point, with high susceptibility values that is absent from the gradient map. The explanation of these differences is most likely to be found in the actual landscape dynamics, and more accurately in the impact of modern agricultural practices. As an example, we have often observed that the straw remaining after the harvest is burnt. This could fairly modify the magnetic susceptibility of the top most layers but have no effect on the gradient measure.

The variograms for the three sampling meshes (5 m, 10 m and 15 m) have been processed (Figure 4). It shows that the spatial structure of the data is still present on the 15 m mesh. It allows us to say that this mesh chosen for practical reason is valid for delineating the settled areas from the others.

As preliminary conclusions, we find that the large grid surveys by using CS60 instrument are fully able to help us to detect ancient areas of occupation within the Persepolis Settled Zone. The grid space of 15 m seems suitable to map them with an acceptable combination of sampling speed and results accuracy. Actually, we will extend the surface surveyed onto several places in the Persepolis vicinity, and by gathering results on wider areas we hope to be able to fully validate the method. We also have to combine our interpretations by taking into account the results of the out of phase (i.e. apparent conductivity) measures, which could bring complementary data. Nevertheless, to offer a confident archaeological interpretation we have to determine the influences of modern activity and occupation. We will also be able to rely upon the archaeological base maps provided by former and ongoing archaeological surveys in order to determine the place and the period of the ancient settlements zones with the capability to reveal more accurately their real extent thanks to geophysical large grid survey.

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Figure 3: *In phase raw map obtained with the CS60 slingram prototype.*

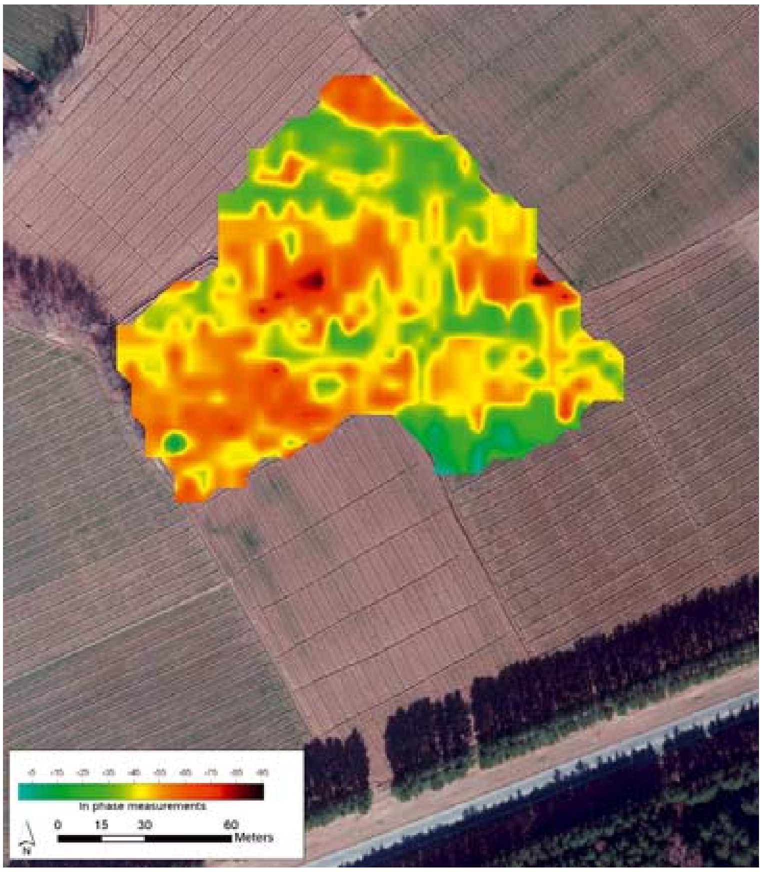

Figure 4: *Variograms processed on the test area data for the mesh spacing 5 m, 10 m and 15 m.*

GEOPHYSICAL PROSPECTION OF ROMAN VILLAE RUSTICAE IN THE BAVARIAN PART OF NORICUM

L. Kühne, R. Linck, J.W.E. Fassbinder

ABSTRACT

Roman *villae rusticae* in the Bavarian part of Noricum have their own tradition of architecture and house types, which show more influence from Rome than any other north-western Province. However, the present state of archaeological research made it difficult to get a coherent view of the whole countryside. Compared to other landscapes, this area is rarely used for agriculture and hence very restricted for aerial archaeology. The analysis of Airborne Laser Scanning data, combined with detailed but large-scale geophysical prospection, was applied to discover and trace new sites and enhance the archaeological knowledge in this field of archaeological research.

1. INTRODUCTION

The kingdom Noricum was in close economic and cultural contact with the Roman Empire long before it became a Roman Province. This seems to be the reason why the Roman villae rusticae in this area have their own tradition of architecture, showing strong Roman influences.

The precise localization of earlier excavations is sometimes a challenge for recent research. Therefore, the analysis, procession and interpretation of aerial photographs and airborne laser scanning (ALS), or LIDAR, can help. In some cases, both methods result in an increase of information, but the possibilities remain limited in this region. In comparison with other regions of Bavarian, soils in ancient Noricum are not very fertile, and the land is mainly used for stock farming. The application of aerial archaeology is hence limited. Several case studies show that large-scale magnetometer prospection and ALS makes it possible to discover and map new sites and enhance the archaeological knowledge in this field of archaeological research.

The aim of the project is to document a larger number of *villae rusticae* as comprehensively as possible. Therefore, archaeological records were examined, and places selected where excavations already took place, or where a high number of surface findings provide detailed information about the site and where a comprehensive geophysical prospection is possible. Along with these archaeological records and finds, the project sets out to show how the countryside of the Bavarian part of Noricum fits into the rest of the North-West Noricum and what the conditions were for the development of agrarian provincial architecture. These seem to be different from the rest of the North-Western Provinces.

At the current state of research, 51 Roman *villae rusticae* are known in the Bavarian part of Noricum (Figure 1). Twenty-two are fully accessible, twelve are partly overbuilt, nine totally covered and eight are located in forests. Thus, half of the sites are accessible for geophysical prospection. During the last 25 years, eight sites have already been prospected by geophysical methods through the Bavarian State Department for Monuments and Sites, and eight were prospected in 2012 for this project.

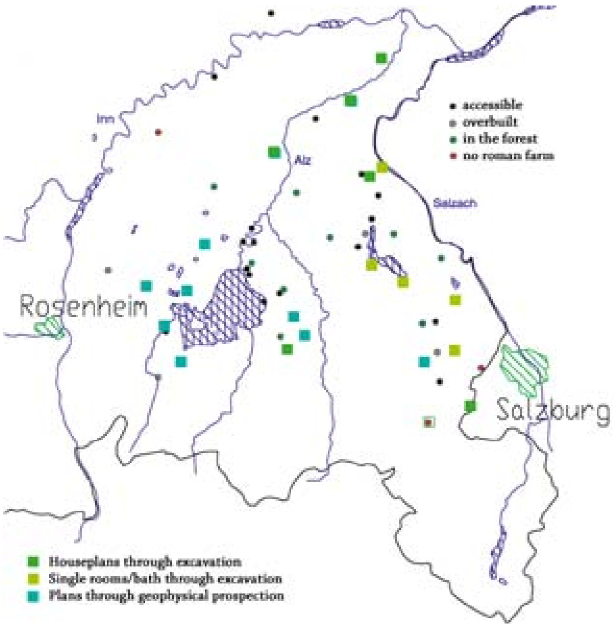

Figure 1: *Map of villae rusticae in the Bavarian part of the Roman province Noricum.*

2. RESULTS

2.1. Bad Endorf

One case study from the 2012 season is Bad Endorf (Lkr. Rosenheim), which is located west of the Chiemsee. In 1899, an excavation of a mural structure was made, which was recorded in a description note and an imprecise drawing of the location. From these, it was possible to narrow the area down to two large grass fields in the village of Bad Endorf. In these areas, large scale magnetometer measurements were undertaken (Figure 2). The results allowed us to locate the Roman villa rustica. However, the clear layout of the foundations was covered by the high magnetic anomalies of fireplaces and hypocausts.

Resistivity and radar prospecting where used to get more detailed information about the stone structures. The GPR depth slices (Figure 3) show the remains of the Roman *villa rustica* between 0.35 and 1.3 m depth. The huge areas of high reflection amplitude in 40 – 60 cm under the surface are due to accumulated water at the archaeological features, caused by precipitation in the weeks before the survey. Nevertheless, four buildings can be identified.

The first one depicts the smaller main building and is situated in the middle of the survey grid. In the southwest it has two corner risalits which are linked with a porticus. In the northeast of the building an annex can be detected. Several rooms, including the annex hall and the two risalits, have preserved floors at

Figure 2: *Bad Endorf. Magnetogram, Caesium-Magnetometer Smartmag SM4G- Special, Duo-Sensor-Configuration, Sensitivity ±10pT, Dynamics ± 10nT, 0.5 × 0.25 m sample spacing, interpolated to 0.25 × 0.25 m, 40-m-grid. Overlay with aerial photograph (Photo: K. Leidorf, Nr. L 8138/102-1 Image 5D249991).*

60 – 100 cm depth, and in the case of the hall, several pillars of the hypocaust system can be identified. In the interior there is a small court surrounded by small rooms. Hence, this part could be interpreted as a residential area and the hall with floor heating was used for representative purposes. East of this building, a linear anomaly can perhaps be identified as a part of the water supply system. The enclosed area in the west of the smaller main building could probably have been a courtyard whose southern end is formed by a building of unknown function. In the interior of the court, there are lower reflection amplitudes in the radargram supporting this interpretation.

The second and larger main building is situated west of this court. As in the previous example, the interior layout with small rooms can be distinguished clearly. Again, several remains of the ancient paved floors were identified as high reflective regions. The western completion of the building is formed by two parallel walls that simply end. Perhaps the missing parts of the foundations have been completely destroyed over the centuries.

Southeast of the small main building is a nearly quadratic stone-outbuilding with two annexes in the north and the south. The northern annex is rectangular too, and has hypocaust pillars, whereas the southern one is semicircular. A subdivision of the interior of the house is not possible because there are no inner walls visible.

The whole complex differs from the well-known types of villae rusticae in the other Northwest- Provinces, but there are very similar examples to this type in the Austrian part of Noricum. Like in Glas (Traxler and Kastler, 2010) we have two main houses and they seem to be connected through a courtyard. It is supposed that one of the main buildings was for the farm owners and so was part of the *pars urbana*, the living area. The other one belonged to the *pars rustica* and was owned by the administrator of the *villa rustica* (Kastler, 2010). In Erlstätt, 25 km away from Bad Endorf on the East side of the Chiemsee, there is another example with two main buildings.

2.2. Erlstätt

In the 19th century, several parts of a Roman *villa rustica* were discovered on a hill near Erlstätt (Lkr. Traunstein). In some case, seven mosaics and hypocaust systems have been uncovered. In 1980, the bigger main building showed up as a snow mark in an aerial photo because of its debris walls, which are also identifiable in a LIDAR image.

Buildings 1 and 3 were surveyed in 1997 by resistivity prospection. The results show evidence of the internal walls of the big main building as well as the detailed layout of a nearby side building (Fassbinder and Pietsch, 2000; Pietsch, 2007). To survey the area at a larger scale, we performed magnetometer and radar prospecting in 2009 (Figure 4) (Linck and Deller, 2010).

Several interpretation problems from the first resistivity measurement were solved through the application of additional

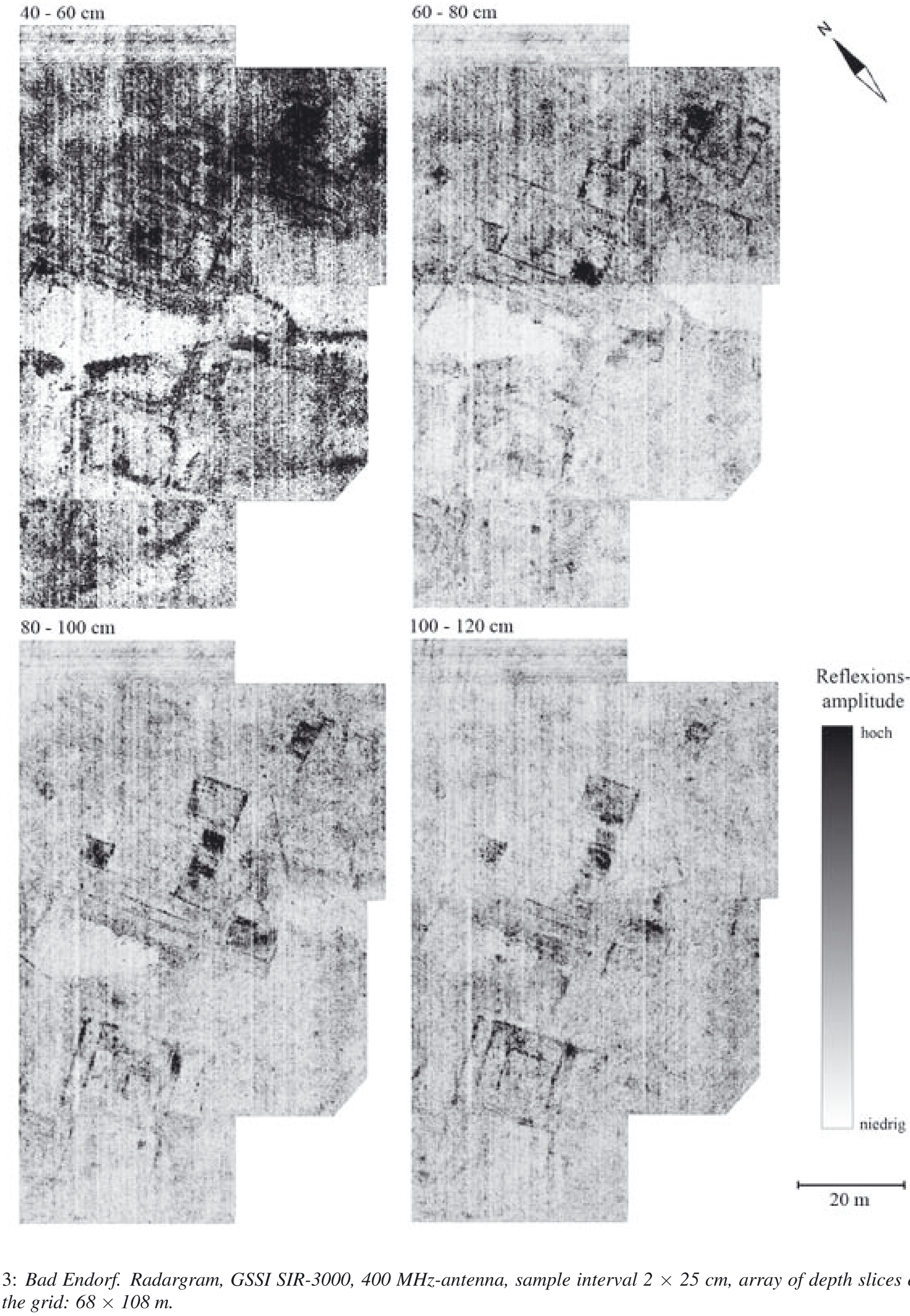

Figure 3: *Bad Endorf. Radargram, GSSI SIR-3000, 400 MHz-antenna, sample interval 2 × 25 cm, array of depth slices of the area. Size of the grid: 68 × 108 m.*

methods. Because the radar depth slices provide a 3D image of the buried structures, it became apparent that the remains of the large main building are covered with a thick layer of debris, which obscured the resistivity prospection quite heavily. Hence, the toppled outer walls were interpreted as another wall, and an exterior corridor was created which had never existed. This could be corrected and clarified by the radargrams, and the new interpretation thus shows a much narrower floor plan with a sim-

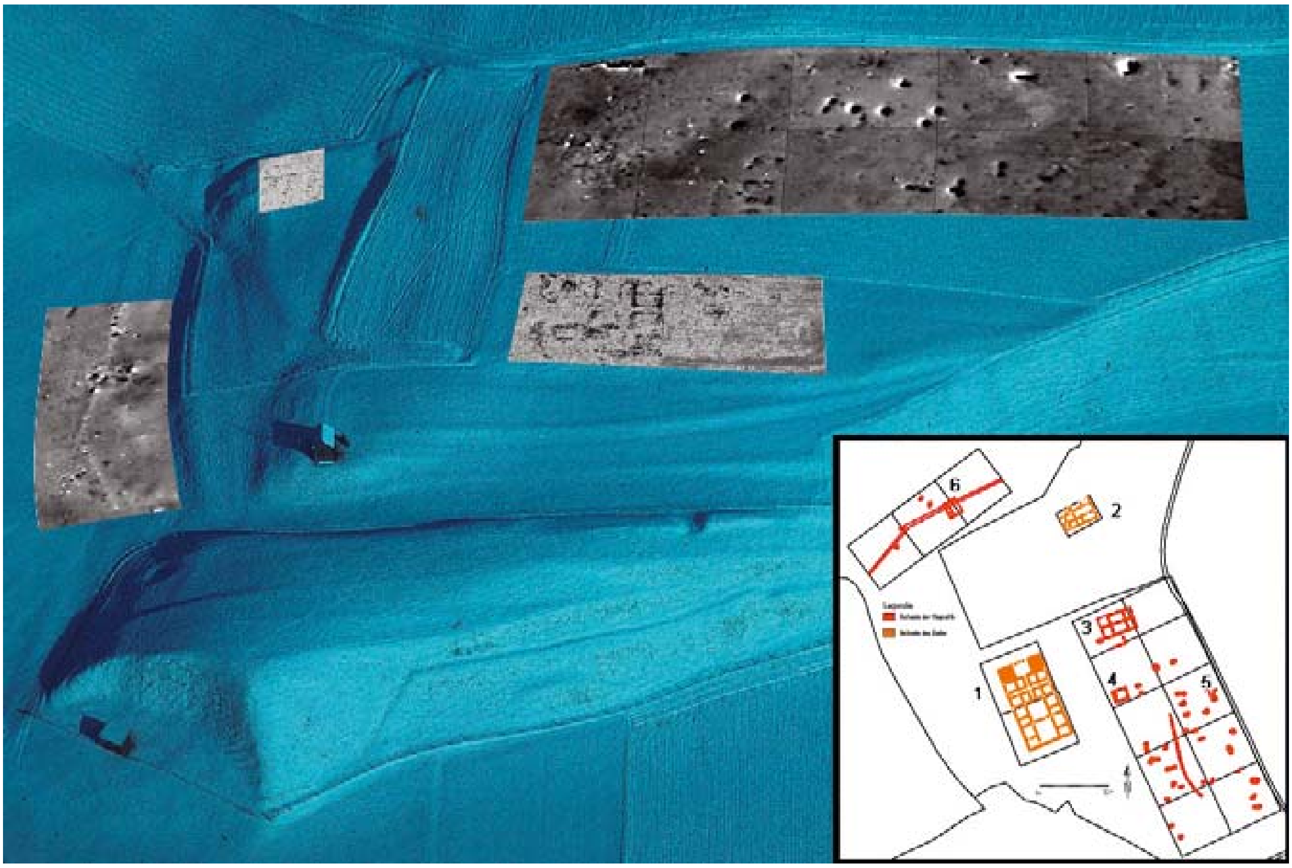

Figure 4: *Erlstätt. Magnetometer- and radar prospection of the Roman villa rustica, overlay with the aerial photo (Photo: O. Braasch, Nr. L 8140/059 Dia 5741-09) and the interpretation. Magnetometer: Caesium- Magnetometer Smartmag SM4G- Special, Duo-Sensor-Configuration, Sensitivity ±10pT, Dynamics ± 10nT, 0.5 × 0.25 m sample spacing, interpolated to 0.25 × 0.25 m, 40-m-grid. Radar: GSSI SIR-3000, 400 MHz-antenna, sample interval 2 × 25 cm.*

ilar, but better structured room division. Furthermore, the southern wing could be interpreted archaeologically in much greater detail, as the possibilities of the resistivity prospection were influenced here most by the debris. The detected column or pilaster bases, however, could not be identified in the GPR depth slices. The anomaly originally interpreted as a staircase at the northern narrow side could now be identified as toppled columns of a portico between the risalits.

In addition to the main building 1, another building 2, which was already partly excavated in the 19th century, was surveyed by radar (Figure 4). The results correlate very well with the 1890 excavation plans. Misalignment only occurred in some parts, caused by poor documentation in the 19th century (Linck and Deller, 2010). Acting on the assumption that the rooms were equipped with mosaics and hypocausts, it can be certainly interpreted as a second residential building.

3. CONCLUSION

The analytical interpretation of our geophysical data, together with the archaeological records, reveals an architectural structure that is different from the homogeneous villa-types in Rhaetia. It indicates a differentiated arrangement, and the layout of rooms and houses relating much more to each other. In addition, the complexes with two main buildings seem to be typical for North-Western Noricum. They can be arranged differently, but the larger building always seems to be more oblong, while the smaller one mostly is quadratic. Therefore, there is often a co-existence of house types in one *villa rustica* complex. Maybe this is also a result of the much earlier influence of Rome in Noricum. This, however, has yet to be proved by a chronology of the known *villae rusticae* in Noricum.

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GEOPHYSICAL SURVEYING IN EGYPT: PERIODIC REPORT FOR 2011-2012

T. Herbich

The paper discusses geophysical projects carried out by the author in Egypt in 2011-2012. Results of geophysical surveying by the author since 1999 have been presented regularly at Archaeological Prospection conferences in Vienna (Herbich, 2001), Rome (Herbich, 2005), Nitra (Herbich, 2007), Paris (Herbich, 2009) and Izmir (Herbich, 2011), whereas a more exhaustive discussion of research in 1998-2003 has been published in the proceedings of the conference held in Kraków (Herbich, 2003). The following projects – Berenike (Egyptian Red Sea coast), Ayn Birbiyeh (Dakhleh Oasis), Watfa (Fayum Oasis) and el-Deir (Kharga Oasis) – represent ongoing undertakings, running over a number of years, and in the case of Tell el-Dabca (Delta) yearly since 1999. In Deir el-Barsha (Middle Egypt) it was a return after an eight-year break. New projects included work in the area of Kom el-Gir (Delta), Malkata (West Thebes) and Heliopolis (suburbs of Cairo). So far, the new political situation in Egypt has affected only work in the Sinai, which is currently out of bounds; this has stopped the projects in Tell el-Ghaba and Pelusium.

Magnetic and electric resistivity methods were applied in the research. Magnetic measurements were taken with Geoscan Research FM256 fluxgate gradiometers, always in parallel mode (with the exception of Watfa where the zigzag mode was applied), sampling density always 0.25 × 0.50 m in 20 × 20 m grids. The vertical electrical soundings (VES) and profiling method was used with Polish-made equipment ADA-05.

OLD KINGDOM/MIDDLE KINGDOM (2575-1640 BC)

Deir al-Barsha

Expedition of the Catholic University in Leuven
Project director H. Willems

Previous work in 2002-2004 had demonstrated the magnetic method to be effective in locating shaft graves with mud-brick lining of the walls in a desert environment between the base of the Eastern Desert plateau and the cultivated land in the Nile Valley. In 2012, the team aimed at verifying the presence of shaft graves in further sections of this desert area, as well as locating earlier burials from the Old Kingdom, which were characterized by the use of small terracotta coffins placed in shallow pits and covered with boulders. The research covered an area of 8 ha. An area with shaft graves demonstrating diverse architecture was located (from one to a few adjacent shafts, Figure 1). A few anomalies recorded at the base of the plateau could be associated with terracotta coffin burials (although their number was smaller than expected).

SECOND INTERMEDIATE PERIOD (1640-1532 BC))

Tell el-Dabca

Expedition of the Austrian Archaeological Institute in Cairo
Project director I. Forstner-Müller

A magnetic project at Tell el-Dabca was completed in 2011, taking complementary measurements in areas of current excavations. The electrical resistivity program is being continued in an effort to establish the exact extent of land beyond the reach of the annual Nile flood in antiquity, which is tantamount to areas of sustainable settlement. Additional electrical resistivity measurements (VES) were taken in two regions (Ezbet Ezzawin and Mehessin), where magnetic research had indicated the presence of small river harbours. The results demonstrated that structures identified in the wake of magnetic prospection as hardened riverfront banks were formed of materials featuring higher resistivity than the surroundings (Figure 2); shallow drilling revealed that these features had been constructed of mud brick with extensive amounts of sand temper. Identical structures had been recorded previously by H. Becker and J. Fassbinder in nearby Qantir, which is about five hundred years later. This shows a lasting tradition of intentionally formed waterfronts designed to expedite river transport.

NEW KINGDOM (1550-1070 BC)

Malkata

Expedition of the Metropolitan Museum of Art
Project director D. Craig-Patch

This project was doubly significant to the author, who has recently been involved in studying the application of geophysical prospection in archaeology from a historical perspective. Namely, the present work refers to research carried out by a pioneer of the application of the magnetic surveying method in archaeology, E. Ralph, in the early 1970s. Her work appears to have been the first prospection of an archaeological site in Egypt using the magnetic method, and most certainly the first survey to be carried out with a caesium magnetometer. Ralph recorded fragments of a palatial complex of Amenhotep III, rising on the western bank of the Nile. The present work was charged with the task of locating on the ground the excavations carried out by a MMA expedition in the early 20th century. Detailed plans exist of the architecture uncovered at the time, but the exact location of these remains cannot be pinpointed owing to extensive site destruction. The prospection so far has clarified the plan of a temple.

Heliopolis

Joint project of the University of Leipzig and Supreme Council of Antiquities of Egypt
Project directors D. Raue and A. Ashmawy

The temple of the god Ra in Heliopolis was an important cult place starting from Old Kingdom. Current excavation work,

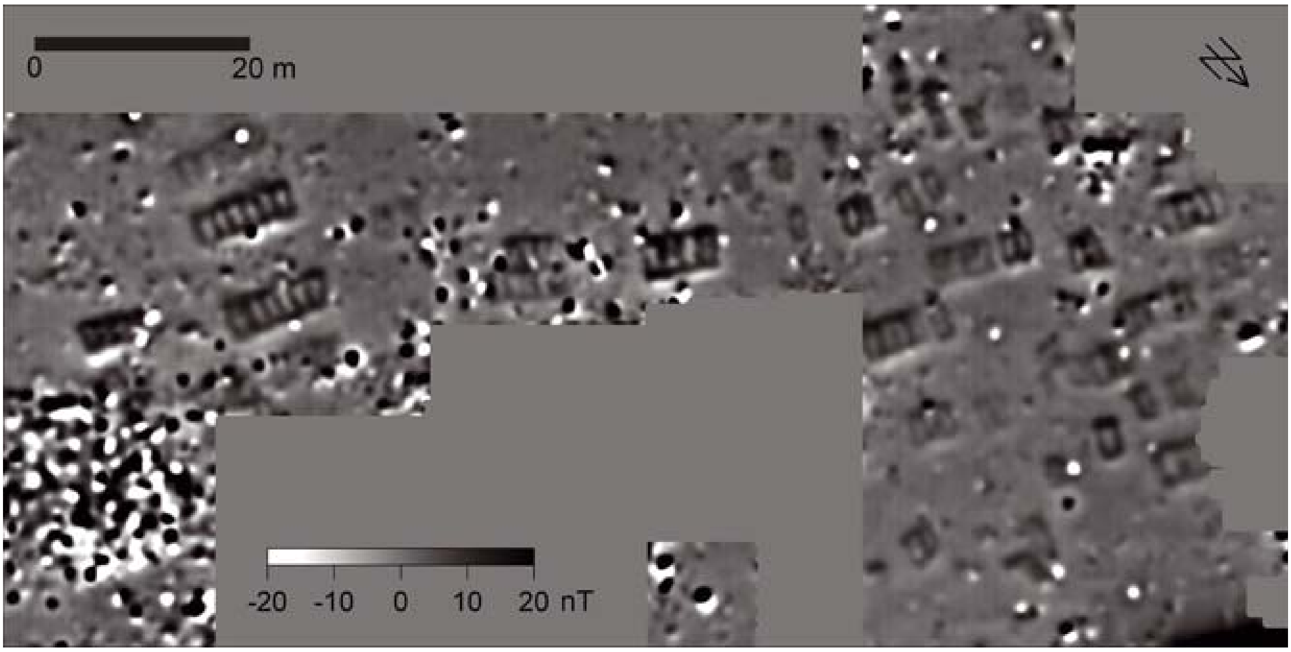

Figure 1: *Deir el-Barsha. Magnetic map.*

however, has reached only levels from the New Kingdom. The site had remained clear of modern architecture until the last decade, when it attracted the attention of building developers. Salvage archaeological excavations had to be undertaken in view of the threat that this posed to the ancient remains, especially as the area had started to suffer from unchecked rubbish and rubble dumping resulting from weakened authority in a situation of political change (Figure 3). The objective of two short seasons was to choose the proper geophysical method for recording the remains of architecture more than 2 m underground (the extent of mud deposits accumulated over most of the area in modern times) in an effort to trace the most promising location for archaeological excavations. The magnetic method proved useful only in a small part of the area where the overlying mud deposits were not so deep. Measurements demonstrated the orientation of the architecture and sporadically identified architectural remains. VES across the line of fortifications from the Hyxos age recorded the inner edge of the north section of the fortifications. Testing of different probe arrangements led to the selection of the asymmetrical Schlumberger arrangement with probes AM=7 m, MN=2 m for surveying to be conducted in the next season.

LATE PERIOD (712-332 BC)

El – Deir
Expedition of University of Limoges
Project director G. Tallet

Following prospection of the Roman fort, the project moved to a Late Period settlement situated to the west of the fort. Traces on the ground indicated sun-dried mud brick to be the chief building material. This kind of brick has no magnetic properties, but there was hope that, similarly to earlier work in the fort, the magnetic method would give good results with regard to tracing architecture by recording the fill of individual rooms, which was found to have magnetic properties. Unfortunately, the magnetic prospection did not record any traces of architecture.

GRAECO-ROMAN AND BYZANTINE PERIOD (332 BC-640 AD)

Berenike
(joint project of the Polish Centre of Mediterranean Archaeology of the University of Warsaw and the University of Delaware
Project directors I. Zych and S. Sidebotham

Measurements were concentrated in the harbour area and at the interface of this area with urban architecture on the western and southern side of the Roman-age town, in the area of Ptolemaic-age architecture and a late necropolis. Measurements in the harbour and at the southern edge of the Roman town established the exact course of the seashore. In the cemetery area, the location of individual tombs could be traced. The prospection in the Ptolemaic district repeated the original survey of 1999 but changed the angle of the traverses (the traverses during the first survey turned out to be parallel to the orientation of the main walls). The aim of the repeated prospection was to obtain a more precise image of a feature currently interpreted as a large Hellenistic army fort.

Ayn Birbiyeh
Dakhleh Oasis Project
Project director A. Mills

The continuing project is aimed at reconstructing the plan of a hitherto completely unknown settlement around a Roman-period temple. Magnetic prospection mapped architecture over a combined area of 5 ha, tracing the unique layout of the settlement with streets running concentrically toward the temple. Areas of dense building were identified, as well as open squares and a number of streets. Measurements in the northern part of the prospected area gave an especially clear image. Here, the highly magnetically susceptible matrix permitted walls made of non-magnetic sandstone to be traced in the negative (Figure 4).

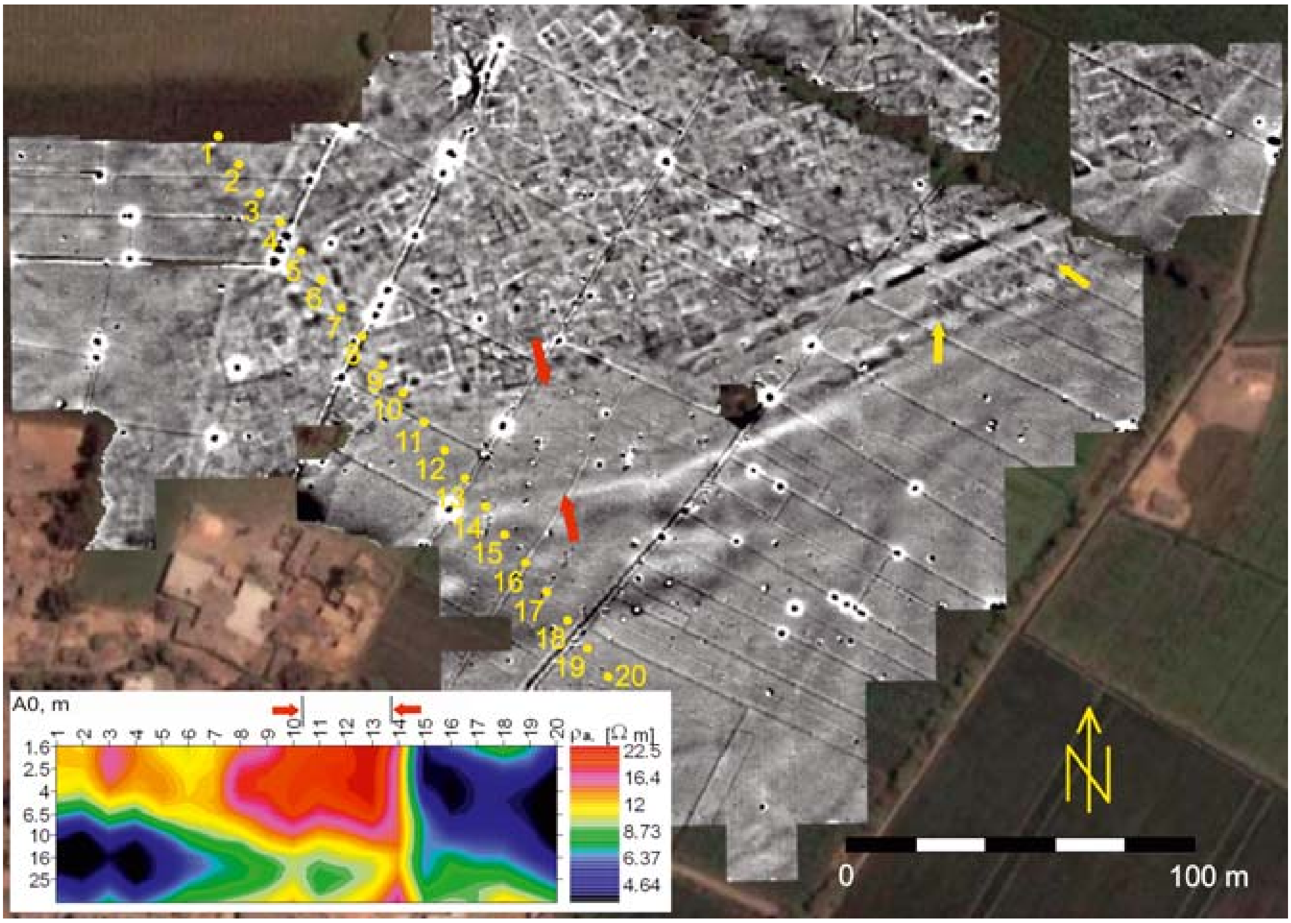

Figure 2: *Tell el-Dabca (Ezzawin). Magnetic map. A reinforced waterfront may be reflected by a feature with homogeneous values of magnetic field intensity (indicated with red arrows). A recess in the waterline (yellow arrows) suggests a harbor. Yellow dots are VES locations. Box: apparent resistivity pseudo-section. The higher-resistivity structure between arrows corresponds to the feature characterized by homogeneous magnetic field intensity values – the presumed waterfront made of material with gravel and sand added in considerable quantities.*

Figure 3: *Heliopolis. Vertical electrical sounding measurements. Photo J. Ordutowski.*

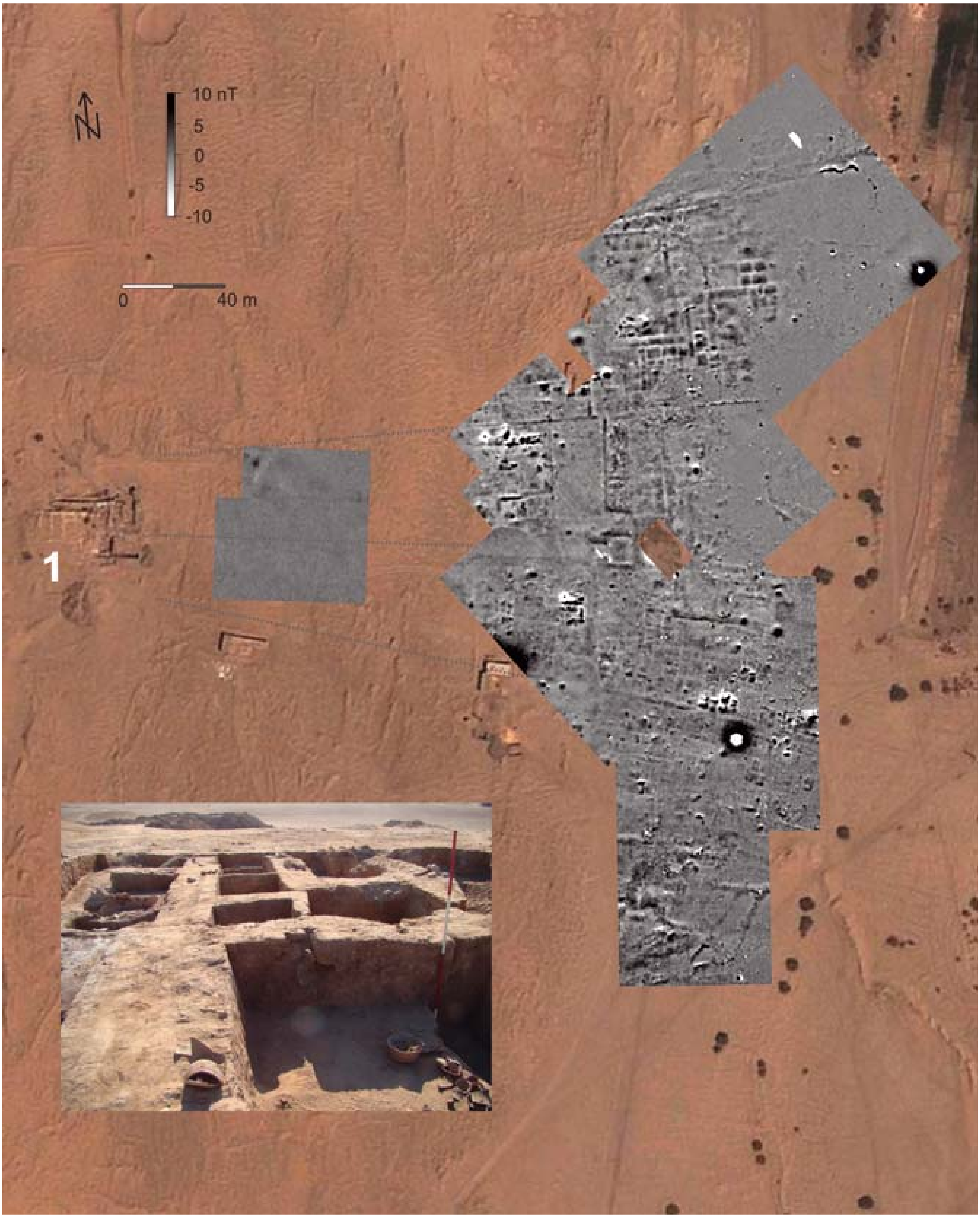

Figure 4: *Ayn Birbiyeh. Magnetic map. 1–Roman temple. Box: Remains of mud-brick architecture. Excavation in the area surveyed in the south-eastern part of the site. Photo A. Zieliński.*

Medinet Watfa (ancient Philoteris)
Expedition of the German Archaeological Institute
Project director C. Römer

The objective of the survey was to trace architecture inside the settled area and reconstruct the network of canals supplying water to the town and watering the surrounding fields. The results are discussed elsewhere in this volume.

Kom el-Gir/Buto area
Expedition of the German Archaeological Institute
Project director R. Schiestl

Measurements with the magnetic method were part of an extensive project to reconstruct settlement in the neighbourhood of Buto. The survey was conducted in two places: on Kom el-Gir (a low artificial mound formed of cultural deposits, currently not under cultivation) and in the cultivated fields between Kom el-Gir and Buto. Prospection of Kom el-Gir gave a very precise image of the architecture, identified as being of Roman age based on surface finds. The map revealed a clear network of streets and traced individual building plans. Following the completion of the survey on the mound (planned for the autumn 2012), it should be possible to reconstruct the function of particular districts of the site. The survey in the cultivated fields was designed to verify observations made from a study of aerial photographs from the 1950s, which had revealed the presence of a trapezoid structure measuring approximately 480 m by 230 m, perhaps the remains of one of the monumental temples that Herodotus saw at Buto. The prospection, carried out in extremely difficult conditions, did not produce unequivocal results: the magnetic map reveals linear structures lined up parallel to the expected course of the enclosure walls, but the image is hardly as convincing as the images of foundations of temple enclosures in Buto or Balamun. It is therefore still risky to report the presence of a temple in this location. VES also did not give positive results.

ACKNOWLEDGMENTS

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THE APPLICATION OF REMOTE SENSING TECHNOLOGY AND GEOPHYSICAL METHODS IN THE TOPOGRAPHIC SURVEY OF THE LATE IRON AGE FORTIFICATIONS IN TRANSDANUBIA

Z. Czajlik, B. Holl, G. Király

The Institute of Archaeological Sciences of the Eötvös Loránd University started topographical survey and the systematic research of Prehistoric fortified settlements in 1998. With the help of Gyula Nováki, we studied about 200 fortifications which were already known (Nováki *et al.*, 2006), and from the year 2000, we identified new fortification patterns at many sites with the use of aerial archaeology and field surveys (e.g. Czajlik-Holl, 2003). In addition, we found more than 50 new fortified settlements. The research based on aerial photography proved to be efficient on land that was under cultivation, but snow cover also helped to discover many new details of fortifications located in forested areas. The phenomena observed in aerial photos were investigated by different methods: we used magnetometry on open surfaces, and – in cooperation with the University of West Hungary (Sopron) – ALS (Airborne Laser Scanning) in forests. Here, we present the most important results in the research of the Late Iron Age fortified settlements of the Transdanubian region.

Nagyberki – Szalacska

The settlement of Nagyberki-Szalacska was probably founded in the Early Iron Age, in the same period when the tumulus cemetery was established (see Czajlik *et al.*, 2012). The research of Kálmán Darnay from the early 20^{th} century suggest the presence of a Celtic mint here, and this site is considered as a Celtic oppidum according to the modern investigations of Szilvia Honti. These settings seem to be confirmed by topographical evidence as well, with the help aerial photos and the field surveys. The most important discovery is the identification of two gates of the Zangentor type, typical of the Late Iron Age, which presumably mark the main road into the settlement. However, the gates do not represent the 'classical' or masonry form of the Zangentor type, but a peculiar adaptation of its schema, which fits well to the surface of the loess plateau

Figure 1: *Nagyberki — Szalacska. Iron Age settlement built on a loess plateau, possibly gates of the 'Zangentor type' (Z. Czajlik, 8. February, 2010).*

Báta – Öreghegy (see Czajlik 2010)

Despite the attention raised by the finding of the boar figurine on the important sites of Báta – Öreghegy at the beginning of the 20th century (see e.g. Szabó, 1992, 193), only its central part, overlooking the Danube and dated mainly to the Bronze Age, was known from previous research. A significant improvement in our knowledge of the site developed through the detailed examination of Google Earth images. These examinations allowed us to identify many outer fortification lines, which could then be verified with aerial archaeology and geophysical surveys in the spring of 2011. As far we know, this is the greatest oppidum in Hungary, with a surface area of 70 hectares. Its size is considerable in European context too, and it seems to belong to the most important settlements of the Scordisci (Figure 2).

Sopron – Sánchegy

It seems to be feasible that some Late Iron Age oppida were linked to smaller fortifications (castellum). There is strong evidence for this in the context of Sopron-Várhely and Sopron-

Figure 2: *Báta — Öreghegy. Late Iron Age fortified settlement built on a loess plateau as shown on the Google Earth image. The central part is marked yellow, the outer fortification line is red. (B. Holl, 2011).*

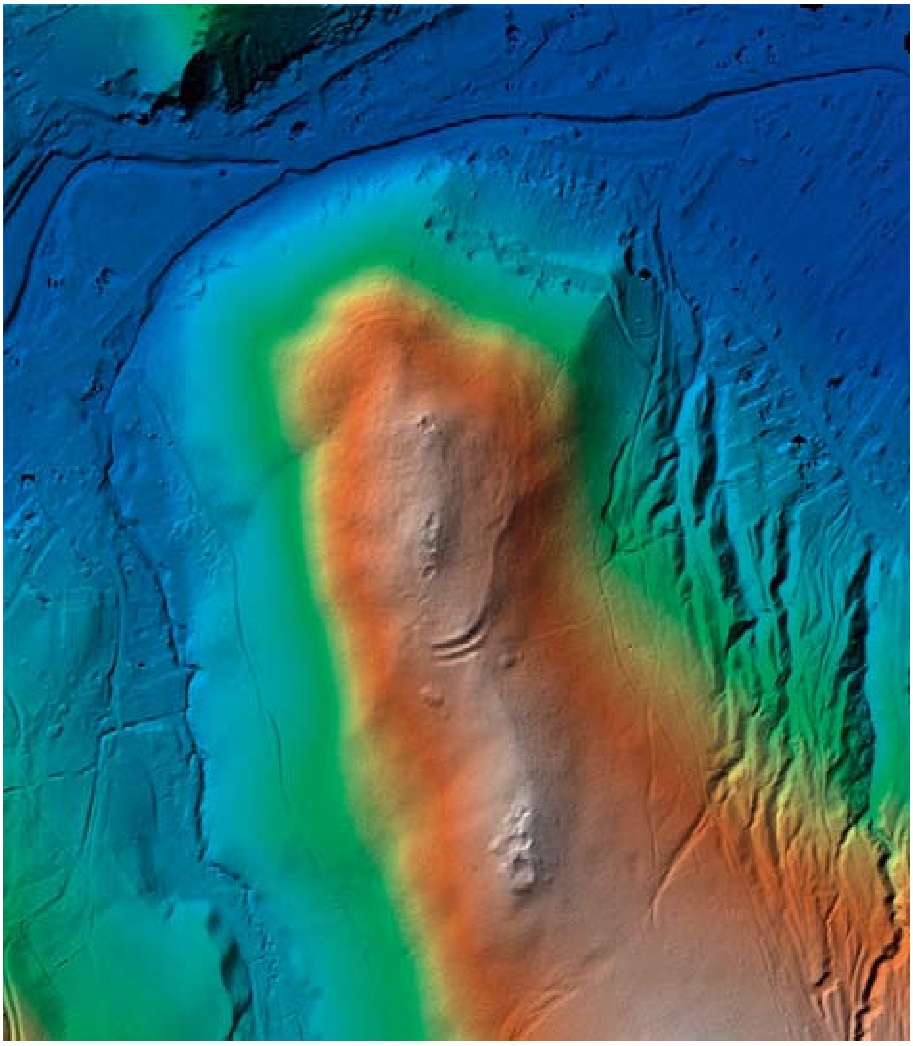

Figure 3: *Sopron – Sánchegy. Late Iron Age promontory fortress (?). (G. Király, 2012).*

Sánchegy, which are situated very close to each other. Although Sopron-Sánchegy looks like a promontory fortress of the Bronze Age, the finds on the surface refer to the Celtic period, and the layout of the fortifications is not typical of the Bronze Age. The traces of the rampart are visible not just on the plateau, but in addition to the earlier observations of Nováki (1998), on the ALS survey they could be traced everywhere with the exception of the western side. The small colony, which seems to be something like an outpost due to its size, would have provided control over the important road leading to the Várhely on the western side (Figure 3). Figure 3. Sopron – Sánchegy. Late Iron Age promontory fortress (?). (G. Király, 2012).

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ENCLOSURES AND THEIR CONTEXT IN THE LATE URN FIELD CULTURE UP TO THE EARLY LA TENE PERIOD IN THE ADMINISTRATIVE DISTRICT LANDSHUT (LOWER BAVARIA, GERMANY) – POTENTIAL OF MAGNETIC PROSPECTION

M. Geelhaar, J.W.E. Fassbinder, R. Linck

1. INTRODUCTION

The aim of this study, which was created within the framework of a master's thesis, was to prove and illustrate the potential of interpreting magnetic prospection data by comparing the results with those of excavations of the same or of comparable sites. Since numerous archaeological sites are in danger due to intensive land use and erosion, the significance of archaeological prospection increases rapidly. Therefore, the common line of proceedings, from survey to excavation to typological research, should be open for alterations in order to create more interaction between survey and typological research. The combination of the typological comparison of magnetograms, documentation of excavations and aerial photos can lead to results that allow a more accurate dating of the prospected sites, complement archaeological studies of other sites and even reveal typical phenomena that were not observed in archaeological excavations.

With this intention, a significant contribution to the understanding of early Iron Age enclosures in a microregion in the Lower Isar valley was achieved based on magnetometric measurements. The study subject, the so-called Hallstatt "Herrenhöfe", is a widely spread phenomenon of the Bavarian Iron Age. Typically, these settlements comprise rectangular ditch systems with mostly rounded corners. It is widely agreed that the enclosures are not fortifications, because the locations of the settlements are difficult to defend. Moreover, an interpretation as princely sites is excluded due to the numerous appearances of the enclosures as well as their small size, with an internal area of 1,600 – 2,500 square metres measured for most instances in the study area. The sites are of a rural character and are related to agriculture. Therefore, the ditch systems are often thought to have a representative function within a rural community; however, the real intention of the builders cannot yet be reconstructed. The transition to this particular form of settlement occurred in the Late Urnfield period and ended in the Early La Tène period. Though many of the rectangular enclosures are known, and a certain number of them have been investigated, we still do not know why this type of settlement was so popular in this region during this period, especially compared to earlier and later periods as well as adjacent regions, where the Hallstatt culture deposits in a different way.

To achieve significant results, the investigation concentrated on a small region, the administrative district Landshut (Lower Bavaria, Germany). The area around Landshut was also quite convenient thanks to extensive prior research regarding geophysical and aerial prospection, as well as excavations. During the study, every rectangular enclosure which had already been assessed as dating to the early Iron Age (the latest catalogue of Bavarian Iron Age enclosures was compiled by Berg-Hobohm 2005), could be documented regarding form, size, and internal and external house building. To create this basis for comparison, four new magnetic measurements had to be made. The old magnetometer data of several other sites, collected since 1978, had to be edited and adapted to the current state of technology. Altogether, maps of 21 enclosures now exist (Figure 1; Table 1).

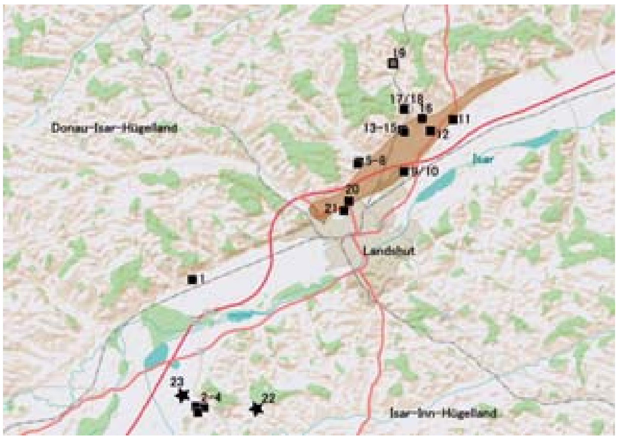

Figure 1: *Map of the research area. Filled squares: rectangular enclosures with Early Iron Age dating; not filled square: rectangular enclosure without dating; stars: barrow cemeteries; grey: town of Landshut; brown: Altdorfer Hochterrasse; evidence of find spots see Tab.1 (Map: ESRI Inc.; ed. by M. Geelhaar)*

Inside the administrative district and the town of Landshut, the rectangular enclosed settlements in Early Iron Age context concentrate in the Lower Isar Valley and its periphery. Very frequently, the enclosures appear on the Altdorfer Hochterrasse, a 14.5 km long loess terrace located northeast of the town of Landshut; 16 of the 21 enclosures are located in this area. A viewshed analysis based on a digital ground model (DGM) demonstrated that most of these settlements on the Altdorfer Hochterrasse are located within the visibility range of the others.

For a better understanding of this category of archaeological sites, it was necessary to study the rectangular enclosures of Landshut in a supraregional context. For this purpose, a data base of all identified early Iron Age enclosures in Bavaria was created, based on the catalogue of Berg-Hobohm 2005, so that attributes could be compared. Beyond that, the shapes of the prospected features in the study area were compared to those of excavated settlements (with or without enclosures).

2. THE ENCLOSED SETTLEMENTS INVESTIGATED IN 2011

The new measurements for the study were executed in 2011. The first investigated site was Mirskofen II, which was known from an aerial photo as a double rectangular ditch system. As the prospected area was heavily disturbed by an electrical tower, only the ditches could be visualized. It is possible that any ap-

Figure 2: *Pettenkofen. Aerial photo overlaid with the magnetogram of the enclosure. BLfD Aerial photo documentation 29/07/1993, Photographer Klaus Leidorf, Archive-Nr.7338/373 Film Nr. 6949-17. Magnetogram: Caesium-magnetometer Smartmag SM4G-Special in a duo-sensor-configuration, sensitivity ±10 pT, dynamics ±7 nT in 256 gray scales, sampling rate of 25 × 50 cm, interpolated to 25 × 25 cm, grid 40 × 40 m.*

pending house structures will have disappeared completely due to the high erosion in the area. By further data processing, the disturbance could be minimized and thus parts of a second enclosure with exactly the same orientation and similar shape and dimensions appeared near the first rectangular enclosure.

The second investigated site, Pettenkofen, located a few kilometres north of the Isar valley, dates back to an earlier period. Its trapezoid shape and its special kind of entrance rather resemble to the enclosures of the Neolithic Altheim culture than of the Early Iron Age. Therefore, Pettenkofen has been eliminated from the catalogue of rectangular enclosures dating between the Late Urnfield and the Early La Tène culture for the present (Figure 2).

The following two investigations were both conducted on sites with a lot of collected surface finds, especially from the Hallstatt and Bronze Age periods. Essenbach-Altheimer Feld as well as Ergolding-Siechenhausfeld (enclosure B) are complex rectangular ditch systems with house building inside and outside the enclosures. The magnetograms showed a detailed plan of both settlements, including a couple of house remnants and in Ergolding-Siechenhausfeld even the foundation of a gatehouse. The enclosure A of Ergolding-Siechenhausfeld had already been prospected in 1986. In combination with a rectification and interpretation of the aerial photos, the whole complex can be mapped now (Figures 3, 4).

3. THE PREVIOUSLY INVESTIGATED ENCLOSURED SETTLEMENTS

The enclosure Holzen III was prospected before the 2011 studies. Thereby, the survey of an ensemble of three rectangular enclosures with Hallstatt stray finds near Holzen was completed.

During the revision of the interpretation of Holzen III an important house remnant was found. The old magnetometer data was mostly carried out with the first generation of caesium-magnetometers with a sampling rate of 50×50 cm and a sensitivity of 0.1 nT. Therefore, smaller postholes could not be identified here. Only large postholes, for example those of the gatehouse in Ergolding-Siechenhausfeld, enclosure A, or pit houses could be visualised. All data were reprocessed during the study and therefore some data had to be converted into common data format.

Besides the magnetometer investigations, several excavations were made in enclosed settlements around Landshut since 1978, e.g. Landshut-Hascherkeller, Galgenberg, Niedererlbach, enclosure I and Altheim-Andreasweg.

4. RESUME

The analysis of all results led to some interesting conclusions. First, the orientation of every investigated rectangular enclosure is NW-SE. This is similar to Early Iron Age houses in Bavaria, which are generally known to be orientated this way. In addition, the entrances, being identified by earth bridges, are often located at the north-western or south-eastern side of the enclosures. The shapes of the enclosures could be classified into three types: single rectangular enclosures, double rectangular enclosures and split rectangular enclosures. Unfortunately, this system can only be applied regionally.

Common post structures are rather difficult to assign to a particular period. Small houses of different periods often have a similar shape, and so do pit houses. However, during the studies on rectangular enclosures an unusual phenomenon attracted the attention of the surveyors. Many sites featured long rectangular pits (much bigger than the so called Schlitzgruben) inside the enclosures, equispaced and with the same orientation as the ditches. Soon it could be assumed that these pits are related to houses. This was confirmed by comparison with excavations. Documentation of Landshut-Hascherkeller (Wells, 1983) and Altheim-Andreasweg (Nagler, 1993) show similar structures

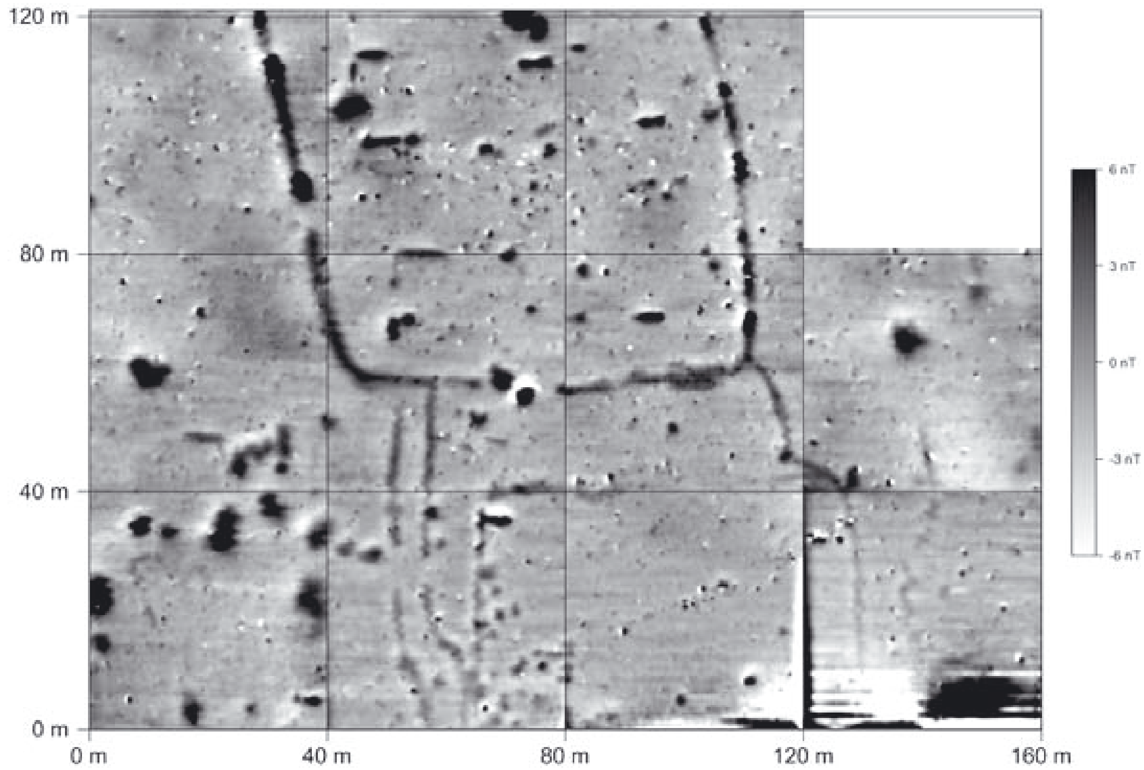

Figure 3: *Essenbach-Altheimer Feld. Magnetogram of the enclosure. Caesium-magnetometer Smartmag SM4G-Special in a duo-sensor-configuration, sensitivity ±10 pT, dynamics ± 6nT in 256 gray scales, sampling rate of 25 × 50 cm, interpolated to 25 × 25 cm, grid 40 × 40 m.*

being interpreted as cellar pits. However, they also appear in many excavations of Urnfield and Hallstatt sites along the Isar and Danube valleys (details can be found in Geelhaar, 2012). Sometimes they are integrated into a house, in other situations there is no evidence of a house (which in some cases might be due to erosion). Generally they cannot be interpreted specifically. Where the pits are located inside a house, the ground plan shows two naves. In one of them the pit, which is usually 7-10 m long, is situated. The buildings have about the double length. The magnetogram of the Holzen III enclosure shows a ground plan that correlates exactly with these features. Evidently, the pits were a typical element of particular Late Urnfield and Hallstatt houses. At this point, we reached a rare situation in the interaction of archaeological and geophysical research. The magnetograms point out a frequently appearing phenomenon, which seems to be a typological aspect of a particular region and period. By comparison with excavations, this can be confirmed, and in turn the geophysically investigated features can be dated. On the other hand, the interpretation of the archaeological features can refer to the basis the geophysical research created for this type of feature along with the typological comparison.

It is highly advisable to intensify this kind of data analysis, as the geophysical prospection can contribute valuable information (in terms of dating and typology), and not only 'nice pictures'. This is especially true in light of the fact, that a lot of sites cannot be excavated and are endangered by building projects, erosion and agriculture; some of their archaeological potential can still be saved by prospection results.

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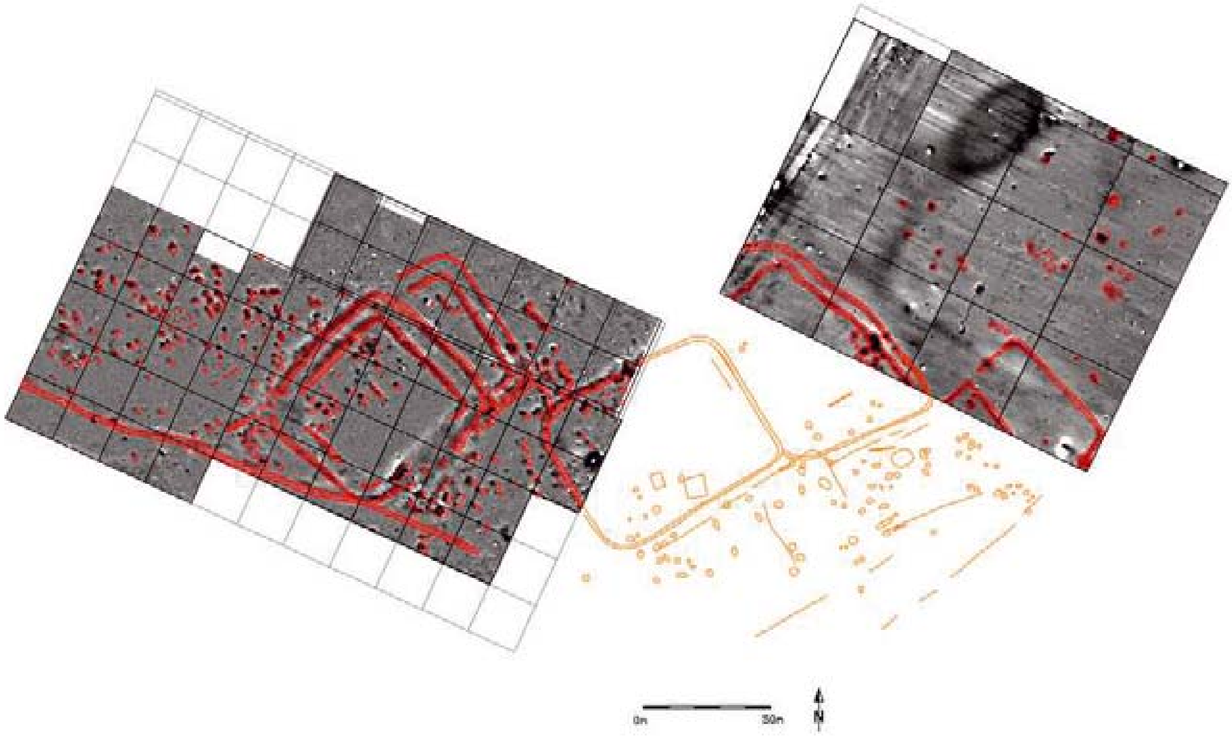

Figure 4: *Ergolding-Siechenhausfeld. Magnetograms of the enclosures overlaid with the corresponding interpretation (red) and the aerial photo rectification (orange). Measurement of 1986 (left): Caesium-magnetometer Varian V101, in gradiometer-configuration, vertical gradient of 0.3 and 1.8 m, sensitivity ±0.1 nT, dynamics ±6 nT in 256 gray scales, sampling rate of 50 × 50 cm, interpolated to 25 × 25 cm, grid 20 × 20 m. Measurement of 2011 (right): Caesium-magnetometer Smartmag SM4G-Special in a duo-sensor-configuration, sensitivity ±10 pT, dynamics ±6 nT in 256 gray scales, sampling rate of 25 × 50 cm, interpolated to 25 × 25 cm, grid 40 × 40 m.*

No	Location	Excavation	Magnetic Survey	Cat.No in Berg-Hobohm 2005 or other
1	Bruckberg	–	1986	82
2	Buch a. Erlbach, Niedererlbach, enclosure I	1980-84, 1987-90, 1994	1981	83
3	Buch a. Erlbach, Niedererlbach, enclosure II	1986, 2006	1986, 2006	84
4	Buch a. Erlbach, Niedererlbach, enclosure III	2006	–	Koch/ Reichold 2006
5	Ergolding, "Galgenberg", enclosure B and C	1981-84	1981/82	85
6	Ergolding, "Galgenberg", enclosure D	–	1981/82	85
7	Ergolding, "Galgenberg", enclosure E	–	1981/82	85
8	Ergolding, "Galgenberg", enclosure F	–	1981/82	85
9	Ergolding, "Siechenhausfeld", enclosure A	–	1987	86
10	Ergolding, "Siechenhausfeld", enclosure B	–	1987, 2011	86
11	Essenbach, "Altheimer Feld"	–	2011	93
12	Essenbach, Altheim	1989-1991	–	87
13	Essenbach, Holzen, enclosure I	–	1986	88
14	Essenbach, Holzen, enclosure II	–	1990	89
15	Essenbach, Holzen, enclosure III	–	2010	90
16	Essenbach, Mirskofen, enclosure I	–	1986	91
17	Essenbach, Mirskofen, enclosure IIA	–	2011	92
18	Essenbach, Mirskofen, enclosure IIB	–	2011	92
19	Essenbach, Pettenkofen	–	2011	94
20	Landshut, Hascherkeller	1978-1983	1978	95
21	Landshut, Kellerberg	–	1986	96
22	Buch a. Erlbach, Hartbeckerforst (cemetery)	–	2011	i.a. Kossack 1959, Nr. 368
23	Buch a. Erlbach, Niedererlbach (cemetery)	–	2011	Braasch/ Christlein 1982, 54 Abb.38

Table 1: *List of rectangular enclosures investigated in the study. Mostly Early Iron Age context with the exception of no. 19 (Pettenkofen). (Koch and Reichold, 2007; Christlein and Braasch, 1982; Kossack, 1959)*

THE ANOMALY THAT WASN'T THERE – ON THE VISIBILITY OF ARCHAEOLOGICAL PROSPECTION ANOMALIES AND THEIR CAUSATIVE STRUCTURES IN THE SUBSURFACE

S. Seren, I. Trinks, A. Hinterleitner, W. Neubauer

Geophysical prospection methods are increasingly used in archaeology to locate and investigate buried cultural heritage. Pro- spection surveys conducted with magnetic, earth resistance, ground penetrating radar and electro-magnetic methods can, in the presence of manmade subsurface structures, result in data showing anomalous measurement values, revealing the structures' location and possibly permitting their identification. Verification of anomalies through archaeological excavations can reveal the cause of geophysical anomalies. In many cases, anomalies observed in geophysical prospection data have led to the discovery of previously unknown archaeological structures during subsequent archaeological excavations. However, it is possible that archaeological structures present in the ground do not cause any measureable physical anomaly and therefore can be missed by some or all geophysical archaeological prospection methods. Conversely, relevant archaeological structures might produce anomalies in geophysical prospection data, while they remain undetected in subsequent archaeological excavations. The various issues related to these physical facts have to be discussed to enhance the appreciation of non-invasive approaches by archaeologists.

Geophysical archaeological prospection is the "examination of the Earth's physical properties using non-invasive ground survey techniques to reveal buried archaeological features, sites and landscapes" (Gaffney and Gather, 2003). Buried remains of manmade constructions such as postholes, pits, trenches, hearths, graves, tracks, cavities, artefacts, walls and wells can cause local changes in the physical properties of the subsoil that are measureable using suitable geophysical prospection methods, sensitive instruments and appropriate sampling intervals. There are many cases in which geophysical prospection methods have been successfully used to located and investigate previously unknown archaeological sites. The preconditions for the successful detection of archaeological structures using magnetic, electrical or electromagnetic geophysical methods are:

- the presence of a measurable contrast in the physical properties of distinct archaeological structures, or parts thereof, and the surrounding subsoil or the archaeological stratification
- a sufficient measurement sensitivity of the instrumentation used in respect to the background noise levels
- a sufficiently large area of investigation and measurement/ sampling density in regard to the dimension of the buried structures
- appropriate data processing and data visualization techniques
- appropriate interpretation by an experienced specialist, including any available information

Figure 1: *Magnetic survey (Foerster Ferex STD with 4 Foerster gradiometer probes) in Syria.*

In general, a professional approach to the task is required, demanding considerable specific training and experience in determining the appropriate choice of method, knowledge about the method's shortcomings, diligent fieldwork routines and careful data processing and analysis. In the field of geophysical prospection, the principle of "negative evidence" refers to the fact that the absence of evidence cannot be used as evidence for absence. Speaking in terms of geophysical anomalies, this means that the absence of anomalies in the data cannot be used, within reason, as a proof for the absence of structures in the subsurface. Three general scenarios exist regarding the verification of observed geophysical anomalies:

1. Positive feedback case: An anomaly is observed in the archaeological prospection data and a corresponding causative structure is found during subsequent archaeological excavation.
2. Negative evidence case: No anomaly is observed in the archaeological prospection data, while a relevant archaeological structure is found in the subsurface during archaeological excavation.
3. Negative feedback case: An anomaly is observed in the archaeological prospection data but no corresponding causative structure is found during (conventional) archaeological excavation.

The positive feedback case is frequently used to demonstrate the value of (geophysical) archaeological prospection. With respect to the spatial resolution limits of the prospection methods used more or less good agreement between the imaged/predicted and subsequently excavated structures is given.
While the negative evidence case can present a severe problem to exploration archaeologists, it does not per se present a problem

Figure 2: *GPR survey of the same site using a 500 MHz Noggin Plus system.*

to the geophysical prospector, since it is covered by the principle of negative evidence. If for example the sample spacing is too large to permit the detection of small archaeological structures, then these will not be imaged in the data. Likewise, often no sufficiently measureable contrast is present between an archaeological structure (e.g. between the filling of a posthole and the surrounding soil matrix) in order to give rise to an interpretable magnetic anomaly or to cause a detectable reflection in GPR data. When highest sample spacing and instruments of highest sensitivity are used, then there is not much that can be done about these cases with a given method. However, the use of different methods actually may permit the detection of a structure that is not visible using another method (e.g. GPR versus magnetics). Therefore, it is advisable to investigate any site with at least two complimentary methods.

The negative feedback case is posing the greatest practical problem, while at the same time highlighting the greatest potential of archaeological prospection methods. Anomalies in prospection data that are assumed to be manmade and of archaeological interest only possess a value from an exploratory or rescue archaeological point of view if their archaeological relevance can be proven. Currently, if archaeological excavation fails to detect anomalies that are clearly evident in prospection data, many excavators tend to question the value and usefulness of the method. Without doubt, there exist physically measureable variations in the subsurface that are caused by archaeological structures and that are not visible to the human eye in the form of objects, changes in colour or tangible properties (density, texture). Examples are variations in the magnetic properties or relative permittivity of soils.

In extreme cases of negative feedback, it is possible that an entire archaeological structure, for example a trench, pit or posthole, has been destroyed in the plough-layer, or even completely eroded, but that the former presence of the structure has caused alterations in the subsoil that still give rise to measureable physical anomalies. Examples could be the deposition of heavy, highly magnetic minerals along preferential flow paths of percolating water formed under trenches, pits or postholes, as well as soil density changes due to compaction under buildings, pits or heavy constructions. In Sweden, it has been reported that refilled trenches, which were dug in prehistoric times, had caused imprints in the underlying sediments, despite the fact that the trenches never reached below the layer that forms the topsoil or plough-layer today. This imprint-effect could be explained with the formation of preferential flow paths of surface water through the trench, which may at times have been filled with water, into the subsurface, as well as related leaching, sedimentation and oxidation processes, and local changes of soil chemistry and mineralisation in underlying soil layers. Thus, prehistoric trenches, as well as pits, may have caused physical changes in underlying sediments, which may be detectable with geophysical means, even if the original archaeological structure has already been eroded or removed. Magnetic prospection is able to detect areas of increased magnetization originating from the plough layer, a source of information that without prospection generally would be overlooked.

In general, the negative feedback case is not as surprising as it may seem: comparable visibility problems are commonly observed in archaeological excavations when structures are, or become, only visible under certain conditions regarding soil humidity or lighting. It is a well-known phenomenon that structures such as pits, postholes or trenches may only be visible while the soil surface is still humid after removal of the topsoil, or that under certain lighting conditions (e.g. in twilight) such structures can appear or disappear depending on the viewpoint of the observer relative to the structure and the source of light.

An increase in magnetic susceptibility or a decrease in soil density (causing an increased soil humidity and decrease in local earth resistance) need not necessarily correspond with visible changes of soil colour or soil texture. Magnetic, GPR or earth resistance prospection may map subsurface structures of archaeological interest which would be missed by solely visible inspection.

A related issue concerns poorly understood examples of negative evidence cases in which strongly expressed archaeological structures buried at shallow depth do not give rise to any detectable anomaly in prospection data. Examples comprise massive stone walls at a site in Turkey that did not produce any reflections in GPR data, or buried architecture at a site from Syria that did show well in magnetic prospection data but only partly caused reflections in GPR data.

While archaeologists commonly have accepted physical measurements of otherwise "invisible" properties (i.e. the age of an object) by using the radiocarbon method to date archaeological objects, the occurrence of invisible structures of likely archaeological origin detected by geophysical prospection seem to cause incomprehension amongst many archaeologists, which affects the acceptance of non-invasive approaches, as "they do not reflect the truth". However, it has to be stated that geophysical prospection methods do not measure "archaeology" but contrasts in the physical properties of the subsoil that may reflect information on respective archaeological structures.

The greatest argument for the routine use of prospection methods is their potential to detect traces of archaeological structures or prehistoric human activity that otherwise would be missed entirely. This argument also supports the use of prospection methods on development sites that would be excavated. Without established and officially approved guidelines on how to deal with intangible anomalies mapped by near-surface geophysical prospection, professional exploration archaeologists tend to deny the archaeological significance of structures that are only visible in geophysical prospection data.

In the past, the archaeological prospection community often has been keen to show off the prettiest prospection results. Now, however, more effort is needed to understand and explain the problematic cases. Attention paid to the causes of failures of prospection projects (assuming that the survey was profes-

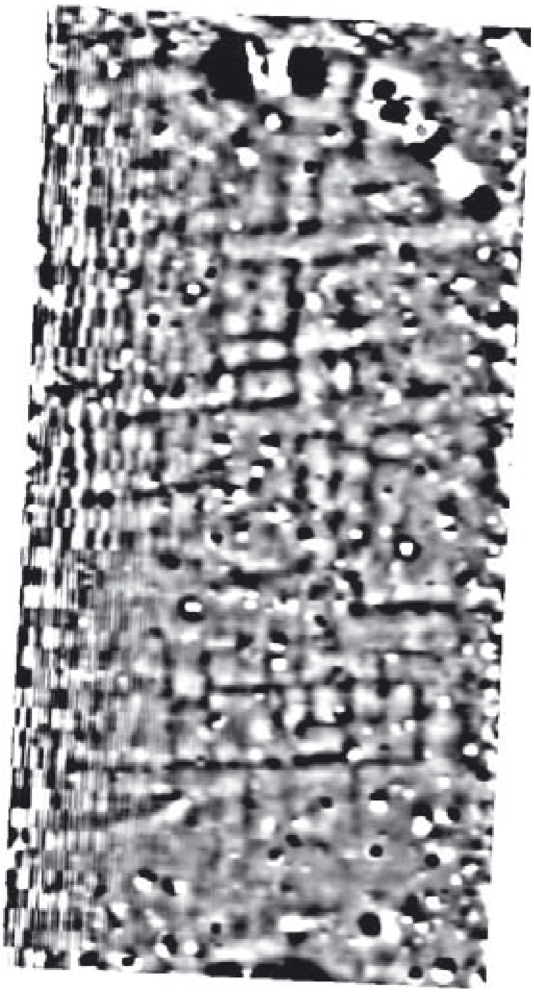

Figure 3: *Corresponding magnetic data image (±8nT).*

Figure 4: *Corresponding GPR depth-slice representative for the entire data volume.*

sionally conducted with sufficient sample spacing, sensitive instruments and appropriate data processing and visualisation) will eventually lead to a better understanding of the method' s potential and the causes of observed anomalies. For example, little research has thus far gone into the investigation of the underlying physical causes for observed reflections or signal attenuations in GPR prospection data acquired on archaeological sites. The desire for a greater integration of non-invasive prospection methods into exploration as well as archaeological research projects demands that these issues be addressed. Comprehensive ground verification case studies conducted as research projects, using a wide range of prospection methods as well as auxiliary physical, geological and pedological investigations prior to and during detailed archaeological excavations, may contribute to a better understanding of the underlying principles.

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GEOPHYSICAL PROSPECTING INTEGRATED IN ARCHAEOLOGICAL RESTITUTION : THE CASE OF BAYEUX (NORMANDY, FRANCE)

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S. Pasquet, S. Buvat, L. Bodet, R. Guérin

1. ARCHAEOLOGICAL AND HISTORICAL BACKGROUND

Bayeux is a city located in the western part of the Calvados, north-western France. The city is about 7 km away from The Channel beaches, and has developed mainly on the left bank of the Aure River.

At the beginning of the 1st century BC, the Baïocasses, peoples of the "Gaule Lyonnaise", are mentioned by Pliny the Elder. They settled in the actual Bessin area and their main oppidum was located 10 km southwest of Bayeux, in the Castillon city district.

The first noticeable settlement on the site of Bayeux is mentioned on the 1st century BC as Augustodurum on the Peutinger roadmap[1] (Omont 1911). Of the remains known from this period, the main ones are two public baths and a public place, probably the forum. These remains are complemented by a sparse distribution of well-preserved Roman remains over the city (Figure 1). In spite of the fact that we know of these remains, the structure of the Roman city, especially the road organization, is largely unknown. In its heyday, the area of the city reach 50 ha and the Notitia Dignitatum[2] (Weber, 2004) mentioning the presence of a prefect of the Lèves Bataves confirms the administrative and military role of the city. During this period, enclosing walls and ditches were realized, enclosing a 15 ha area. After the fall of Aregenua, capital city of the Viducasses, Bayeux integrated it and began to rule its district.

In the early Middle Ages, Bayeux became a bishopric. After the arrival of the Vikings, Bayeux became the home of the dukes of Normandy, who had a castle in the city. Bayeux remained an important place until Guillaume the Conqueror chose Caen as its capital city. The following centuries, up until the 18th century, were marked by the wars between Guillaume the Conqueror's sons, conflicts between England and France, and religious wars.

Finally, in June 1944, Bayeux was the first French city freed by the Allied armies after landing on the Normandy coast. Therefore, the city was not subjected to systematic bombing as were other cities nearby. Because of this, there is exceptional preservation of the ancient buildings and other small areas, which are protected for their heritage value. Archaeological documentation, however, is poor and comes mainly from old and random discoveries, or, for the later ones, only small areas are available and need to be completed.

2. AIMS OF THE GEOPHYSICAL INVESTIGATION

In the urban context of Bayeux (few transformations of the urban map since the 17th century), few archaeological soundings of limited area could be undertaken. Because of this, geophysical prospecting might appear to be the best option to complete and/or bring new elements to interpret the evolution of the city during ancient times.

We show two examples of surveys illustrating that unfortunately geophysical methods are less adapted to urban contexts. Nonetheless, their use in specific way could provide useful archaeological information.

3. EXTENT OF THE ROMAN FORUM

(yellow dot on Figure 1)

During an archaeological survey, evidence of what could be the Roman forum were found. Unfortunately, the area excavated did not show any limits of the place. Thus, it was decided to investigate the gardens and the roads surrounding the area. Electrical resistivity appeared to be the best method to use in that context. As a first step, we used a dipole-dipole square array with 1 m spacing as the remains were supposed to be located less than 1 m in depth. Only areas in grass were prospected. The results are shown in Figure 2. Various electrical resistivity anomalies were identified. The ones related to the trees roots system are identified by the dots in Figure 2. It appears that other anomalies follow the same WNW-ESE orientation as other remains in the city (highlighted by the dashed lines), and some perpendicular patterns appear too.

The limits of the forum do not appear clearly, but the orientation of the features is consistent with those corresponding to the Roman period found in excavations all over the city. As the limits are not clear, capacitively coupled resistivity measurement (Panissod *et al*., 1998; Flageul *et al*., 2012) will be undertaken in the spring of 2013 to complete the maps, especially over places where classical electrical prospecting method are not affordable.

4. THE CHARLES DE GAULLE PLACE

(blue dot on figure 1)

The Charles de Gaulle place is the largest park in the area of the ancient castrum (about 2 ha). As described in the archive plan, before it was turned into green space, a castrum was located there. The main objective of the prospection was to add information to the existing maps. The idea was to benefit from a practical training session of a geophysical course of the university to do multi-method investigation. The maps were obtained with the following methods:

- Electrical resistivity measured with pole-pole array (RM15 from Geoscan Research) and spacing of 0.5, 1 and 1.5 m between the mobile probes.
- Electrical conductivity measured with a slingram EMI device (EM31 from Geonics Ltd) in vertical and horizontal dipole mode.

[1] The Peutinger roadmap: a roadmap of the whole Roman Empire from Brittany to India. It was copied by a monk during the 13th century and is now conserved at the National Austrian Library in Vienna.

[2] The Notitia Dignitatum: a list of dignitaries and their areas of responsibility, for the Late Roman Empire period, about AD 400.

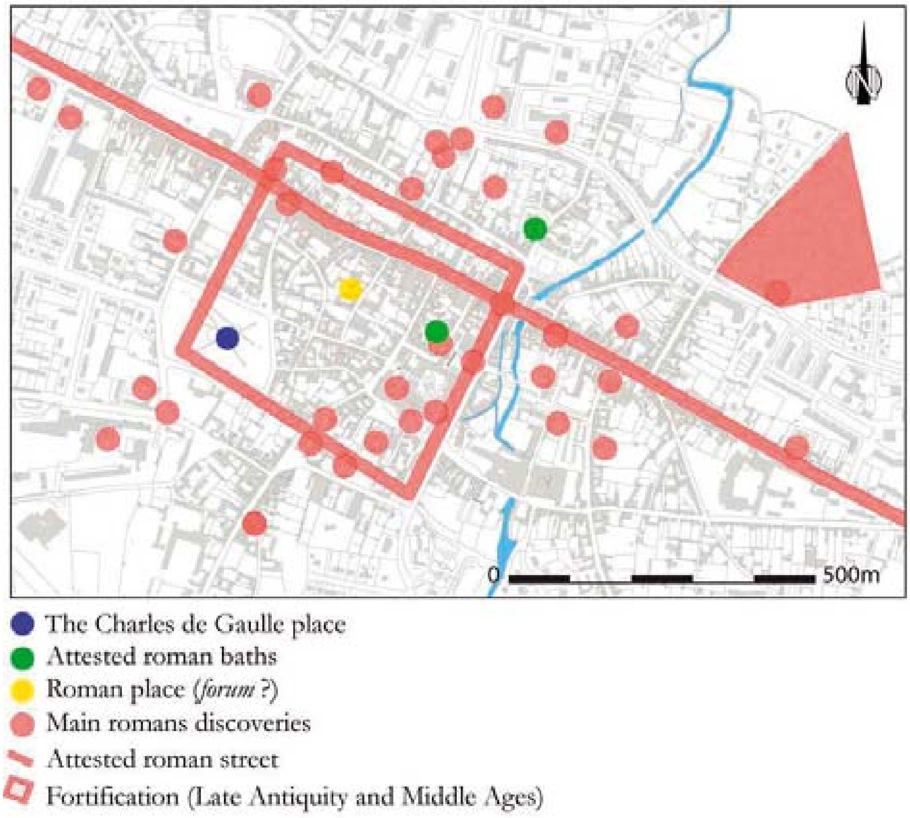

Figure 1: *Map of the city of Bayeux locating the roman period remains (red and green) and the geophysical surveys (blue and yellow).*

- Magnetic field anomalies and pseudo gradient map (G858 from Geometrics Ltd).
- Ground Penetrating Radar survey with 250 and 500 MHz antennas (Pulse EKKO Pro from Sensors and Software).

These maps have been completed with various kind of soundings (electrical resistivity, penetrometer) and tomography (electrical resistivity, seismic).

Despite the urban context, all maps exhibit results that can be interpreted. In particular, the electrical survey shows several resistive anomalies which correspond to the walls and buildings depicted on the ancient map. For example, on the electrical resistivity map obtained with the 1 m pole-pole device (Figure 3), several interesting features can be highlighted:

- The A anomalies appear to be located were the city wall should have been.
- The B anomalies could be linked to the wall closing the castellum.
- The C anomalies correspond to modern pipe trenches.

Looking at the magnetic anomaly map (Figure 4), it appears that the A anomalies exhibit very high magnetization, indicating burnt or iron compounds. This is also the case for the B anomalies corresponding to the wall on the western part. Pipes and path are also visible (C anomalies). Buildings appear as a disorder of dipolar anomalies (D anomalies) and some anomalies detected with electrical resistivity simply not appears on the magnetic anomaly map (B? anomalies).

It is noticeable that the A anomalies also appears as a chevron pattern on GPR time slices.

5. CONCLUSIONS AND PERSPECTIVES

The city of Bayeux is a particular context where there have been few changes in the urban plan since the 17th century. Today, with the centre of the city being a protected area, there are few archaeological studies of limited extent. Geophysical prospecting permits exploration and data acquisition where excavation is not possible. It appears to be a useful tool when integrated into the archaeological and historical reconstruction of the evolution of the city from the Roman period until modern times. However, as the geophysical prospecting gives diachronic information, some questions rises from the data:

- Why the western anomalies (A ones) stop where the wall of the city should still be there?
- What are the changes in the wall construction that might explain the variation of recorded signals?
- Are the anomalies of the Roman period or the Middle Ages?

Future archaeological soundings and geophysical prospection will try to answer these questions.

ACKNOWLEDGEMENTS

The authors want to thanks the students of the Polytech Paris-UPMC engineer school, specialty Earth Sciences, for acquiring the data on the Charles de Gaulle place.

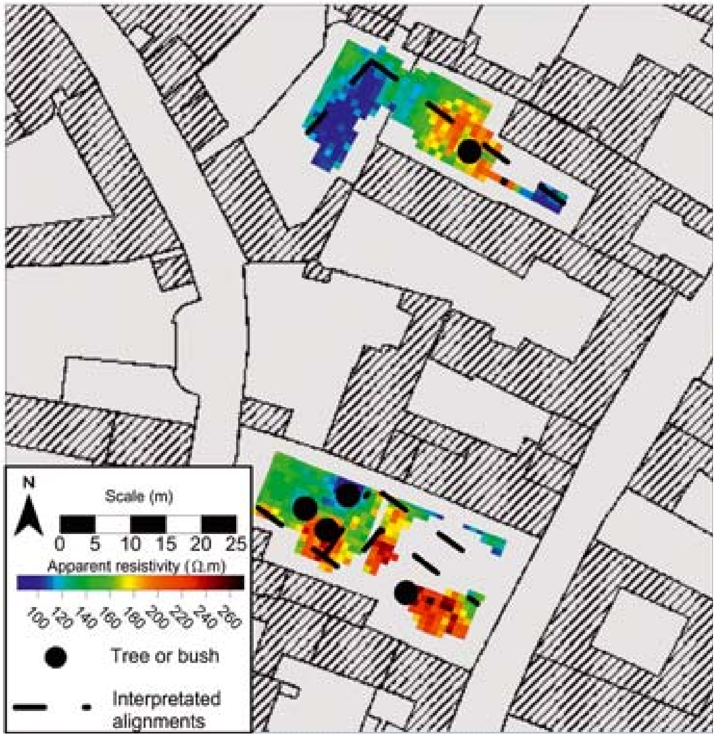

Figure 2: *Square array apparent resistivity map with the interpretated alignements.*

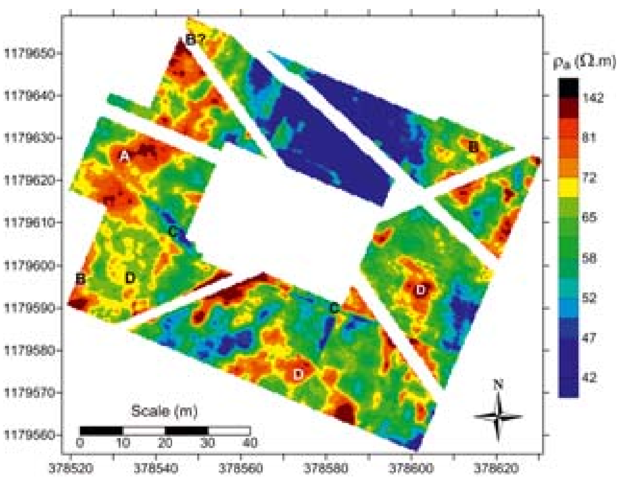

Figure 3: *Apparent resistivity map obtained over the place Charles de Gaulle area (1 m spacing).*

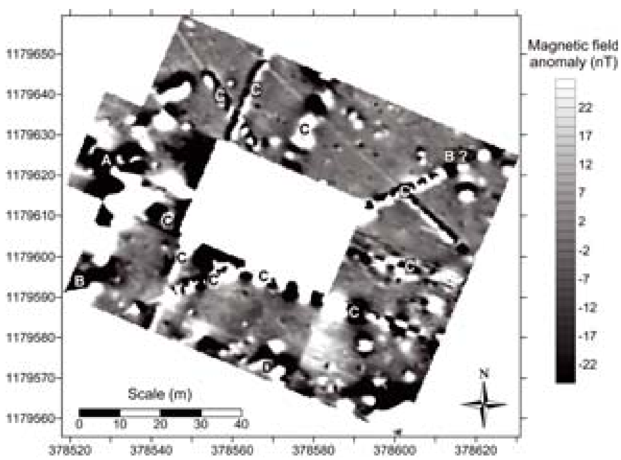

Figure 4: *Magnetic field anomaly map obtained over the place Charles de Gaulle area (measured at 0.80 m above the ground).*

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AN EXAMPLE OF MAGNETOMETER SURVEY FROM CENTRAL ANATOLIA, TURKEY

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1. INTRODUCTION

In this study, a magnetometer survey was carried out on a multi-layered settlement located in the central Anatolia, Turkey. Ovaören archaeological site, which consists of different occupation periods from the Chalcolithic to the Iron Age, was investigated to reveal the distribution of the buried structures. The settlement has two burial mounds named Yassıhöyük and Topakhöyük (Figure 1). The dimensions of Yassıhöyük are 500×350 m and this burial mound is partly surrounded by fortification walls reaching a height of about 10 m (Figure 1). Yassıhöyük is defined as citadel and it is estimated to have at least 5 m thick cultural deposits in the inner part of the walls. The excavations, which have been conducted since 2007, revealed that the walls were made in the Hittite Empire period, repaired at least two times in the Iron Age, and the most recent structures on the wall belong to the period of the Kingdom of Tabal (Şenyurt, 2011). Thus, the magnetic measurements performed in 2009 focused on the Yassıhöyük settlement. Geologically, the Ovaören archaeological site is situated in a volcanic environment that is one of the important parts of Cappadocian volcanic region. Basalts and tuffs are mostly seen on the surface, whilst the geological "basement" consists of limestone.

2. METHOD

A magnetic gradiometer, one of the most commonly used methods of archaeological prospection, was employed to obtain the magnetic maps of the study area. Two fluxgate gradiometers (FM36 and FM256 of Geoscan Research) were run independently over the field. Data was collected on grids with dimensions of 10×10 m, with 0.5 m line and 0.25 m sampling intervals. During the measurements, visible agricultural borders, resulting from cultivation processes, were noted in order to distinguish them on the magnetic maps. Two separate investigation areas were selected to conduct the measurements. Sector-A, which is located in the inner part of the citadel, presents the structures of residential and living places. Sector-B is partly on the fortification walls, and our purpose is to reveal the main gate of the citadel and related structures on this sector (Figure 1).

3. RESULTS

3.1. Sector A

Magnetic data measured over 52 grids of Sector-A were combined and corrected. Then, a low-pass filter was applied to reduce the noise effect on the data. The resulting magnetic map is given in Figure 2a. We think that high magnetic values on this map correspond to possible buried kilns and volcanic rocks. Apart from these, the NW-SE and NE-SW oriented magnetic anomalies could be followed. These traces are not related with visible borders of cultivation process. However, excavations conducted on eastern part of this site revealed N-S to E-W oriented Iron Age architecture of two phases (Figure 2b). These shallow buried structures made of limestone have rectangular shape and their magnetic properties are very close to the covering soil. These rectangular shaped structures were used as kilns, ovens and workshops. In this architecture, mud-brick was not used and volcanic rocks are seldom observed. Thus, the unearthed structures could not be clearly defined on the magnetic map. We think that the NW-SE and NE-SW oriented magnetic anomalies may be related with an earlier settlement plan on this site. However, excavations reached to bedrock at a depth of 4 m without any earlier structural plan. In addition, magnetic anomalies in the grids of IJ-176 and IN-176 (shown by green circles) are correlated with burned places. The excavation on the northern face of the grid IJ-176 verified this with a burned layer.

In the last season of the excavation, archaeologists investigated also the western part of Sector-A (IY-176, IZ-176 and JA-176 grids). This site is one of the highest points in the Yassıhöyük. The unearthed structures related with Late Iron Age period are shown similar properties with previous excavations (Figure 2c). The orientation of the walls is NE-SW direction. Top of these stone-based walls are damaged due to the agricultural activities.

3.2. Sector B

In order to reveal the southern gate of Yassıhöyük, magnetic measurements were performed on Sector-B. The elevation of the fortification walls are decreased in the south-eastern part of this sector. Excavation revealed that the wall is 5 m long and constructed from stone and mud-brick materials (Figure 3a). A corrected and filtered magnetic map of Sector-B is shown in Figure 3b. The walls showing high magnetic values are marked with green ellipses. Orientation of the walls is changed around the grid of IJ-195 (shown by yellow rectangle). This magnetic anomaly should be related to a gate on the fortification wall. In the western part of the Sector-B, weak magnetic anomalies with regular orientations are also observed. These structures could be extensions of the gate. Along with these anomalies, recent cultivation effects are observed as shallow ditches on the surface. These are shown as parallel lines on the magnetic map. Recent excavation on the grid IJ-195 and surrounds revealed the possible main gate of the citadel (Figure 3c). The unearthed western wing of the gate is square-shaped and 7 m long in each direction. The interval between western and eastern wings of the gate is 5 m.

4. CONCLUSION

Magnetic gradiometer survey revealed important information about the buried structures and fortification wall of Yassıhöyük settlement. In Sector-A, we could not clearly define the buried structures, because of the poor magnetic contrast between the structures and covering soil. Different methods of archaeological prospection such as GPR and ERT are suggested to test on this part of Yassıhöyük. However, the gate observed on magnetic

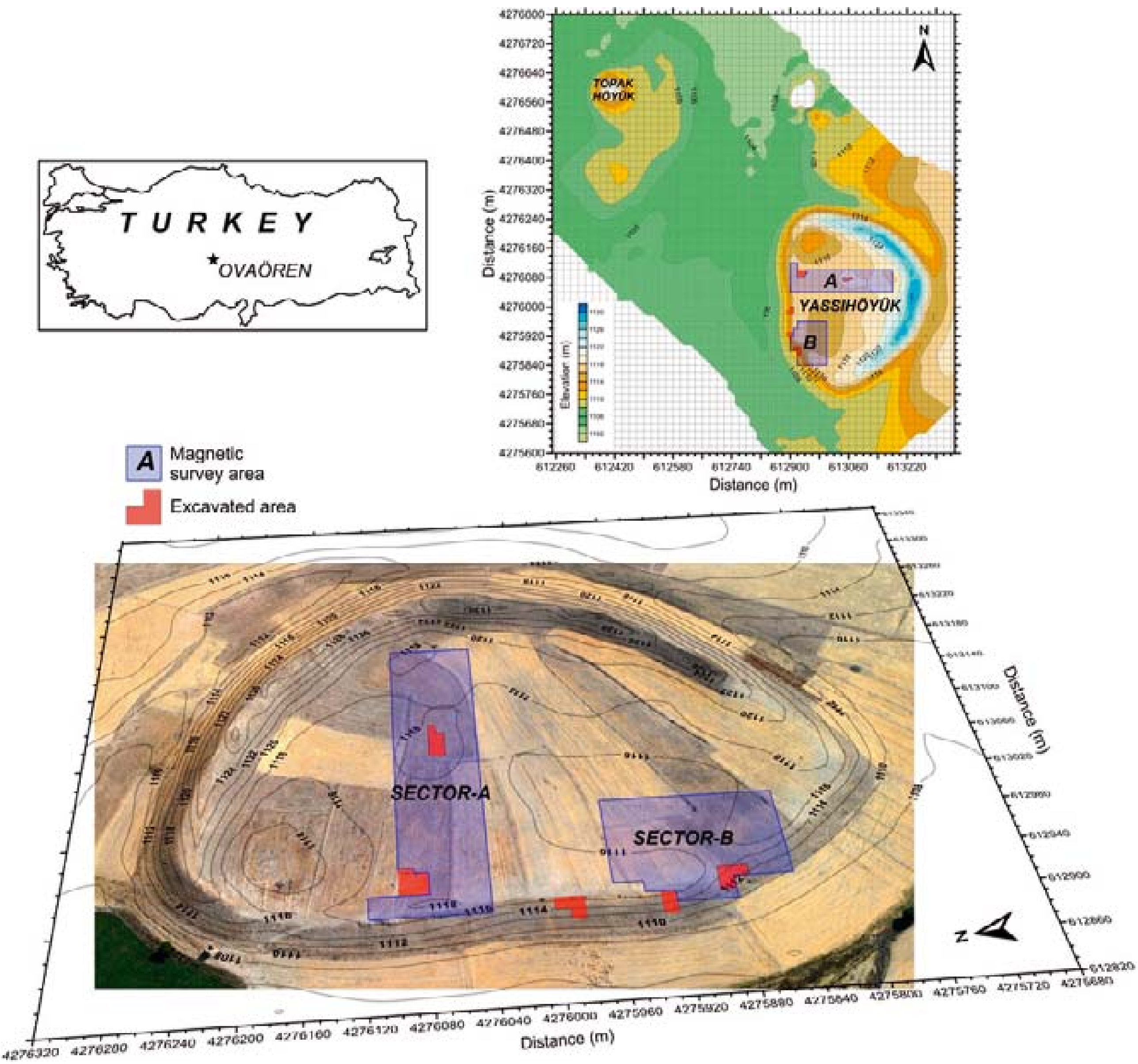

Figure 1: *Location map of the study area, and aerial photograph of Yassıhöyük with topographical contours.*

map of Sector-B is verified with excavation.

ACKNOWLEDGEMENT

Authors are grateful to Prof. Dr. S. Yücel Şenyurt, the director of archaeological excavation, for his cordial interest.

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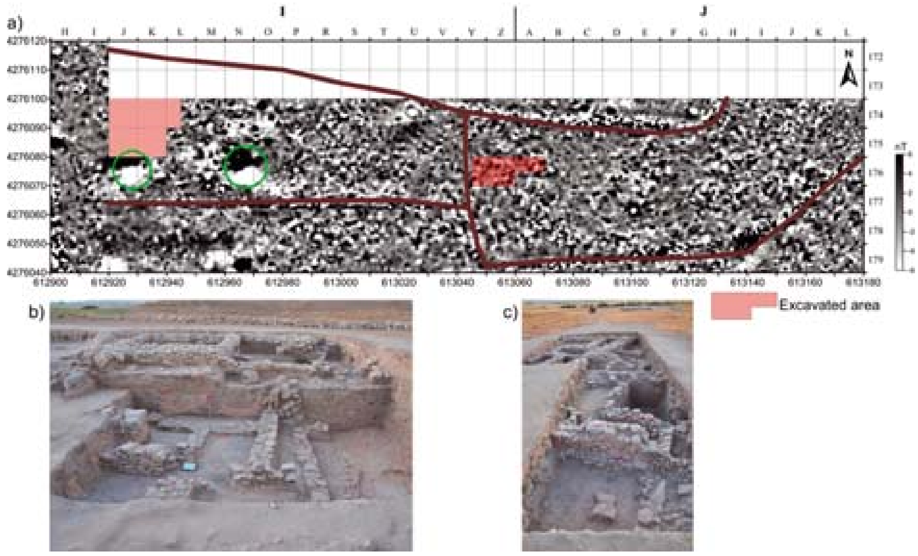

Figure 2: *a) magnetic map obtained from Sector-A; b) and c) photographs of the excavated sites (Şenyurt, 2011).*

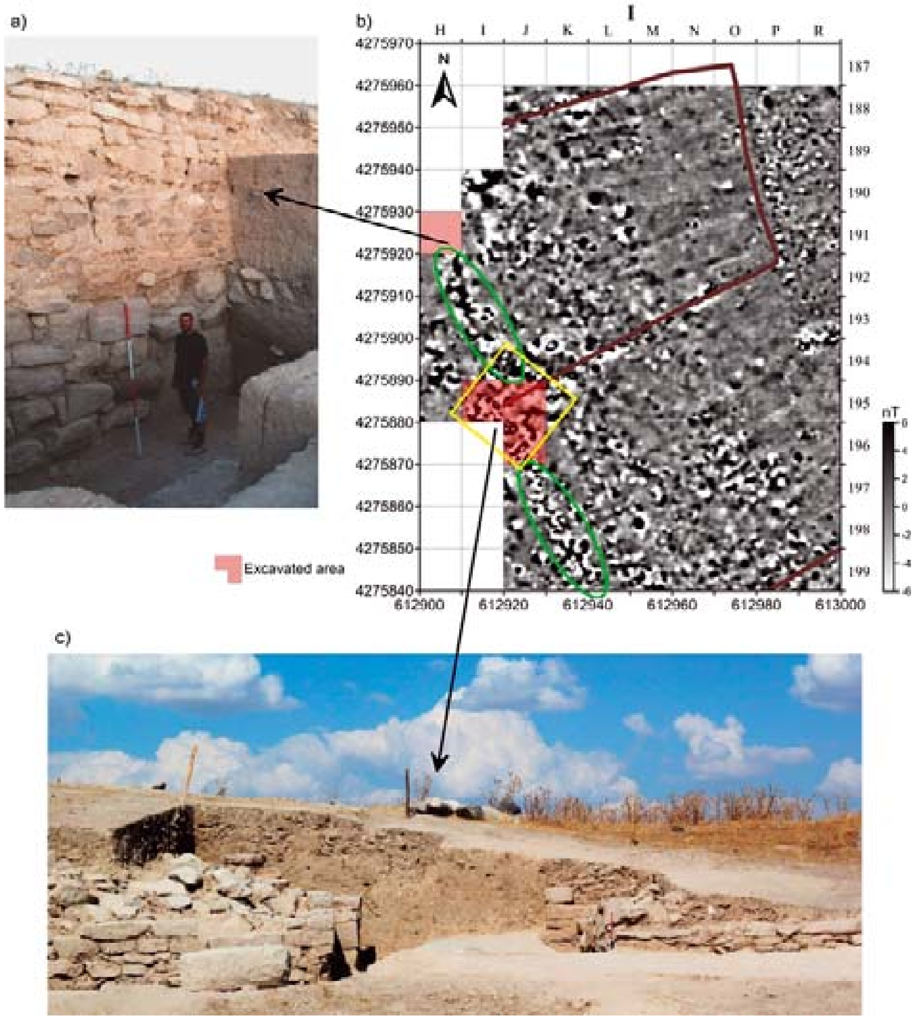

Figure 3: *a) photograph of the excavated fortification wall (Şenyurt, 2011); b) magnetic map obtained from Sector-B; c) photograph of the excavated gate (Şenyurt, 2011).*

MAGNETIC RESEARCH OF AN ANCIENT VILLAGE AND ITS WATER RESOURCES: THE CASE OF PHILOTERIS/MEDINET WATFA IN OASIS FAYUM, EGYPT

T. Herbich, C. Roemer

Philoteris, modern Medinet Watfa, is located in the north-western part of the Fayum Oasis, which lies to the west of the Nile Valley south-west of Cairo. As the other settlements in this area, Philoteris was founded by Ptolemy II around 270 BC. The village was named after Ptolemy's sister, Philotera. Our detailed knowledge of the history of this village and of the people living here comes from archaeological evidence and from papyri excavated on the site itself and in the surrounding area. The village is first mentioned in a papyrus from 242 BC; at the time, it had 719 tax paying inhabitants.

The founding of this village and other settlements in the region was possible only through the creation of a new irrigation system for the north-western part of the Fayum. The main feeder canal for this area started in the south-west of the oasis, at a village now called Abu el-Nur. The water had to be channelled carefully, since its course was repeatedly in danger of falling into a large ravine, the modern-day Wadi Nazlah. It was for this reason that the first Ptolemies erected a huge, 9 km long dam between what is today Itsa and Abu el-Nur, preventing the water from pouring into the Wadi Nazlah. It appears that during the 3rd century AD, the dam was damaged several times, eventually depleting the north-western part of the oasis of water. Several papyri reveal the despair of the people of Theadelphia in the neighbourhood of Philoteris, who were left without means to pay their taxes because their fields were barren. However, the decline of Philoteris and Theadelphia did not occur suddenly. As we see in the papyri, it took several decades before the area was completely abandoned in about 370 AD. The lack of water caused the collapse and eventually the complete depopulation of the region. This situation lasted until the early 20th century.

Over time, the abandoned village was completely destroyed and the lack of irrigation turned the entire region into a desert. Today, buildings are preserved only to foundation-level (Figure 1). In only two places does the topography of the land indicate that some walls are preserved to a height of 2 – 3 meters. In some places one can see the outlines of the walls clearly enough on the surface to draw both rough plans of particular buildings and an outline of the settlement plan; a surface configuration of the majority of the site, however, does not allow for such reconstructions. Surface traces indicate that the basic building material consisted of sun-dried bricks made either of dark-grey Nile mud (characterized by strong magnetic properties: its susceptibility raging between 2×10^{-3} SI and 4×10^{-3} SI) or of yellowish local clays (of very low magnetic properties: below 0.1×10^{-3} SI). In some instances, both types of bricks were used in constructing the same building. In some areas, burnt bricks are visible on the surface, and stone was occasionally used (mainly local limestone).

In contrast to neighbouring Dionysias, Philoteris has not been a subject of special interest to archaeologists. British papyrologists Bernard Grenfell and Arthur Hunt visited the site in the late 19th century, and excavated for two weeks. However, the two scholars did not have any interest in the remaining archaeological features on the site and, after they had found enough papyri to establish the name of the ancient village (around 40 papyri were excavated then), they moved on to the next site. The way Grenfell and Hunt conducted excavation, which involved rapid unfolding of large surfaces, caused significant mixing of the surface layers and the subsequent formation of areas with very uneven surfaces. No documentation of any architectural features was carried out during their work; only surface traces make it possible to locate these works in the northern part of the site.

Figure 1: *Philoteris/Medinet Watfa. Traces of canals in the north-eastern part of the site. View towards the west (Photo T. Herbich).*

The whole region has been heavily endangered by recent land reclamation projects. This led to the decision to undertake an archaeological survey of the area around Philoteris by an international team under the guidance of Cornelia Römer. The survey took place between 2000 and 2006. The task was to map the site with its remaining buildings and features visible on the ground, and to collect and analyze the pottery and small objects. Research has quite accurately estimated the extent of the site and made it possible to reconstruct the outlines of dozens of buildings, in some cases determining their function. Studies have established the positions of the at least two temples, one Hellenistic bath, and two granaries, as well as the residential part of the village, which was looking to the north. In the north-west, a military camp has now been identified, obviously of the same type as the larger military camp in nearby Dionysias. Studies have also determined that the settlement covered an area of at least 450×250 m.

Analysis of aerial and satellite imagery and careful surface prospection of areas around the village showed that traces of a complex system of water supply and storage has been preserved. Several parallel canals approaching the village from the east unite into two main water streams, which then divide again, before one of them continues westwards. The latter reaches the village of Dionysias after 5.5 km downstream. Goggle Earth reveals a further striking feature. To the north of the village lie huge basins, interconnected and clearly controlled from a house sitting on a ridge between two of the basins. The presence of these basins in the north sheds light on the purpose of the double canals at the northern side of the village: while the larger canal, which flowed close to the village, provided the necessary supply for the people living there, the northern one poured regulated amounts of water into the basins in the north. It is not yet clear, from which period the large basins stem, but they could evidence a growing concern over failing water supply, which people started to prevent by creating these huge reservoirs for difficult times.

A grant from the German Archaeological Institute in Cairo allowed Römer to resume research in 2011, this time using geophysical methods. The goal of the survey was to complete archaeological knowledge of the site based on previous studies both in the settlement area and in areas that include the remains of waterways. The geophysical team headed by Tomasz Herbich opted for the magnetic method of prospection, due to the properties of the main material used for construction. The survey, carried out in the area of 30 hectares, covered about 85 % of the village. The remains of canals were traced to the north and west of the village. The measurement has been taken with a use of fluxgate gradiometers Geoscan Research FM256, in zig-zag mode. The sampling grid used was 0.25 $\times$ 0.50 m, within grids of 20 $\times$ 20 m. Geoplot software has been used to process the data and maps were plotted with the use of Surfer software.

These studies greatly improved our understanding of both the village architecture and the canal network (Figure 2-4). The research facilitated the drawing up of building plans in a number of areas, particularly in the south-eastern part of the settlement. The shape of the buildings indicate that this was a residential area. This observation is supported the presence of a small bath, partly exposed due to the recent looting of the site. In two places, the survey allowed us to determine the structures (in small part visible on the surface) as granaries. The plan of the granary found in western part of the settlement is especially clear (Figure 4). Readability of the plan allows for comparative analysis with other known structures of this type within the Fayum area, such as those found in Karanis by the American excavators of the University of Michigan.

The magnetic survey provided a far more accurate picture of the courses of canals, which were previously known primarily from surface surveys (Figure 3). The research allowed us to register sections of canals not visible on satellite photographs and not identified in the surface study. The clarity of the magnetic image of the channels (resulting from the presence of Nile silt deposited in the channel beds) allows for their precise location as well as places where they underwent reconstruction (e.g. strengthening the banks). It also allows us to better understand the relations between the settlement and channels, for instance it indicates the location of the sakija (a device to transport water to a higher level into the village) and allows us to point out small harbours (in the form of a bay). Projections on both sides of the channel that serve to reduce its width can be interpreted as the foundations of the small bridge over the canal. Another feature registered on the magnetic map may reveal the dramatic situation of the village in its late history. Surface traces suggest the presence of the canal in the south-west of the village, which stops abruptly on the magnetic map, but continues to the west on the ground. It appears as if it had been excavated to be filled with water, but was then never used because of the lack of the necessary amount of water arriving from the east.

As mentioned above, the site survived to the present day due to the desertification of the region during late Antiquity. The land reclamation projects in the region at the beginning of the 20th century and the need for irrigated land led to the dramatic reduction of the free zone around the site. The area covered with architectural remains is likely to be saved, however the next decade will most certainly see traces of canals undergo irrevocable damage. Being the best means to investigate the water management in the region, geophysical prospection is of particular value alongside excavation, which would have been impossible to carry out in such a large area. One phenomenon, however, cannot be prevented. The raising of the ground water level as a result of irrigation increases soil moisture, permanently destroying the papyri preserved in the soil: invaluable evidence to the history of the region is being lost.

Figure 2: *Philoteris/Medinet Watfa. Magnetic map of the site. Fluxgate gradiometers Geoscan Research FM256, sampling grid 0.25 × 0.5 m, interpolated to 0.25 × 0.25. Grids 20 × 20 m. Dynamics: -3.6 nT/+3.5 nT. Measurements: Krzysztof Kiersnowski, Jakub Ordutowski, Dawid wich and Tomasz Herbich. Data processing T. Herbich. Background image ©Google Earth.*

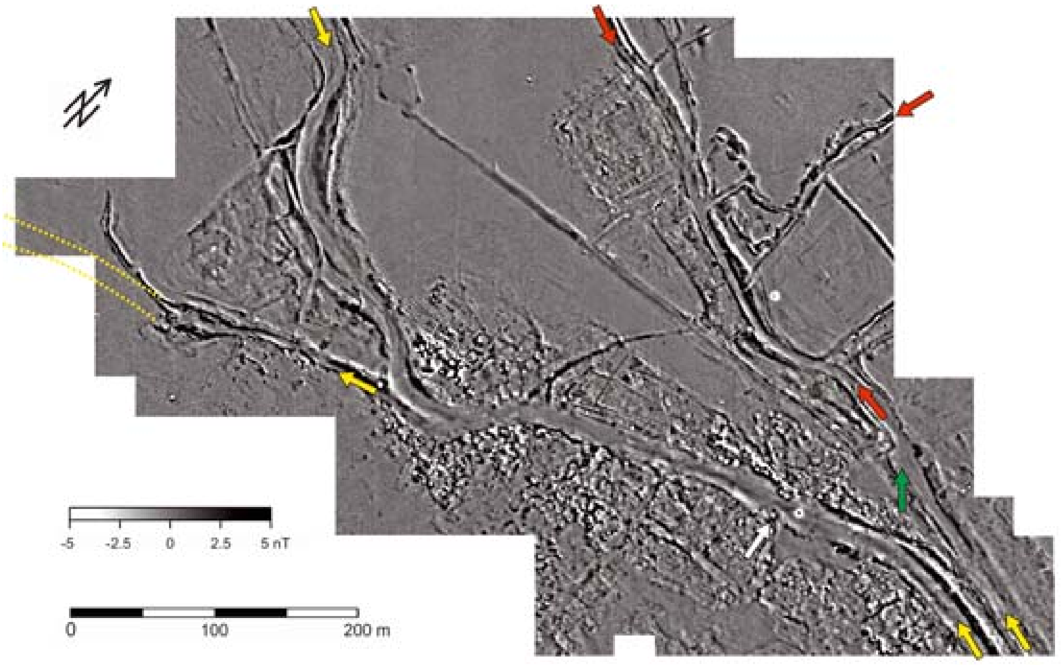

Figure 3: *Philoteris/Medinet Watfa. Magnetic map of the western part of the site. Red arrows indicate canals identified by magnetic survey alone, yellow arrows illustrate canals traced on the ground, the green arrow indicate hypothetical small harbor and the white arrow shows hypothetical foundations of a bridge. The yellow dotted lines mark a canal traced on the ground not present on the magnetic map owing to the absence in its bed of alluvial (silt) deposits, indicating that the canal was never used.*

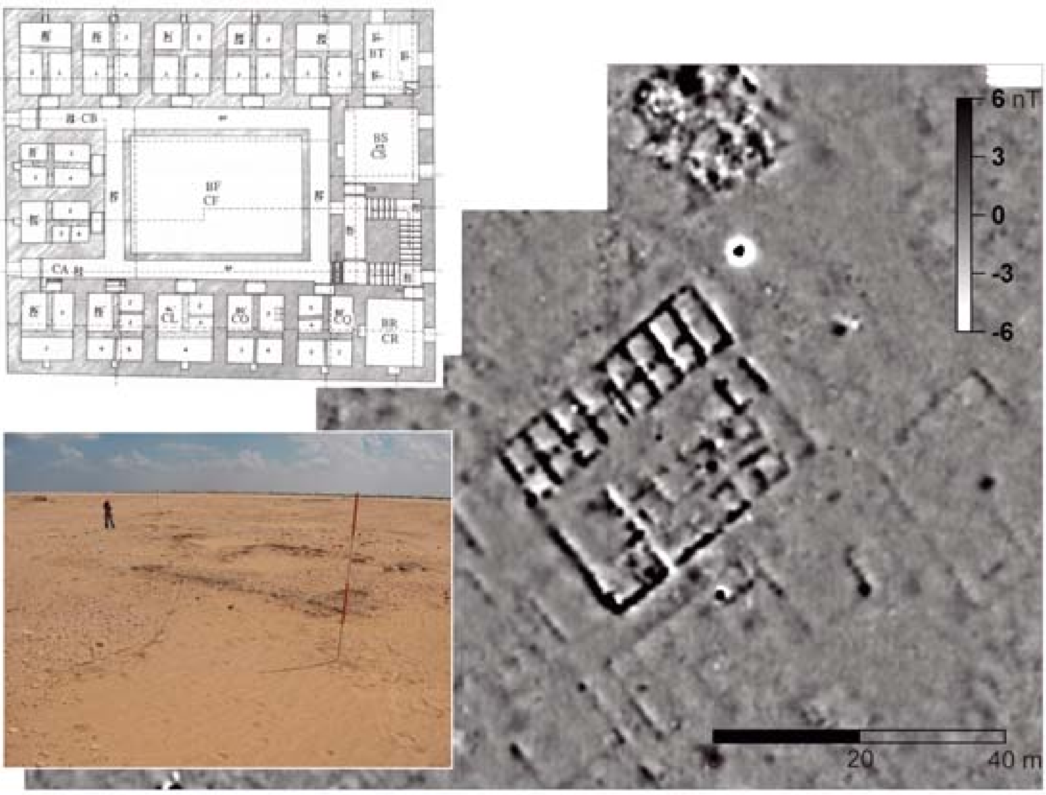

Figure 4: *Philoteris/Medinet Watfa. Magnetic map of a structure identified as a granary. Lower box: remains of a structure identified as granary (Photo T. Herbich). Upper box: plan of a granary excavated by the Michigan expedition in Karanis, after: E. M. Husselman, Karanis Excavations of the University of Michigan in Egypt 1928 – 1935, Ann Arbor 1979, Plans 18 - 20.*

THE LAYOUT OF THE VICI IN DACIA: ARCHAEOLOGY AND GEOPHYSICS

F. Marcu, D. Isac, G. Cupcea

We will present a comparison between different settlements on the Northern limes of Dacia, as a result of archaeological and geophysical prospection in the past years. Geophysical prospection was conducted with a variety of instruments, including magnetometer, ground penetrating radar (GPR) and electrical resistance tomography (ERT).

This research highlights the necessity of large-scale non-invasive methods mapping the layout and dimension of the military vici. There are no typologies regarding the vici of Dacia, as there are almost none that has been surveyed on large-scale investigations. The development and application of geophysical survey methods to identify Roman settlement typologies have recently improved, but there are very few cases where these methods have been applied in the former Roman provinces.

We are trying to establish the degree of planning control in contrast with the dependency on the landscape and regional necessities in two military vici located a marching day apart on the northern limes of Dacia. The settlements near the forts at Căşeiu and Ilişua have been subject of geophysical survey and archaeological excavation campaigns. At first sight, there could have been a considerable level of planning control, disregarding the landscape in the case of Ilişua, and similar patterns might have been used when the military agrimensores surveyed the settlements. Instead, geophysical prospection results suggest that the internal planning of the two forts is unrelated, according to the different needs of the garrisons of the forts.

Nevertheless, the correspondence of the planning control between the two vici could be apparent, and only the spread of the settlements on the right and back sides of the forts would be not enough to establish patterns. Details reflect distinct arrangement of the available space. An interesting feature is that geophysical survey at Căşeiu shows a clear delimitation between the fort and the first buildings of the settlement, which are not set directly near the defences.

CONFRONTATION OF GEOPHYSICAL SURVEYING AND ARCHAEOLOGICAL EXCAVATIONS IN THE SOUTHERN QUARTERS OF AREGENUA (VIEUX-CALVADOS, FRANCE): RESULTS FOR RESEARCH AND SITE MANAGEMENT

K. Jardel, M. Dabas

Nineteenth century excavations in the Roman capital of Aregenua (Vieux, Calvados, France) resulted in a confusing interpretation of the monumental remains, then interpreted as two thermal buildings. In 1991, the rediscovery of archived documents led to new interpretations and the formulation of a new hypothesis, the location of a forum and a single thermal building. This meant that the monumental complex of the Roman town, where both civil and religious functions took place, had been erected in what is now a pasture of 4 ha. Aiming both at furthering research and promoting site enhancement, the dual approach that characterizes the Calavados departmental archaeological service's activities, led to the establishment of a comprehensive project for investigating the then unexcavated remains.

It started with the implementation of a geophysical survey to confirm (or not), the presence of the alleged forum, to establish its precise location (geo-reference) and to ascertain its state of preservation (to evaluate any possible 19th century excavation damage, for example). Furthermore, assuming the identification of a forum, the aim was to identify the southern area of the ancient town, which thus became the heart of the town and thereby, the central pole of political, administrative, economic, judicial, and religious activities of this capital of Gaule Lyonnaise.

In 2005, a geophysical survey was conducted with the ARP© system (Géocarta), a continuous system for measurement of apparent electrical resistivity. The system is mechanized, towed continuously by a quad-bike, and was able to measure the whole field (3.5 ha) in 4 hours at three different depths of investigation (0 to 50 cm; 0 to 1 and 0 to 2 m). The in-line sampling was 20 cm and across-line was 1 m. Spatial positioning was recorded by dGPS using broadcasted corrections by a stationary satellite. Apparent electrical resistivity spans 40 to 190 Ωm. The majority of anomalies are resistive and correspond to via and buildings (walls, columns). Use of the three depths of investigations together with the derived Digital Elevation Model from satellite data was very important in the interpretation phase. Aerial photos were also orthorectified in the final process of interpretation.

The results obtained are convincing: their interpretation enabled the archaeologist to precisely locate the main axes of the town, to identify several buildings and to confirm the existence of the Gallo-Roman forum. The derived plan enables us to make comparisons with similar fora like those of Augst, Trèves, Wroxeter, Caerwent, Silchester, Bavay or Lutece.

Between 2007 and 2011, several excavation seasons on part of the forum, have allowed us to compare the interpretations of the electrical prospecting and the reality of the archaeological remains. This assessment, which acted as 'ground-truthing', took into account new information revealed by geophysical prospection on other, as yet unexcavated, sectors.

Figure 1: *Combined results of recent excavations (in yellow), old plans (orange) and geophysics.*

DIGGING THE DIRT: GROUND TRUTHING, FEEDBACK AND STATISTICS FROM IRISH MAGNETOMETER SURVEYS

J. Bonsall, C. Gaffney, I. Armit

1. INTRODUCTION

Geophysical assessments are frequently used in commercial developer-led projects as part of a wider programme of archaeological investigation. A common problem shared by many archaeological geophysicists is a lack of adequate and accurate feedback from subsequent phases of an archaeological investigation. Interpretations are based upon the known physical properties of soils, archaeological features, assumptions and experiences from previous investigations. All too frequently, grey literature reports from intrusive investigations remain unpublished or inaccessible, often resulting in anecdotal feedback via the very simple form of 'it worked' or otherwise. When presented with evidence, both positive and negative, geophysicists can make better, more accurate archaeological interpretations in the future through the experiential learning process, but only if suitable ground-truthed data is available. Recent research has afforded the opportunity to generate a statistical analysis of examples from ground-truthed magnetometer surveys over linear road corridors in Ireland.

2. ANALYSIS OF GEOPHYSICAL AND EXCAVATION LEGACY DATA

A review of archaeological geophysical surveys on road corridors assessed 174 geophysical reports, which represent a body of 'Legacy Data' from 2001-10 (Bonsall, 2012). The details of each report were entered into a database that documents how, when, what, and where geophysical data were collected, processed, interpreted and presented, as well as why the geophysical survey was commissioned in the first place. Important local information, such as geology, land use and the weather were also recorded for each geophysical survey.

Geophysical surveys were used on 73 road schemes across Ireland, covering a total area of just over 1,750 hectares (Figure 1). 733 surveys occurred at isolated points along a road scheme including known monuments or 'Areas of Archaeological Potential', areas that archaeologists were concerned might contain significant archaeological features. Geophysical surveys also occurred along the entire length of 26 road schemes and were used for prospecting areas of unknown archaeological potential (Figure 2). Just over 1,100 hectares of detailed magnetometer survey were used to assess multiple linear corridors across Ireland (Figure 3). Magnetometer surveys were the preferred method of assessment due to their ability to rapidly map a wide range of archaeological features.

The success of a geophysical survey can only be determined by ground-truthing the survey area. 67% of all the geophysical surveys carried out for the research were complemented by ground-truthed information in the form of excavation reports. Geophysical data and interpretation plots, as well as some of the archaeological excavation plans, were available in a digital format. Where these two sets of data coincided, the geophysical re-

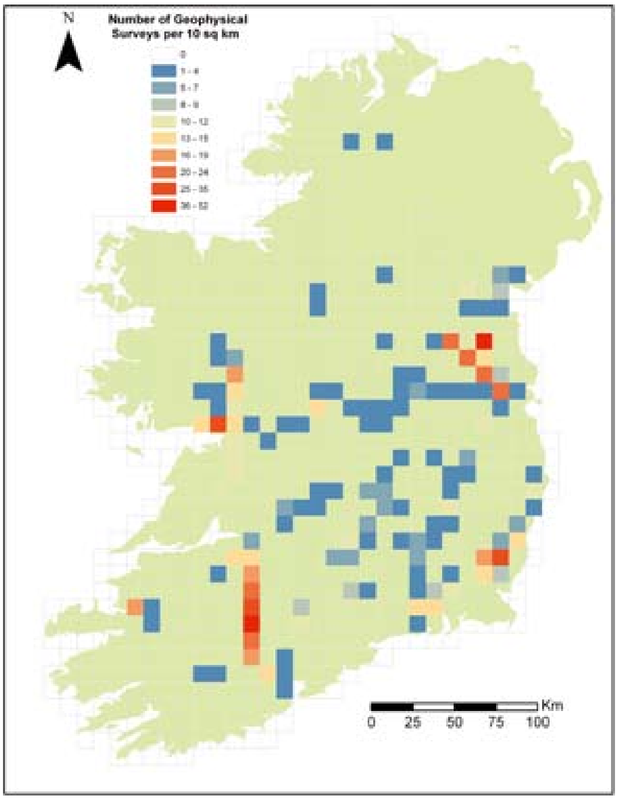

Figure 1: *Number of geophysical survey per 10 sq. km on road schemes in Ireland.*

sults and archaeological excavations could be directly compared (Figure 4) and interrogated using a Global Information System (GIS). The GIS was used to assess the results of geophysical surveys and to determine which influences were most important to the success or otherwise of a geophysical survey.

3. DEFINING SUCCESS

The assessment of ground-truthed geophysical data resulted in four terms that are collectively used to define 'success' (Table 1). These terms simply assess the interpretation of the geophysical data compared to the excavated evidence and do not take account of 'ghost' features (high contrast, coherent anomalies of probable archaeological origin that cannot be substantiated by excavated evidence), which are difficult to incorporate within such an analysis.

Due to the inherent bias of test trenches for the assessment of large and linear features, comparisons have been made only between detailed magnetometer surveys (typically carried out at 1 m $\times$ 0.25 m) and open area excavations, ensuring that small

Term	Geophysical Interpretation	Ground Truthing
True Positive	Anomaly = Archaeological Feature	Confirmed
False Positive	Anomaly = Archaeological Feature	Disproved
True Negative	No signifianct anomalies present	Confirmed
False Negative	No significant anomalies present	Disproved

Table 1: *Terms Used to Define and Analyse the 'Success' of a Geophysical Survey.*

features, such as pits, hearths, post-holes etc. were also assessed. Irish legislation requires a 100% soil recovery rate for development-led investigations / threatened sites; therefore the entirety of the archaeological features were excavated (with no sampling), greatly improving the confidence in the statistical analysis. Irish road schemes engineers try to avoid all known archaeological features where possible therefore the statistical analysis represents a reasonably 'random' sample of the landscape, as opposed to those surveys that occur upon known archaeological features or sites.

Very low instances of True Positive responses demonstrate not only problems with boulder clay / tills, which are present for 58% of the sites examined, but also a tendency to over-interpret geophysical data derived from narrow linear corridors that limit the 'wider appreciation' of anomalies within their local geological / landscape context. Irish fields are 3-5 hectares in size on average; when traversed by linear corridors only very small portions of these fields are examined, often in irregular shapes, therefore a constantly changeable background impacted by cultivation furrows, current vegetation etc., is apparent, often making it difficult to judge and interpret the importance of individual anomalies.

Whilst archaeologists may place emphasis on the importance of True/False Positive responses, a significant outcome for the research has been the consistently high percentage of True Negative occurrences (and low rates of False Negative occurrences). True Negative responses are important because they give a confidence level to the curator / end-user for a particular survey / geology / location type; demonstrating a level to which the results can be relied upon for an entire road scheme. This is commercially very important as the timetable for a major infrastructure project can be adversely affected by the discovery of previously unknown archaeological features. However, we are keenly aware that the majority of a road corridor area is likely to be devoid of archaeological deposits.

Figure 2: *Location of isolated point surveys, including known archaeological monuments, along road schemes in Ireland.*

4. OUTCOMES

Geology has been found to be a significant driver in the success or otherwise of magnetometer surveys (Table 2). The technique is particularly successful at identifying burnt features and enclosed occupation sites upon favourable geology such as shales and calp limestone. However, many ditched enclosure features have been missed due to poor magnetic contrasts on carboniferous limestone, or obscured by strongly magnetic igneous and metamorphic geology. Some of the geological problems faced by geophysicists working on limestone are demonstrated by the site of Magherboy, Co. Sligo (Danaher, 2007). The remains of a large ditched medieval ringfort enclosure were not identified by a high resolution magnetometer survey (0.5 m $\times$ 0.1 m), despite the same dataset clearly identifying the subtle remains of a Neolithic structure just 20m away. In other areas of limestone, high instances of False Positive responses are indicative of natural anomalies that appear to be coherent archaeological features, particularly circular doline responses that share a similar morphology and signal strength with ditched enclosure. Statistical analyses of entire route corridors suggest that shales and calp have been particularly good for magnetometer surveys, whilst limestone is quite poor. Limestone overlain by peat is very poor as a result of having a reduced or impeded magnetic response due to waterlogging (Weston, 2004).

Magnetometer data collected on near surface igneous rock at Clonhaston, Co. Wexford were severely affected by strong geological anomalies (Leigh, 2011), whilst igneous rocks covered by a suitable thickness of drift deposits at Chapelstown, Co. Carlow allowed for the collection of very clear and coherent magnetometer data, capable of identifying a range of archaeological features (GSB Prospection, 2004). Small earth-cut features such as post-pits, post-holes and inhumations, could not be identified using a standard methodology (1 m $\times$ 0.25 m), even upon the most favourable geologies.

The academic analysis of ground-truthed geophysical data is expected to have a great impact beyond Ireland, as it defines the capabilities and limitations of magnetometer surveys in terms of geology, landscape and site type that can be applied elsewhere. The assessment of non-magnetic archaeological features or sites on unfavourable geologies, require alternative – and in some

Geology	True Positive	False Positive	True Negative	False Negative
Shales & Calp Limestone	74%	26%	83%	0.82%
Carboniferous Limestone	12%	88%	94%	1.5%
Igneous Intrusions	25%	75%	91%	13%

Table 2: *Statistics for Geologies Encountered Across Entire Road Schemes, Rather than Specific Archaeological Sites.*

Road Scheme	True Positive	False Positive	True Negative	False Negative	Common Area (Geophysical & Excavation)
M3 Clonee-Kells	74%	26%	83%	0.8%	5.4 ha
N25 Waterford-Glenmore	15%	85%	76%	0.6%	0.6 ha
N8 F-M	95%	5%	92%	18.2%	1.6 ha

Table 3: *Statistical Analysis of Some Selected Road Schemes.*

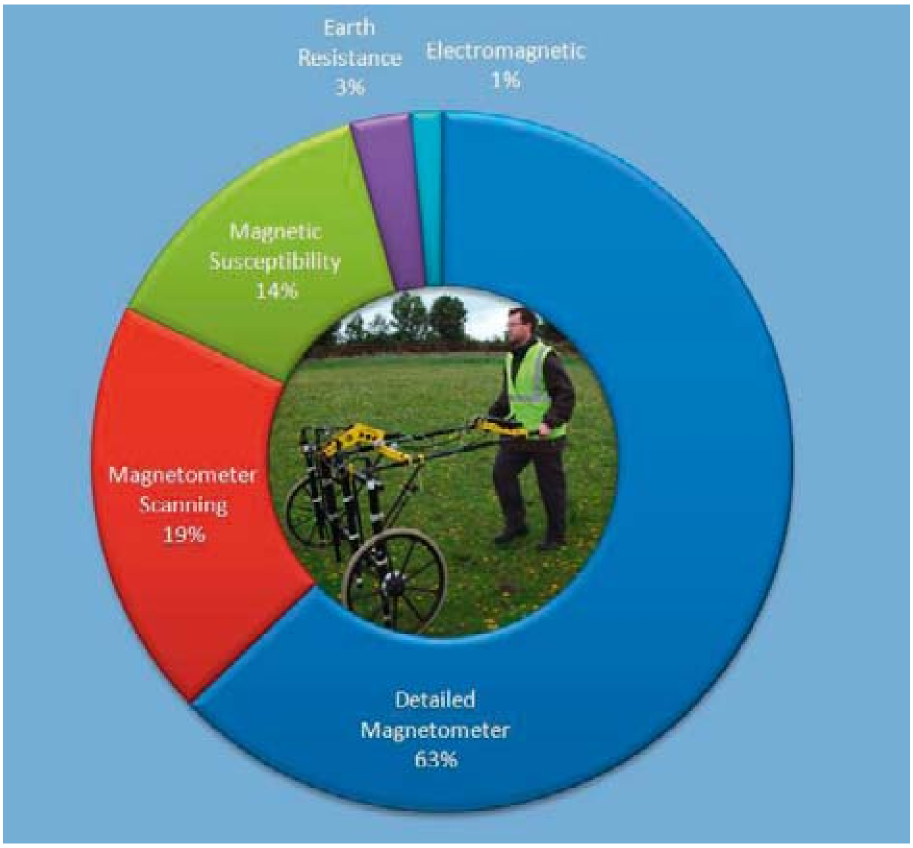

Figure 3: *Relative percentages of geophysical prospection methods employed in Ireland.*

cases, more labour intensive – techniques, to suitably appreciate the underlying archaeology. In light of this information, Irish curators are beginning to respond to this by considering how and where magnetometer surveys should be used in the future and where other, more appropriate techniques, might be beneficial.

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EVALUATING AND INTERPRETING MULTI-RECEIVER EMI DATA WITH THREE-DIMENSIONAL EXCAVATION DATA

P. De Smedt, W. De Clercq, J. De Reu, D. Herremans, M. Van Meirvenne

Although increasing amounts of archaeogeophysical data are collected each year, detailed validation of these datasets through extensive ground truthing (e.g. augering and excavations) remains limited. In developer-led archaeological projects, geophysical surveys are often succeeded by trenching and or surface excavations, but the invasive follow-up fieldwork aims mainly at completing the archaeological evaluation of the study area or to conduct rescue excavations. Excavations that are conducted from an academic perspective with the evaluation of geophysical survey results as a primary goal rarely take place or remain confined to small test pits (examples include Arısoy *et al.*, 2007; Kvamme, 2006). Here we present the results of two excavation campaigns planned to evaluate the results of an extensive multi-receiver EMI survey in the north of Belgium. We compared excavation data, gathered with computer-vision based three-dimensional recording (De Reu *et al.*, in press), to the multi-layered EMI data. This allowed for detailed insight into the relationship between the geophysical data, the unearthed archaeological remains and the pedological variability at the site. Furthermore, it allowed a high-resolution validation of the inversion of the EMI dataset.

The level of information that can be derived from geophysical survey results increases drastically once true ground information about the surveyed area is incorporated. This information exchange between excavators and geophysical surveyors often remains limited to the findings presented in final archaeological reports, which limits the potential for comprehensive validation of the geophysical data and makes a true integration of both datasets impossible. Research excavations aimed primarily at understanding and explaining survey datasets remain scarce, and in such studies, the objective comparison of excavations and geophysical results poses new challenges. For one, the geophysical data need to be taken in to account during the entire excavation process, which can require the presence of the geophysical surveyor. Furthermore, the lack of high-resolution continuous excavation data makes it difficult to compile a validation dataset for the geophysical data. In particular, the occasionally subjective character of metrical excavation data (e.g. drawing, delineating and interpreting soil variations) can limit their use in evaluating geophysical surveys. Another challenge comes from the recent advances in three-dimensional (3D) geophysical datasets, requiring a different approach for collecting evaluation data. While researchers have already stressed the importance of a combining geophysical data and excavation results in geographical information systems (Neubauer, 2004), a different approach is needed when working with 3D datasets. Here, the integration of photogrammetric data recording may offer the best outcome, as this allows obtaining geometrically correct and objective information about the excavated area (Doneus *et al.*, 2011).

In February 2011, a mobile, multi-receiver EMI-survey with a Dualem-21S sensor (Simpson *et al.*, 2009) revealed a previously unknown buried medieval landscape in the north of Flanders (BE). Located near the boundary of a 25 km^2 wetland area, traces were detected of multiple ditch systems together with a number of brick structures. Based on these survey results, two excavation trenches were set out across the most characteristic anomalies in the geophysical dataset. Both excavations were conducted based on the apparent electrical conductivity (ECa) and apparent magnetic susceptibility (MSa) data from the EMI-survey (Figure 1). These excavations were planned to further interpret the geophysical data and to identify possible discrepancies between the detected anomalies and the archaeological reality.

During each phase of the excavations, computer-vision based 3D recording was used to map archaeological features, excavated soil surfaces and soil profiles (De Reu *et al.*, in press). In a second stage, these data were combined with the multi-layered EMI dataset to compose a detailed model of the medieval topography. While stratigraphical information from one excavation trench was used to calibrate this topographical model, geometrically corrected profile information was used from the other trench to test the validity of the model.

This is the first extensive study whereby multi-receiver EMI data was evaluated by excavation trenches. The integration of the 3D-recorded excavation data within the geophysical dataset to compose an accurate model of the medieval topography shows how the combination of these 3D data volumes allows an unprecedented geoarchaeological landscape analysis. The added information from this approach, together with the results from the landscape reconstruction, forms the core of this paper.

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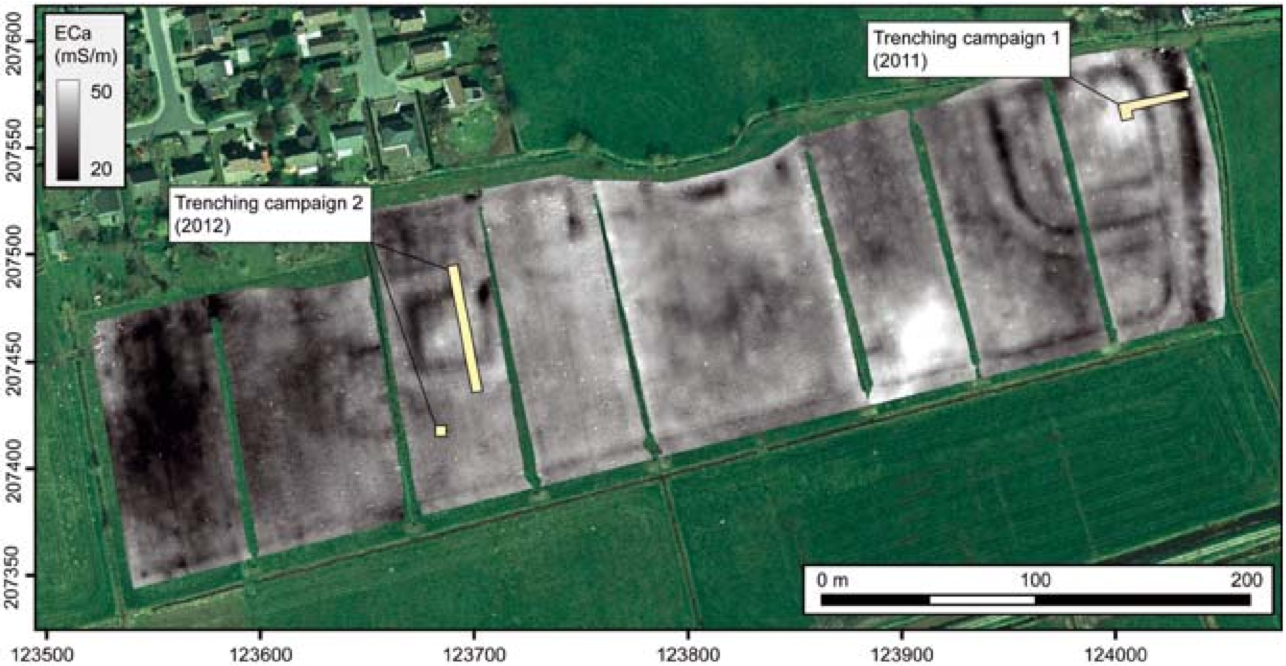

Figure 1: *ECa data of the surveyed area with indication of the excavated areas.*

Figure 2: *Photographing excavated features and georeferenced ground control points for 3D recording.*

ROMAN VILLAS IN THE VICINITY OF VIMINACIUM

N. Mrđić, M. Jovičić, M. Korać

The landscape surrounding Roman Viminacium is one of the best explored urban area in the former province of *Moesia Superior* (later Moesia Prima), now eastern Serbia. Although the urban core of the Roman *colonia* – provincial capital and legionary fort – are protected, the surrounding fields between the villages of Stari Kostolac and Drmno are endangered by building activities of a power plant, Kostolac B, and expansion of the Drmno surface coal mine. Because of these threats, research efforts since 1973 are focused predominately on these surrounding areas. This means that hundreds of hectares are systematically surveyed using all available methods in order to narrow the area with archaeological remains that must be quickly excavated and if possible relocated.

This paper deals with Roman villas located by different geophysical survey methods and excavated afterwards as part of a major salvage project. Only villas discovered since 2002 are included in this research. Standard procedure for Viminacium excavation includes detailed imagery analysis (aerial images from 1967 to the present) followed by systematic field survey and surface collection of archaeological remains. The primary geophysical method used in surveys is magnetic, using a proton magnetometer, as this is the method that requires the least preparation in the field. After surveying confirmed sites, this method is then used to cover as much area as possible before ultimate destruction. We are also using electrical resistance and ground penetrating radar (GPR), focusing on already defined archaeological sites. All geophysical data and results of archaeological excavations are then compiled in the project's central GIS database.

We will present four villas to the east and southeast of Viminacium: These villas are of different character, individually remote from each other, and were surveyed using three different methods. All mentioned distances in text are measured from the eastern gate (*porta principalis dextra*) of the legionary fort (*castra Septimae Claudiae Piae Fidelis*). All villas are badly preserved, since they suffered systematic destruction as a source for secondary building material.

Conditions for use of geophysics were very suitable compared to those that are present in the other ancient cities and in Viminacium itself. All villas were located in fields used for intensive agriculture. There was no gigh vegetation over the sites, there is no overlapping of buildings, and stratigraphy is relatively simple. All were built in solid materials with the opus cementicium or opus mixtum techniques. The amount of rubble was not very high. On the other hand, preservation of buildings was very bad. Most of walls were preserved only in foundations or even negatives. Hypocausts were discovered in two villas (Rit and Nad Klepečkom).

The villa on the site "Nad Klepečkom" is located 2300 m east of Viminacium, and dated to the second centruy AD. The geophysical method used to survey this villa was electrical resistivity.

Villa suburbana on the site "Rit" was excavated in 2005, and was surveyed by proton magnetometer prior to excavations. The villa is located 300 m to the northeast of the legionary fort. It was determined and archaeologically confirmed that it had a protective stone wall 1 m thick and that it had at least 2 sewer channels that merged into one larger taking wastewater towards north. Dates for *Villa suburbana* are from the early second century to early third century AD.

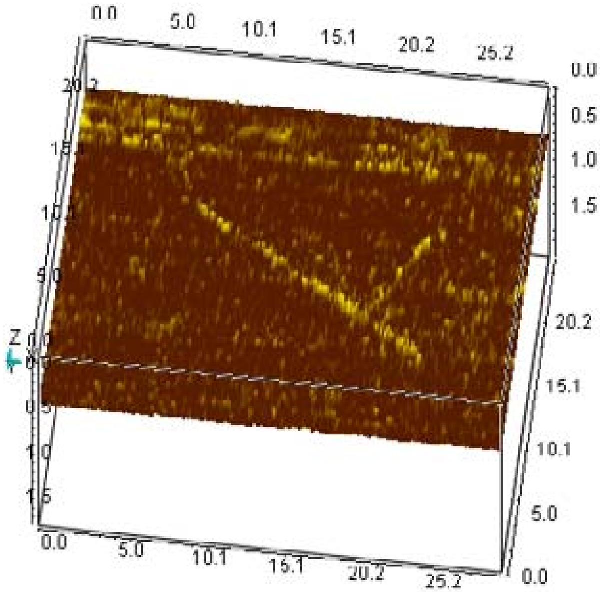

Figure 1: *Radargram of the Roman villa on site "Stig".*

Villa rustica, on the site "Na kamenju", dates to the fourth century AD and is located 1800 m to the southeast of the legionary fort. This area was surveyed and excavated in campaigns 2007/2008. The geophysical method used in survey was Ground Penetrating Radar (GPR).

A villa on the "Stig" site was excavated in 2003 during salvage excavations of the two aqueducts. It was located less than 200 m from gravitation channels and 2900 m from Viminacium, to the southeast. The building was dated into the middle of the fourth century AD. This building belongs to the basilica type villa and has analogies with villas found in *Pannonia*. This site was surveyed by GPR (Figures 1 and 2).

All the villas in the vicinity of Viminacium were adjacent to the roads except the villa at "Stig" (road not found). They can be all divided into two periods of existence: second to third century AD, and fourth century AD.

Figure 2: *Excavations at the Roman villa on site "Stig".*

WHEN, WHERE, HOW? THE ARCHAEOLOGICAL NEED FOR GREATER PREDICTABILITY FOR ARCHAEOLOGICAL PROSPECTION

P. Karlsson

The Swedish National Heritage Board, Department of Contract Archaeology, has since 2005 pursued its own state of the art geophysical archaeological prospection with ground penetrating radar and magnetometer. Initially, the field archaeologists considered the results as very valuable. In recent years, the perception has changed towards a more hesitant attitude. The change is mainly due to the discovery that large discrepancies between interpretations of the geophysical data and the archaeological survey results.

Discrepancy between geophysical data and archaeological excavation data is in itself not remarkable. Without a physically measurable contrast between the anomaly and the surroundings, anomalies cannot be identified in the geophysical data. Similarly, the investigative archaeology often struggles to identify structures that do not exhibit sufficient optical contrast with the environment. However, it is problematic when, for example, well-preserved one-metre thick medieval wall, less than 20 cm below the surface, are difficult to identify in ground penetrating radar data. Problems like this are primarily related to geophysical techniques and methods, but become archaeological problems the moment the prospection claims to be just archaeological prospection. What can archaeologists expect of ground penetrating radar (GPR) surveys, and what can providers of GPR surveys promise?

In this presentation, a number of examples are presented from sites in Sweden that have been the target of both geophysical prospection by GPR and a subsequent archaeological investigation. The examples are chosen to represent essentially the same geological conditions and a variety of archaeological remains, but all were examined with the same geophysical instrumentation and the same geophysical survey method. The examples represent cases where features / anomalies in the ground have been found:

- geophysically as well as archaeologically
- only archaeologically, or
- only in geophysical data

In the presentation, there are no attempts made to explain the variability of coherence between archaeological results and data, and results from the geophysical prospection, which the cited examples illustrate. The aim is instead to highlight the need for more qualitative studies of archaeological prospection from an archaeological perspective, with the aim of making archaeological prospection more predictable. In the presentation, there are proposals on how such research could be carried out, where in particular the importance of an open-minded collaboration between several disciplines is emphasized.

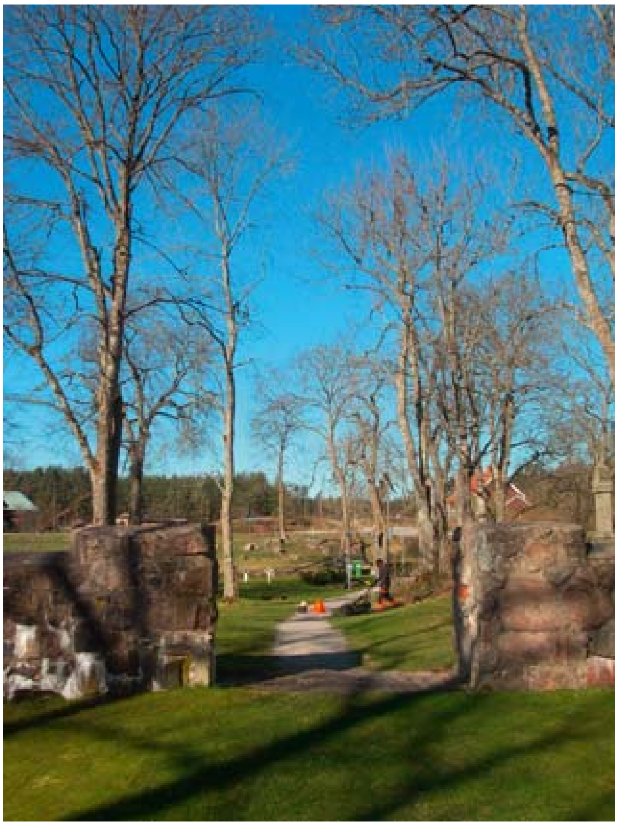

Figure 1: *Photo from a medieval Franciscan convent in Krokek, Sweden. The GPR survey showed vague traces of preserved walls. The following excavation reviled well preserved, one meter thick brick walls 10-15 centimetres below the surface. The implications of situations like this is discussed in the paper. Photo Immo Trinks.*

PROSPECTION OF THE EASTERN PART OF THE AGER OF VIMINACIUM

S. Redžić, I. Danković

This paper will present data gathered during systematic prospection and follow-on excavations on the area located to the east of Viminacium legionary fortress and civil settlement. The area in question has been investigated since 2002, as part of rescue excavations conducted because of the expansion of the Drmno coalmine.

Initially, the emphasis was laid on the route of the road leading from the *castrum* to the east. A section of this road, closest to the eastern gate of the fortress, was archaeologically confirmed in the early phases of investigations. Field and geophysical surveys, combined with analysis of aerial photography, followed, and to date, the route of the road is precisely reconstructed to the length of ca. 4 km.

Aerial photography was of great help in interpreting concentrations of surface rubble, previously considered to be a branch road separating from the main route. The result was the discovery of three aqueducts that supplied the town with fresh water.

Remote sensing, namely geoelectric resistivity and geomagnetic gradiometer methods, also suggested existence of numerous archaeological features along the road in question.

In the areas in which necropoles were constructed near the road, several rectangular shapes could be distinguished on images provided by geophysics. Archaeological excavations showed that these anomalies represented enclosures of two or more graves probably belonging to members of the same family.

At 2.4 km along the road, measured from the eastern gate of the *castrum*, geoelectric resistivity surveys showed the presence of large buildings, sixteen of which were subsequently excavated and proved to be part of previously unknown Roman settlement.

The combination of ground reconnaissance surveys, analysis of aerial photography and geophysical surveys led to maximal efficiency of archaeological excavations, which was very important, given the vastness of the endangered territory and the lack of time, allowing the best possible reconstruction of infrastructure of the eastern part of the *ager* of Viminacium.

GEOPHYSICAL PROSPECTIONS IN PIAMMIANO (BOMARZO, ITALY): INTERPRETING AN ETRUSCAN AND ROMAN SETTLEMENT

C. Joncheray, M. Dabas, V. Jolivet

The settlement of Piammiano lies between Orvieto and Viterbo, in current Latium, near the Western border of Umbria, on a tuff plateau overlooking the Tiber valley. The main development of the site, whose extension is about 15 hectares, took place between the Archaic and Hellenistic Age, according to the results of various survey campaigns and the excavation of its necropoles. Recent historic interpretations suggested that this site could correspond, in the Roman period, with the praefectura of Statonia, which can be located, following ancient texts, near the Eastern border of the Tarquinian territory.

Obtaining the status of praefectura should have made Piammiano a major site in the region, but its urban planning is still completely unknown. Starting from this paradox, our work aims to understand the town planning of the city through geophysical prospection, as part of a broader archaeological project led by the Soprintendenza archeologica per l'Etruria meridionale and the Università of Viterbo. T. Peña (UC Berkeley) and E. Papi (Università di Siena) already carried out a first campaign of magnetic prospection in 1998-2001, gaining interesting results, which unfortunately remain unpublished. For our own work, performed in April 2012 by the firm GEOCARTA, we preferred to use the mechanized electrical resistivity method (Automatic Resistivity Profiling, ARP), which was applied on a surface of about 7 ha in the northern and central part of the plateau.

The presence of structures or peculiar features can be identified in three different areas. In the northern part of the plateau, just above a steep slope that still gives access to the plateau, a curved feature could indicate the presence of a defensive structure. The second interesting area is situated in the central part of the plateau, which presents a series of punctuated anomalies (from 5 to 8 m wide). The clearest result of this work, however, appears in the southwest part of the site, where the prospection shows the presence, on both sides of the current road, of numerous structures orthogonally planned, forming a network of axes mainly orientated 33°N, which can be identified as a concentration of houses, a small part of which had been excavated during the 1998-2001 campaign.

At the present, the extent of the identified structures and their characteristics offer interesting clues to the study of the site, but the project is not far enough along to allow confirmation of its identification with the Roman praefectura of Statonia.

MAPPING PREHISTORIC WOODEN TRACKWAYS USING TIME DOMAIN INDUCED POLARISATION

J. Bonsall, R. Fry, F. Pope-Carter, C. Gaffney, I. Armit

Peatlands are a highly valued resource for archaeologists as they are capable of preserving a wide range of organic objects. Peatlands cover approximately 16.5% (11,392 km^2) of Ireland, the third highest per cent in Europe (Montanarella *et al.*, 2006). The location of rare and high-profile archaeological objects such as bog butter, psalters and bog bodies cannot be detected by archaeological geophysical surveys. However, structural features comprised of organic materials, such as wooden trackways, can potentially be mapped by geophysical techniques. Wooden trackway remains (or *toghers*) are sometimes encountered on Irish state owned bogland, which is milled for fuel, as well as on linear infrastructure projects that cross bogland.

It is difficult to determine the purpose and destination of a wooden trackway, as these features do not necessarily link archaeological sites together; for example, the Iron Age trackway of Corlea 3, Co. Longford was found to terminate within a bog for no apparent reason (Raftery, 1996). For geophysical assessments, it is particularly difficult to predict where a trackway is likely to be located.

Trackways are difficult to identify from conventional geophysical prospection data; they are narrow features, buried at often unknown depths and have little or no magnetic or electrical contrast with the surrounding organic peat. Recent case studies have shown promise for the detection of known wooden trackways located in waterlogged peat. GPR was used on the Sweet Track in the Somerset Levels, UK (Armstrong, 2010), although mixed results were reported due to changeable hydrology. The most suitable method for the assessment of large and dense wooden remains is Induced Polarisation (IP) a technique that exploits the polarisable properties of wood to create contrasts with the surrounding peat material. Schleifer *et al.* (2002) demonstrated that frequency-domain spectral induced polarisation (SIP) was capable of identifying wooden planks in a waterlogged environment. SIP measuring instruments however are not widely available whereas time-domain IP measurements can be commonly collected by most resistivity instruments.

Figure 1: *Archaeological excavation at Edercloon, Co. Longford revealed a large complex of wooden structures (After Moore and O'Connor, 2009).*

1. CASE STUDY: EDERCLOON BOG TRACKWAY COMPLEX

In 2006, a large complex of wooden trackways components were found in a 0.51 hectare excavation at Edercloon, Co. Longford, prior to the construction of a road scheme (Moore and O'Connor, 2009). Investigations showed the site consisted of a large complex of wooden structures, predominantly toghers and platforms with occasional smaller deposits of archaeological wood (Figure 1). The complex was extremely dense, with forty-five individual sites located in very close proximity with many abutting and crossing over and beneath each other. These consisted of:

- 4 primary *toghers*
- 8 secondary *toghers*
- 12 tertiary *toghers*
- 5 platforms
- 13 deposits of archaeological wood

Thirty-six radiocarbon and dendrochronological dates indicated that the structures date from the Neolithic to the medieval period, with the majority dating to the centuries of the Late Bronze Age and Early Iron Age (Figure 2).

There were indications that up to three primary or secondary toghers continued beyond the excavation to the northeast into undisturbed pasture land (Table 1). The full and detailed excavation records afforded the opportunity to trace the undisturbed extent of the trackways using induced polarisation (IP).

The trackways at Edercloon Bog were assessed using a FlashRES64 instrument to collect time-domain IP measurements along an 80 m traverse, with probes spaced 0.5 m apart. The traverse was located 10 m from the known edge of the excavation to avoid anomalous data generated by the disturbed and backfilled soil, thus the last known morphology and trajectory of the trackways were located 10 m from the traverse. It was assumed and hoped that at least one of the trackways would continue in to the survey area – given that the excavated toghers were known to be 12-34 m in length, this seemed a reasonable assumption.

2. RESULTS

The IP data indicate the presence of a high contrast anomaly at 43 m along the traverse (Figure 3). The anomaly coincides with the projected trajectory of EDC5 (a Middle to Late Bronze Age primary togher) and EDC31 (a Late Bronze Age to Iron Age secondary togher). Both of these were quite substantial; EDC5 was 1.3 m in depth, 3.6 m in width and 32.5 m in length (Figure 4);

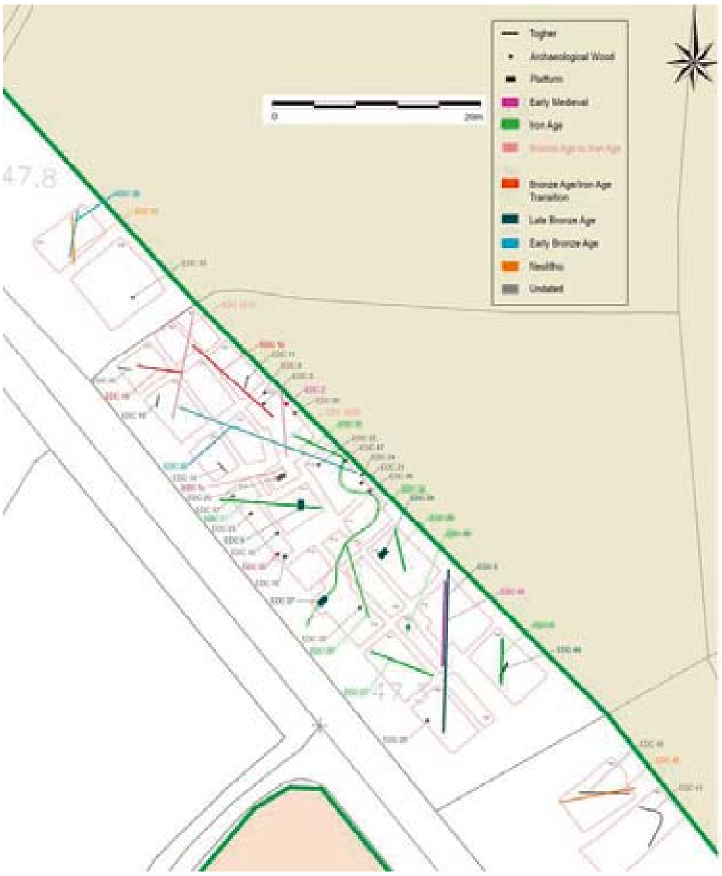

Figure 2: *Wooden structures assigned to temporal periods based on 36 radiocarbon and dendrochronological dates (After Moore and O'Connor, 2009).*

	EDC5	EDC26	EDC31
Orientation	N–S	NE–SE & E–W	NW–SE
Elevation	-1.95m	unknown	-1.56m
Length	32.5m	34m	12m
Depth	1.3m	1.53m	0.6m

Table 1: *Dimensions of toghers projected to cross the area of investigation.*

EDC31 was 0.6 m in depth, 4.8 m in width and 12 m in length. The anomaly highlighted at 43 m is assumed to be EDC5 or EDC31, or potentially an amalgam of both trackways abutting or crossing over and beneath one another. It is also possible that the anomaly could represent a previously unrecorded trackway.

A number of moderate contrasting anomalies were also identified in the IP data at 18 m, 25 m and 60 m along the 80 m traverse. EDC26 is a curvilinear trackway that could potentially correspond to either of the IP anomalies at 18 m or 25 m along the traverse.

Some of the anomalies were also traced across a number of shorter traverses (32 m long, lines spaced 0.5 m apart, probes 0.5 m apart, lines parallel to the 80 m traverse), over a distance of 8 m, which emphasises a consistency of the trackway anomalies.

The study at Edercloon Bog indicates that time-domain IP is capable of identifying a range of differently sized wooden trackways in peat. The survey was able to map the extent of some trackways beyond the road scheme. The method is not suited for use as a 'blind' prospection technique in areas of unknown archaeological potential as it depends upon an assumed knowledge of the features orientation and an estimate of likely depth. Time-domain IP will be particularly useful for the mapping of trackway extent and direction, in cases where a trackway has been identified by small-scale intrusive investigations.

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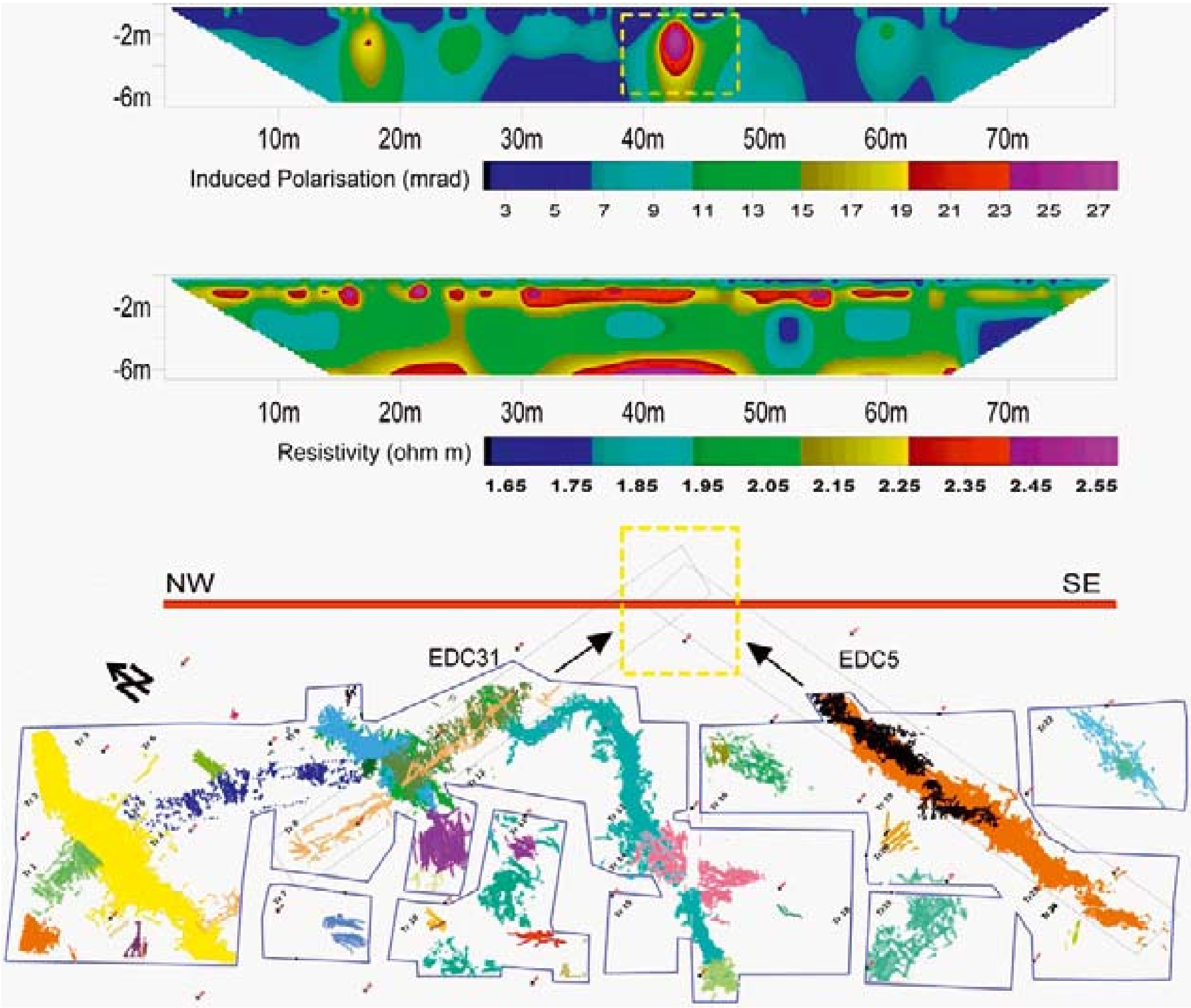

Figure 3: *A high-contrast anomaly in the IP data suggest the possible junction of two togher: EDC5 and EDC31.*

Figure 4: *Toghers in situ during excavations at Edercloon Bog (After Moore and O'Connor, 2009).*

GEOPHYSICAL PROSPECTING REGARDING THE FORTIFICATION SYSTEMS IN CHALCOLITHIC CUCUTENI CULTURE FROM ROMANIA

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Extensive archaeological research on settlements belonging to Cucuteni culture in Romania have revealed the existence of defensive systems, especially in the case of those settlements located on elevated areas within the landscape. The settlements, located on higher ground and representing the object of our study, are always naturally defended from three sides, while the remaining open side has a ditch with rampart and sometimes stockade. The fact that the researched fortification systems are in many cases made up of two parallel trenches, quite close to one another, convinced the specialists to consider it as an extension of the settlement, through wrapping the interior fortified line and digging of another one pointing outward.

The geophysical surveys conducted at many Cucuteni settlements within the space bordered in the west by the Eastern Carphatians and by the Prut River in the east, offered precious data regarding the defensive systems, as well as their planimetry. Combining the magnetic and georadar (GPR) methods led to the identification of complex defensive systems, which were located on the most easily accessible side of the settlement and made up of two vaulted parallel ditches that effectively closed the open side. It is worth noting the results of prospection at Brăteşti point, Dealul Chicera (Figure 1): alongside the two large trenches, a third trench was observed, parallel with those, at small distance within the settlement. The shape, dimensions and position of the documented anomaly convinced us that it is most probably part of a stockade.

Our investigations disagree with the hypothesis presented in the professional literature, that the second defensive ditch is a result of the settlement's extension. The prospection results show, in a clear manner, that there are no traces of archaeological complexes between the trenches; therefore, we consider it could be a complex defensive system, typical for Cucuteni settlements located on higher ground in this area. Our hypothesis has been confirmed by archaeological investigations carried out at the archaeological site of Fulgeriş, La trei cireşi. These investigations are based on the magnetic interpretations.

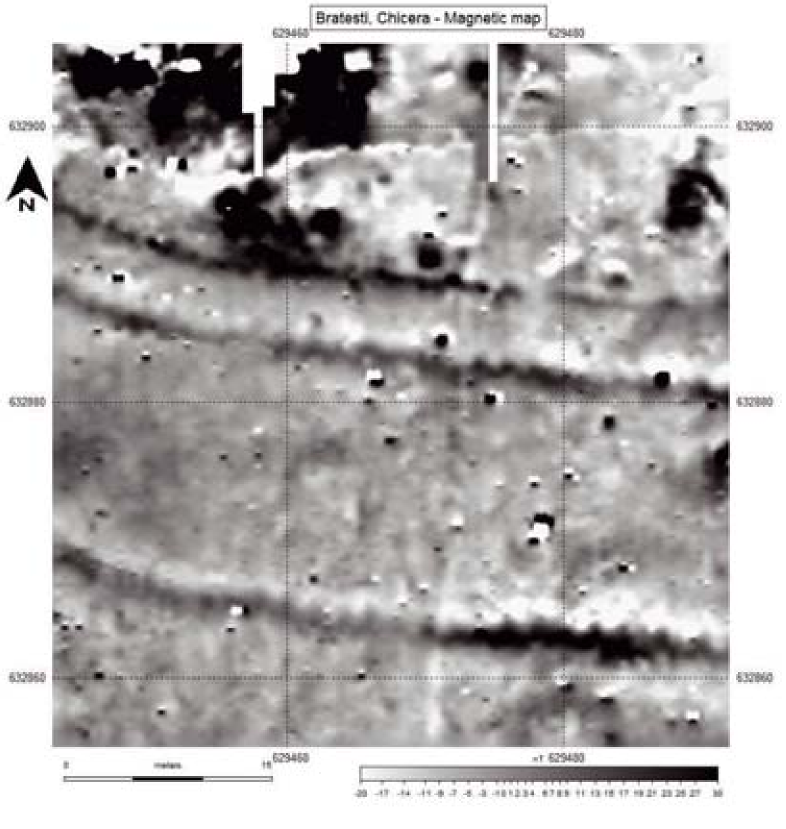

Figure 1: *Magnetogram from the Cucuteni site at Brăteşti point, Dealul Chicera showing three ditches.*

CHANGES OF STRUCTURE AND EXTENT OF EARLY MEDIEVAL STRONGHOLDS IN CENTRAL BOHEMIA FROM GEOPHYSICAL SURVEYS OF SITES

R. Křivánek

1. INTRODUCTION

Geophysical survey of Early Medieval fortified sites is one of the subtopics of the internal archaeogeophysical project of the Institute of Archaeology in Prague, which focuses more generally on the observation of enclosed areas in prehistory and the Early Medieval period (AV0Z80020508). Slavic strongholds had been explored previously, by partial geophysical surveys in several archaeological projects. Examples include "The Identification of Destroyed Fortifications and Internal Structure of Settlement of Hillforts" (PK99P04OPP007), Křivánek 1999-2001 (Křivánek, 2000, 2001, 2003b); "The Přemyslid Hillfort at Stará Boleslav – its role and status in the early Přemyslid state" 404/99/1060, Boháová *et al.* 1999-2001 (Křivánek, 2003a); and "Inner bailey of Libice stronghold – possibilities of non-destructive archaeology and modern technology in the process of study of archaeological sources" KJB800020803, Mařík *et al.*, 2008-2010 (Křivánek and Mařík, 2009; Mařík and Křivánek, 2012). Aside from the these projects, geophysical surveys have been conducted in response to previous archaeological excavations (Křivánek, 1999) or in connection with the planned new landscape changes of sites (Křivánek, 2008, 2010). Recent geophysical surveys have focused more on monitoring the larger areas of sites, and on surveys of hilltop settlements or outer baileys.

2. ARCHAEOLOGICAL CHARACTERISTIC OF SITES

The Central Bohemian region is characterized by intensive Slavic settlement with numerous fortified hilltop sites, which were built between end of 8th and beginning of 13th century AD. These Early Medieval strongholds are mostly situated on promontories, which are fortified with systems of ramparts and ditches on their accessible sides. Some of these fortified strongholds already used sites with earlier prehistoric settlements or even prehistoric fortifications, where in the Early Medieval period there was a substantial rebuilding of fortifications and expansion of the surface extent of sites. In other cases, there were new settlements based on new strategic positions in the landscape, the promontories of the meanders of rivers or near major roads. In the past, archaeological research or individual trenches were used to investigate Early Medieval strongholds (or hillforts). However, most large areas of Slavic fortified settlement (the normal range of units to tens of hectares) remains unrecognized. In the last decade, there has therefore been intensive use of various non-destructive methods, including geophysical prospection.

3. METHODS OF SURVEY

Magnetic and geoelectric resistivity survey are the two main geophysical methods used for surveys of strongholds in Bohemia. For magnetometric surveys of larger areas of arable fields or meadows, two different types of magnetometers are used. Gradient variants of the Scintrex Smartmag SM-4g caesium vapour magnetometer with one profile measurements was carried out within a network of approximately 1×0.25 m (details in density 0.5×0.2 m). The newer five-channel magnetometer system Magneto-Arch with Sensys fluxgate gradiometers FMG-650B offered parallel five profile measurements with the density of data 0.5×0.2 m or 0.25×0.1 m. For geoelectric resistivity surveys of particular areas (gates, communications, ramparts, small recently settled or forested areas), the Geoscan Research RM-15 instrument was used. Chosen areas were additionally surveyed with Wenner configuration of electrodes A0.5M0.5N0.5B (or A1M1N1B) with a data density of 1 *times* 1 or 0.5×0.5 m.

4. EXAMPLES OF RESULTS

4.1. Stronghold Prague-Bohnice

District Prague 8, location: "Zámka", dating: end of 8th – end of 9th century AD (+ multi-cultural prehistoric settlement, probably also prehistoric hillfort), fortified area from archaeological evidence: approx. 6.5 ha, actual terrain: fields, forest, meadows

Geophysical survey of inner and outer areas of multi-cultural site was conducted in cooperation with archaeological department of the city of Prague museum and preliminary planning of rescue excavation for a motorway circle north of Prague. The results of the magnetometric prospection inside the known part of the stronghold confirmed intensive settlement and identified previously unknown internal division of the central area. The result of extensive magnetometric prospection identified unexpected systems of outer transverse and also perimeter ditch fortifications within interruptions (Figure 1). Additional geoelectric resistivity measurements of magnetically disturbed area in front of central area on the promontory helped to separate another remnant of of a destroyed rampart and ditch outside. Geophysical survey changed the origin ideas about the extent of the fortified area (now approximately 11-12 ha), structure (3 outer baileys) and intensity of settlement of Early Medieval stronghold (Křivánek, 2008).

4.2. Stronghold Kouřim (St. John)

District Kolín, location: "U sv. Jiří", dating: end of 10th – beginning of 13th century AD, fortified area from archaeological evidence: approximately 6.2 ha, actual terrain: fields, meadows, modern private settlement and gardens, forest

Comprehensive geophysical measurements of Přemyslid site was carried out in cooperation with other field surveys of the Institute for Archaeology of the Faculty of Arts, Charles University in Prague. The result of magnetometric prospection of the inner settlement (meadow), outer bailey and other outer areas (fields) confirmed the location of previous known fortifications, but also identified another outside ditch and previously unknown concentrations of settlement (Figure 2). Additional geoelectric resistiv-

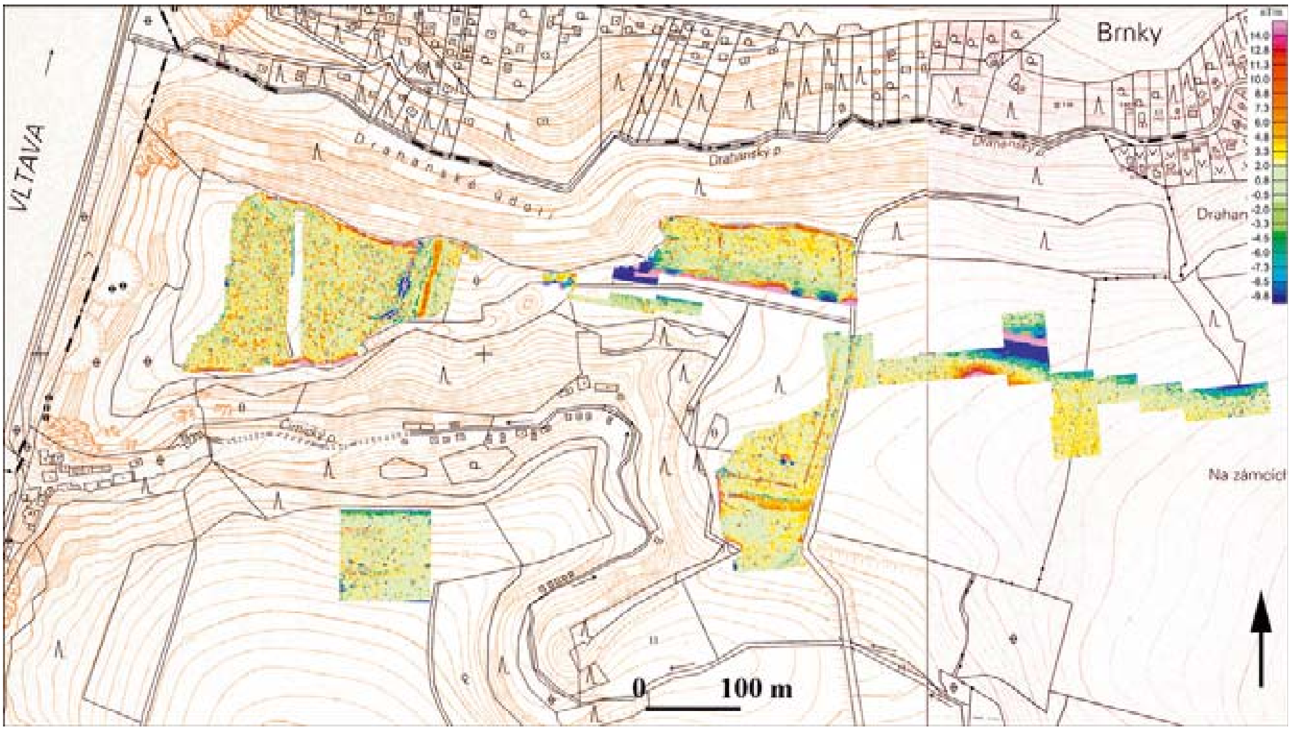

Figure 1: *Prague-Bohnice, district Prague 8. Combination of the results of the magnetometric and geoelectric resistivity survey with the segment of contour map (source: regional map 1:5000). Identification of unknown inner ploughed out divisions and settlement remains of the early medieval stronghold, ploughed out remains of inner divisions, settlement and ditch fortifications in eastern outer area of the Early Medieval stronghold (total surveyed area: approximately 11.5 ha; geophysical survey: Křivánek 2005-2006).*

ity measurements of chosen areas over a ploughed-out rampart fortification and inner platform identified subsurface remains of stone walls inside the rampart and local bedrock changes. Geophysical survey probably confirmed the presence of another (second) southern fortified bailey of the stronghold, and in combination of with surface artifact collection data, delimited the wider extent of settlement of the fortified Early Medieval site (fortified area at least 10 ha).

4.3. Stronghold Vraný

District Kladno, location: "Žižkaperk" or "Práče", dating: probably 10th – 12th century AD (+ Eneolithic settlement), fortified area from archaeological evidence: approx. 2.5 ha, actual terrain: forest, fields

New geophysical survey was conducted on arable fields in the eastern and northern surroundings of the forested sandstone headland terrace within the central part of stronghold. The result of magnetometric prospection identified two previously unknown (not currently visible on the surface of the ploughed fields) outer ditch fortifications of the stronghold (Figure 3). Geophysical survey confirmed three different fortified parts of stronghold (Křivánek 2012). The combination of geophysical and surface artifact collection results changed previous archaeological ideas regarding the scale, extent (fortified area approximately 5-6 ha) and intensity of settlement of fortified Early Medieval site.

4.4. Stronghold Prague-Královice

District Prague 10, location: "U Markéty", dating: 11th – 12th century AD, fortified area from archaeological evidence: approx. 7.5 ha, actual terrain: fields, modern private settlement and meadows, cemetery

New systematic geophysical survey of a Slavic site was carried out in cooperation with field surveys and excavations by the Institute for Archaeology of the Faculty of Arts, the Charles University in Prague. The result of magnetic prospection of complete arable fields of the hilltop settlement and outer bailey identified remains of deeply ploughed-out ditches and variable intensity of sunken features (Figure 4). Additional geoelectric resistivity measurements of chosen small areas around St. Margaret church and the destroyed rampart helped to verify subsurface continuations of the destroyed rampart fortification. Geophysical survey updated existing information about the internal divisions of the Early Medieval stronghold and the state of subsurface preservation of archaeological remains.

5. CONCLUSION

There is a long history in Czech archaeology of the systematic use of geophysical methods to monitor the different hillforts. Magnetometric survey complemented by geoelectrical resistivity measurement seems an appropriate combination of geophysical methods to survey strongholds. The expansion of geophysical methods is also expected, for those situations where the use of electromagnetic measurements and GPR is advised (for example for surveys of churches or ramparts with stone walls in the Early Medieval fortified strongholds).

In the case of Early Medieval strongholds, a broad set of non-destructive geophysical results from several similar sites already exists. These offer comparative datasets of survey results

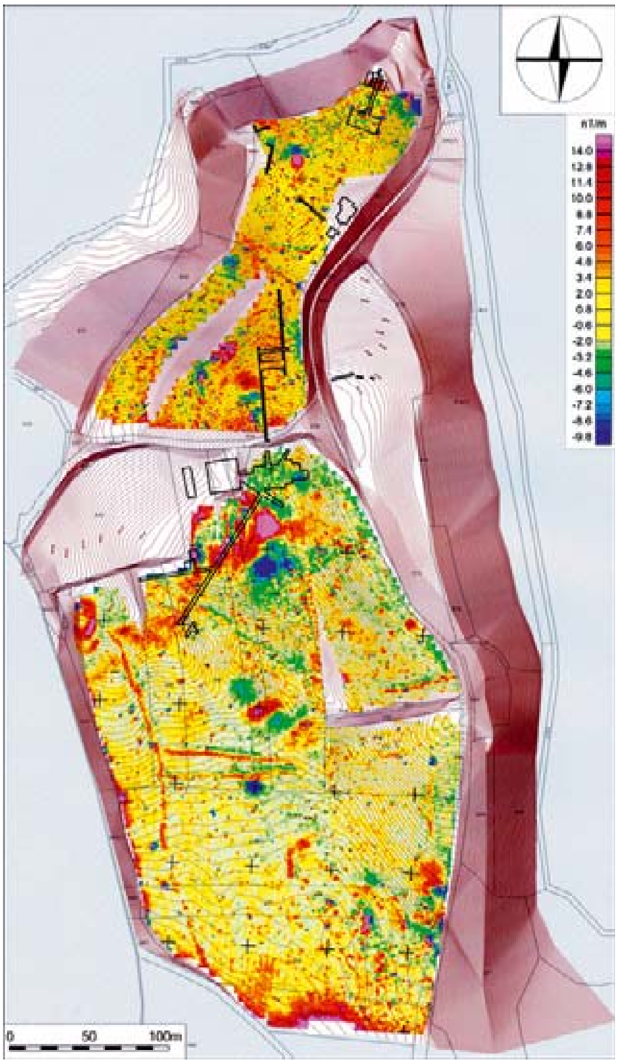

Figure 2: *Kouřim (St. John), district Kolín. Combination of the results of the magnetometric survey with a new contour map of site (source: Institute for Archaeology of the Faculty of Arts of the Charles University in Prague). Identification of ploughed out remains of rampart and more ditch fortifications and settlement concentrations in southern outer area of the Early Medieval stronghold (surveyed area: approximately 7.7 ha; geophysical survey: Křivánek 2010).*

and the nature of fortification of sites with respect to land use. The results can be valuable not only in terms of archaeology, but also for the interest of archaeological heritage, conservation and the protection of archaeological monuments. Spatial results can also be used for subsequent surface artifact collection, metal detector surveys or effective planning of future archaeological projects and archaeological excavations.

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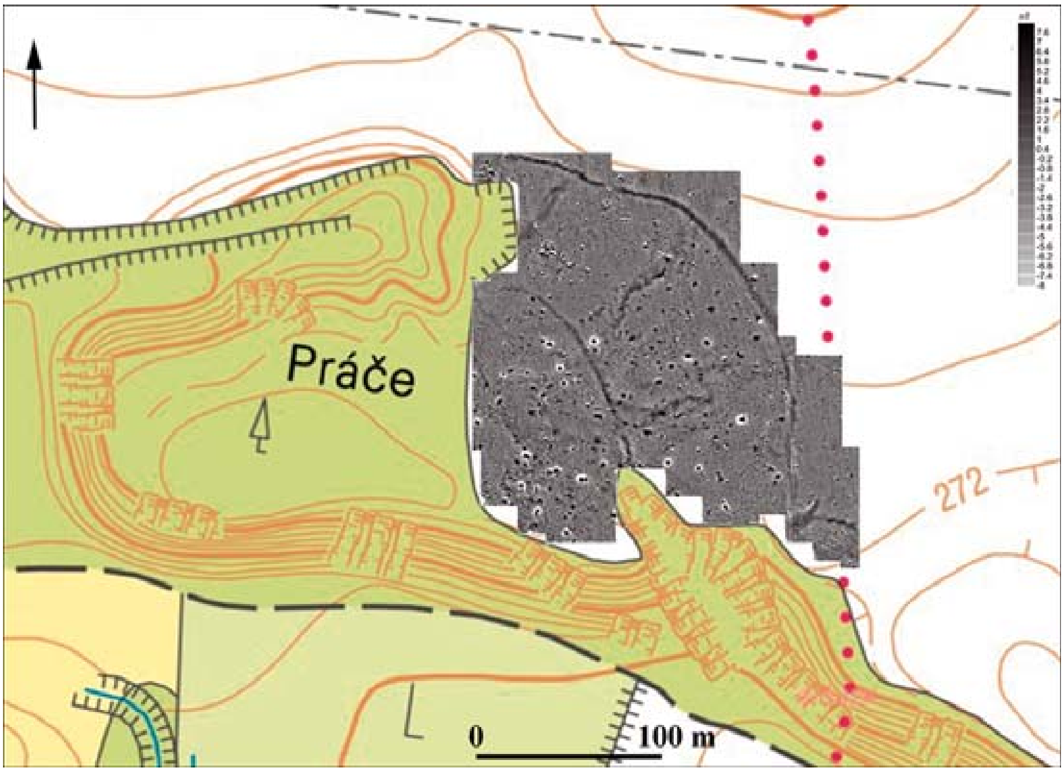

Figure 3: *Vraný, district Kladno. Combination of the results of the magnetometric survey with the segment of contour map (source: www.kontaminace.cenia.cz). Identification of two unknown settled outer baileys of the Early Medieval stronghold (surveyed area: approx. 3.1 ha; geophysical survey: Křivánek 2012).*

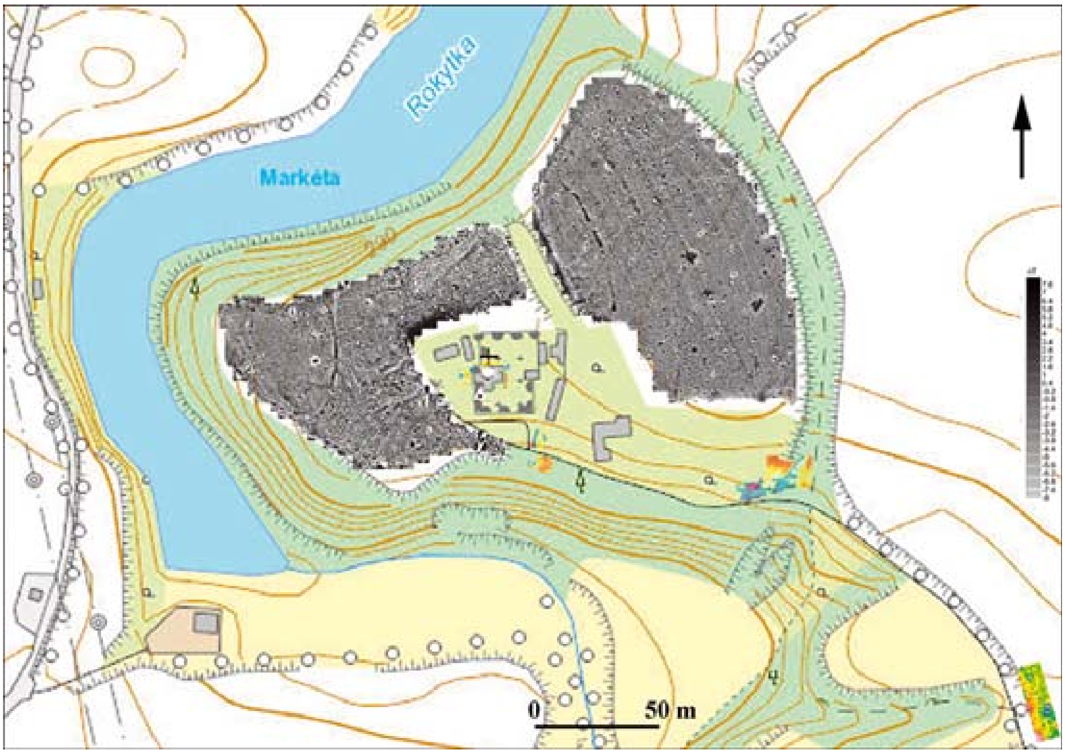

Figure 4: *Prague-Královice, district Prague 10. Combination of the results of the magnetometric and geoelectric resistivity survey with the segment of contour map (source: www.kontaminace.cenia.cz). Identification of unknown inner ploughed out divisions and settlement remains of the Early Medieval stronghold (total surveyed area: approximately 4.3 ha; geophysical survey: Křivánek 2011).*

HALA SULTAN TEKKE REVISITED – ARCHAEOLOGICAL GPR PROSPECTION ON CYPRUS 1980 AND 2010/12

I. Trinks, P. Fischer, K. Löcker, S. Flöry

1. INTRODUCTION

Hala Sultan Tekke is situated near the town of Larnaca in Cyprus, south of the Salt Lake, which is separated from the Mediterranean Sea by the airport. The site is named after the nearby Mosque of Umm Haram, which is an important Muslim shrine. Excavations here have been carried out by Swedish archaeologists since the 1970s. In 1980, one of the very first applications of a ground penetrating radar (GPR) system in European archaeology took place at Hala Sultan Tekke. That survey was carried out by Peter M. Fischer using a simple analogous radar system, resulting in data showing reflections from underground structures that later excavation confirmed as walls of Bronze Age structures. The considerable development of the GPR hardware, data processing and visualization methods over the past 30 years have opened new possibilities for the use of the GPR method in archaeological prospection. In 2010, a successful small-scale archaeological prospection survey was conducted at Hala Sultan Tekke to evaluate the potential of high-resolution archaeological prospection using modern GPR technology and methods. The results of this study guided the subsequent archaeological excavations of the New Swedish Cyprus Expedition, directed by Peter M. Fischer, resulting in very good agreement between the predicted and excavated structures. This survey was followed by a second, larger survey in 2012. We present the GPR surveys and the potential for non-invasive geophysical archaeological prospection at one of Cyprus' largest Bronze Age cities.

2. FIRST ARCHAEOLOGICAL PROSPECTION AT HALA SULTAN TEKKE

The archaeological site of Hala Sultan Tekke is located to the west of the Mosque of Umm Haram and south of Larnaca's Salt Lake, under gently rolling hills that are covered with crops during the growing season. After initial investigations in 1971, the late P. Åström carried out the first large-scale archaeological excavations at Hala Sultan Tekke in 1976. In the 12$^{\text{th}}$ century BC, at the end of the Late Bronze Age, Hala Sultan Tekke was intensively populated as demonstrated by Åström by his excavations (Åström, 1976-2007). Finds originating from the Levant and Egypt dominate the imported goods of high artistic value. In addition, a number of objects have been found with Cypro-Minoan, Hittite and Hieroglyphic inscriptions. Åström's excavations concentrated almost exclusively on the occupational levels of the 12$^{\text{th}}$ century BC. The town, which has been destroyed at least twice in the 12$^{\text{th}}$ century, according to Åström, experienced a brief revival in the Archaic, Classical and Hellenistic periods.

Following an invitation by Åström in August 1972, R.E. Linington, in collaboration with B. Zapicchi from the Fondazione Leirici Prospezioni Archeologiche of Rome, conducted a magnetic prospecting survey at Hala Sultan Tekke using a differential proton magnetometer. In 1978, a metal detector (C-Scope TR 400/500) was used by P.M. Fischer for archaeological prospection at Hala Sultan Tekke, covering some 2,000 square metres (Fischer, 1980, p.28). In 1979, Fischer carried out resistivity measurements with the goal of overcoming heat related problems observed during Linington's magnetic survey, and to compare the results with both the magnetic prospection results and the excavation results (Fischer, 1980, p.19). At the same time, Fischer tested an electro-magnetic Very Low Frequency Discriminative (VLF) detector and compared it against a Pulsed Induction and an Induction Balance detector (Fischer, 1980, p.33). The VLF-detector survey led to the discovery of one of the richest tombs in Cyprus, which was excavated the same year (the finds are on display in the Archaeological Museum in Nicosia). In 1980, Fischer conducted a soil conductivity meter survey at Hala Sultan Tekke using a "Pipe Seeker 5" instrument.

In July/August 1980, in a cooperation between Fischer and the Departments of Ancient Culture and Civilizations at the University of Gothenburg and Engineering Geology at Lund Institute of Technology, a GPR survey was performed at Hala Sultan Tekke using a GSSI Surface-Interface Radar (SIR) system (Figure 1). The goal was to trace buried archaeological structures in support of Åström's excavations (Fischer, 1980, p.48). The data was recorded on heat-sensitive paper. The soil at the survey site is generally dry and has high clay content. Both 400 and 900 MHz antennae were used, towed by hand at a slow walking speed along grid lines with 2 m spacing. Initially, tests conducted at locations where excavations had revealed underground walls showed clearly interpretable echoes, with the 400 MHz antenna being preferable to the 900 MHz antenna due to the strong absorption of the high-frequency signal. Some 5,000 square metres were surveyed, and significant echoes were marked directly on the ground. Of the twelve test trenches that were excavated as indicated by radar, eleven resulted in walls or blocks of stones to be found. In the case where no corresponding subsurface structure was found it is possible that a heap of soil near the survey line could have caused the reflection. While the deepest detected structure had a depth of 60 cm, it was assumed that the 400 MHz antenna had a maximum penetration depth of 2 m. It was concluded that GPR measurements were a valuable archaeological prospection method, partly due to the fact that results were available immediately in the field, and was superior to the magnetic and resistivity methods. A combination of wild-cat survey with more detailed survey along grid lines was suggested, noting the risk of failing to detect linear structures if the measurement is performed in the direction of the target structure. Scollar *et al.* (1990) published data images of these measurements, as well as of the corresponding structures, in order to illustrate one of the first uses of the GPR method in archaeology.

3. GPR SURVEYS AND EXCAVATIONS 2010 & 2012

After the premature death of Paul Åström in 2008, Fischer (University of Gothenburg) took over the direction of the New Swedish Cyprus Expedition in 2010. With permission to carry

Figure 1: *GPR survey at Hala Sultan Tekke in 1980.*

Figure 2: *View of the survey Area 6 with Larnaca Salt Lake and the Mosque of Umm Haram in the background.*

out a pre-excavation archaeological prospection survey followed by excavations proper for Area 6 and its surroundings (Figure 2) granted by director M. Hadjicosti from the Cypriot Department of Antiquities, a high-resolution GPR survey of the entire accessible area was conducted over the course of three days in 2010. With the support of P. Georgiou, a rectangular survey grid was marked on the ground of the survey area measuring approximately 40x47 m. Between the base lines running in east-west direction, parallel survey lines were fixed with 50 cm spacing for orientation in order to guarantee exact cross-line positioning of the GPR measurements. The ground conditions, signal penetration depth and system performance of the Sensors & Software NogginPlus 500 MHz antenna system were tested along several trial profiles. Low signal-to-noise ratio allowed the use of a trace stacking of eight instead of the standard fold of four, and to reduce the cross-line profile spacing to 12.5 cm with an in-line GPR trace spacing of 2.5 cm. The recording time window was set to 49 ns, corresponding an approximate maximum signal penetration depth of 2 to 2.5 m (assuming an average signal velocity of 8-10 cm/ns). Over the course of three days, the entire accessible survey area inside the fence was covered with 371 parallel GPR profiles, amounting to a total profile length of 18,855 m.

The GPR data were processed and analysed on spot. The 371 parallel GPR profiles were merged into a 3D data volume, which after time-to-depth conversion using a constant velocity of 10 cm/ns was cut into horizontal depth-slice images representing slices of approximately 10 cm thickness. The survey site was geo-referenced by S. Zervos from the Cypriot Department of Public Works using a Realtime-Kinematic GPS with centimetre accuracy.

Structures indicating architectural remains started to appear in the GPR depth-slice images at a depth of approximately 30 cm below the surface and were visible down to at least 100 cm depth (Figure 3). The most clearly expressed anomalies were concentrated in the south-western part of Area 6. There are, however, further rectangular structures, although not as distinct, in the central and eastern parts of Area 6. In the north-western part of the area traces of an earlier excavation can be seen in the data.

Two days after the end of the fieldwork the survey results were discussed with the director of the excavation, his assistant and the excavation architect. The location of the major structures observed in the GPR data were marked on the surface of Area 6 using pegs, and the placement of two excavation trench was decided on basis of the architectural structures visible in the data. The GPR survey led to the discovery of a large Late Cypriote complex in the southern part of Area 6, where no substantial structures were found during test soundings made in the 1970s. The expidition decided to open a 10×10 m square in the south-western corner of Area 6 where the GPR images had indicated fairly detailed, stone-built architecture. The GPR results were verified during the same year (2010) by the New Swedish Cyprus Expedition, which exposed a compound at least 25 m long, bordered to the north by a wall running roughly east-west, against which a number of rooms were built towards the south (Figure 4). Using the GPR data, it was possible to discern details such as openings in the walls and circular stone structures within the compound, all of which were verified within narrow margins during the course of the excavations in 2010.

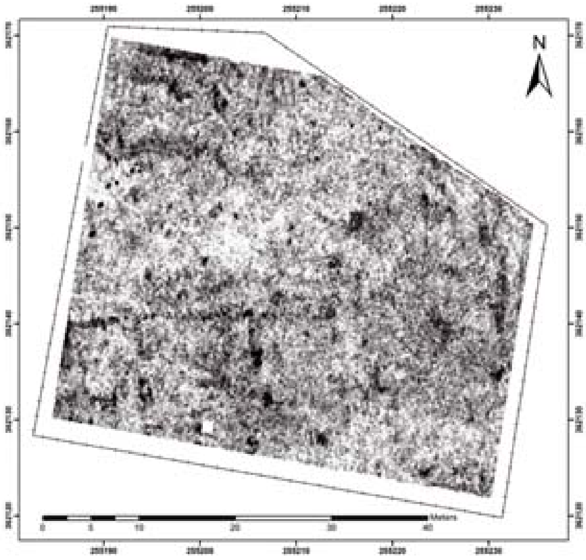

Figure 3: *GPR depth-slice showing wall structures in the SW part of the survey area.*

During the three seasons of 2010-2012, the expedition exposed architectural remains in the south-western part of Area 6, which are dominated by a stone wall running east-west, 0.8 m wide, and preserved to a height of approximately 0.7 m (Fischer, 2011). This wall corresponds to a linear GPR anomaly, at least 25 m long and stretching from the western fence towards the east. Division walls of 0.4-0.7 m width separate walled spaces

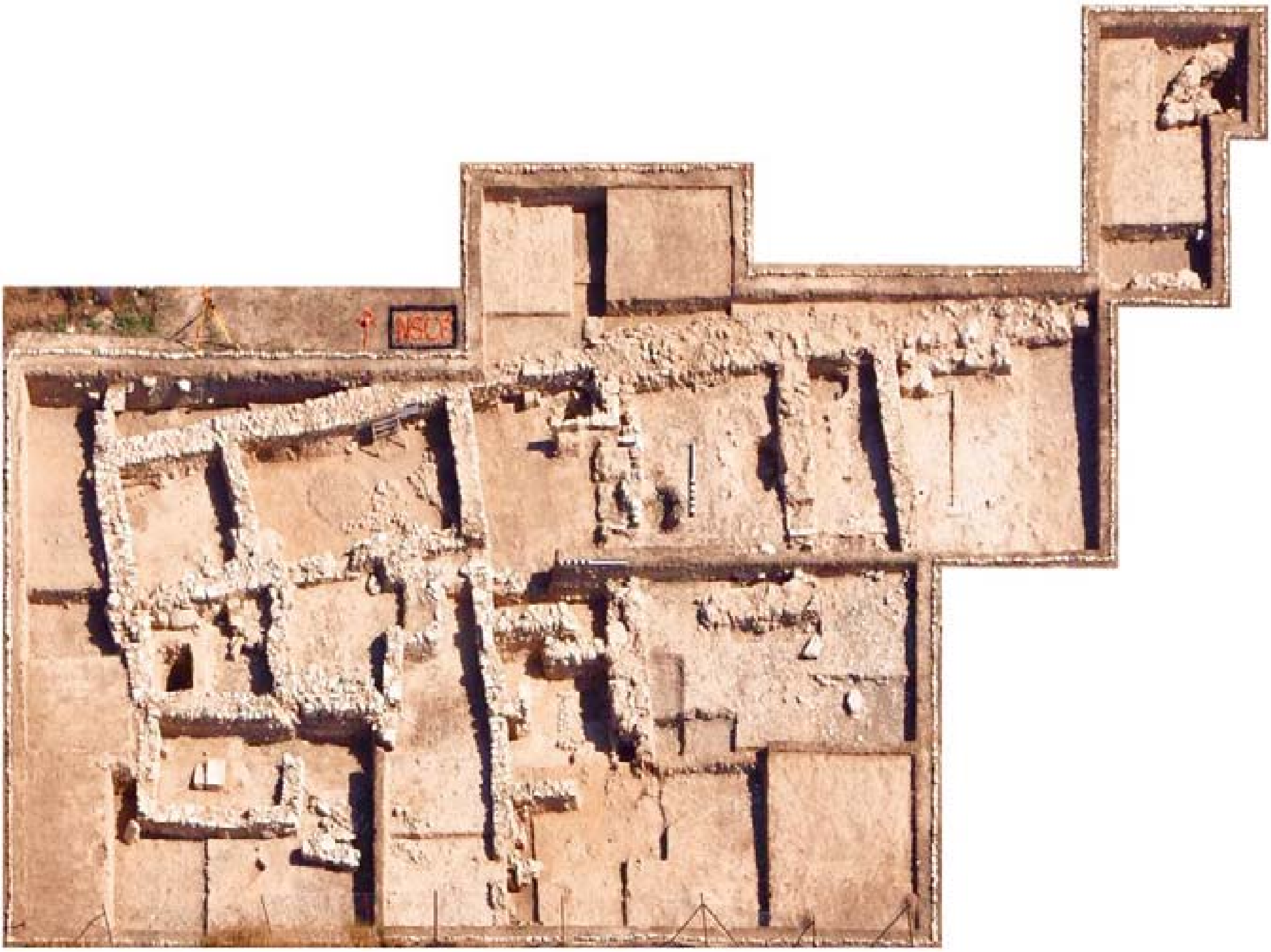

Figure 4: *Bronze Age complex excavated by the New Swedish Cyprus Expedition in 2010 and 2012.*

that extend to the south. Several ceramic vessels or parts thereof where discovered during the excavation, in particular a large krater with skilfully painted motifs – one of the most important pieces of Late Cypriot decorated pottery ever found, according to V. Karageorghis, the most eminent authority in Cypriot archaeology (pers. communication Nicosia May, 2012). In a second trench, placed in the eastern part of Area 6 where the GPR data had indicated a 1-2 m wide anomaly, a circular stone built structure of 1 m diameter, a grain silo, was found at circa 30 cm depth. At the bottom of this structure, an exquisite bull's head made of bronze was discovered.

In May 2012, an additional 10,000 square metres of area were successfully surveyed using GPR measurements with 25 cm crossline spacing to the west and south of Area 6. The aim of this survey is to guide further targeted excavations, and to serve as test data supporting a proposal for the large-scale archaeological prospection of the entire site. It is proposed that an area comprising some 60 ha, covering the entire Bronze Age settlement south-west of Larnaca salt lake, be surveyed using motorized magnetic and GPR prospection.

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DUGGLEBY HOWE: FROM PROSPECTION TO DIGITAL STRATIGRAPHIC DOCUMENTATION

E. Nau, W. Neubauer, A. Gibson, M. Kucera, P. Schneidhofer, R. Totschnig

The site of Duggleby Howe, located in North Yorkshire, United Kingdom, comprises a large central burial mound, measuring 40 m in diameter and up to 6 m in height, known to be one of the largest round barrows in Britain. Two ditches with a diameter of 360 to 380 m surround the mound. Whereas little was known about the ditch system, the mound itself has been subject to investigations (Gibson and Bayliss, 2010) which focused on the stratigraphy and chronology of the mound complex. The results proved that Duggleby Howe was not a single-phased Neolithic round barrow, but rather had a complex burial and constructional sequence consisting of a central pit burial (35^{th} century cal BC) followed by the construction of a small primary mound (29^{th} century cal BC). The final phase is marked by a layer of large chalk rubble (24^{th} century cal BC) topping the mound and resulting in its present shape and height.

The surrounding ditches were known from crop-marks in aerial photographs. Recent survey data, however, showed that parts of the inner ditch survived as a shallow earthwork. The correlation of data sets showed a difference in shape and size of the ditches. Further research, therefore, was necessary to gain an accurate map of the entire site and to place the ditches within the chronological sequence of the site.

In 2009, a joint prospection and excavation project at Duggleby Howe was conducted by the University of Bradford and the Vienna Institute for Archaeological Science (VIAS), University of Vienna. The main purpose of the project was to investigate the structure of the ditch system by geophysical prospection and partial excavation in order to gain detailed information on construction and dating.

The following three central research objectives were carried out by the VIAS team:

- Geophysical prospection of the study area using high resolution magnetometry and ground penetrating radar
- 3D single context recording of the entire excavation process, followed by GIS-based data post-processing
- In-situ magnetic susceptibility measurements for enhancing feature recognition

The project was used as a pilot study to test the stratigraphic documentation method as developed in previous years by VIAS (Neubauer, 2007).

The complete site of Duggleby Howe had been previously surveyed using a Geoscan FM256 Fluxgate magnetometer with a spatial resolution of 1.0 *times* 0.25 m. This data was reprocessed and re-interpreted by VIAS prior to the excavation project. The reprocessing of the raw data showed low resolution and some errors in the initial data set. Due to these problems, it was decided to repeat the magnetic survey on a selected area. Therefore, a Förster gradiometer array, with four sensors (Ferex CON650) mounted on a non-magnetic sensor cart was used. A total area of about 1.4 ha was surveyed with a resolution of 0.5×0.16 m – higher than the survey of 2008. Data processing included resampling on a regular grid of 0.16×0.16 m and visualization with various dynamic ranges. Optimal data representation selected for subsequent archaeological interpretation was found within the interval [-3.0/4.0] nT and visualized as a greyscale image.

The same area was also covered with a high-resolution GPR survey in order to provide 3D information on the expected ditches and pits – a survey technique not used before at Duggleby Howe. The geological background promised suitable results, and, together with the higher resolution, was expected to provide a clear depiction of the expected features. The GPR survey was carried out with a Sensors&Software PulseEKKO Pro device with a 250 MHz antenna mounted on a SmartCart system. An area of 1.37 ha was surveyed with a spatial resolution of 0.5×0.05 m. Data processing was carried out with the software APradar (ZAMG ArcheoProspections®). The data was transformed into a regular 3D data block representing summarized amplitudes of reflectivity. A mean propagation velocity of the electromagnetic wave was defined by adjustment of reflection hyperbolas and used to derive depth information to be integrated in the 3D data block. The data was visualized as georeferenced depth slices – greyscale representations of the summarized reflectivity – at depth intervals of 5 and 10 cm (Figure 1). In parallel to the geophysical survey, the area under investigation was scanned with a terrestrial 3D laser scanner to produce a high resolution digital terrain model.

The magnetogram (Figure 1) shows a massive scatter of permanently magnetized iron objects, most probably displaying iron debris in the ploughed topsoil. Traces of ploughing are clearly visible in the surveyed area. Linear anomalies in the northern part indicate a former field system with 16 – 18 m wide plots. The main archaeologically relevant features are two more or less concentric ditches as well as large pits and complex pit-like features.

The outer of the two ditches is 2.5 – 3.0 m wide and shows a more highly magnetized fill than the inner ditch. Discontinuities in the ditch, which might be interpreted as an entrance into the interior, are missing. Outside this ditch, a 17×10 and a 7×13 m wide rectangular complex of sunken features can be observed. These features seem to be partly superimposed by larger pits.

The inner ditch is 5.5 – 6 m wide and shows a fill with lower magnetization. This indicates different filling processes for the inner and the outer ditch. The inner ditch shows an irregular shape differentiated by distinct segments with a length of 15 – 20 m. The ditch is interrupted in the southern and in northern part and could be interpreted as a causewayed enclosure. A large, ca. 6.5 m wide pit is partly superimposed on the inner ditch in the interior of the enclosure.

The results from the GPR survey show clear plough marks down to 0.4 m depth. Below this depth, ditches and pits already known from the magnetic survey become visible. These structures display low reflectivity indicating silty or clayey fills of actual archaeological features. The lateral definition of the detected features shows better than in the magnetic survey. The ir-

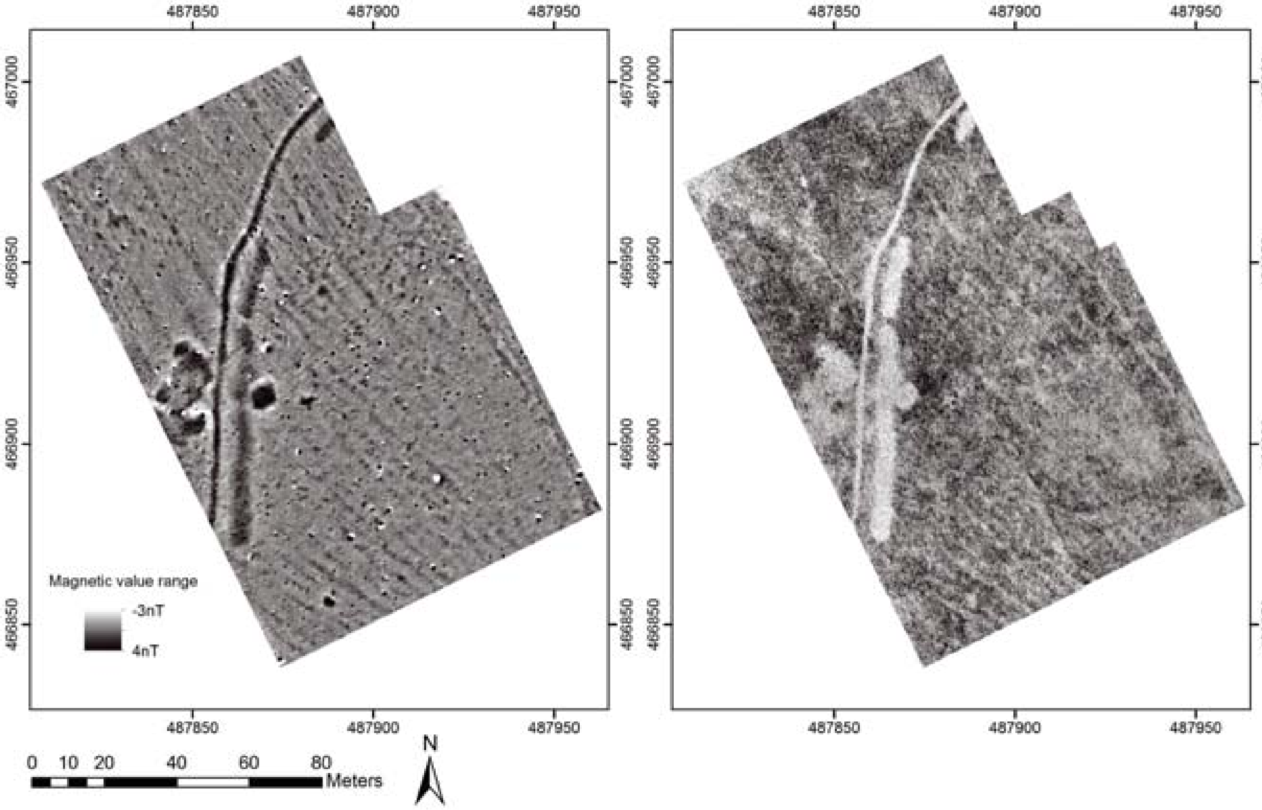

Figure 1: *Left: Magnetogram Right: GPR depth-slice of approximately 0.8 – 0.9 m depth.*

regular outline of the ditch as derived from the magnetic results could not be verified by GPR, therefore it most likely represents different magnetizations of the fills. This initial test survey using GPR demonstrated the high potential of the method at this type of site and shows a clear definition of features cut into the bedrock. Using higher spatial resolution would lead in provide even better results.

Both magnetic and GPR data were processed directly in the field providing preliminary results to be used a basis for the actual trench location, which aimed to include both ditches. For a better understanding of the measured magnetic anomalies, the excavation was accompanied by in-situ magnetic susceptibility measurements (Figure 2). For magnetic susceptibility measurements, a Bartington MS2 magnetic susceptibility meter was used. The in-situ measurements of the entire trench area before and after removal of the topsoil were carried out using a MS2D loop sensor. The apparent magnetic susceptibility of both surface areas was measured in a 0.5 m grid with a sensitivity of 1 E-5 SI. Trench profiles were measured in a 0.25 m grid to avoid data scatter due to local non-homogenous stratification. The measured values were converted into greyscale images and geo-referenced for direct comparison with the prospection and excavation results.

In recent years, VIAS developed a digital 3D single context/surface recording process for archaeological excavations, in both theory and practice (Neubauer, 2007). This standardized workflow is divided into successive steps to be repeated for every excavated stratigraphical unit. Every single unit – surface or deposit – is given a unique number and documented by its boundary polygon, its topography as well as its texture. Terrestrial 3D laser scanners combined with digital imagery are effective tools for the single-surface mapping and provide the ability to reconstruct the excavated volumes and specific surfaces in 3D space.

The entire excavation process at Duggleby Howe was monitored by taking scans and images from 58 different scanner positions using a Riegl LMS Z420i laser scanner with a Canon EOS 450 digital camera mounted on top of the scanner. The photo series generated directly by the scanner proved to be difficult due to rapidly changing lighting conditions. Therefore, external vertical photographs using a Sony DSC-R1 digital camera were taken in order to provide additional imagery for the production of orthophotos based on the DTM derived from laser scanning.

Post-processing of the recorded 3D laser scanner data was carried out using the companion software RiSCAN PRO, for further analysis the resulting datasets were integrated into a GIS project.

The original point cloud data was triangulated, without any prior point decimation, using the RiSCAN PRO function polar triangulation followed by an extraction of the outer surface. This led to good results for the excavated surface with many small stones and rough bedrock. The full information content of the images was maintained by applying the image information as a texture to the triangulated surface. Accurately textured surfaces provided the basis for 3D measurements with resolutions and accuracy exceeding the resolution of the original scan data (Figure 3).

The resulting meshes were used for a direct digitalisation of the boundary polygons of each excavated deposit. Meshed data of two sequential scans, containing top and bottom surface of a single deposit, were placed on top of each other resulting in a visible boundary of the actual excavated deposit. This bound-

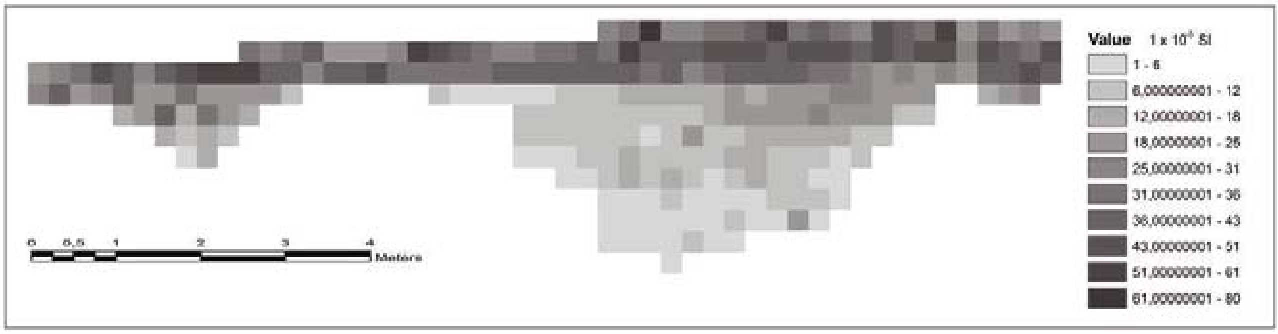

Figure 2: *North section of both ditches, apparent magnetic susceptibility using the Bartington MS2D sensor, cellsize 0.25 m.*

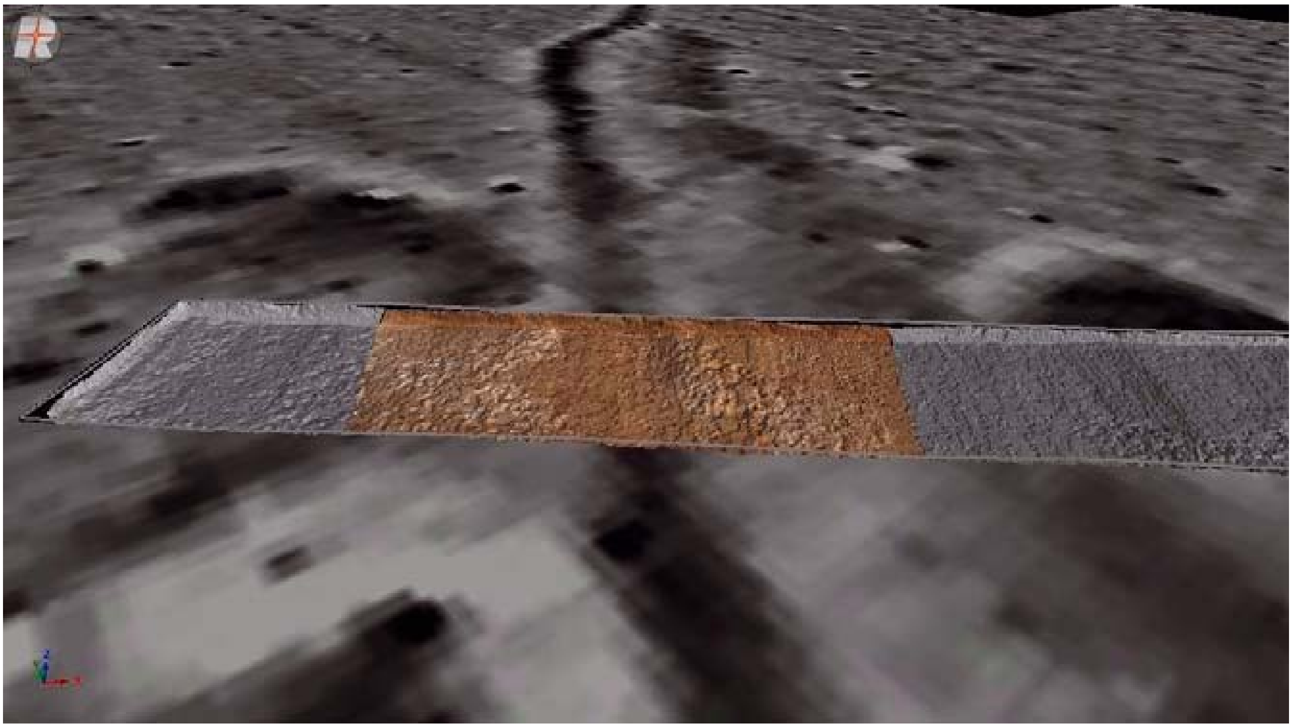

Figure 3: *Combined 3D visualization of the magnetogram used to texture the topography model and the textured surface of the trench after removal of topsoil.*

ary was digitized overlying the topographic information. This new procedure led to a highly accurate boundary polygon of the stratigraphic unit, probably far more accurate than boundary polygons recorded during the excavation using a total station. These polygon data were used to clip the relevant top and bottom surfaces from the single scans to be used for the following reconstruction of single 3D volumes of each deposit.

The complete 3D record of all single surfaces provides the basis for the automatic generation of any desired sectional view, defined by a plane placed through the dataset (Figure 4). High-resolution orthophotographs of the single surfaces as well as of sections were produced using the triangulated surfaces and the texture information from either the camera mounted on top of the scanner or the external photographs. The result led to geo-referenced images as a basis for further analysis.

Further excavation results supported the results from both magnetic and electromagnetic prospection. Both ditches show different processes of refilling, most likely explained by their different chronological settings. The inner ditch was constructed between 25th and 23rd century cal BC, whereas the outer ditch produced a Late Roman date from bone in its secondary fill. This date and the shape of the outer ditch with its connected linear features suggest that it represents the remains of a Roman field system, which respected the Neolithic monument.

Due to the volume calculations of the excavated Neolithic ditch and the prospection data, it was possible to estimate the extracted volume of the complete Neolithic ditch. The result correlates well with the volume of the chalk capping of the central mound. The complete range of acquired data could be used for archaeological documentation purposes only. However, further processing could provide virtual reconstructions and lead to products generating a wider public awareness of the monument.

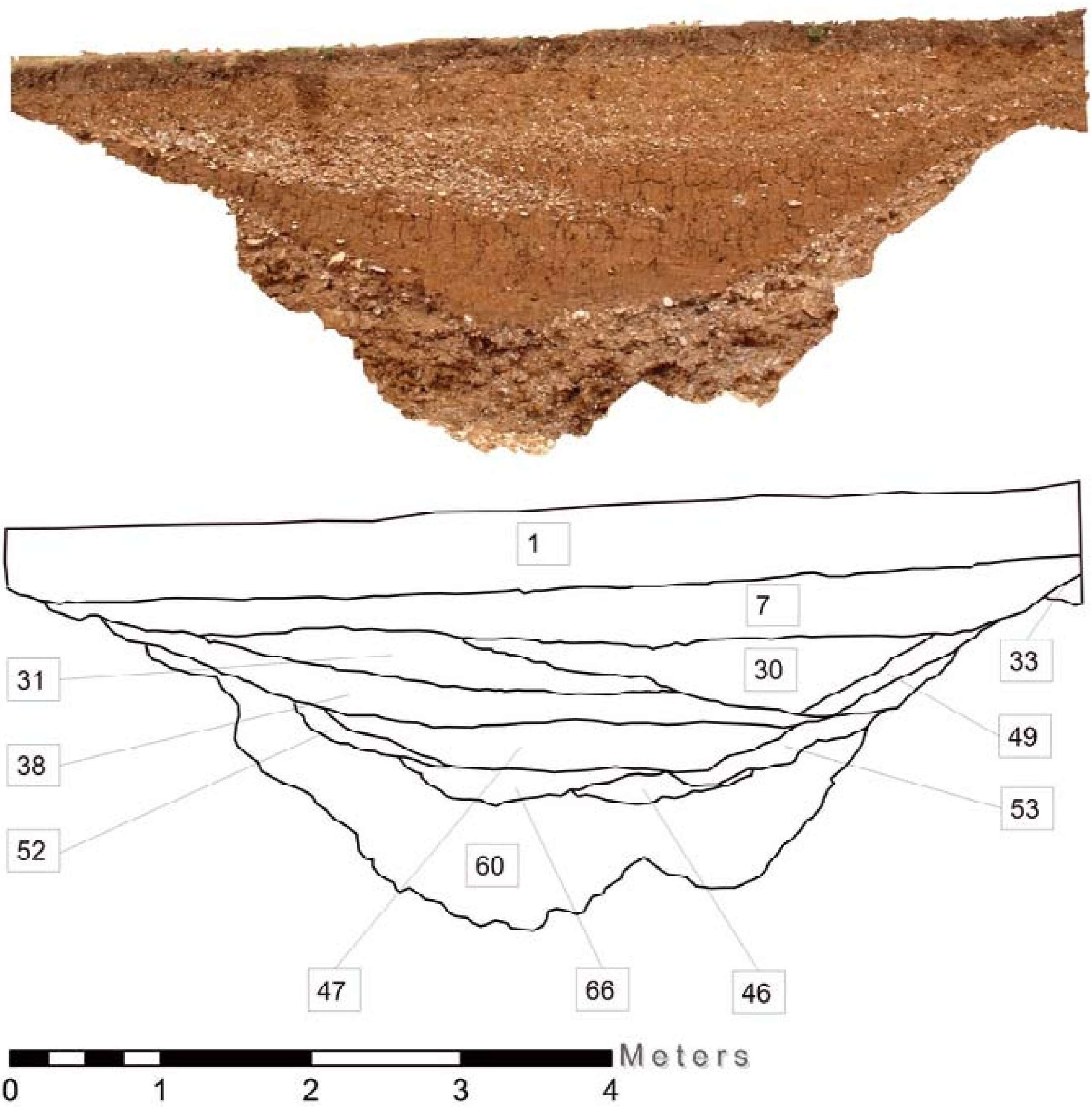

Figure 4: *North section of the Neolithic ditch, orthophotograph and deposit boundaries derived from laser scanning data.*

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REDISCOVERING A CISTERCIAN CONVENT: FIELD WORK TRAINING OF HTW BERLIN STUDENTS ON MARIENWERDER PENINSULA (SEEHAUSEN, UCKERMARK, GERMANY)

C. Meyer, F. Biermann, T. Schenk

From the beginning of the new master course "Geoarchaeology and field archaeology" at the HTW Berlin (University of Applied Sciences) in 2010, the concept for the module "Archaeological prospection" has been strictly practise-oriented. The module includes both lectures on the physical bases of geophysical prospection methods and their application in archaeology and practical fieldwork at archaeological sites in the areas around Berlin.

For the practical training in the 2011 and 2012 summer semesters, an ideally suited archaeological site was chosen: the Marienwerder peninsula at the lake Oberueckersee near Prenzlau in the Uckermark district of Brandenburg. From historical sources and investigations during the 1980s, this area is known as the location of a convent of Cistercian nuns, founded before 1250 AD. The convent existed until its dissolution in the middle of the 16th century. Remains of the buildings had been recognisable until the end of 18th century. Since then, however, the exact situation of the convent buildings remained unclear until the beginning of the field course in June 2011.

In two short field campaigns, the students of field archaeology tried out magnetic, electric and GPR measurements under the guidance of experienced geophysicists and archaeologists from Eastern Atlas, HTW Berlin and Göttingen University. The magnetic data, covering an area of approximately 3 hectares, already showed very clearly the typical ground plan of a Cistercian convent with many construction details (Figure 1). Additionally, GPR and geoelectric measurements were carried out to highlight construction details and to determine the depth of preserved foundations. Data processing and interpretation were undertaken collectively.

Subsequent excavations under the direction of Felix Biermann largely confirmed the results of geophysical prospection and revealed more interesting details of the construction history of the convent buildings.

The investigation of the Marienwerder convent is an extraordinary example for the successful pooling of interests in archaeological works:

- Practical training combined with substantiated classes in theory of prospection methods can bring forward the sensible application of those investigation methods in archaeological practice.
- The scientific use of both prospection and excavation results has significantly contributed to medieval and modern history, since the location of the convent's remains fills a gap in the regional history.
- The future project of a meaningful visualisation of the convent ground plan in the landscape can stimulate tourism in the microregion of the Uecker lakes, a part of rural Brandenburg in social and economic transition.

Figure 1: *On-site examination of magnetic prospection data.*

MAGNETIC PROSPECTION ON THE ARCHAEOLOGICAL SITE OF QASR SHEMAMOK (AUTONOMOUS REGION OF KURDISTAN, IRAK): FIRST RESULTS

P. Kessouri, Q. Vital

1. CONTEXT – SITE PRESENTATION

Located in the autonomous region of Kurdistan in Irak, near the city of Erbil, the archaeological site of Qasr Shemamok is particularly known for its role in the Assyrian empire system. Indeed, its location half way between the Tigris River and the Assyrian capital city of Calah/Nimrud (Figure 1) suggests that the city could have played a key role during the Assyrian period. Since the beginning of archaeological research in north Mesopotamia, the antic city was identified under the name of "Kakzu". After the discovery of cuneiform inscriptions on bricks, its name was transformed into "Kilizi". Those inscriptions also refer to the erection of a double urban enclosure system during the reign of the Assyrian king Sennacherib (end of the 8^{th} century BP). Although the city probably has a more ancient origin dating back to the Chalcolithic period, its maximal expansion was during the medio- and neo-Assyrian empire. The city was then an important urban centre, a stopover between the capital cities of the Tigris region and those close to Erbil/Arbalès, on the road leading to the Zagros and the Iranian world.

Stretched over 70 hectares, and including a tell (Figure 1), a citadel and a lower town, the archaeological site of Qasr Shemamok is located 25 km south-west from the city centre of Erbil, near the villages of Tarjan and Sa'adwa. As the industrial suburbs of Erbil are growing exponentially with time, it is important to precisely define the total area dedicated to the antic city in order to preserve it for further research. Geophysical prospection is one of the tools used to reach this goal. So far, two missions of 10 days each were led in October 2011 and more recently, from 14 to 24 October 2012.

For a first global vision of the archaeological site, a magnetic survey was planned, using a Magmapper G-858 (GEOMETRICS) magnetometer. The pseudo-gradient configuration was chosen in order to reduce the effects of the natural diurnal variations of the magnetic field and to enhance the superficial, low (a dozen nanotesla) magnetic variations. The area was divided into squares of 50 m across. The measurements were acquired every 0.1 seconds on profiles one meter apart. Two transects north-south and east-west were chosen to explore the geographical limits of the lower town. As the east-west transect showed the most promising results, it was decided to enlarge it north and south. Moreover, if the tell is the only area of the archaeological site that has never been cultivated or ploughed, it is also the one that suffered the most from bombing attacks: craters are still visible on it. Tests were led on three square areas at the top of the mound in order to measure the magnetic field variations and check the ability of the magnetometer to detect features in this particular area. During the two geophysical missions in 2011 and 2012, almost 98,300 m^2 were prospected.

2. FIRST RESULTS

As the final prospection only ended on the 24^{th} of October, only the most important features were identified and interpreted. The work is still in progress, and a complete study of the data will be carried out in collaboration with the archaeologists in the next months. Meanwhile, some preliminary observations can be made (Figure 2).

Concerning the data acquired on the tell, the measurements are incomplete because of the presence of Islamic burials and deep craters. In the "clean" areas, some linear magnetic features can be observed. They have a preferential direction north-east – south-west. This direction is in good accordance with the direction of the neo-Assyrian walls observed in the excavated area. The magnetic variations observed on tell are higher than those measured in the lower town. Further post-processing must be applied to the maps in order to clearly distinguish the different features.

The north-south transect was not very well suited for a magnetic survey, because the soils were completely ploughed and an irrigation system was constructed. Moreover, measurements in the southeast area were disturbed by some contact malfunctions of the magnetometer and the proximity of an electrical line. The presence of the village of Sa'adawa made measurements further south impossible. The surrounding wall of the lower city could therefore not be reached. These simultaneous perturbations make it difficult to interpret the maps. Further post-processing must be applied to the data sets in order to discriminate the archaeological features.

The east-west transect offers much more promising results that will be roughly developed in the next session.

3. DETAILS OF THE WESTERN TRANSECT

A clear distinction can be made between the three square areas that are on the far west side and the rest of the maps. After a stronger linear magnetic anomaly oriented north-south (1), the magnetic pseudo-gradient becomes almost constant and close to 0 nT/m. In comparison, many magnetic anomalies are observed on the eastern part of this linear feature. The feature (1) is interpreted as the enclosure of the lower town. Its localization also corroborate the topographical observations: the altitude is becoming lower and constant to the west of the linear anomaly. Two disruptions (1') are observed in the layout of the linear anomaly (1). They can be interpreted as the presence of a city gate in the enclosure wall.

Another finer linear anomaly is visible on (2). It orientation varies from NE-SW to NW-SE. According to the archaeologists, this feature can be interpreted as part of the drainage system of the Assyrian city. Indeed, the Assyrian used large pipes built of fired bricks. The linear feature (3), presenting almost parallel direction with the anomaly (2) is also interpreted as an Assyrian drainage pipe. These linear anomalies are linked to circular

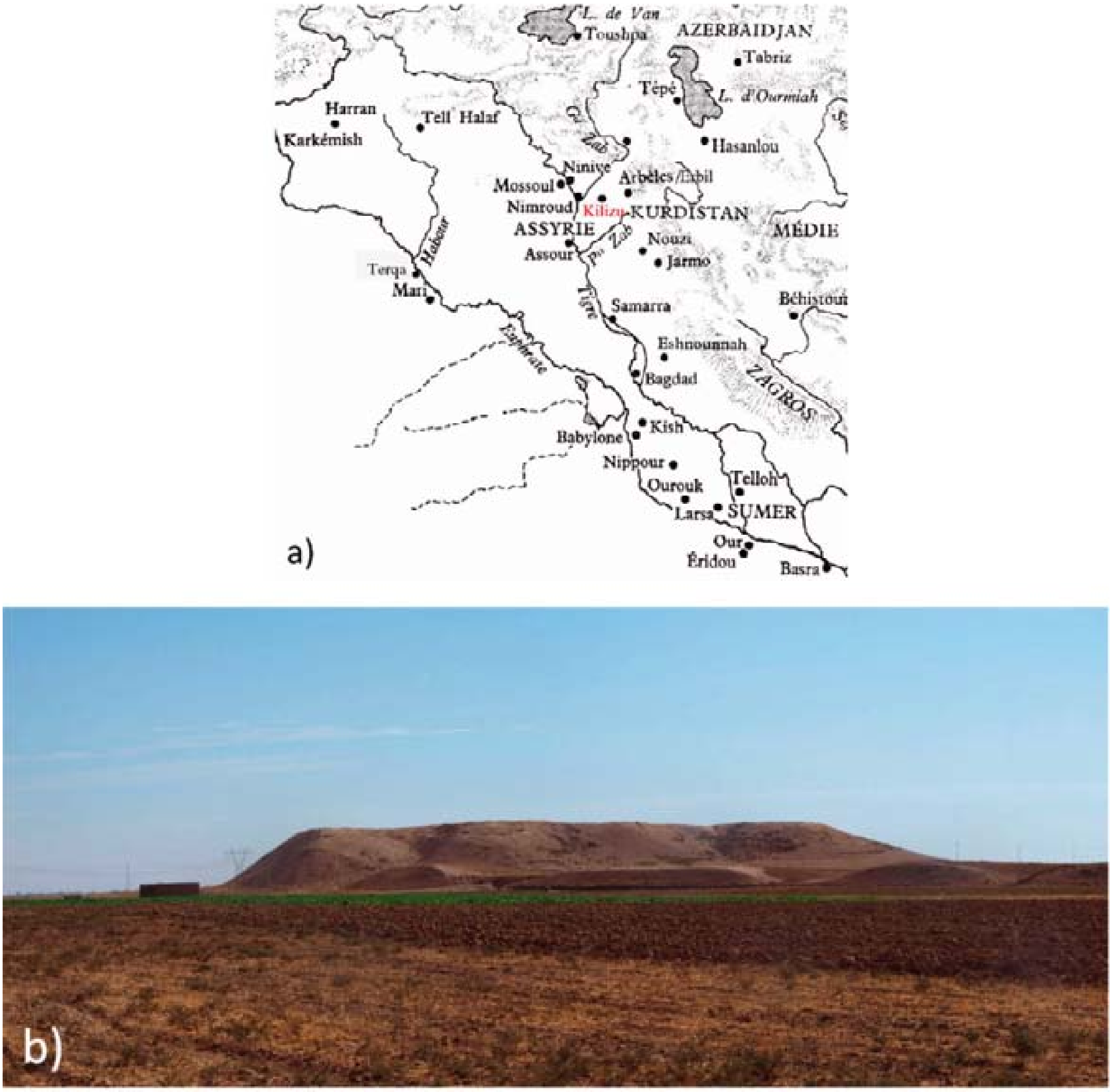

Figure 1: *a) Map of Mesopotamia, localisation of Qasr Shemamok /Kilizu (Rouault et Masetti-Rouault, 2012); b) Qasr Shemamok tell, western view.*

features (2') and (3') that have not yet been explained. The linear anomaly (4) oriented north-south could also be part of the same drainage system. Some circular magnetic features are also observed close to this anomaly.

Many other smaller linear anomalies cover all the magnetic maps inside the lower city enclosure (1). On the other hand, some areas, like (5), seem to have been less occupied. A systematic drawing of all of those will be undertaken to establish a first map of the lower city districts.

Even if the vertical pseudo-gradient is close to 0 nT/m on the west part of the city wall, some anomalies can be distinguished in the area (6), showing the presence of a building outside the city wall. This observation was correlated by surface observation: many neo-assyrian pottery fragments were observed in the area (6). The east-west transect presents very promising initial results. The identification and interpretation of the different anomalies observed will be in collaboration with archaeologists during the next months to establish a first insight of the organization of the lower town during the Assyrian period.

4. CONCLUSIONS AND PROSPECTS

The first data sets acquired show promising results. Many features that can be associated with archaeological remains have been detected. On the top of the tell, the results of the magnetic prospection must be compared to the observations made during

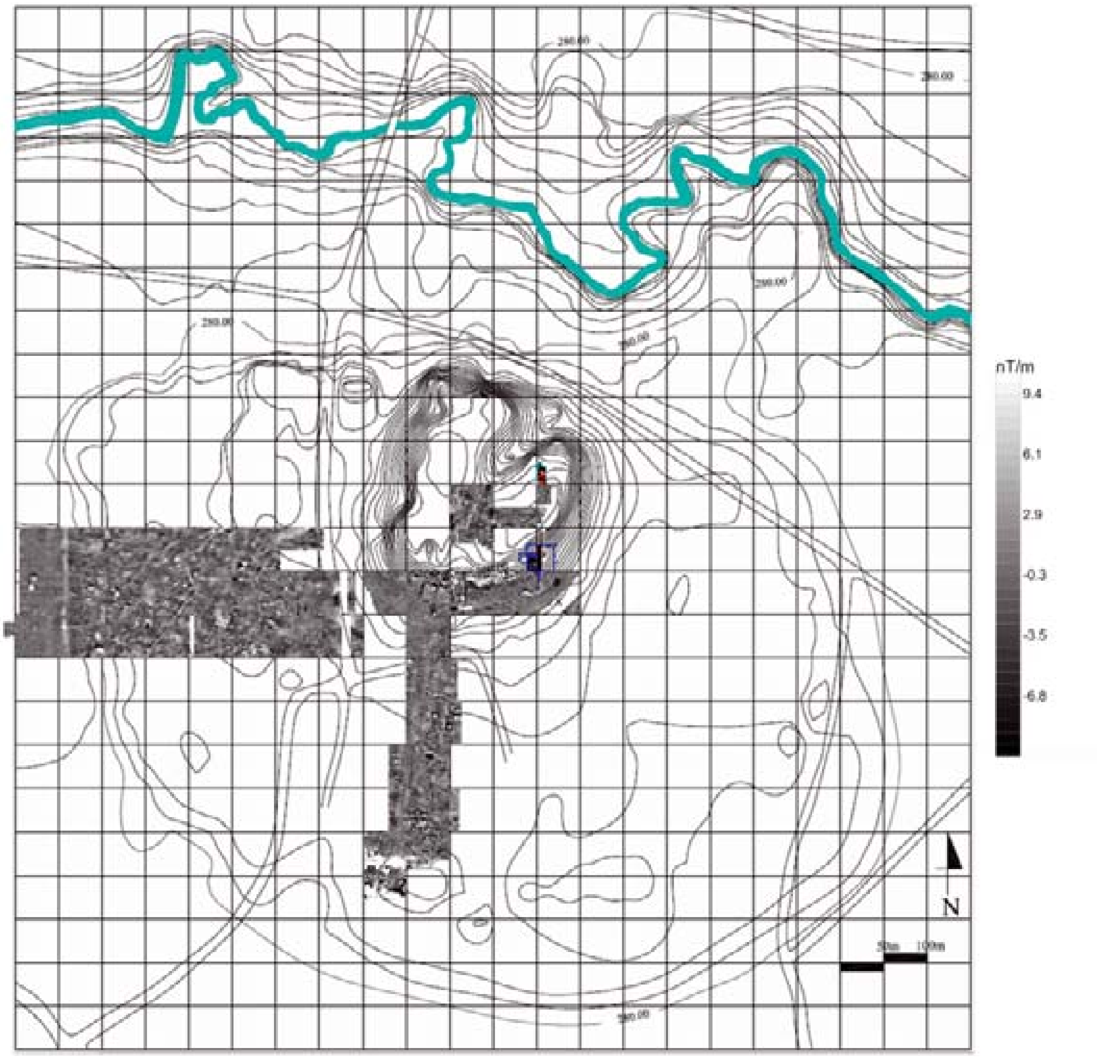

Figure 2: *Results of the magnetic prospection (vertical gradient configuration) on the Qasr Shemamok archeological site in 2011 and 2012 and topographic map associated.*

the excavations in order to identify the anomalies corresponding to Assyrian constructions. The magnetic prospection led on the lower city is even more interesting. As the area of the lower town is huge, the magnetic survey will be one of the ways to understand its organization.

The magnetic survey will be part of a larger geophysical investigation program of the Qasr Shemamok archaeological site. Indeed, one of the goals of the study of this site is to understand the mutual influence of an Assyrian city and its environment. With the combined help of geophysical, geomorphological and hydrological methods, efforts will be made to understand the past environment of the site. Some electromagnetic measurements are therefore planned for future campaigns.

ACKNOWLEDGMENT

We would like to thank O. Rouault, professor of the ancient Near East archaeology (Lyon2) and M.G. Masetti-Rouault, director at the Ecole Pratique des Hautes Etudes (Sorbonne, Paris, UMR 8167 Orient et Méditerranée) for letting us join the Qasr Shemamok project. We also want to thank all the researchers involved in this project and the Kurdish authorities for their help.

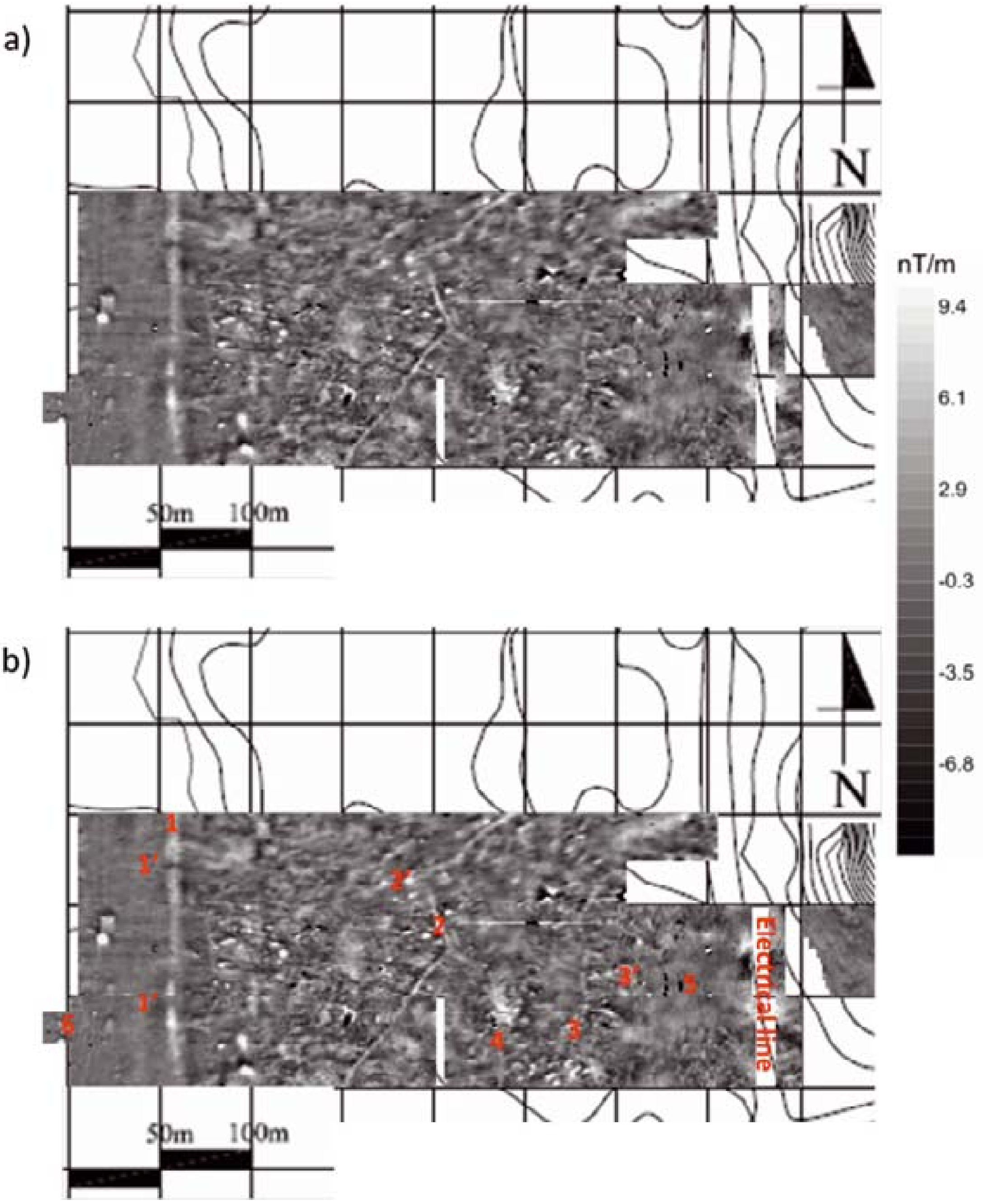

Figure 3: *a) Results of the magnetic prospection (vertical gradient configuration) on the Qasr Shemamok archaeological site – Western transect. b) Interpretation of the maps in terms of archaeological features.*

TO THE PROBLEM OF SETTLEMENT STRUCTURE IDENTIFICATION IN MAGNETIC DATA

P. Milo

In the past few years, many geophysical measurements focusing on early medieval settlement sites have been conducted in south-eastern Moravia (Czech Republic). Based on the results of these surveys, we can often address questions about the extent and internal structure of settlements, the density and character of building development, and sometimes about the specific functional and chronological classification of individual features. In some cases, however, the results of geophysical measurements are quite disputable and can differ considerably from the actual archaeological finds and features. One of these study areas is the location Kostice – Zadní hrúd 1, a multi-cultural settlement dominated by early medieval features. Magnetic survey, which was conducted here prior to intended archaeological excavation, was not able to locate exactly where individual settlement features were situated. Before and in the course of archaeological excavation, therefore, further survey activities were performed together with comparative analysis of data from aerial survey, field walking, magnetic and GPR survey and measurements of magnetic susceptibility in exposed archaeological contexts.

The settlement extends on a sand dune that protrudes slightly from the floodplain of the river Dyje. Aerial photos exhibit many cropmarks on the site, which can be interpreted as structures of archaeological origin. Archaeological excavation conducted in 2009 – 2011 have demonstrated that these structures are settlement features associated with prehistoric and medieval occupation and land-use (Dresler *et al.*, 2010, 2011).

The first magnetic measurements on the site took place in the years 2007 and 2009 (Figure 1). The whole settlement area and its adjacent neighbourhood were examined using a caesium magnetometer. The surveyed area covered approximately 56 000 m^2. Subsequently, the area to the east and south of the settlement was examined in 2010 using a fluxgate magnetometer. These measurements covered approximately 24 000 m^2. The aim of magnetic survey was to provide basic information on the type of archaeological features, density of building development and extent of the inhabited area. The information obtained was intended to be used in planning archaeological excavations. The magnetic survey, however, has only made a small contribution to detailed knowledge of the site. It already became apparent at the beginning of measurements that individual features could not be located and identified exactly. Magnetic anomalies caused by the presence of archaeological features show low magnetic values here, and are difficult to identify. In the resulting magnetogram, we can observe numerous positive anomalies that can be interpreted as settlement features, but these represent only a part of the overall number of features on the site.

The magnetogram is dominated by tiny strongly magnetic dipoles, which are attributable to metal objects of various origins (Figure 1). The largest concentration of them can be observed in the area of the sand dune; that is, in the settlement area. In lower altitudes, which are also less densely inhabited, zones, the number of magnetic dipoles is much lower. Some of them represent recent waste, which got to the site primarily through fertilisation of fields. Others, however, surely belong to objects of medieval origin. There are also large positive magnetic bands, which can be attributed to pedo-geological structures. The talk is of terrain depressions situated below the present-day ground surface and filled with magnetic material.

A comparison between the magnetogram from the archaeologically examined area and the results of field survey has shown that only about 20% of all features are visible in geophysical data (Figure 2). There can be several reasons why some features have shown themselves on the magnetogram, whereas others have not. In features which are smaller than the distance between measured sections we can assume that they were either situated in between two sections, or only partially recorded. Shallow pits, those with depths distinctly smaller than the thickness of the topsoil, may also have evaded detection. The topsoil itself is magnetically positive. Shallow recession into the subsoil layer thus does not imply any distinct increase in magnetic values. Features whose backfills are saturated with material from their crumbling walls, in our case with pure sand, need not necessarily create anomalies, and in this case would not be distinguishable from the subsoil. However, the magnetic survey also missed features with backfills rich in dark ashy layers and organic material. On the magnetogram, on the other hand, we can observe numerous anomalies, which were not identified during archaeological excavations. A correct interpretation of the magnetogram would thus be very problematic without being proved by archaeological excavations.

There are several possible explanations for these discrepancies between magnetic and excavation results. Magnetic survey conducted over a selected segment of the area of archaeological excavations after the removal of topsoil was able to locate virtually all features (except the extremely shallow features and postholes; see Figure 4). One of the reasons why ordinary survey provides unsatisfactory results can therefore be explained: a strongly positive magnetic topsoil layer overlying the settlement features masks the results. This conclusion was supported by measurements of magnetic susceptibility on sections of the archaeologically excavated area. Whereas the underlying sand layer has yielded values from about 0 to 20 $\times$ 10^{-5} SI units, the values of the overlying layer (topsoil) have varied between about 30 and 60 $\times$ 10^{-5} SI units. Values similar to those of the topsoil, mostly 30 – 50 $\times$ 10^{-5} SI units, were also obtained from the backfills of examined features. The thickness of the topsoil layer was approximately 30 – 40 cm. Many features were sunk into the subsoil by 30 cm or less. The reason why these features are invisible on the resulting magnetograms is that there is almost no difference in values of magnetic susceptibility and only a small difference in thickness of the layer of positive magnetic material compared to surroundings.

The measurements of magnetic susceptibility on sections of several deep features have indicated a second reason for their invisibility for magnetic survey. It turns out that their backfills are mixed with large amounts of non-magnetic sand. On the north-

Figure 1: *Kostice – Zadní hrúd 1. Magnetogram, caesium magnetometer SM-5 Navmag Scintrex, raster 0.10 m/1.00 m and fluxgate-gradiometer Foerster Ferex 4.032 DLG, raster 0.25 m/0.50 m, dynamics of measured values -2/+2 nT in 256 shades of grey (white/black) and the area of archaeological excavation (black line).*

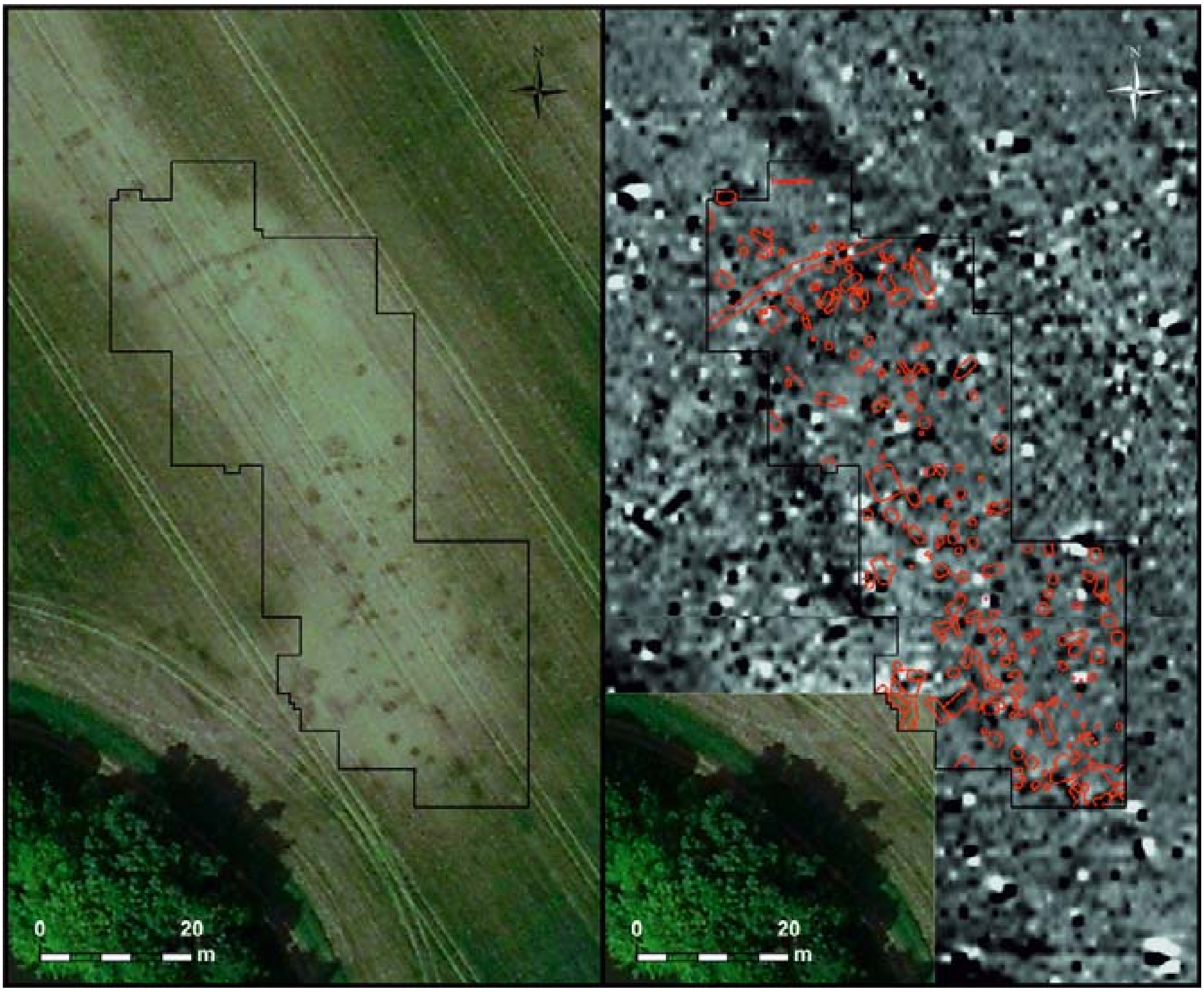

Figure 2: *Kostice – Zadní hrúd 1. left: Crop marks on an orthophoto of the locality; right: A comparison between the results of magnetic survey and archaeological excavations.*

ern section of Feature 68 we found that higher magnetic values are obtained only in the topmost layer of the feature's backfill. The remaining part of the backfill is composed of material with the same magnetic values as obtained in the sediments surrounding the feature. A similar situation was also observed for example in Feature 69 (Figure 3). Material with higher magnetic values was found at the bottom of the feature and in its upper part. The middle part of the feature was filled with sand having the same magnetic values as the surrounding terrain. The presence of pure sand within the feature can be explained by spontaneous disintegration of the feature walls or as a backfill that originated when some other deep pit was dug. Such features show themselves only as weak anomalies in magnetic survey.

Values of magnetic susceptibility only a little higher than those of the topsoil layer and of dark backfills of settlement pits were shown by features containing burnt layers, such as for example the batteries of ovens from the south-west corner of the excavated area. Areal measurements of magnetic susceptibility after the removal of topsoil were in this case able to outline individual features in relatively fine detail. They have shown three to five times higher values compared to surrounding terrain. They were, however, in no significant way different from the values of the topsoil layer. We can assume that the reason for a weak magnetic contrast on the site is that the magnetic components of backfills of features, such as ferromagnetic minerals, were partly washed away into the sandy surroundings. We have met with similar problems at other locations within the study region and in its neighbourhood. Geophysical survey of locations on sand dunes situated in river floodplains does not provide results anything like those from locations situated on more remote river terraces. To elucidate this phenomenon requires a more detailed explanation, but this is a task for future detailed research.

Prior to archaeological excavation works on the site, a ground-penetrating radar survey was also conducted. A particularly negative factor proved to be the deep ploughing, which can be observed on horizontal time slices in the form of regular lines. As deep as 40-60 cm we can observe possible archaeological situation consisting of a group of features, but individual structures are relatively hard to locate and identify. A test measurement on a limited area after the removal of topsoil provided a much better image, in much the same way as with magnetic survey. Most of the features present were identified. It is, however, necessary

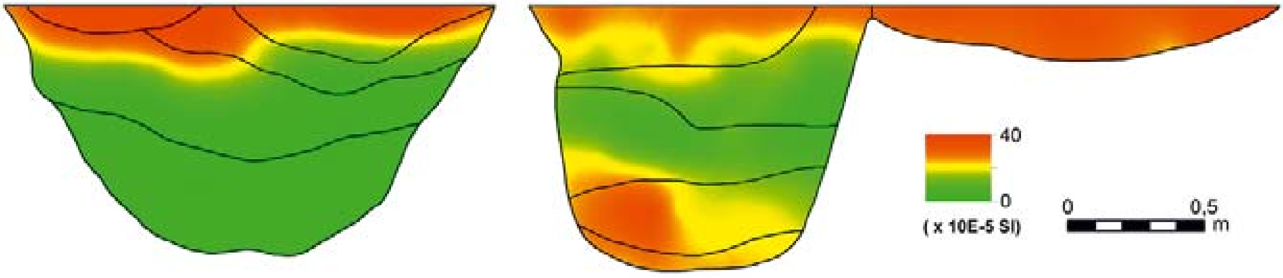

Figure 3: *Kostice – Zadní hrúd 1. The result of magnetic susceptibility measurement distinguishing the backfill layers on sections of features 68 (left) and 69 (right).*

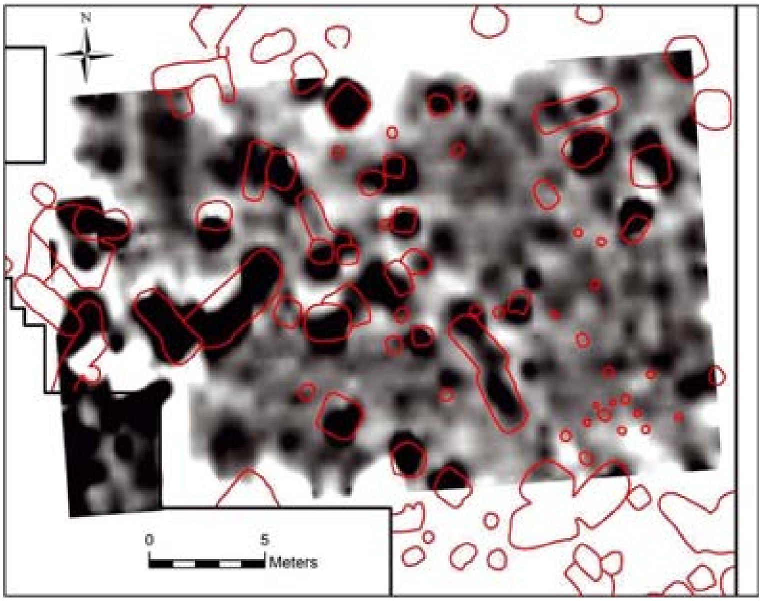

Figure 4: *Kostice – Zadní hrúd 1. The result of magnetic survey after the removal of topsoil and the result of archaeological excavation.*

to take external conditions into consideration. The survey took place in a period of frequent rain, so how significant a role wetness played in the measurement results is an important question.

The relevance of results of geophysical measurements conducted on settlement sites within the region under review is varied. The survey at the locality of Kostice – Zadní hrúd 1 clearly shows that there can be marked differences between the results of geophysical survey and those of archaeological excavations. Here, soil is the factor that most affects the final survey results. Archaeological features sunk into the sandy subsoil show only weak magnetic anomalies, which considerably complicates their identification and interpretation. The permeability of sandy soils, on which the studied site is situated, causes a relatively rapid decalcification, decomposition of organic materials, and washing away or dispersion of ferromagnetic materials from feature fills into the surrounding sediments. Shallow features remain unidentified due to high magnetic values of the topsoil above them. The reason why some features are invisible in geophysical data is the high content of non-magnetic sand from the surroundings that has made its way into their fills. We can thus be sure that the structures identified by magnetic survey represent only a part of the overall number of features present. Nevertheless, we can at least consider the extent of habitation based on the magnetogram. The highest density of settlement features centre around the highest point of the dune, that is in the area that was archaeologically examined. The incidence of magnetic anomalies indicating archaeological features are recorded on an area of approximately 1.6 ha. In the peripheral zones of the dune, however, we must take into account decreased habitation density. The locality was not isolated: there is a concentration of settlement features in the north-west corner of the surveyed area, and a less dense habitation immediately to the east of the settlement area. Magnetic survey has also demonstrated the presence of archaeological features to the south. These concentrate in a narrow band in higher parts of a terrain contour. The settlement in the location Kostice – Zadní hrúd 1 thus was at least partly interconnected with a second settlement site extending in the location Kostice – Zadní hrúd 2.

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THE PUIG CIUTAT PROJECT. MULTI-METHOD GEOPHYSICS AND ARCHAEOLOGICAL FEEDBACK TO MAP A DESTRUCTION

R. Sala, E. Garcia

A multidisciplinary team has investigated the archaeological site of Puig Ciutat, dated to the 2nd to 1st centuries BC, since 2010. The site occupies a high plain of around 5 hectares surrounded by a river, about 70 km north from Barcelona. The first excavation works revealed a Roman Republican settlement, presumably destroyed between 80-30 BC.

Between May of 2010 and July of 2012, multiple geophysical surveys have been carried out in the two main fields of the site (Figure 1). Although some of the surveys had other objectives, such as system developments or system tests, there have been two basic functions of geophysics within the project: a practical application has used magnetics, GPR, resistivity and EMI to map the site and plan the excavation areas, and methodological revision of survey results, based on comparative analysis with results from archaeological excavation.

In Field 1, the geophysical surveys have been useful to locate building remains and fired areas. A building placed in the centre of the field (building 1), already described in 2005, was partially excavated (Figure 2). The comparison between magnetic results and GPR survey time-slices revealed a square, 11.5 × 11.5 m building with a particularly symmetrical shape. The excavation of the southeast quadrant of the building showed that the interpretation of the magnetic survey as a fired area was correct, as the excavation located the remains of fired wooden beams and a group of burned pottery interpreted as a wood shelf fallen during the destruction of the site. The excavation also revealed how the weak magnetic contrast of building materials and the lower spatial resolution of magnetic survey failed to describe the particular shape of the building door clearly traced by GPR surveys, while the remains of a mud wall, an internal division, was detected by the magnetic survey but not by GPR.

Another group of buildings have been described by a GPR survey in June of 2011, in the northeast area of Field 1 (Figure 3). The magnetic survey of the same area showed a group of dipoles without a clear definition of building features. After a higher detail GPR area survey with a resolution of 10 × 2 cm, one of the rooms was partially excavated in November of 2011. The objective of the excavation was to check if this area preserves evidences of firing, or at least, destruction. The excavation results located the perimeter of the room and a debris layer with fired wooden beams remains and well-preserved pottery items.

In Field 2, the GPR surveys revealed multiple linear anomalies interpreted as building remains, while magnetic surveys just showed weak linear anomalies and a predominance of north-south oriented dipoles. The western edge of the field showed weak magnetic gradient values but a highly reflective response in the GPR area survey.

In July of 2011 and July of 2012, one of the excavation trenches was placed over a C-shaped feature described in the GPR survey, where the magnetic survey results showed a group of dipoles without a clear geometry (Figure 4). An excavation trench was placed from east to west of the field to explore the

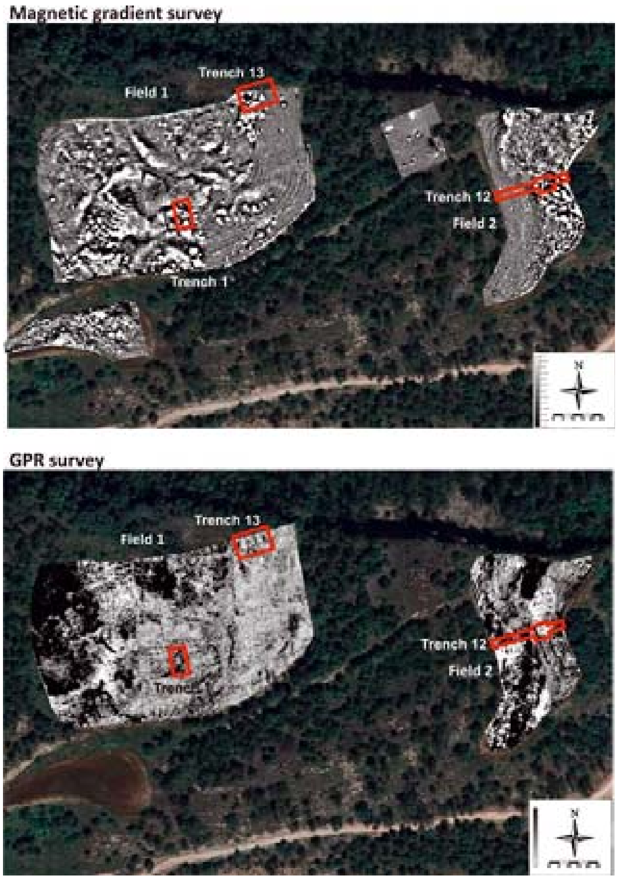

Figure 1: *Two main fields at the site of Puig Ciutat.*

building and the western edge of the field.

The excavation revealed a good morphological matching of the real perimeter of the building with GPR results and the remains of fired, fallen wood beams belonging to a roof. An interesting aspect was a possible intrusion after the firing in the northern half of the building. This could explain why the magnetic survey revealed a high-contrast convulse response area rather than a single north-oriented dipole. In 2012, a new wall not detected in any survey, presumably belonging to the eastern perimeter of the building, was excavated. Its position, 30-40 cm deeper than the rest of the walls, and its thinner dimension (30 cm) could explain why it was not detected, since at this level, the bedrock amplitude nearby could have overwhelmed traces in GPR surveys.

Out from the building, the trench showed that the western fringe with low magnetic contrast and a highly reflective response in GPR corresponds to the shallower bedrock position at 35-40 cm under surface.

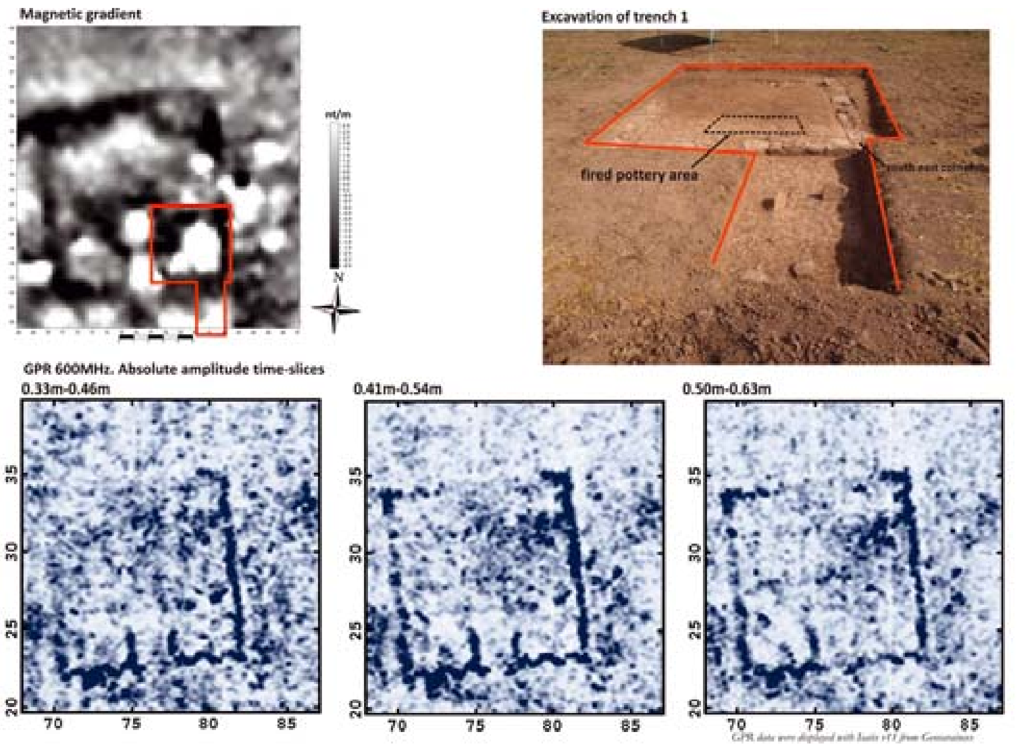

Figure 2: *Results of the magnetic survey (top) and GPR survey (bottom) and locations of archaeological test trenches at Puig Ciutat.*

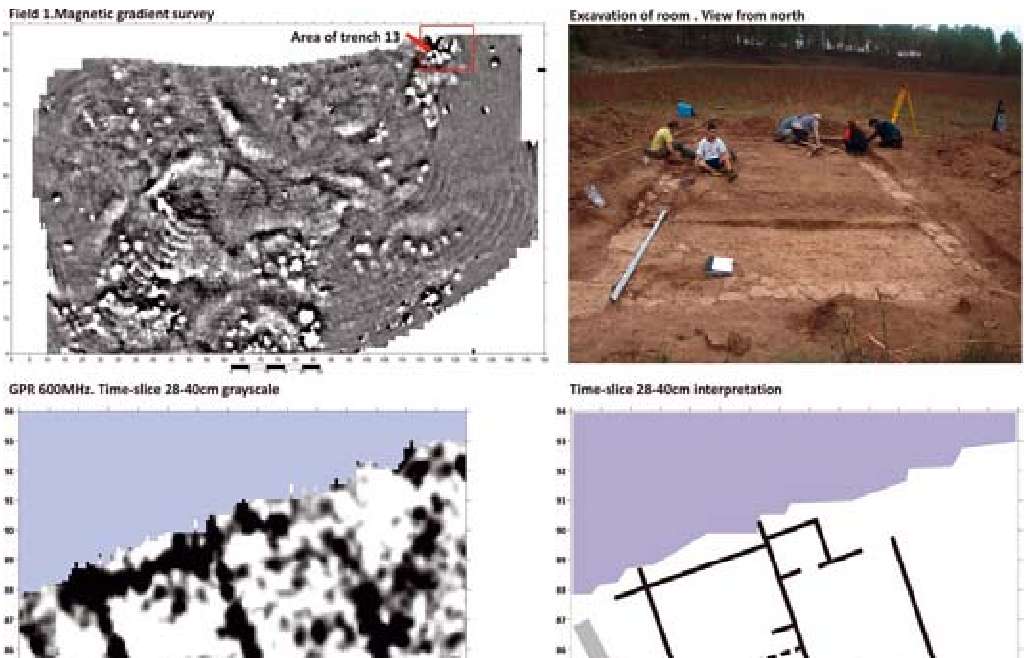

Figure 3: *GPR depth-slices and comparison with results of magnetic survey and excavations.*

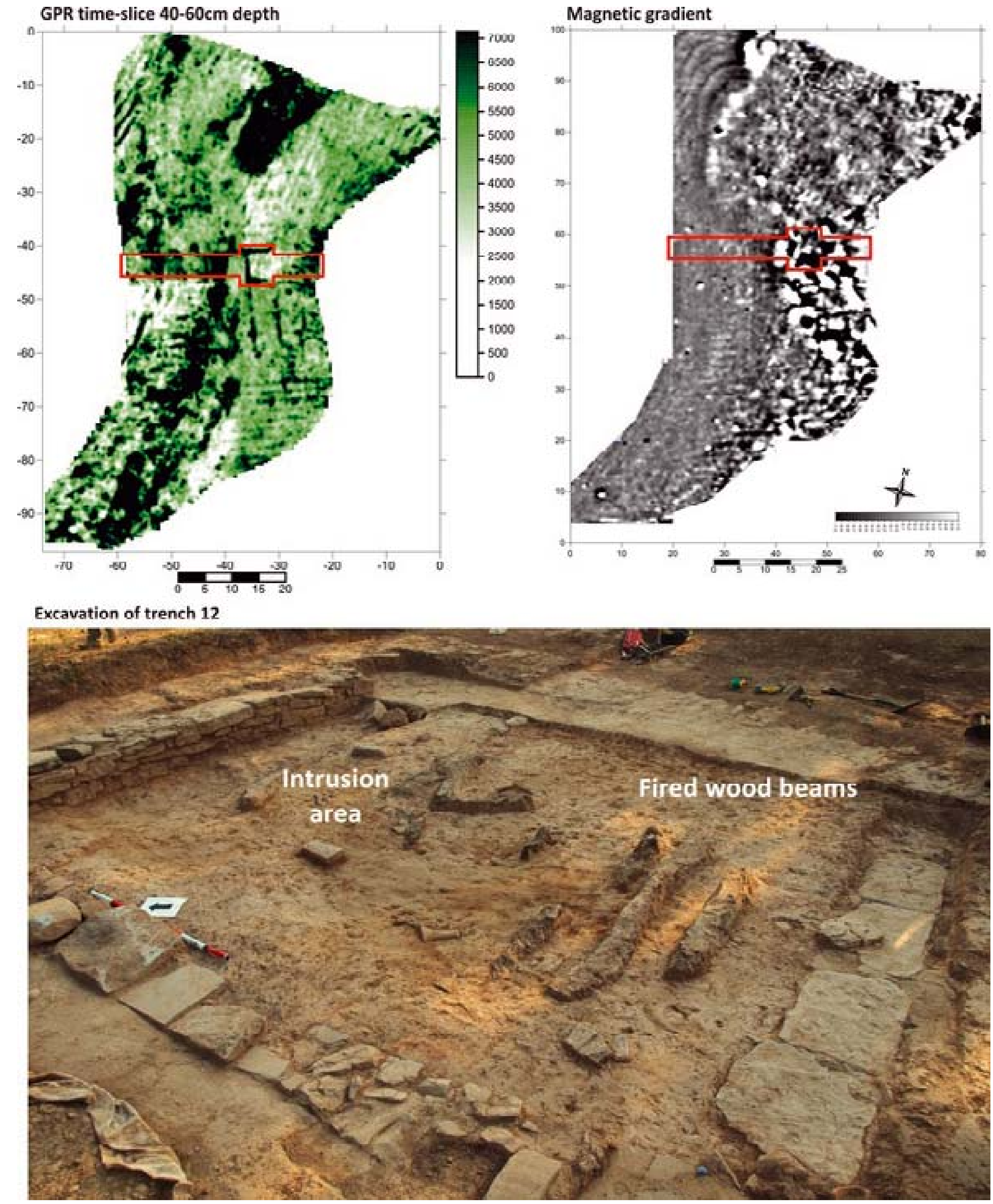

Figure 4: *Building identified in GPR and verified by excavation.*

CONCLUSION

As the destruction of Puig Ciutat is one of the main investigation lines of the archaeological project, the characterization of fired areas using gradiometer surveys have been helpful to direct the excavations and to extrapolate the results to other areas of the site. The three examples of excavations in Puig Ciutat showed how in low magnetic contrast context, the fired areas could act as a contrast enhancer, but areas not completely burnt or modified after firings could bring convulse, high-contrast anomalies with no direct relation with its building geometries.

In the other hand, the excavation results of selected areas brought additional interpretation criteria for areas which were not clearly understood, as the western fringe of Field 2. Indeed, the sustained interaction between Archaeology and Geophysics in the exploration and characterisation of a new site could help to optimize time and resources of the whole project, not only in the description of building remains, but also helping to understand qualitative aspects of the archaeological context.

ARCHAEOLANDSCAPES EUROPE – A NETWORK FOR ARCHAEOLOGICAL PROSPECTION

A.G. Posluschny, C.R. Musson

1. INTRODUCTION

Initiated in September 2010, the *ArchaeoLandscapes Europe Project (ArcLand)* represents the culmination of a growing European cooperation from the mid-1990s onwards. Now federating 61 prestigious institutions in the field of archaeology and heritage protection (27 Coordinator/Co-organisers and 34 Associated Partners) from 31 countries, it will bring that process to a sustainable and self-supporting future as the long-term legacy of this and earlier EU-assisted initiatives.

The project's long-term legacy will be better appreciation of the landscape and archaeological heritage of Europe, closer contact between heritage professionals and the general public, more effective conservation of the shared cultural heritage, international sharing of skills and employment opportunities, better public and professional education, wider use of archive resources and modern survey techniques, and higher professional standards in landscape exploration and conservation.

2. AIMS OF THE PROJECT

The ultimate aim of the *ArchaeoLandscapes Europe Project* is the use throughout Europe of aerial survey and 'remote sensing' to promote understanding, conservation and public enjoyment of the shared landscape and archaeological heritage of the countries of the European Union.

ArcLand wants to increase public appreciation, understanding and conservation of the landscape and archaeological heritage of Europe through the application and international sharing of skills and experience in airborne and other forms of remote sensing.

The Project will achieve this through eight key Actions/Working Parties:

WP1 – Create a self-supporting *ArchaeoLandscapes* Network

The key element in attaining long-term sustainability will be the formation of a pan-European network of 'centres of expertise', to be known as the *ArchaeoLandscapes* Network. This cooperative partnership will secure funding from its members and from grant-giving bodies to support a small professional secretariat or 'nerve-centre'. This in turn will provide expertise, advice and support for organizations or institutions that wish to pursue agreed objectives or to undertake partnership projects within the fields of landscape studies, heritage survey, conservation and public education.

The strength of *ArchaeoLandscapes* Network will lie in its heterogeneous nature and its total coverage of the countries of Europe, with a membership of various heritage bodies in the fields of education, research, conservation and public service.

WP2 – Communicate the value of aerial survey, remote sensing and landscape studies

In many parts of Europe, the last decade has seen a surge of interest in the traces of the past, not only in archaeological and historical sites and objects but also in the broader context of the landscapes within which these individual cultural features achieve their full meaning and impact.

A key action within the project is the use of traditional and new techniques to foster this interest and to show a broader audience how cultural landscapes and heritage sites can contribute to European as well as local identity and 'sense of place'. The power of aerial images, or the vision of our cities and rural landscapes on GoogleEarth and similar web sites, can bring this kind of appreciation to a wider audience than that reached by traditional hard-copy publications or carefully mounted exhibitions.

The main focus in the project's communication strategy, however, is the web-based output that can speak directly to a wider and in particular a younger audience. If the interest and commitment of these previously uninvolved members of the public can be captured and then nurtured, public appreciation of the shared cultural heritage of Europe will be enhanced, enjoyment increased and a sense of caring instilled in citizens who would not formerly have realized the significance of these living tokens of the past.

WP3 –Promote the pan-European exchange of people, skills and experience

In a field with a relatively small number of professionals, spread thinly across Europe, it is essential to share understandings, skills, experience and research results. Together, the heritage community needs to learn from instances where countries, regions or institutions have managed to make a real contribution to landscape and archaeological conservation through the application of air-photographic and remote-sensing techniques.

Exchange visits between experts, and placements of 2 weeks to 3 months' duration, will also figure in the work-programme so as to give students or professionals the opportunity to gain experience and specialist training in European countries other than their own. There will be an emphasis on on-the-job learning and specialist instruction by staff or institutions, which have made particular advances in data-interpretation, methodology, instrumentation or communication techniques etc.

WP4 – Enhance teaching in aerial survey, remote sensing and landscape studies

The theory and practice of 'aerial archaeology' are taught in relatively few universities and polytechnics across Europe. Much the same applies to other forms of remote sensing (ground-based geophysics, airborne laser scanning etc). There is an urgent need to improve the range of opportunities open to intending students, as well as to professionals who wish to extend their range of skills. This challenge is addressed by creating contacts, facilitating exchanges and prompting discussion between teachers, professionals working in these fields and those who wish to apply these techniques in their research or conservation work. The improvement and broadening of course-content has a priority, with the shared and comparative experience of existing teachers and professionals as key factors.

A particular, but inevitably long-term, objective is the creation of a year-long European Masters degree (or equivalent) which will enable students to build up a special range of skills and experience by undertaking learning or research work at various locations around Europe.

WP5 – Exploit existing air-photo archives more effectively

Europe has a rich but seriously underexploited inheritance of aerial photographs from the last eighty years, documenting the dramatic landscape transformations of recent decades and containing a wealth of information about as yet unknown (and therefore unprotected) landscape features and archaeological sites from the more distant past.

The very existence of these archives, which are scattered throughout large and small institutions across Europe, is often hardly known in the broader heritage field, and their potential for landscape and archaeological studies remains largely unassessed. The project compiles at least a preliminary guide to the existence and possible heritage value of these archives. It is recognized, however, that the full exploitation of these archives is a task, which will stretch far beyond the lifetime of the present project.

WP6 – Support aerial survey, remote sensing and landscape exploration

The concentration in this Action is on providing support, both financial and technical, for aerial and ground-based survey work in parts of Europe where the use of remote sensing techniques is still in its infancy. While Britain, Germany, France and (more recently) Italy have used aerial survey extensively in recent decades, there are other parts of Europe where remote sensing and aerial survey have yet to become everyday tools in the armoury of archaeologists and landscape specialists, whether for research, conservation or public communication.

Intensive training schools for aerial archaeology will be organised in the coming years of the project. Smaller and less costly ground-based workshops have been held to introduce students and professionals from various countries to interpretation of aerial photographs, LiDAR scans and geophysical data, mapping and uses of the results in conservation work and so on. These workshops have been mounted in France, Spain, Ireland, Poland, Lithuania and Greece; more workshops are planned in Serbia, Germany, Greece, Hungary and Ireland.

WP7 – Explore laser, satellite and other forms of remote sensing

The use of satellite imagery for cultural, conservation and communication purposes has long been a goal within archaeology and landscape studies. New possibilities have been raised in recent years through the development of high-resolution satellite systems and other forms of 'aerial' recording such as thermal imaging, airborne radar and laser scanning or LiDAR. Considerable technical expertise is required to process the raw data for heritage purposes. The project therefore supports experimentation and skill-sharing amongst partners who can gain access to LiDAR and satellite imagery or who have already used it for cultural purposes.

The enormous amount of data that can be derived from airborne and ground-based surveying techniques does offer new insights into archaeological sites and landscapes but on the other hand is not always easy to handle and to analyse. *ArchaeoLandscapes* therefore supports the development of freely available and easy to use software tools, especially for air photo handling (AutoGR-Toolkit; http://www.ims.forth.gr/index_main.php?c=90&l=e&d=7) and for LiDAR data (a toolbox will be available in early 2013 to be downloaded from the project's webpage).

WP8 – Provide technical guidance and advice on best practice

An effective way of improving standards in any activity is the dissemination of information on best practice and reports on successful approaches to shared problems or possibilities. Within the relatively scattered heritage community, this kind of information sharing is particularly important, maximizing the value of experience gained in one institution or country by bringing it to the notice of others elsewhere in Europe.

Throughout its life, the project will therefore compile and publish recommendations for best practice in such things as specialist teaching, communication with the general public and the use of planning procedures in heritage conservation. Technical guidance will also be issued on such subjects as LiDAR survey, aerial photography, geophysical investigations and the Internet presentation of heritage data.

3. PROJECT PARTNER

It is one of the ideas of the *ArchaeoLandscapes* Project to include Europe as a whole in the *ArchaeoLandscapes* Network. The project membership therefore consists of partners from nearly every European country and will even be expanded during the next years. The cover the range of all kinds of archaeological and cultural heritage institutions like research institutes, museums, universities, state heritage offices and stakeholders of topics related to the ArcLand interests. Recent & Future Project Activities Besides the various aerial archaeological training schools and workshops (e.g. French/Slovenian workshop "Training and Research in the Archaeological Interpretation of LiDAR" in Glux-en-Glenne (FR), workshop "Introduction to Multi-Method Archaeological Site Survey: Surface Collection and Remote Sensing" in Slane/IE, aerial schools in Kostolac/SR, Velling/DK, Merida/ES, etc.; see also http://www.archaeolandscapes.eu/index.php/en/outreach/training-schools.html and http://www. archaeolandscapes.eu/index.php/en/outreach/workshops.html), a number of conferences, conference sessions and other scientific meetings have been organised by *ArcLand* and its partners. The Dutch/Flemish/German conference "New Developments in Archaeological Remote Sensing and Geophysics" in Münster/DE and the International workshop "Technological Advances in Landscape and Heritage Management and Recording" in Dublin/IE brought together experts from all over Europe and the USA, fostering an exchange of ideas and expertise. Members from the *ArcLand* consortium organised sessions or presented papers and posters at the annual conferences of the CAA (Computer Applications and Quantitative Methods in Archaeology) in Beijing/CN (2011), in Southampton/UK (2012), at the annual conference of the European Association of Archaeologists (EAA) in Oslo/NO (2011) and in Helsinki/FI (2012), at the World Universities Congress in Çannakkale/TR (2010) and at other similar opportunities.

ArcLand is preparing a travelling exhibition, which will be starting in Dublin 2013, accompanied by a conference (8^{th} -11^{th} May 2013), which will focus on the use of remote sensing for community archaeology. The Roman-Germanic Commission of the German Archaeological Institute in Frankfurt/DE will host the final international conference of the ArcLand project in 2015.

A great range of smaller and larger publications, dealing with various aspects of remote sensing, LiDAR, geophysics and other surveying techniques in archaeology, have already been published or will be published within the next years of the project. The project's webpage will provide more information on the publications as well as on future activities and on how to participate. Partners from the project will also proviede case studies, best practice guides and other sorts of information during the lifetime of the project, which can be accessed at http://www.archaeolandscapes.eu.

ACKNOWLEDGEMENTS

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APPLYING GEOINFORMATICS IN MODERN AGE ARCHAEOLOGY

A. Juhász

Geoinformatics has recently developed as a well-known and widely applied discipline in different human sciences. There are several interesting examples of the application of geographical information systems (GIS) to manage information from various periods in military history and archaeology. Our research topic covers the military history of the modern era, so it is a very sensitive topic. Therefore, we always used objective data acquisition techniques and an applied engineering type of approach. The military historical GIS database, which was created in this way, can be handled as an objective and reliable basis for further research by scholars in the human sciences in object or even in event reconstructions.

We specifically selected the final months of World War II in Hungary for our research. Our major objective was to create a GIS database representing the period's national defence system and the main military historical events. This defence system was located approximately on the diagonal across Hungary, starting from the north-eastern part, then across the foreground of the Northern Mid-Mountains, Budapest, Lake Velence, Lake Balaton and ending at the river Dráva. Naturally, this complex system was composed of different parts. The three major defence lines were the Karola-, Attila- and the Margit-lines. In addition, there were several auxiliary defence lines in the system, but the importance and impact of these lines were minimal compared to the three major ones. The aim of this system was to stop the Soviet attack coming from the southeast at the end of 1944, and it was partially successful.

First, we created a GIS-supported reconstruction of the Attila-line from our previous research, then added the eastern sector of the Margit-line. Before the particular data acquisition, we had to define a strategy, a methodology, which was suitable to achieve our aims – a uniform GIS database – considering the existing and currently accessible data sources. This methodology consists of three main parts: the reconstruction of the period environment, the military objects and finally the military historical events (Figures 1-3).

During the data acquisition and processing, we had to take into account the large deficiency in information of this period, especially for military defensive features. The plans and the connected documentation were either destroyed or are difficult to access. Furthermore, while the literature of these years is substantial, it contains very little information or data about the defence lines. This is true for the Soviet era (before 1989, i.e. the end of the communist regime) and for current publications, which are based mostly on archival data.

Recognizing the challenges of these circumstances, we approached data acquisition from an engineering perspective, which was suitable for the preliminary objectives. The various archive and current remotely sensed and map data, and the additional field measurements, meet the requirements. There were various maps (mostly created a few years before or after the war) used to reconstruct the environment of the period and to define the digital base map for further analysis and research. Similarly, these maps were used to identify the military objects and features, but primarily as a complementary data source. The most

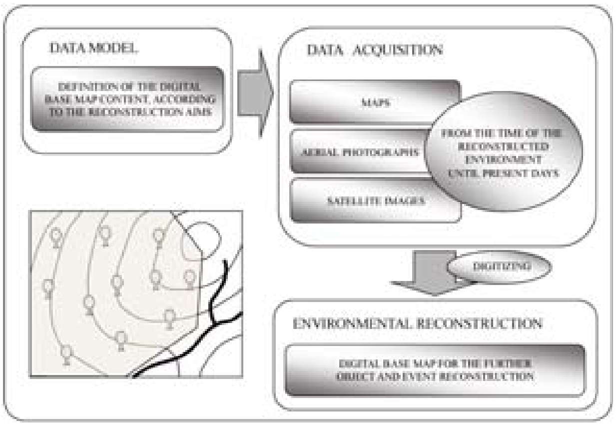

Figure 1: *The environmental reconstruction process.*

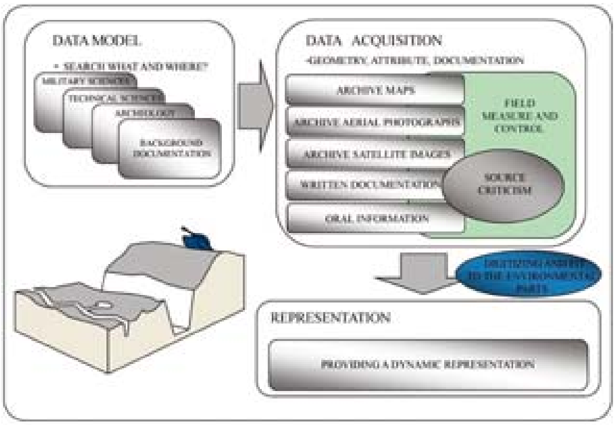

Figure 2: *The military object reconstruction process.*

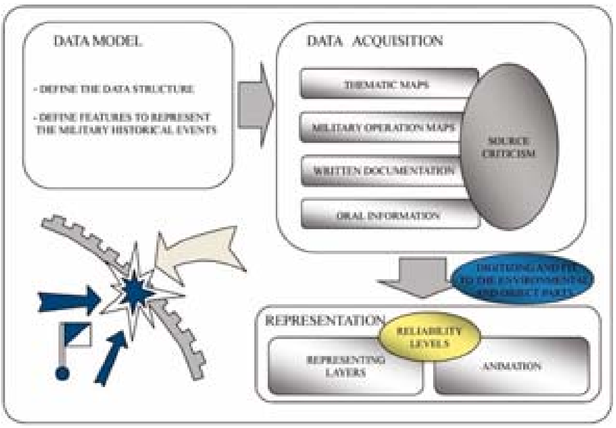

Figure 3: *The military event reconstruction process.*

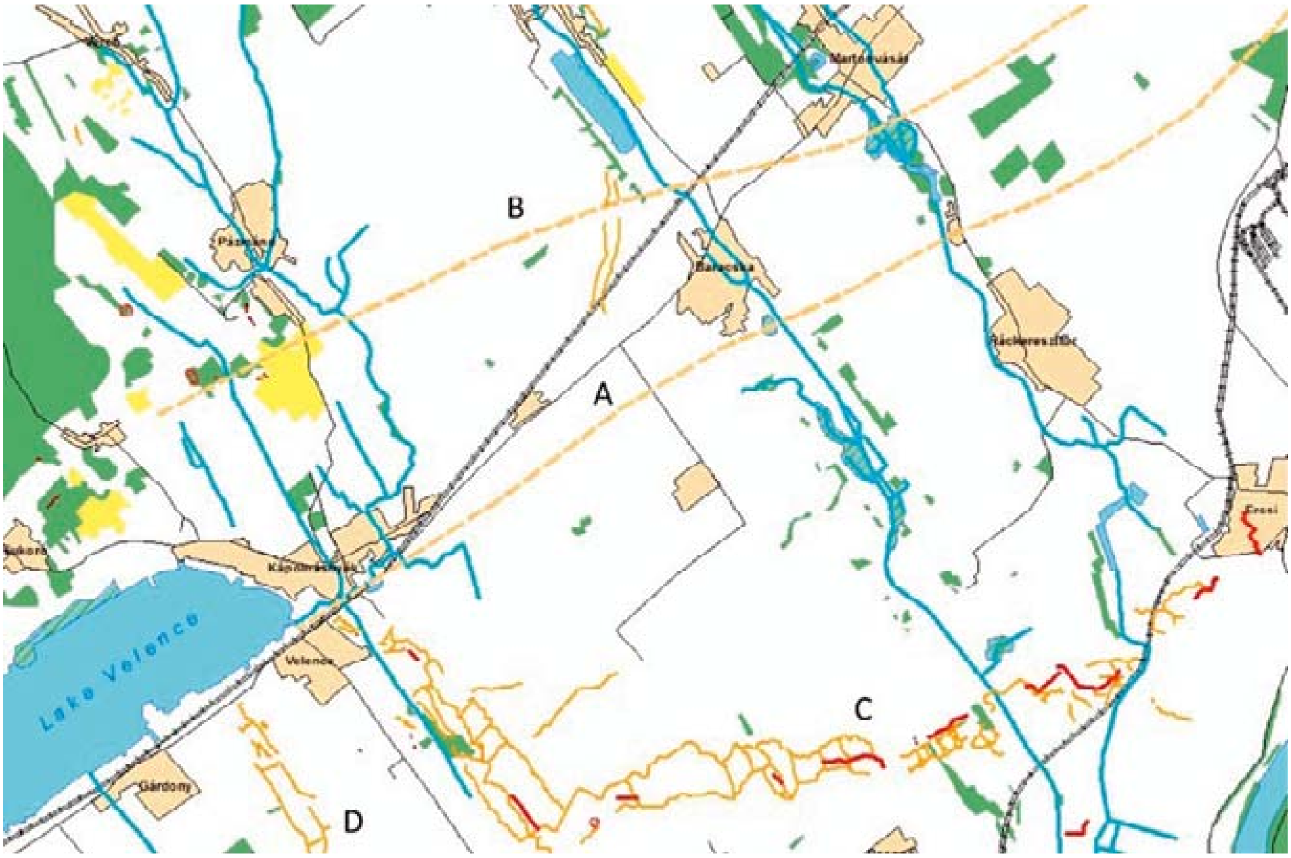

Figure 4: *The eastern sector of the Margit-line (A,B: the potential lines; C,D: the reconstructed lines).*

useful data sources were those archive aerial photographs, which were taken in the beginning of the 1950s. It was the first nationwide aerial photographic campaign in Hungary after the World War II. The third main step (the military event reconstruction) would be a huge task if all the accessible information would be managed in the system. Due to the extension of the investigated area, the accessible data quality and the research circumstances, we decided to reconstruct the period's military events in sample areas to represent the potential of GIS application. We believe that it is more important to investigate and represent a complete system, or the main part of a complex, in lower quality, in contrast to limited areas with higher quality data.

The whole Attila-line was reconstructed in our previous research. This defensive line was built in a horseshoe shape around Budapest, on the Pest side, to protect the capital of Hungary. The accessible documentation describes this line as a complex, multilevel structured system and it consists of three main lines or zones, each with anti-tank ditches, artillery installations, bunkers and infantry earthworks. Based on the object reconstruction, we identified and mapped just two lines in that area, with the main characteristics of the period's defence systems. There was no third line with same features.

In our latest research, we reconstructed the eastern sector of the Margit-line located between the River Danube and Lake Balaton. Similar to the Attila-line, there are contradictions between the locations described in the written documentation and that of the reconstructed lines. In the area between the Danube and Lake Velence there are no signs of the two potential defence zones, but there are significant dike systems in the south part of the investigated territory (Figure 4). Additionally, the identification (i.e. defining the construction date and the army that created it) of the defence lines is more complicated in this area, because numerous military operations occurred there over a short period; the major soviet breakthrough during the encirclement of Budapest, the three "Conrad" operations and the "Spring awakening" operation.

Along with the GIS based reconstructions of the environment, the military objects and the events, we investigated further analytical and representational functions, which can also support these kinds of applications. The methods enable various spatial and attribute queries and animation possibilities that are also useful and sometimes necessary. The typical examples of these functions are also discussed in the paper.

STUDY OF DESERTED CULTIVATED LANDSCAPE IN THE AREA OF CZECH SWITZERLAND

L. Starkova

1. INTRODUCTION

This poster deals with the deserted cultivated historic landscape in the Czech Republic (Figure 1). Of major interest here are the remains of agricultural activities and the continuity of settlement. The aim of this study is to look at the issue of searching for these archaeological features using remote sensing. Furthermore, this paper deals with the transformation of the identified features to digital format, syntheses of spatial relationships of fields, landscape elements and settlement, and finally the evaluation of airborne laser scanning method for solving these issues.

2. STUDY OF DESERTED CULTIVATED LANDSCAPE

The study of extensive parts of landscape, whether extinct or partially preserved to the present day, necessarily requires a comprehensive approach, a combination of methods (e.g. aerial archaeology, airborne laser scanning) and an entire spectrum of survey methods (e.g. surface survey). The basic goal of this study is to reconstruct the past landscape and to monitor the impact of human activities on the landscape.

Of major interest here are the remains of agricultural activities and the continuity of settlement. The aim of this study is to look at the issue of how archaeologists search for these archaeological features (using orthophotomapping, lidar data) and how features thus identified can be validated through other sources (e.g. historical maps). Furthermore, this paper deals with the transformation of the identified features to digital format, syntheses of spatial relationships of fields, landscape elements and settlement, and finally the evaluation of airborne laser scanning method for solving these issues.

Figure 1: *Area of interest. DTM hillshade combined with actual topographic map 1:50 000.*

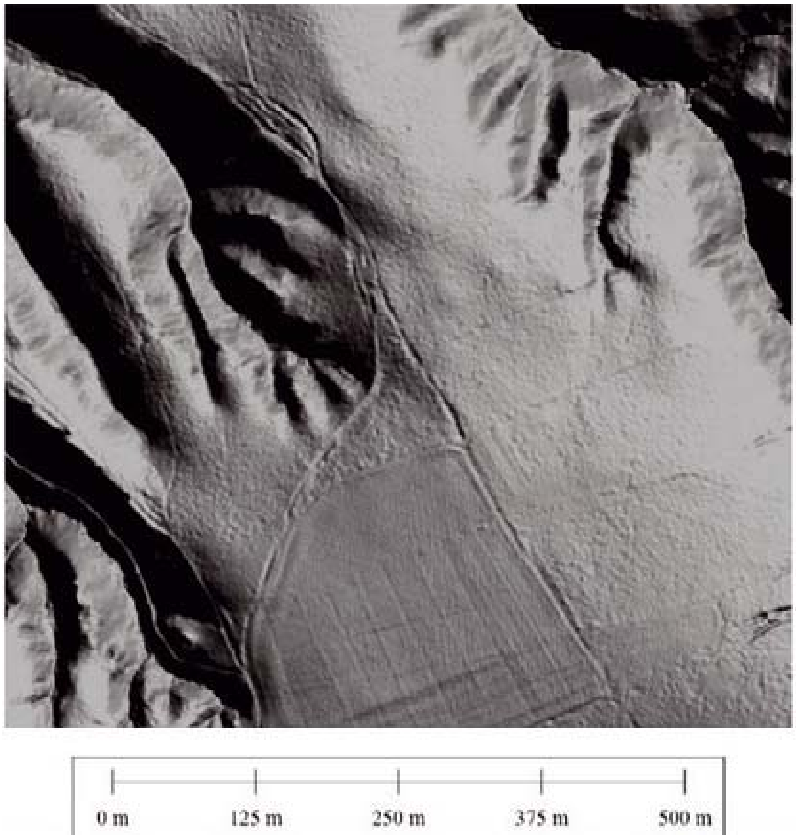

Figure 2: *Comparison of features visibility depending on used visualisation algorithm.*

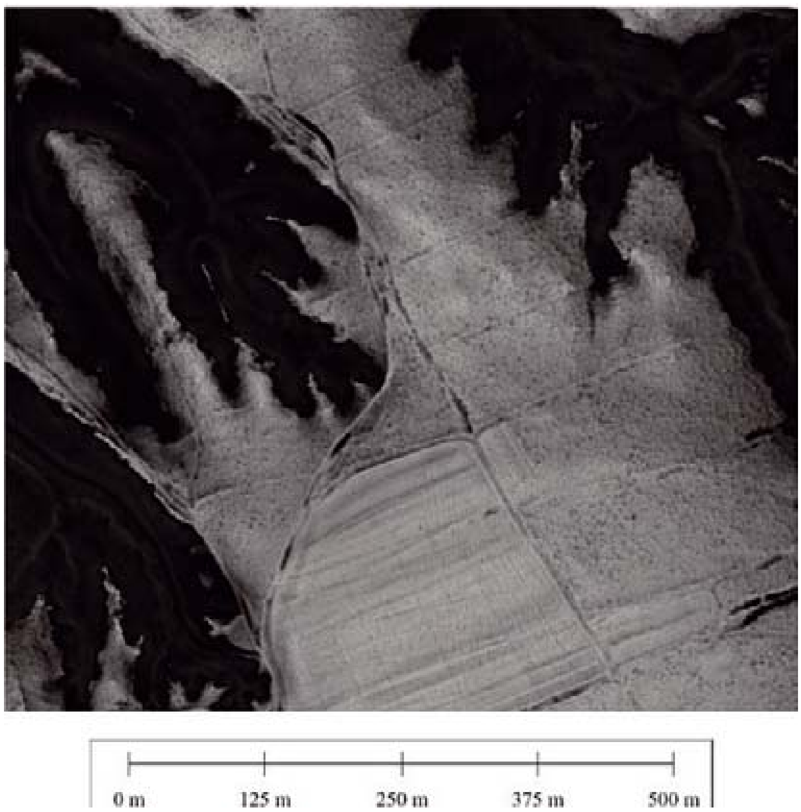

Figure 3: *Comparison of features visibility depending on used visualisation algorithm.*

Figure 4: *Main results of lidar and ortophotos potential field systems interpretation.*

ArcGIS was used as the main software environment in which all partial results of the analytical phases were transformed. For basic data processing of aerial laser scanning, several types of software were used to work with three-dimensional data collections (e.g. Global Mapper, Quantum GIS). The algorithms Sky-view factor and Trend Removal were used as other forms of visualization of aerial laser scanning (Figures 2-3).

Displaying digitized remains of fields on historical maps and on orthophotomaps provides the opportunity to monitor and compare changes in the appearance of the recorded fields. This comparison shows the intensity of the human impact and of the natural processes that can destroy the archaeological traces of past agricultural activities.

GAMLA UPPSALA REVISITED – ARCHAEOLOGICAL EXCAVATION AND PROSPECTION IN OLD UPPSALA

A. Biwall, L. Beronius, I. Trinks

Gamla Uppsala (Old Uppsala) is one of Sweden's most important prehistoric sites. In 2012, extensive rescue archaeological excavations were performed there in connection with the construction of a railway tunnel that is planned straight through the centre of the Iron Age settlement. Almost 50,000 square meters of area have been excavated and a large number of interesting features and finds dating from prehistoric to historic periods have been discovered at the settlement and the grave field.

Swedish archaeologists working in exploration archaeology are in general only allowed to excavate in the areas affected by the construction of, for example, new roads, building sites or railway corridors. Therefore, it is not often possible to explore the entire extent of archaeological sites, such as settlements or grave fields, and important archaeological knowledge crucial for the understanding of an archaeological site remains missing.

In the autumn of 2010, an archaeological prospection pilot study funded by the Research and Development Funds (FoU) of the Swedish Central National Heritage Board was conducted at Old Uppsala using the latest motorized magnetometer (Figure 2) and ground penetrating radar (Figure 3) technology for the efficient large-scale mapping of buried archaeology. Substantial areas were surveyed in a short time, resulting in numerous new archaeological findings.

Besides modern pipes, drains, remains from buildings as well as geological structures, many traces of prehistoric structures where identified in the form of cultural layers, a roadway, pit houses and postholes belonging to prehistoric buildings. Of greatest archaeological interest was the discovery of two several hundred metre long pit alignments with 5 m interspacing between the large pits (Figure 1), as well as two possible prehistoric buildings. A continuation of the prospected pit alignment has been excavated, permitting a dating of the structure.

We will present excavation results from an area that as well has been prospected by GPR. Further prospection surveys are planned for spring 2013, with the goal of tracing the continuation of the pit alignments. Our presentation will show how large-scale archaeological prospection surveys in combination with conventional rescue archaeological excavations can be of great importance for the understanding of the larger prehistoric landscape. Our results show that the archaeological prospection approach worked very well at Old Uppsala, and that a continued non-invasive archaeological exploration will be able to contribute significant new knowledge about this important site.

Figure 1: *Long pit alignments at Old Uppsala, with 5 m interspacing between the large pits (excavated pits represented by standing archaeologists).*

Figure 2: *Magnetometer survey at Old Uppsala, showing areas surveyed in 2010 in blue.*

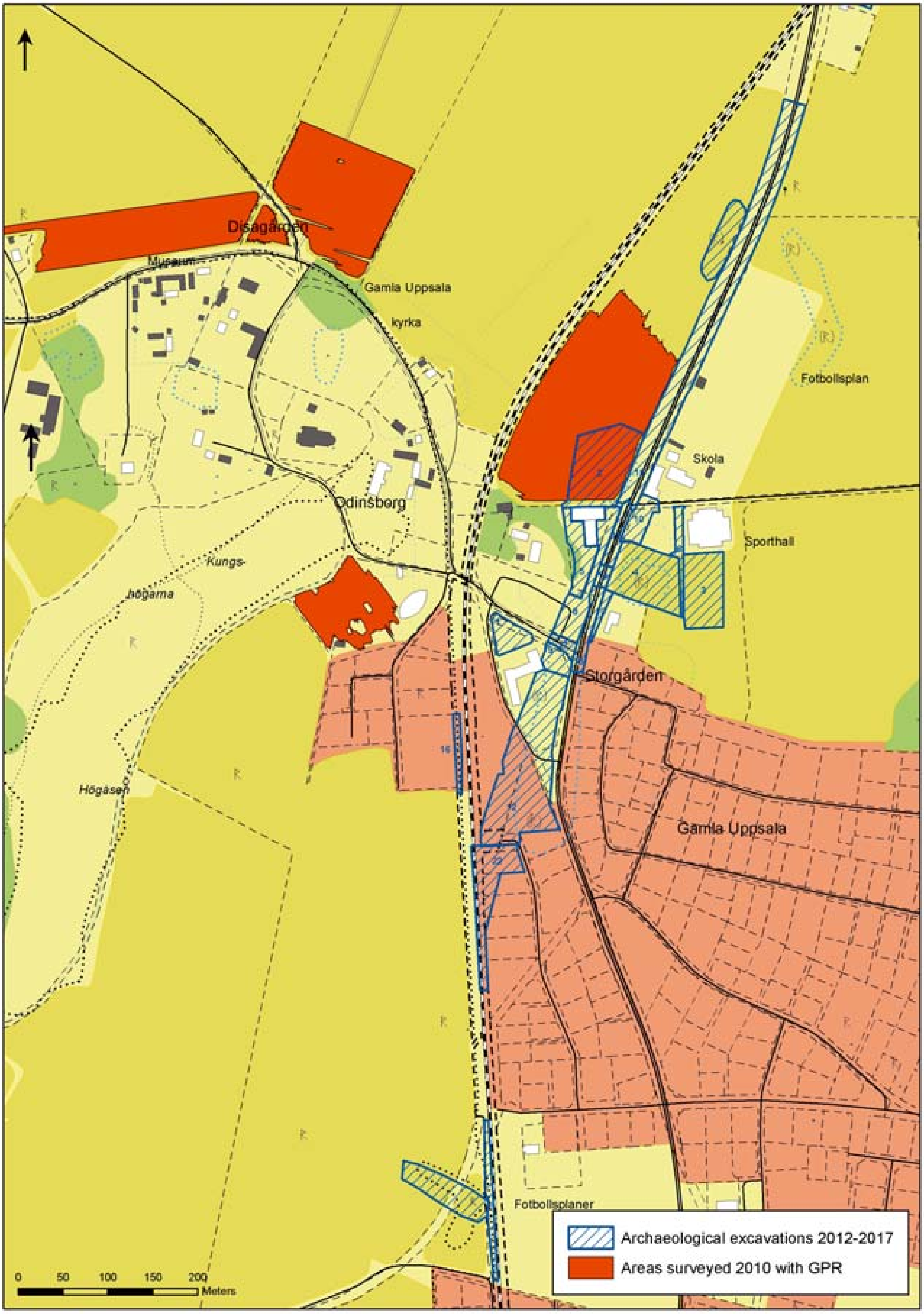

Figure 3: *Ground penetrating radar survey at Old Uppsala, showing areas surveyed in 2010 in red.*

ARCHAEOLOGY AND GEOGRAPHICAL INFORMATION SYSTEMS IN THE CONTEXT OF SPATIAL PLANNING

G. Branco, L. Rocha

1. INTRODUCTION

European regional/spatial planning Charter (DGOT, 1988: 9), approved in 1984 by the Council of Europe, states that spatial planning *"gives geographical expression to the economic, social, cultural and ecological policies of society. It is at the same time a scientific discipline, an administrative technique and a policy developed as an interdisciplinary and comprehensive approach directed towards a balanced regional development and the physical organisation of space according to an overall strategy."*

This document contains the guiding principles for spatial planning at its core, henceforth understood to be the implementation of public policy which is designed to be interdisciplinary and to improve people's quality of life and well-being.

The legal instruments for spatial planning in Portuguese territory establishes the compulsory act of identifying and establishing protection and appraisal measures for architectural and archaeological heritage, considered to be *"testimony of the history of occupation and use of the land (...) relevant for the memory and identities of communities"* (Executive Law no. 380/99 of 22 September 1999).

In this paper, we intend to deal with the possible interaction between the process of creating local council spatial planning programmes and identifying, protecting and appraising archaeological heritage, through the use of prospecting and geographical information systems.

2. ARCHAEOLOGICAL HERITAGE

Land, as we consider it today, is a product of the past: the result of successive acts of management and organisation, with social, symbolic and economic goals, which left material remains in the current landscape. Its current formation can date back as far as prehistoric times.

Archaeology, as a science which studies the past, plays a fundamental role in producing knowledge about the ancient human societies which have, since prehistory, interacted with the environment - shaping, constructing and de-constructing land - and it is up to us understand and organise its results.

Therefore, the field of knowledge known as landscape archaeology studies the origins and evolution of settlement patterns, and the occupation of the land by human communities, analysing and interpreting material remains (González Méndez, 1999). It is one of the disciplines best suited to understanding the long history of organisation and formation of current land.

The importance of archaeological heritage in spatial planning is recognised in the Basic Law on Spatial Planning (Executive Law no. 316/2007 of 19 September 2007) by defining the foundations for predictions, indications and determinations underlying the instruments of spatial planning, which should be based on systematically acquired knowledge about, among others, archaeological heritage resources.

The different types of spatial planning which currently exist in Portugal allow, at different levels of analysis, for planning and managing heritage in order to obtain a good progress/preservation relationship. This interaction between archaeological heritage and spatial planning management should take place at several different levels:

- identifying and recording archaeological resources
- measures for protection and appraisal.

As previously mentioned, identifying archaeological resources, in the context of spatial planning, necessarily involves an exhaustive archaeological record of all the elements resulting from past human activity. This record can only be understood by using archaeological methods, specifically archaeological surface prospecting. This method, specifically identifying and describing heritage values based on field work, with a view to protecting and safeguarding it, is recognised by some management instruments, such as the Central Region Spatial Planning Programme (PROT Centro [CCDRC, 2010]).

Systematic archaeological prospecting should be accompanied by research and data processing, such as:

- Defining the area to be studied which, in this context, is restricted to the administrative area of a county (concelho);
- Compiling and appraising information beforehand, considering: analysis of specific maps; analysis of toponymy and archaeological information (bibliography);
- Field work in order to locate and georeference archaeological information, check toponymy, bibliography and topography evidence;
- Recording and compiling the data collected;
- Processing the knowledge obtained and making it available to others.

In all the methods to be used, Geographical Information Systems are an indispensable work tool. In the words of García Sanjuan (2005, 149), *"one of the widest reaching technological revolutions for knowledge and the archaeological analysis of land, (...) the expansion of GIS in Archaeology has been dramatic, and they are currently a work platform as common and indispensable as processing, managing and analysing the spatial elements of archaeological data"*.

Some of the advantages of using GIS for the archaeological analysis of an area include:

- the possibility to use data and simultaneously view different levels of information, by comparing shapefiles;
- the possibility to use different maps which come together in the same work area;
- the possibility to map the field work data with precision (with GPS);

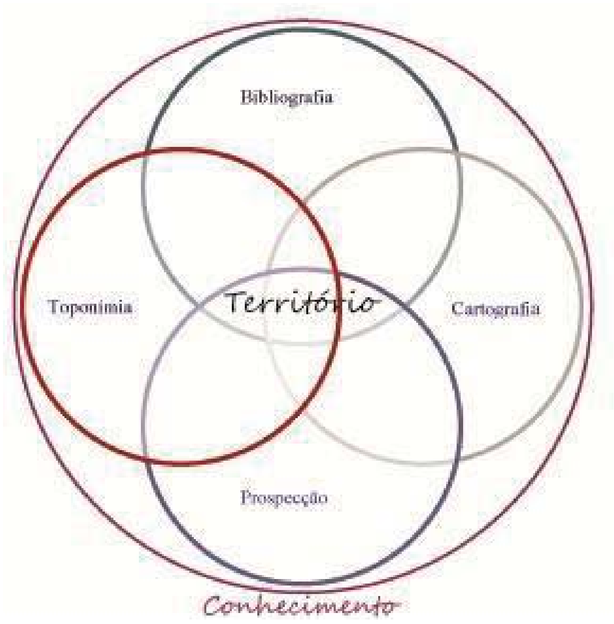

Figure 1: *Interaction of knowledge.*

- the possibility to map information which is intended to stand out in a different way (points, shapes, colours, schemes);
- the possibility to envisage the space, bringing together mapping and archaeological records.

The organised management of heritage values in an area and their integration in heritage maps allows us not only to identify and form a hierarchy of the value of archaeological heritage, but also to balance investment and projects in order to harmonise knowledge and progress.

3. MEASURES FOR PROTECTION AND APPRAISAL

Archaeological heritage is a strategic resource, a structural axis for collective memory which, in the face of its finite and non-renewable character, urges us to protect and safeguard it, in order to guarantee the real right to culture and cultural enjoyment expressed in the Basic Law of Cultural Heritage (*Law no. 107/2001 of 8 September 2001*).

Making archaeological heritage available as part of cultural enjoyment and leisure, can become important especially in areas where it is possible to align these resources with nature, gastronomy, and other types of heritage.

This availability includes the knowledge of existing resources, through proper management, and their integration at different levels of spatial planning, allowing us to balance investment and organise more important clusters, either in terms of scientific or tourist value.

In Portugal, these cultural and natural land resources remain unknown and underused, the result of several imbalances, in which archaeological heritage suffers. Sílvia F. Cacho, in her project on the management of heritage in Andalusia, states that *"(...) Archaeological Heritage (AH) is one of the land resources which is most affected by inadequate environmental management and whose integration into land planning documents is not efficient(...)"* (Fernández Cacho, 2008, 21). This underuse is coupled with legal specifications that favour classified monuments.

In this context, our considerations include ways of safeguarding and protecting cultural heritage and, specifically, archaeological heritage. Its importance as heritage is not questioned, either by national legislation or the numerous international conventions signed by Portugal. However, in contrast with the criteria established for the legal classification of cultural assets (national monument, property of public interest) there are currently no criteria made available by the Portuguese state that make it possible to appraise and create a hierarchy of archaeological heritage, establishing different levels of protection and ways of integrating land planning instruments.

The supervisory body for archaeological heritage should establish explicit, consistent criteria that allow us to define: which sites deserve to be safeguarded for future generations, based on their importance as heritage and for scientific reasons; which sites require intervention, preferably as part of research projects; which sites should have priority intervention as part of public enjoyment projects, among other categories.

Value and the need for safeguarding underlie the classification of cultural heritage. Nevertheless, not all elements have the same scientific importance or the same value as assets for public enjoyment. Establishing explicit criteria for appraisal makes it possible to create a strategy for managing integrated archaeological heritage, which makes it possible for us to focus our efforts for protection and safeguarding with specific goals.

In our view, these criteria for appraisal should be based on factors such as

- potential for information,
- state of preservation,
- exceptional nature in the chronological and cultural context,
- ability to be understood by the public.

This strategy, based on the categorisation of archaeological sites, necessarily includes creating a database. Linking the database with a Geographical Information System allows it to be integrated into spatial planning programmes, and at the same time make it available on institutional websites for consultation by different interested parties.

In this respect, GIS can be a dynamic tool enabling management of the underlying variables at the heart of an archaeological heritage database. Something that has been classified as a trail of scattered archaeological material can turn out to be, with archaeological intervention, an important Roman villa, just as a villa can turn out to be completely different from preserved contexts and bring about a change of category. It is also in this dynamic management of information that GIS are precious archaeological management tools.

4. CONCLUSION

The specific nature of archaeological heritage makes it a prime example of spatial planning. On the one hand, it can provide useful knowledge for understanding the organisation and structure of current land but, on the other hand, its consideration and appraisal in the context of spatial management instruments has a long way to go.

There is a legal framework and recognition of the importance of archaeological heritage, in terms of spatial planning. However, there is still a lack of proper interaction, due to an absence of practical guidelines to allow us to use these land instruments, a strategy for protecting and safeguarding archaeological heritage.

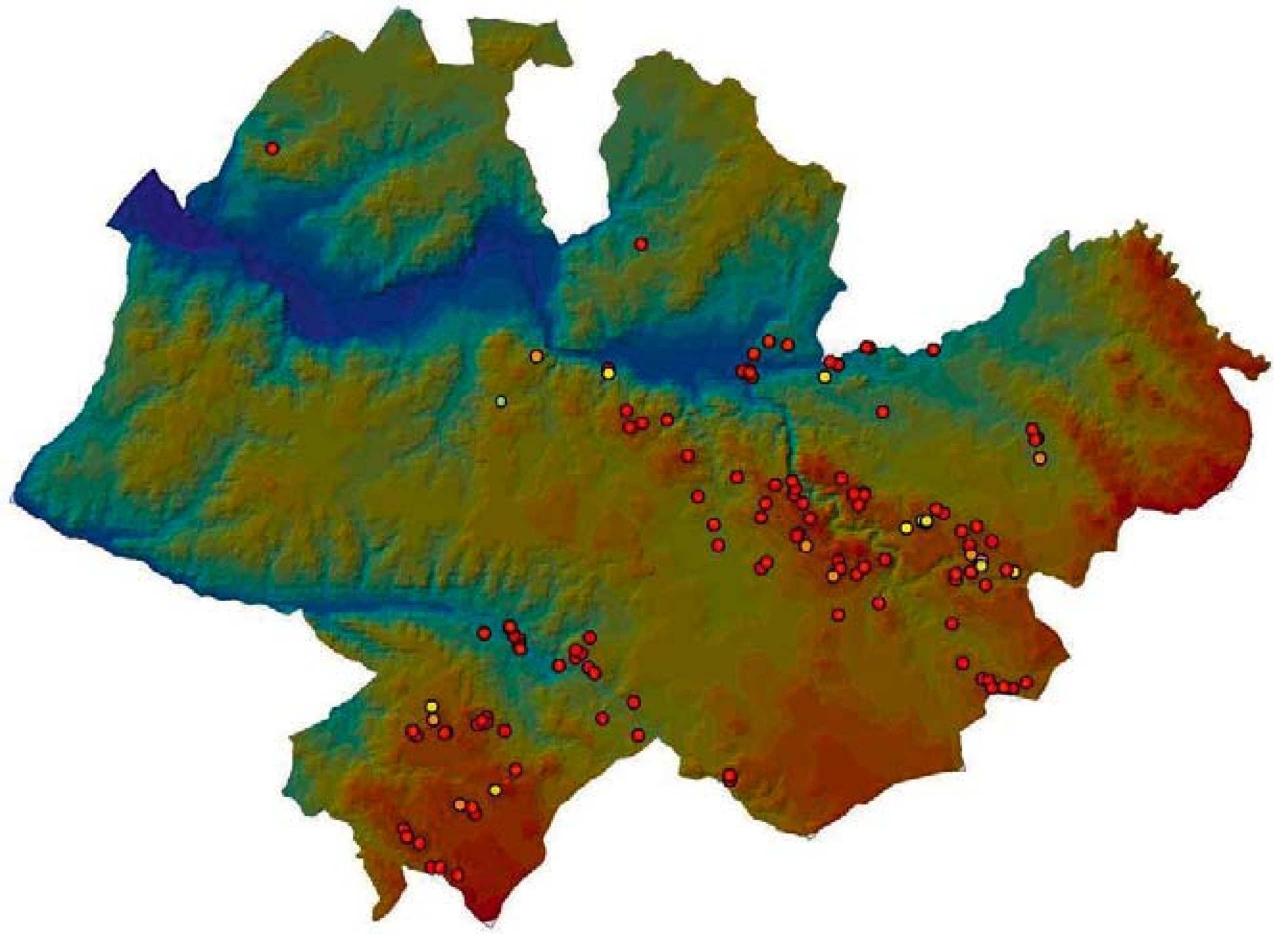

Figure 2: *Location of archaeological sites using GIS technology (county of Mora).*

As we have said, this strategy necessarily includes establishing value categories, based on exhaustive knowledge of the archaeological sites in the country, to allow efforts for safeguarding and protection to be directed based on real values and with specific objectives. In this context, geographical information systems are indispensable tools for properly managing heritage, since they allow all the essential tasks to be performed, from compiling data to the dynamic management of information.

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APIS – ARCHAEOLOGICAL PROSPECTION-INFORMATION-SYSTEM

M. Doneus, U. Fornwagner, C. Kiedl

The aerial archive of the Department of Prehistoric and Medieval Archaeology at the University of Vienna has its roots in the 1960s, when a section for aerial archaeology was founded within the Austrian Society for Prehistoric and Early Historic Archaeology in order to promote the acquisition of aerial photographs in Austria (Friesinger and Nikitsch, 1982). At that time, the first, analogue database was designed to store and manage information on the archive images.

Over the last 50 years, the aerial archive has been constantly growing. At the moment, it comprises more than 120,000 aerial photographs, both obliques and verticals, the latter being on permanent loan from the Austrian Armed Forces. If not made digitally, the aerial photographs are scanned using the Vexcel Ultra Scan 5000. Using its automatic roll film unit, a film is scanned automatically at high resolution. The scanning process of all analogue photographs will be completed in the near future.

The footprints of all images are georeferenced and mapped, which enables fast and easy location and access of the images. During the reconnaissance flights, flightpaths are stored using handheld GPS devices. They provide important information, because they record the areas where no archaeological traces were recorded, although reconnaissance had taken place. The oblique photographs, as well as a considerable number of the verticals, show marks on the ground that can be interpreted as archaeological structures buried in the subsoil. An area of interest covered by such archaeological features is referred to as a "site". So far, the database comprises up to 6,000 sites, more than half of them detected through aerial reconnaissance. The chronology of the sites already dated ranges from prehistoric times up to the present. Within the aerial archaeological workflow, aerial photographs are rectified and stored as orthophotographs. These are consequently interpreted in detail in a GIS-based environment.

Altogether, the aerial archaeological workflow results in an enormous amount of information, which has to be structured and made accessible. The necessity to access and manage not only data for the aerial images but also for the archaeological structures visible on them already led to the implementation of the initial Database in the 1980s (Nikitsch, 1989). This database was restructured in Visual Foxpro during the late 1990s, and in the year 2000 a GIS-based database was implemented in Arcview 3.3 (Doneus and Mayer, 2001). To fully explore its functionality, it has now been redesigned as the "Archaeological Prospection Information System (APIS)" in ArcGIS 10, in co-operation with the company SynerGIS (http://www.esri-austria.at).

APIS, the novel information system based on ArcGIS 10, is designed to store and make accessible all data concerning aerial photographs and archaeological sites, and has been enhanced by a number of additional features, amongst them the option to include information from different prospection methods, i.e. geophysical prospection or field surveying. As different projects based on airborne remote sensing have yielded a huge number of orthorectified images during the past decades, it is now possible to easily access both these rectified images and their metadata (Figure 1) as well as project-related information in APIS. All features visible on the rectified images, archaeological and also geological structures such as palaeochannels, were mapped, so that we are now able to display the aerial archaeological interpretations of about 4,000 sites and access detailed information on each single feature (Figure 2).

The following inventory modules are incorporated into APIS in a Geodatabase:

- Films (containing data about the production of the photographs, as date of flight, used cameras, lenses, films and formats)
- Flight paths (recorded during vertical and oblique reconnaissance flights)
- Aerial photographs (footprints of each image)
- Orthophotos (together with metadata)
- Mapped structures and their interpretations
- Archaeological sites

All relevant data related to each module are entered, managed and accessible directly in APIS. Having different kinds of topographical and thematic (geological, pedological, satellite images) maps in the background, site distributions can be interactively investigated. GPS-recorded flight paths, surveying information and any other kind of mapped data can be automatically loaded and visualised if required. This combination in one single system facilitates an easy workflow, enabling an overview of all archaeological information in Austria known so far and based on aerial archaeological research. Projects and research on integrated prospection methods, landscape approaches, cultural heritage as well as construction projects will benefit from APIS as an up-to-date, straightforward and user-friendly application.

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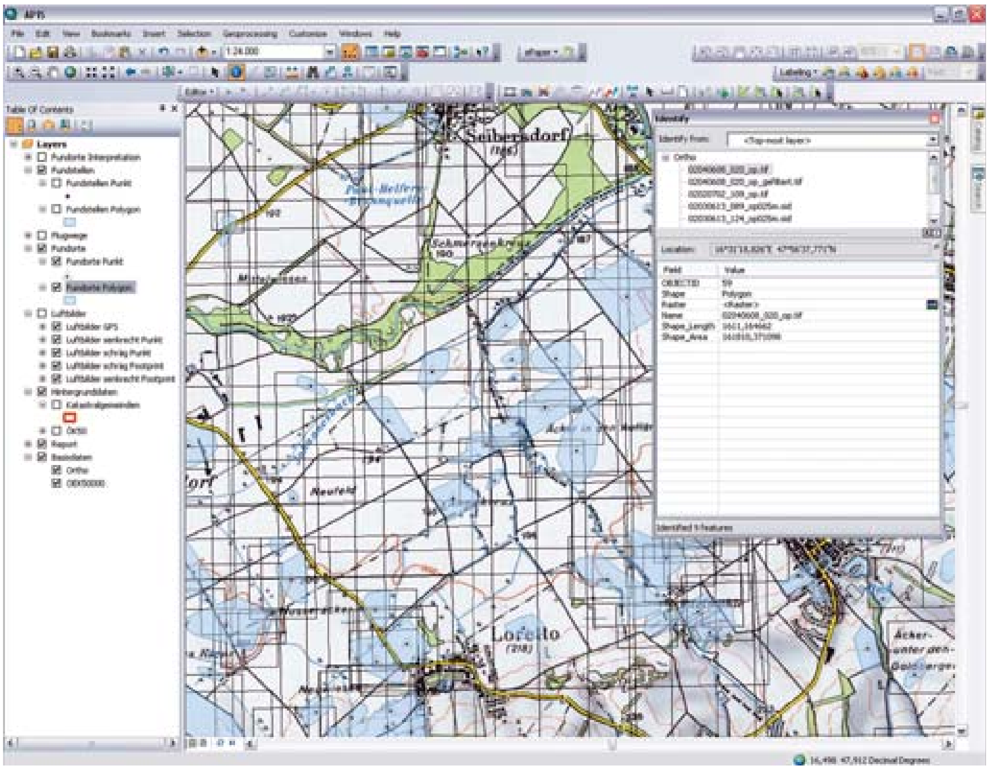

Figure 1: *The light blue polygons represent the sites. Their extents are defined by the archaeological features visible on the orthophotos. The black rectangles represent the footprints of the orthophotos. In the window on the right, a list of all orthophotos covering a certain point on the map and their respective metadata below are displayed.*

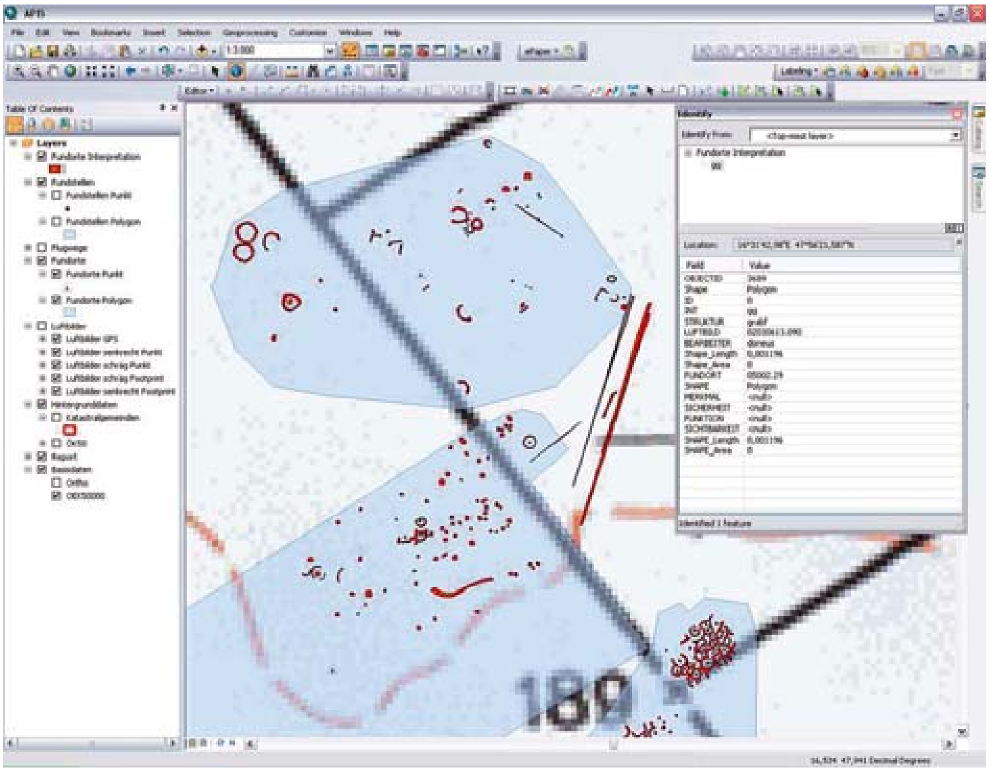

Figure 2: *The archaeological features detected in aerial photographs are displayed in red and detailed information and the interpretation of one single feature are given in the window on the right.*

A MULTI-METHOD EXAMINATION OF AN AMERICAN REVOLUTIONARY WAR ERA HOUSE FORT IN NEW YORK STATE'S MOHAWK VALLEY

M. Rogers, S. Stull

New York State's Mohawk River Valley runs 240 km starting just east of Lake Ontario and connecting with the Hudson River near Albany, New York. During the 18th century the Mohawk Valley was a frontier region with significant economic, military, and political importance in the emerging United States of America. Dutch, French, German, Irish, and Scottish immigrants settled the valley with the establishment of several fortified houses. The way that these houses vary in appearance and spatial organization created cultural identity for each owner. Fort Johnson was built by Sir William Johnson, an immigrant from Ireland who commanded Iroquois and colonial militia during the French and Indian War. Sir William Johnson learned the Mohawk Indian language and customs and was eventually appointed as the Superintendent of Indian Affairs for the Northern Region.

Fort Johnson was the embodiment of Sir Johnson's elite status. The structure is a central passage house with two rooms on either side of the passage, a full second floor with attic, and a working cellar. The attic contained gun swivel mounts in the window frames that were used to defend the house if attacked. Outbuildings provided space for industrial activities, with the house displaying a symmetrical front façade to all who passed by along the King's Road.

Archaeogeophysics, archaeological excavation, architectural examination and historic documentation were combined to obtain a better understanding of how Sir Johnson expressed his cultural identity with Fort Johnson. Ground-penetrating radar, magnetometry, and resistivity surveys of the property surrounding Fort Johnson identified intentional modification of the landscape to include changes over time to access routes to the front door. Excavation identified several layers of varying material to include cobbles, limestone pavers, sand, coal ash, and shale. Ongoing efforts are using 3-D laser scanning to facilitate an architectural analysis of the house, and examining other houses in the valley to better understand this interesting point in American history.

Figure 1: *Ground-penetrating radar survey with Fort Johnson in the background.*

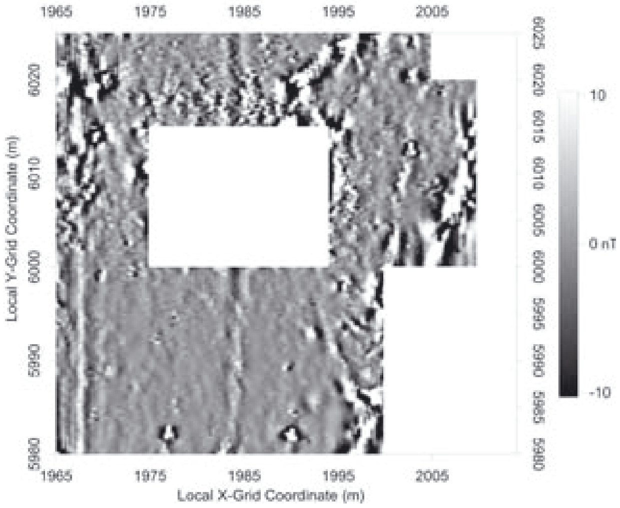

Figure 2: *Results of fluxgate gradiometry survey.*

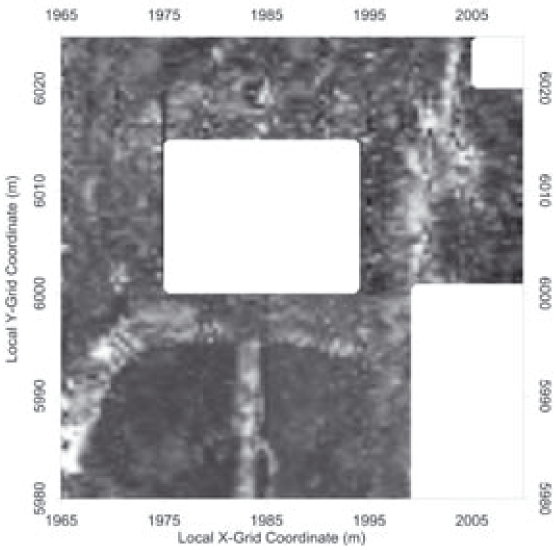

Figure 3: *Results of resistivity survey.*

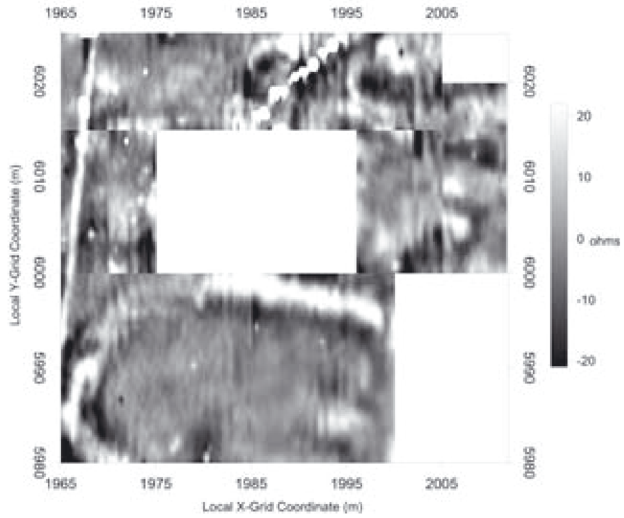

Figure 4: *Ground-penetrating radar time slice from a depth of 52 ns.*

PREDICTIVE MODELLING OF UNKNOWN ROAD AND PATH NETWORKS

W. Vletter

1. INTRODUCTION

In the paper, I will present the preliminary results of research regarding the application of predictive models for reconstruction of unknown road and path networks. The detected road and path networks only partly reflect the whole range of road and path networks that once existed. Roads, paths and tracks can vanish through natural processes, like erosion, or human activities like agriculture and building activities. Together with (palaeo-) environmental information, models can be developed in which the missing parts can be predicted. In this way, the road and path networks can be completed. Therefore, the question is what model based on landscape characteristics, together with known networks, can help us predict paths in order to complete the missing parts of our path networks? In addition, some first implications for predictive models of the research area (Leitha hills, Austria) are discussed.

2. PREDICTIVE MODELLING

Predictive modelling is a technique to predict, at a minimum, the location of archaeological sites or materials in a region, based either on the observed pattern in a sample or on assumptions about human behaviour. Archaeological predictive modelling can be conceptualised as a specialised form of what planners call location-analysis, in which the object is to allocate 'suitable' locations to specific types of human activities (and, by extension, to their archaeological remains), and in which the criteria for suitability are derived by location-analysis – the generation of behavioural rules from a set of observations about how people actually behave or have behaved in the past. One very important reason for producing predictive models is the invisibility of the soil archive (Van Leusen *et al.*, 2005). All predictive models have one thing in common: they are expressions of a probabilistic relationship between human behaviour and prior existing spatial conditions (Whitley, 2005).

A fundamental implicit, but debatable, assumption of all current 'inductive' (and, for that matter, most deductive) models is that the known archaeological remains are a broadly representative sample of all extant archaeological remains (Van Leusen et al., 2005). In practice, quantitative predictive models are almost management-orientated (Whitley, 2005).

Predictive modelling can be carried out in a deductive or inductive manner. Deductive modelling is based on theory and inductive modelling on empirical observations. However, in most of the models a combination of theory and observation is used (Warren, 1990). Hypothesis are built around on identified patterns, forming input for predictive modelling.

In archaeology, most of the predictive models of paths are based on least-cost-path analysis. This is a method wherein the lowest effort for moving between two locations in a certain area is calculated based on a so-called friction surface. In general, the friction-surface is based on the steepness of the terrain (slope). The models can be improved when visibility, waterways, wetland areas and the like are included in the friction-surface. Other applied factors for prediction routes are sky-view-factor and openness. The current models have limitations due to the fact that it is impossible to incorporate all factors. For example, a route that is viable for a walking person can be too narrow or too steep for a horse-drawn carriage. Therefore, different models will be necessary. Moreover, it is not easy to include (changing) soil conditions in these calculations (Doneus, 2013). However, we will incorporate terrain coefficients for different seasons and see how this influences the predicted routes.

Despite the mentioned limitations, predictive modelling in GIS is a necessary technique for discovery and analysis of prehistoric and historic road and path networks. A model that looks appropriate is the Dempster-Schafer Theory, for its applicability in a GIS environment, its capability to deal with uncertainty and its ability to combine different data sources such as soil, height, slope, aspect, geomorphology, groundwater, hydrology and visibility (Kamermans *et al.*, 2009).

Dempster Shafer Theory (DST) provides a less rigid framework for archaeological application than most other approaches do. As defined by Dempster (1967) and Shafer (1976), it is built around the concept of belief, which is a somewhat more relaxed, generalized version of mathematical probability. The theory's hallmark is its capability to explicitly represent uncertainty. In predictive modelling, uncertainty often arises because there is direct evidence for the presence of a site, but only indirect evidence for absence of one. Concerning the relevance of environmental input data, new relevant data sources like LIDAR data elevation models, geological borehole databases, historical maps and remote sensing images are recommended (Kamermans *et al.*, 2009). In the following case study of the Leitha Hills this kind data has been investigated.

3. CASE STUDY LEITHA HILLS

In the Leitha research area, LiDAR is the only effective prospection technique because of the dense (forest) vegetation. Therefore, we will not use other remote sensing images, and combine geological maps (Figure 2), Airborne Laser Scanning data (Figure 1) and historical maps (Figure 3). Airborne Laser Scanning (ALS), the airborne variant of LiDAR, has increased the research possibilities in forested areas in a spectacular way (Doneus et al., 2010). LiDAR, like RADAR, is an acronym and stands for light detection and ranging, which describes the method of determining three-dimensional data points by the application of a laser. It is an active remote sensing technique, using either ground-based (Terrestrial Laser Scanning (TLS)) or airborne systems (Airborne Laser Scanning (ALS)) (Crutchly, 2010). ALS is able to 'see' through the trees. More precisely, a 3-D model of the ground surface can be built from the returning pulses, which are not blocked by the tree canopy. This explains why we can expect more returning pulses from the ground surface with deciduous trees in the winter. However, the surface cover, such as piles of leaves or brush, and snow height also affect the quality of the laser scanning.

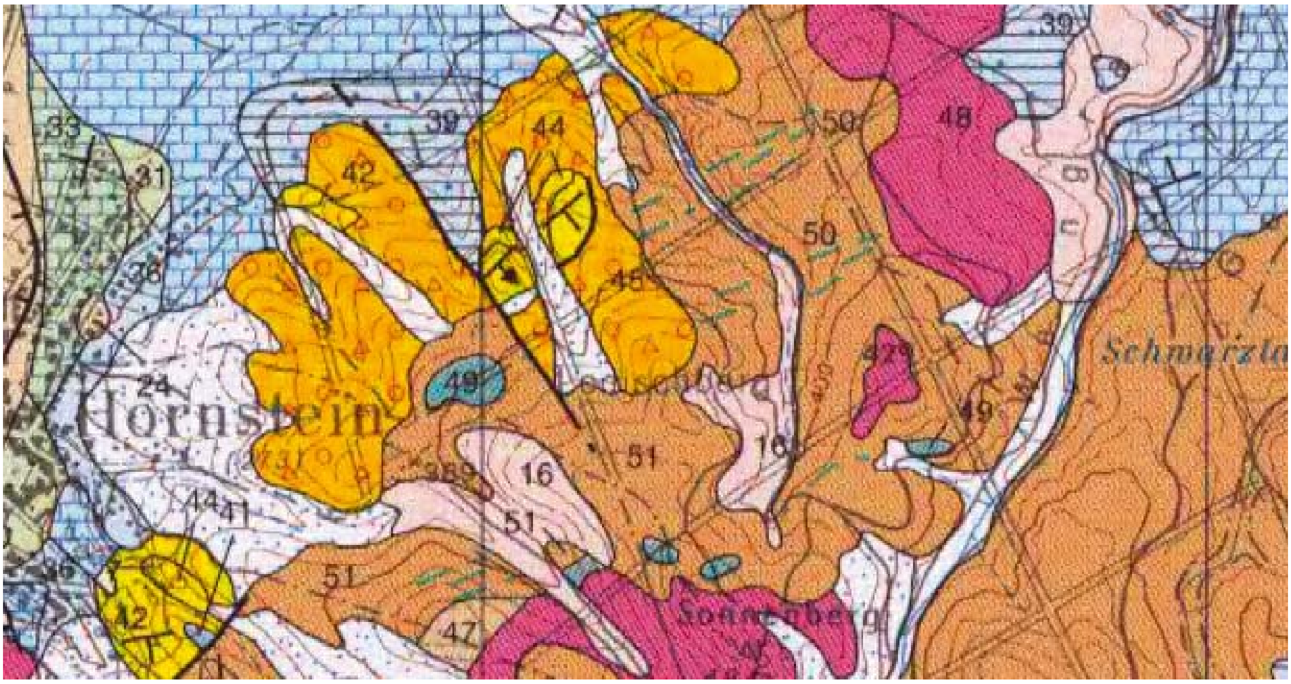

Figure 1: *Geological map near Hornstein in the Leitha hills (source: Austrian Geological Service).*

From examples in South America, we know that roads can be found on a certain soil type (Murrieta-Flores, 2010). This is an important consideration when examining roads and paths detected by LiDAR. However, one should remember that roads and paths might be better preserved on certain soil types. Knowledge of different preservation characteristics of soils can of course provide interesting information about the historical landscape. If no roads and paths are found on ALS data on a certain soil type, historical maps can be used as a secondary information source for identifying historical roads and paths. In addition, historical maps can also to be used for verifying linear features that have been interpreted as roads and paths. A disadvantage of historical maps is that they often lack accuracy and their reliability. LiDAR can help here to correct the course of roads and paths when maps are digitised, for example, when maps are combined with a Digitial Elevation Model (DEM).

The first results of the Leitha hills suggest that the different soil types (mainly limestone-derived) have not influenced the location of roads and paths very much. Other environmental factors have played a more important role. For example, a lot of roads are located in (dry) river valleys. The great number of roads and paths found, and the number of roads that have shifted, indicate that the soil is in general rather soft. These results are to be taken into account for the predictive model to be built. Further, the scale of the available historical maps and information on them did not prove to be very useful for the research goal (Figure 3). Therefore, more detailed cadastral maps will be examined as an additional data source.

4. FURTHER RESEARCH

In future research, the predictive model will be further developed and its function will be statistically tested to judge the quality. Other models, like dynamical system modelling, will be investigated. The environmental parameters will be further determined and will be checked in the field.

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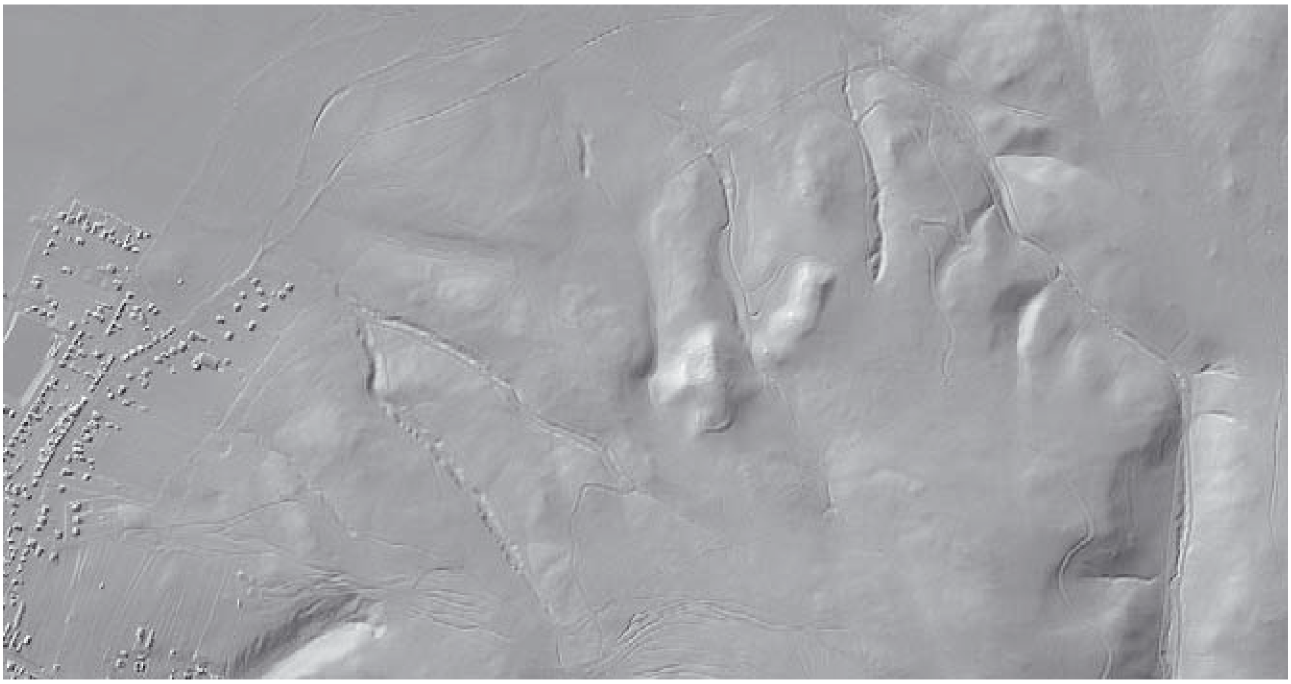

Figure 2: *DEM based on ALS data near Hornstein (source: Michael Doneus, Wien University).*

Figure 3: *Detail of historical map near Hornstein (1869-1887) (source: Hungarian cartographical state service).*

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GIS-BASED MODELLING OF THE DYNAMIC DEVELOPMENT OF CENTRAL PLACES

K. Tolnai

After the fall of the Roman Empire, new central places emerged in many different ways in Europe. In the area of the former Roman Empire, towns emerged in the early Middle Ages, where people could express their social status, and/or their secular or religious power (Wickham, 2001). In the northern and eastern part of Europe, however, in the regions of Scandinavia and in the Slavic world, settlements were founded mainly along trading routes. One of the key features of the Northern towns was that they were often connected to each other by waterways (Clarke and Ambrosiani, 1991).

In historical and archaeological research, the development and decline of these early centres are analyzed from different points of view, and their importance in medieval town formation is frequently discussed. Furthermore, the social rank and hierarchy of sites within a wider region is analyzed likewise. The determination of site-hierarchy is based both on the features at intra-site level and on the organization of settlement structures in a landscape context. However, questions remain regarding how different kinds of data can help in the determination of settlement hierarchy.

The historical development of the sites within the landscape can be observed at both the intra-site and landscape scale. Data from archaeological excavations are traditionally used to determine intra-site dynamics, while landscape elements are mainly recorded by prospection and topographical survey methods. The integration of different kinds of data can be performed using geographical information systems (GIS), in which spatial and temporal modelling methods help to analyze how people acted in the landscape and how land-use is reflected in the environment (Allen *et al.*, 1990; Neubauer, 2004; Wheatley and Gillings, 2002).

In this presentation, archaeological interpretation of geophysical prospection data is shown from two different geographical and historical contexts. In both cases, excavation and prospection data from medieval central places will be analyzed in urban and landscape contexts, aiming for an improved understanding of their spatial organization and hierarchy. From Scandinavia, the Viking Age settlement of Birka (Sweden) within the Mälar region is presented, and from the former Roman province of Pannonia, Visegrád and the Pilis region (Hungary) is displayed (Figure 1). In both examples, the research is based on the integrated interpretation of prospection and excavation data in order to provide new results on the layout of such sites and land-use patterns in the surrounding landscape.

The region around Lake Mälaren, the northern agricultural zone of Scandinavia, witnessed the rise of the Swedish kingdom from the seventh century. In this region, a great number of different types of late Iron Age and Viking Age remains were found. Birka, founded around ca. AD 750, is located on the island of Björkö, one of the major islands of the Lake Mälaren. The main part of the settlement was located in the Black Earth (Svarta Jorden) area. The settlement of Birka is also known from written evidence. The treaties of Adam of Bremen and the work of Rimbert indicate that Ansgar, the Archbishop of Bremen, visited Birka twice, in AD 829-830 and AD 851-852. Furthermore,

Figure 1: *Case study areas in Europe. Birka & Lake Mälaren. Sweden (upper), and Visegrád and Pilis region, Hungary (bottom right).*

when Archbishop Unni of Bremen passed away during a missionary journey in the 930s, his body was buried at Birka.

In 1871-1890, Hjalmar Stolpe excavated an area of 3000-4500 m^2 in Birka's Black Earth. During these excavations, he found a hoard of silver jewellery and 450 Arabic coins, the latest minted not earlier then AD 962. As no Anglo-Saxon coins were found in Birka, its decay is now dated to ca. AD 970. Between 1990 and 1995, Björn Ambrosiani conducted the Birka Project, excavating some 500 m^2 and recovering a huge number of archaeological finds (e.g. a bronze caster's workshop, buildings, housing plots, traces of track ways).

In the cemeteries, several different grave types were observed, including burial mounds, boat-shaped stone settings and triangular graves with concave sides. Furthermore, 1,600 burial mounds lie outside of the rampart separating the cemetery of Hemlanden from the Black Earth, and another 400 lie south of the hill-fort. Viking Age harbours were also recorded on the coast of Björkö in front of the Black Earth (Clarke and Ambrosiani, 1991; Ambrosiani, 1993; Ambrosiani, 2008). Birka might have had strong connections with the aristocratic or royal residential site of Hovgården on Adelsö, which was occupied from the seventh century onwards. The Pilis area, on the other hand, as a part of the medium regni, the triangle of the royal towns of Esztergom – Székesfehérvár – Buda, played a crucial role as a royal centre, hunting domain and site of military structures in the Hungarian Middle Ages.

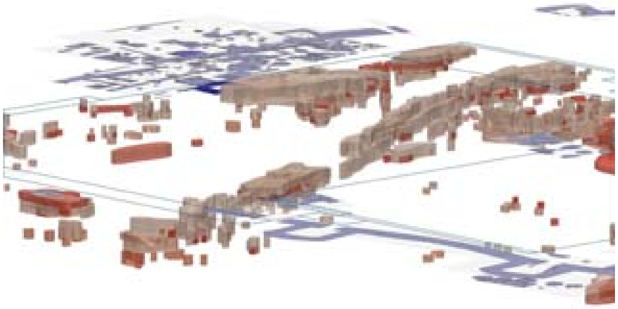

Figure 2: *3D visualization of the GPR data combined with excavated data.*

The *medium regni* was the most densely populated area of the Kingdom in the heart of which was the Medieval Pilis, located at the Visegrád Mountains and the Pilis mountains. The area first belonged to the early county of Visegrád, later to the counties of Pest and Pilis. The forested areas of Pilis were a part of a royal forest, being continuously a royal property. A dense network of royal residences developed here from the eleventh century (Szabó, 2005).

Settlements were also identified within the forested area, based on written documents and field walking. At Visegrád, an early royal administration centre was identified located on the Sibrik-hill. The main structure of this centre was a Roman fortification built in the 4th century AD and rebuilt in the 10th century. At that time a new function was given to the deserted, but presumably still standing Roman walls, and it became an administrative centre or a royal residence. Besides the fortification, other remains of the centre were also unearthed on the hill: a two-phased church with cemetery, a settlement with a parish church and its cemetery, and the ruins of a monastery all illustrate the importance of the site (Buzás, 1999).

The historical sources and archaeological remains of the study areas offer the opportunity to analyze primary data from several different perspectives. One of these is the complex topographical analysis of the main complexes (royal castles, monasteries, settlement sites, land-use patterns, industrial sites, etc.). Their spatial distribution pattern can be investigated as a part of environmental-historical research based on former archaeological investigations and on recent prospection methods.

From a methodological point of view, the analysis is based on different datasets forming different scales of information. At the intra-site level, features detected by geophysical measurements are interpreted and compared to excavation data (Figure 2). Although the precision of data acquisition in geophysical prospection is highly developed, there is a continuous need for the improvement of the archaeological and chronological interpretation of the data. In that regard an optional solution is to combine stratigraphy with ground penetrating radar data at different spatial resolutions, resulting in a stratigraphic interpretation of the data and enhancing its potential use in a three-dimensional interpretation process. In that sense, the aim of the research is the development of a structured approach for interpreting intra-site geophysical prospection data. Another research approach is the potential use of geophysical data in the assessment of the temporality, by identifying the main stratification of the features; in other words, to combine depth information with horizontal data and to combine the measured depths with the stratigraphy (Figure 3). Data integration and visualization is performed with GIS, where features are stored with their accurate geographic location two-, and three-dimensionally, and temporal information is managed (Langran, 1992; Green 2011). Technically, as a first attempt, features identified layer by layer in the GPR data are digitized and stored in a geodatabase. Base heights and descriptive information is given to each feature (Figure 4). Attribute lists are prepared and a coding system is developed and added to features of the same kind in order to create a framework for the interpretation. Coding and interpretation are supported by excavation data if available from the same sites. Excavated features will also be stored in the database to create a basis for the comparison.

In order to be able to better interpret the features at a given site, additional comparison of the features of the same kind is needed. Therefore, as a next step of the analysis, intra-site data will be extended with large-scale prospection data or descriptive secondary sources to determine the geological, archaeological and environmental parameters of the studied landscapes.

The potential of the integrated use of the different kind of prospection and excavation datasets is presented on that scale. Spatiotemporal visualization methods are also studied in order to evaluate the possibilities for modelling the dynamics or the processes of an area, and to determine the site distribution and site hierarchy of the studied landscapes. Drawing from the archaeological interpretations, the dynamics of the land use is presented and visualized for both landscapes.

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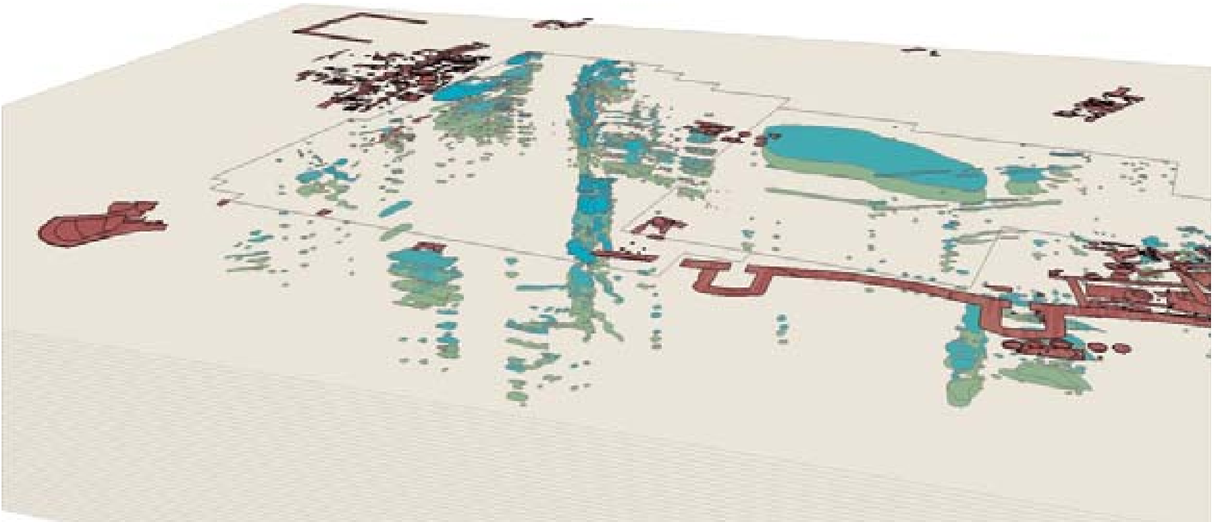

Figure 3: *3D visualization of the GPR depth information.*

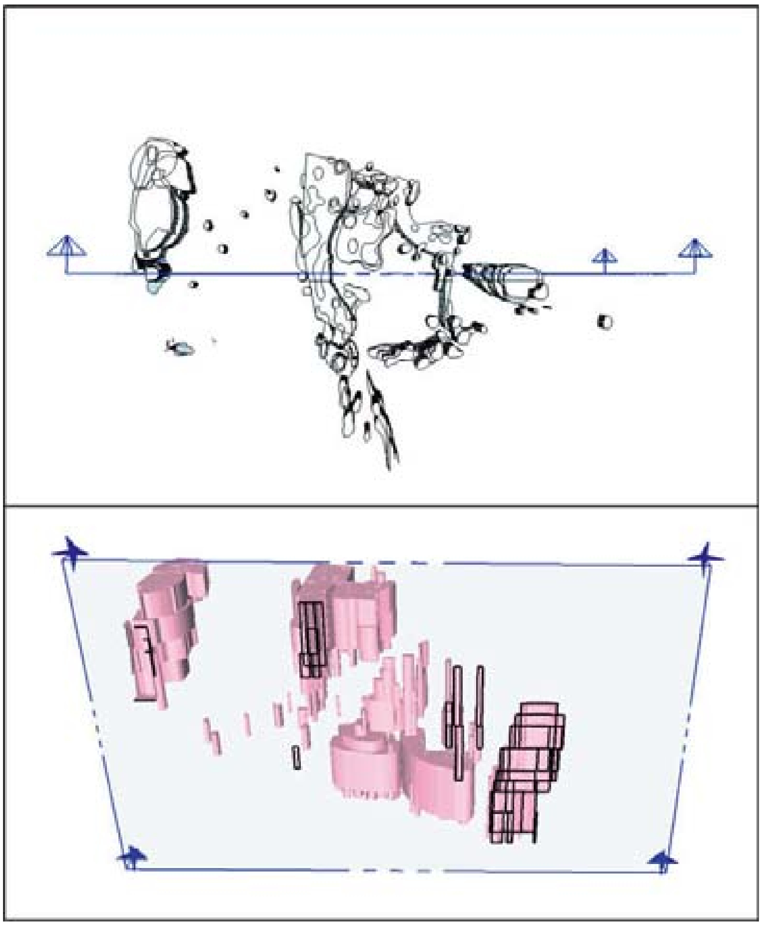

Figure 4: *Displaying stratigraphy within the measured data.*

TEXTURE SEGMENTATION AS A FIRST STEP TOWARDS ARCHAEOLOGICAL OBJECT DETECTION IN HIGH-RESOLUTION SATELLITE IMAGES OF THE SILVRETTA ALPS

K. Lambers, I. Zingman

1. PROJECT BACKGROUND AND GOALS

Since 2007, the Silvretta Archaeological Project in the high Alps on the Swiss-Austrian border has been investigating the prehistoric origins of alpine pasture economy. In an area of about 540 km^2 more than 20 well-preserved archaeological sites associated with alpine pastoralism have been recorded, the earliest of them dating to the Iron Age (Reitmaier (ed.), 2012; Walser and Lambers, 2012). All of the ruined huts, cellars and livestock enclosures at these sites are visible on the surface and show a limited range of shapes and proportions. According to their function, all of them are located in open grassland.

Based on this sample, we are currently developing methods to detect archaeological objects of the kind described above in high-resolution satellite images of our study area (Lambers and Zingman, in press). These methods are intended to assist archaeological survey in vast and/or difficult to access areas by screening large amounts of remotely sensed images in order to detect possible archaeological sites prior to fieldwork (Cowley, 2012).

Our general approach aims at assessing the probability of the presence of objects of our interest based on geometric cues that can be automatically detected in the satellite and aerial images that we use. We here describe our general methodology and the first integral step constituting a new approach to texture segmentation.

2. IMAGE DATA

We use GeoEye-1 satellite images of our study area captured on September 6, 2011. These images feature a panchromatic channel and four colour channels (RGB + NIR) with a spatial resolution of 0.41 m (pan) and 1.64 m (VNIR), respectively. The bundle product that we ordered comprises the panchromatic channel and pansharpened colour channels. Due to legal regulations, after pansharpening all channels were downsampled to a spatial resolution of 0.5 m pixel size. This is also the spatial resolution of our second image data set, a Swisstopo orthophoto of our study area based on aerial images taken between 2005 and 2008.

While lower than that of most aerial images, a spatial resolution of 0.5 m still allows for the detection of structures pertaining to our target objects. Their characteristic size varies roughly between 10 to 100 pixels. Their walls are generally two pixels wide or more. Reliable detection of structures of a few pixels in width is very limited, and in some cases it might not be achievable at all. However, in our case the second dimension of walls, whose length is usually above 10 pixels, makes this task still possible.

3. GENERAL METHODOLOGY

Our method is designed to assess the probability of the presence of archaeological objects of the type described above in a given area based on their geometric properties. Such structures can be modelled as linear features that meet at approximately right angles. In our approach, image features of growing size and complexity are extracted in several stages. In the first stage, local features such as black and white blobs stemming from the background are extracted from the image. This stage can be implemented by means of white or black top-hat transforms (Soille, 2003) or their combinations.

Chains of blob features with possible gaps in between may form linear features. During the second stage, we group extracted blobs into larger, approximately linear features that may correspond to the walls of ruins of huts and enclosures. Near-right-angle intersections of linear features that may be defined by corner points are then searched in the next stage. Evidence of structures of interest can then be inferred from extracted linear features and other contextual keys, if available, for instance surrounding texture.

The output of the last stage is a probability map indicating the presence of objects of interest. Such a map will have zero values at most regions, and a continuous range of probability values at other regions. This map can be further thresholded at the level corresponding to an acceptable rate of false detections.

For our general approach to succeed, it is essential to discriminate between smooth and high contrast texture regions in our images. This is the first step of our approach that is already implemented and that we describe in the following.

4. MORPHOLOGICAL TEXTURE CONTRAST (MTC) TRANSFORMATION

Texture is generally associated with repeated changes in image grey level. In remotely sensed images such as the ones we use in the Silvretta region, high contrast textures are, for example, forests or urban areas (Figure 1). Large amounts of local features are usually extracted in texture areas in the first stage of the described methodology. This is because the local operator does not distinguish isolated features, like blobs or lines, from features that belong to a texture. Grouping at the following stages does not suppress these features since they are easily grouped with other surrounding texture features, resulting in unexpected false detections.

To overcome this problem in areas such as forests, urban areas or rocky mountains, we developed a new texture detector that filters out high contrast textured regions irrespective of texture type. Since the objects of our interest are located in open grassland, i.e. outside the above-mentioned areas, this procedure reduces the number of false detections without affecting sensitivity to true examples.

The approach that we introduced recently (Zingman *et al.*, 2012) is called Morphological Texture Contrast (MTC) transformation since it is based on mathematical morphology, which has proven to be very efficient in the processing of remotely sensed images (Soille and Pesaresi, 2002). In comparison to many other texture detection approaches developed to discriminate different types of texture, the MTC transformation is insensitive to texture

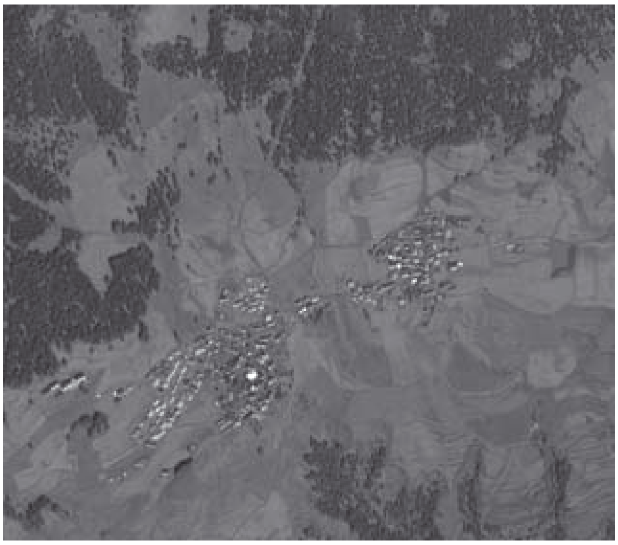

Figure 1: *Pan-chromatic image of 4000 × 3500 pixel size and 0.5 m pixel resolution captured by the GeoEye-1 satellite (©GeoEye 2011, distributed by e-GEOS).*

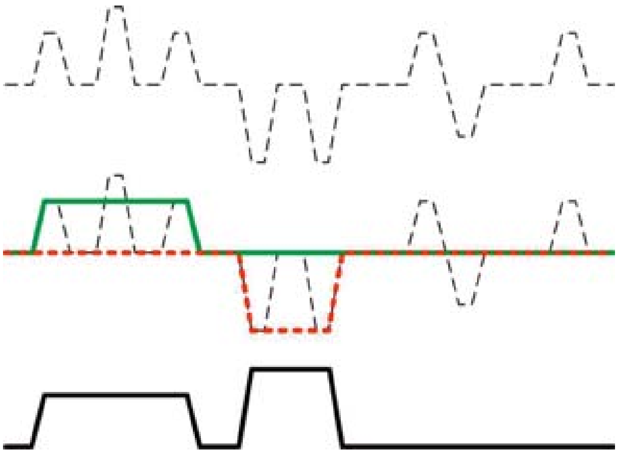

Figure 2: *Top: A 1D signal composed of two textured regions and two isolated features on the right side. Middle: the green signal is an upper texture envelope, the red dashed-line signal is a lower texture envelope. Bottom: The MTC transformation. It is proportional to texture contrast and yields suppressed response at isolated features. Note that the salient feature on the top of the left texture (in the middle) is also suppressed.*

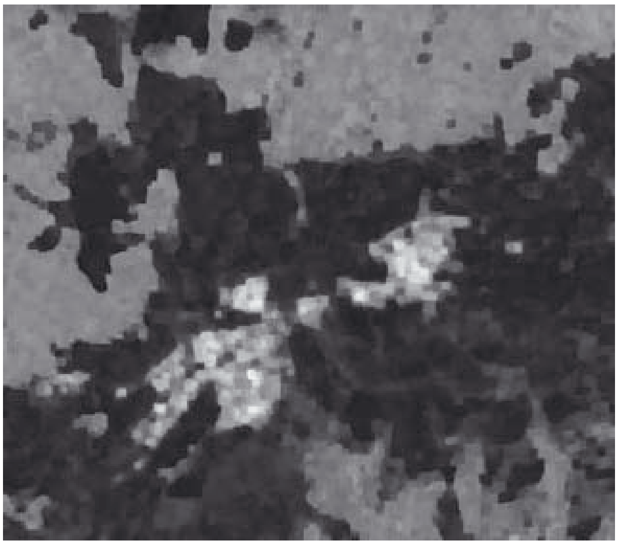

Figure 3: *The MTC descriptor applied to the GeoEye image shown in Fig. 1.*

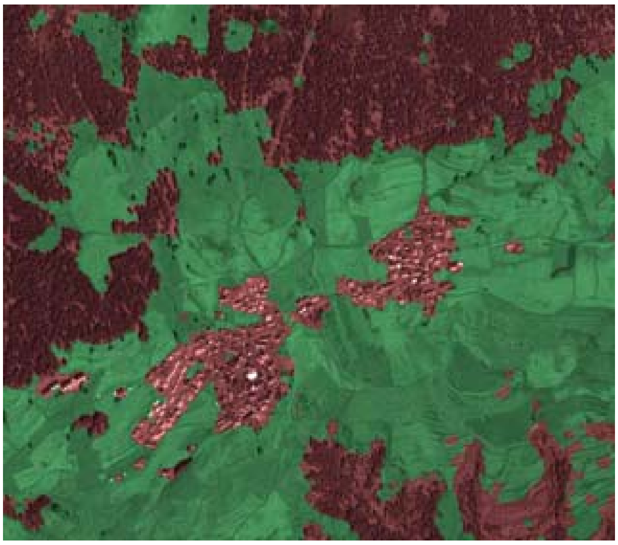

Figure 4: *The segmentation result as obtained by automatic thresholding of the MTC descriptor superimposed on the GeoEye image shown in Fig. 1. Brownish areas correspond to high contrast textured regions, greenish areas to low contrast textured regions.*

properties except of texture contrast. It is intended to discriminate smooth regions corresponding to our regions of interest from regions with high contrast texture, such as forests, urban or rocky areas in remotely sensed images. An essential property of our detector is the ability to provide a low response at isolated or individual features, even if they are of a high contrast, a result that is currently not achieved by other techniques.

The MTC transformation is based on morphological alternating filters, namely morphological closing followed by opening and opening followed by closing (Serra 1988, Soille 2003). These operators are usually used for the suppression of noise in images. We use these operators to build a transformation proportional to texture contrast. The MTC transformation is obtained by taking non-negative values of the difference between morphological closing followed by opening and opening followed by closing. Negative values of the difference are substituted by zero values at the output of the MTC. This transformation results in high response at textured areas and low response at isolated features and in smooth regions.

While in our project the MTC transformation is applied to 2D images, the underlying idea is more easily explained by using an artificial 1D signal as shown in Figure 2. The MTC transformation measures the difference between the upper and lower envelopes of texture providing a response proportional to texture strength. These envelopes, obtained using alternating morphological filters, coincide at isolated features, resulting in a suppressed response at such features. This capability of the MTC

transformation is not available in other approaches.
Figure 3 illustrates the MTC transformation applied to the 2D satellite image of 0.5 m resolution shown in Figure 1. High response, corresponding to bright grey values, is generated in texture areas, while low response is produced in smooth areas and at isolated features.

The distribution of grey levels in the transformed images is highly bi-modal, with one mode corresponding to texture regions (high grey tone values) and the other to smooth regions (low grey tone values). These two modes can easily be separated by finding an appropriate threshold. This provides us with a segmentation that defines two disjoint masks for texture and smooth areas. We used the Otsu thresholding method (Otsu 1979) to find an appropriate threshold automatically. This approach corresponds to an unsupervised classification scheme since input data does not need to be labelled. The segmentation result in Figure 4 is superimposed on the initial image to emphasize the alignment of the results with the original data. As can be seen, the segmentation is quite accurate at the borders of texture regions.

So far, our tests show the MTC transformation to be relatively fast. An image of 6100×5000 pixels is processed in about 21 seconds by our code written in Matlab installed on a standard PC equipped with an Intel Core2 Quad 2.83 GHz processor. This processing time corresponds to a square analysis window of 40×40 pixels. Our technique does not require parameter tuning except for a single scale parameter that defines the size of the analysis window. This parameter should just be roughly adjusted to the characteristic size of texture. For remotely sensed images, it is related to their spatial resolution and the distances between objects on the ground. The technique is robust to illumination changes within the image and also works well with images from different sources. Though our technique was developed to analyse remotely sensed images, its application is not limited to this type of data.

5. SUMMARY AND OUTLOOK

We have identified more than 20 sites in the Silvretta region with ruins associated with alpine pastoralism. These sites are currently serving as examples for the development of automated methods to detect similar sites in high-resolution satellite images. Using a texture segmentation technique that we recently developed, we segment the images into regions of interest and other regions based on texture contrast. This step is a prerequisite for object detection, for which further steps have yet to be developed. By filtering out textured regions where no archaeological objects are to be expected, our approach will greatly reduce false detections.

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DIGITAL PHOTOGRAMMETRY IN MICROGRAVITY DATA PROCESSING: A CASE STUDY FROM ST. CATHERINE'S MONASTERY, SLOVAKIA

J. Panisova, M. Fraštia, T. Wunderlich, R. Pašteka

1. INTRODUCTION

Digital photogrammetry is widely applied in archaeological investigations and the preservation of architectural heritage. The use of the microgravity technique for cavity detection in the exploration of historical buildings requires the calculation of additional corrections that take into account the gravitational effects of surrounding man-made structures (buildings, known underground spaces – cellars, tunnels, crypts). The capability of close-range photogrammetry to improve microgravity data processing was introduced by Panisova *et al.* (2012), where a new method for calculating building corrections based on photogrammetric reconstruction was used. The following case study demonstrates the application of this method with a microgravity survey undertaken at the Slovak archaeological site of St. Catherine's.

The ruins of St. Catherine's monastery are located on a rocky hill in the woods of Little Carpathians in Western Slovakia (Figure 1). A Franciscan monastery was founded in 1618 in an area where a 15th century Gothic chapel dedicated to St. Catherine of Alexandria was situated. The original monastery church was rebuilt in 1646 to a larger Early Baroque edifice with dimensions of 52 $\times$ 13.5 m and with a 30 m high tower. The presbytery of the church was built on the stone foundations of the former Gothic chapel. The monastery complex was abolished by the order of the Emperor Joseph the Second in 1786 (Herceg, 2009).

The preservation project of the St. Catherine's monastery started in 1994. In the framework of this project, complex historical, archaeological, anthropological and geophysical research has been conducted at the site since 1997 (Herceg, 2009). The main objectives for geophysical survey were 1) to map the shallow parts of the subsurface and 2) to identify archaeological anomalies, i.e. potential areas for further archaeological research.

2. PHOTOGRAMMETRIC PROCESSING

The convergent multi-station photogrammetric method was used for the digital spatial reconstruction of the church. The images were taken with calibrated digital cameras, the Olympus C-8080 and Nikon D-200. The photogrammetric processing of the project was carried out using PhotoModeler 6 software (www.photomodeler.com). Exterior and interior parts of the church have been processed separately. Both parts were combined into one project using control points measured by a total station. The reconstructed three-dimensional model of the building comprises 4800 spatial points and 1600 surfaces determined from 46 digital images.

Because it was impossible to use the photogrammetric methods in the interior of the tower due to its narrow and elongated shape, a different approach had to be selected. A Trimble VX total station with built-in camera was used to measure the interior of the tower from the ground. The entire vector model displayed in Figure 2 includes all surfaces of interior and exterior parts of the church and the tower. A total model accuracy of 0.018 m (a mean spatial error) calculated from all points was achieved.

3. MICROGRAVIMETRY

A microgravity survey was undertaken to investigate the area inside the former church, where along with the known aristocratic crypt excavated in 2001 (plan view in Figure 4) another two crypts are supposed to be located. This area was surveyed on a closely spaced grid of 258 stations with a point spacing of 1 m (Figure 3). A Scintrex CG-5 gravimeter was used to acquire the gravity data. The instrumental drift was estimated by regularly repeated readings at a selected base station at hourly intervals. Statistical analysis of the repeated stations from different days provided a mean squared error of less than 4 µGal.

Subsequent data processing included free-air, planar Bouguer, topographic and building corrections. The terrain corrections were computed up to 5.24 km. A density of 2.4 g/cm^3 was used for the calculation of the planar Bouguer and terrain corrections. The final model of the church (Figure 2) served as the direct input to our program for the calculation of the building corrections (Panisova, 2012) that is based on the 3D polyhedral body approximation introduced by Götze and Lahmeyer (1988). The building correction (Figure 3) was calculated for a mean density of 2.2 g/cm^3. The results from the microgravity survey are displayed in the form of a residual Bouguer anomaly map (Figure 4a), with the regional trend removed. Two interpretation methods – Euler deconvolution and harmonic inversion – were used for the estimation of the depth and size of the anomalous sources.

The harmonic inversion method (Pohánka, 2003) enables us to find the position and shape of a set of anomalous bodies embedded in an a-priori known horizontally layered background. The method provides several admissible subsurface density models for the residual gravity field, so the comparison with other interpretation techniques as well as other geophysical methods is necessary to select the most feasible one. The structural index in Euler deconvolution related to the attenuation with distance of the potential field was set to one, thus detecting a horizontal cylinder in gravimetry.

In Figure 4c, the density distribution for 1.8 m depth obtained by means of harmonic inversion is displayed, along with the Euler deconvolution solutions denoted by filled circles. Figure 4d shows selected vertical sections of the density model in two profiles crossing the main gravity low produced by the known crypt. The average depths (approximately 1.6–2.0 m) of the solution cluster fit into the estimated depths of the air-filled crypt obtained by means of the harmonic inversion method.

Figure 1: *Aerial photograph of the St. Catherine's monastery ruins (Herceg 2009). The inset shows a map of the location of the site.*

4. GROUND-PENETRATING RADAR

In order to eliminate the ambiguity inherent in microgravity method, the residual Bouguer anomaly map was overlapped and compared with GPR results from eastern part of the nave (Figure 4b). GPR measurements were taken using a GSSI SIR-20 system with a 400 MHz antenna. Thirty-six GPR profiles were acquired in zig-zag mode with 0.15 m line spacing. For time/depth conversion, the wave propagation velocity was estimated by diffraction hyperbola fitting with an average value of 0.09 m/ns. Processing steps for each profile consisted of t0 - corrections, offset removal, direction ordering and the creation of time slices.

In the GPR horizontal time slice (20–40 ns, approx. 0.9–1.8 m depth, Figure 4b), two distinctive reflection anomalies indicate the existence of two features of archaeological interest. The GPR time section presented in Figure 4e (Profile A in Figure 4b) corresponds to about 0–3.2 m in depth. The top of the known air-filled crypt (C1) is indicated by a strong, almost horizontal reflection, which is caused by the dielectric permittivity contrast between soil or concrete and air. The hyperbolic reflection below is caused by a post, which was installed to support the concrete cover protecting the excavated crypt (Herceg, 2009). The second, almost horizontal reflection at about 25 ns can be interpreted as the bottom of the crypt, taking the high velocity in air (0.30 m/ns) into account. The chaotic reflection patterns of features C2 and C3 suggest that the expected crypts are destroyed and filled by debris. The depth to the top of these crypts is estimated to be around 0.5 m.

The vertical density section (Profile A, Figure 4d) can be correlated with features seen on the GPR vertical time section (Figure 4e). For the air-filled crypt excavated in 2001, the dimensions ($5 \times 1.9 \times 2$ m) and position (its top is situated in a depth of 0.6–0.8 m below the ground) have been confirmed by both geophysical methods. The other two features, which were successfully detected and delineated by both methods, most likely relate to two crypts documented in historical archives. The GPR and microgravity results indicate that these two objects could be partially filled. Recommendations for archaeological excavation were given to the site-excavators.

5. CONCLUSIONS

Close range photogrammetry as a recording technique is an indispensable tool for the preservation of architectural heritage. We have shown that the digital models of the historical buildings can be directly utilized for the calculation of their gravitational effects in microgravimetry. A novel approach of microgravity data processing is designed particularly for archaeological applications.

This case study illustrates the advantage of combining geophysical methods that are based on different physical parameters. The combination of microgravity and GPR surveys has proved to be a very effective and non-destructive tool for archaeological research. The geophysical results obtained could be incorporated to the virtual databases, where valuable monuments are documented for next generations.

ACKNOWLEDGEMENTS

This work was performed mainly with the support of the VEGA Slovak Grant Agency under projects No. 1/0680/10, 1/0095/12 and 2/0067/12, partially with the support of the Slovak Research and Development Agency under the contracts No. APVV-0194-10 and APVV-0724-11. We would like to thank Prof. Hans-Jürgen Götze and Dr. Sabine Schmidt from Kiel University for their subroutine that calculates the gravity effect of triangle. We are also grateful to Vladimír Pohánka from the Geophysical Institute of the Slovak Academy of Sciences for his scientific support with the calculation of the subsurface density distribution using his harmonic inversion method.

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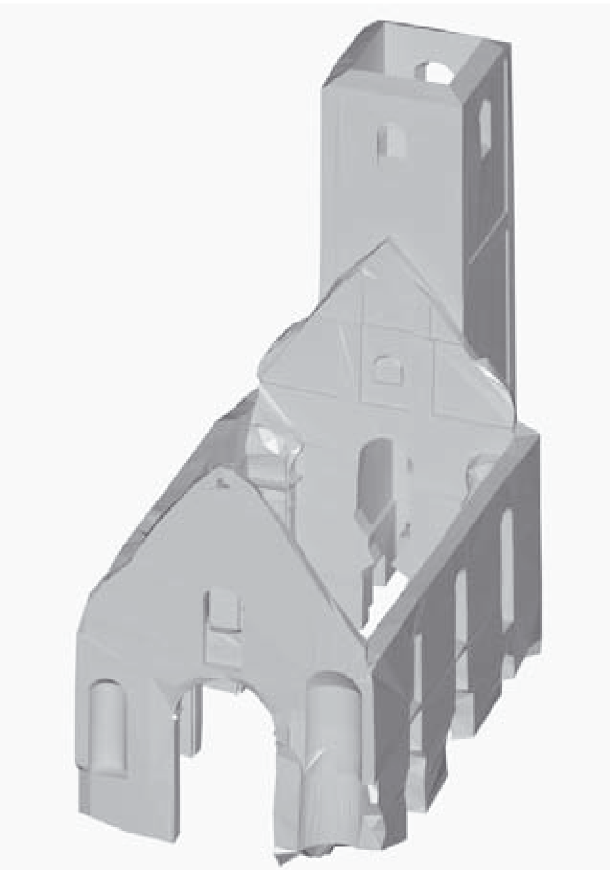

Figure 2: *The polyhedral model of the church.*

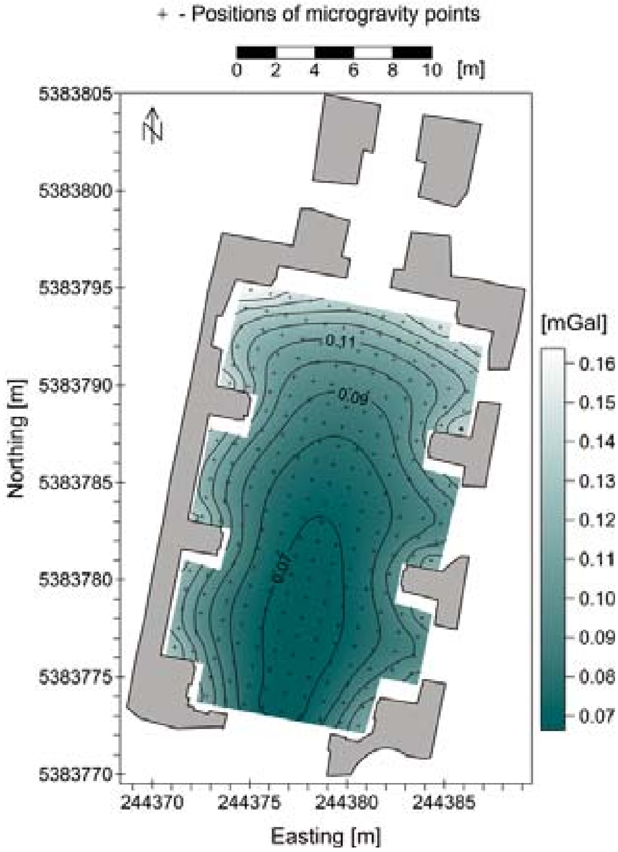

Figure 3: *The building correction in mGal computed from the polyhedral model of the church (Figure 2) for an estimated density of 2.2 g/cm*^{3}*, displayed within the plan of the church.*

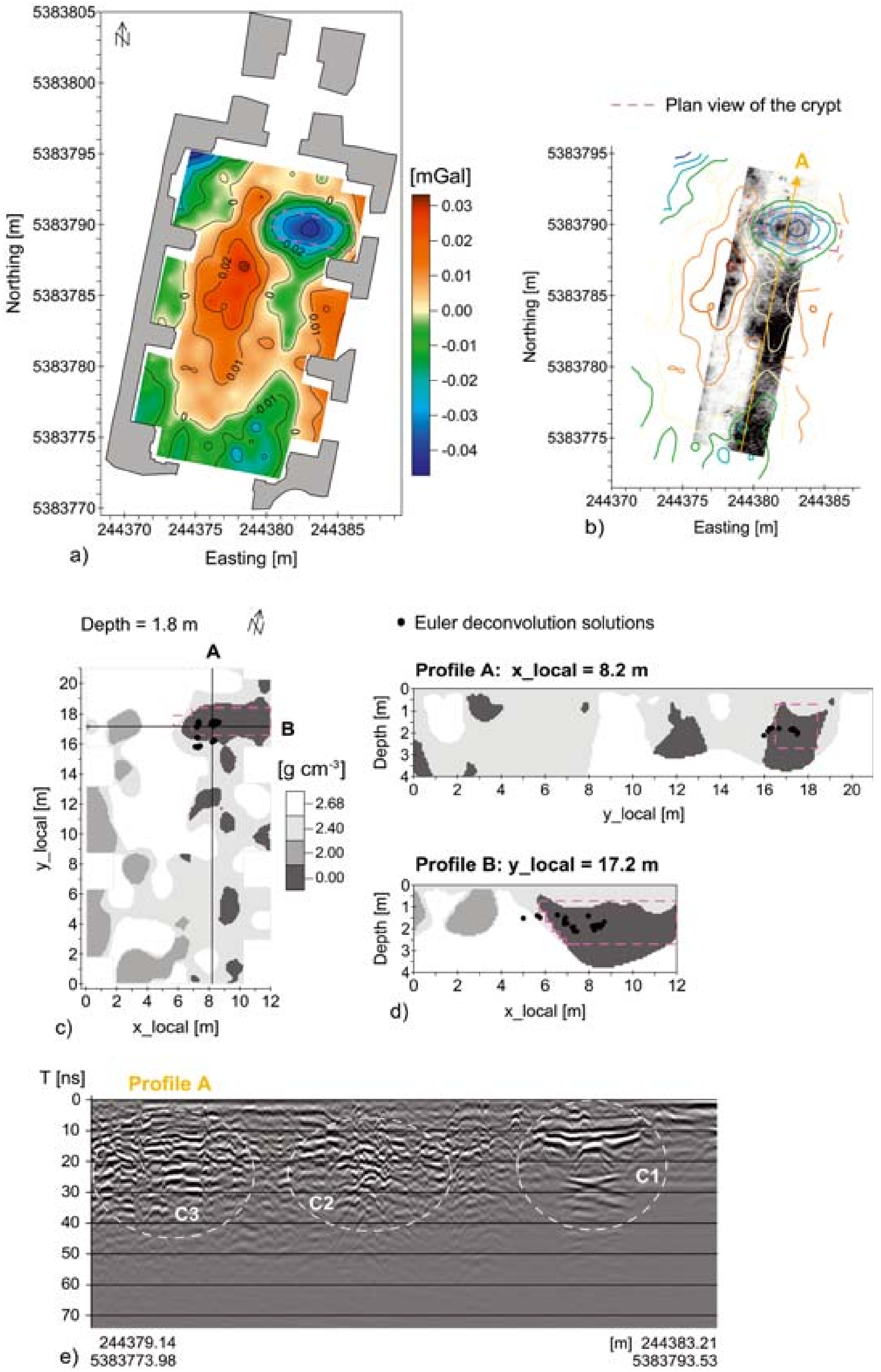

Figure 4: *4a) The residual Bouguer anomaly map in mGal. 4b) The GPR horizontal time slice stack between 20–40 ns (approx. 0.9–1.8 m depth) displayed along with the residual Bouguer anomaly contours. 4c) The interpretation of microgravity results using the harmonic inversion and Euler deconvolution methods for a depth of 1.8 m. 4d) The density distributions in two vertical sections for profiles A and B; the filled circles denote the positions of the 3D Euler deconvolution depth estimates. 4e) The GPR vertical time section (Profile A) running in SW-NE direction.*

FLASHRES64: A FULLY-THREE-DIMENSIONAL ELECTRICAL IMAGING INSTRUMENT?

F. Pope-Carter, R. Fry, C. Gaffney, A. Schmidt

ABSTRACT

The paper displays the recent research undertaken on the applicability of the FlashRes64 electrical imaging system to undertake fully three-dimensional resistivity surveys. Comparisons are made to more traditional semi-fully three-dimensional surveys, and lab and fieldwork tests are displayed.

1. INTRODUCTION

The FlashRes64 is a novel electrical resistivity imaging instrument which, as a multi-channel, free-configuration system is not constrained in its data collection by any one conventional array geometry (Zhe *et al.*, 2007; Fry *et al.*, 2011). The FlashRes64 system undertakes a resistivity imaging survey by recording all possible combinations of potential measurements from a set pair of current electrodes, which change position at each measurement step. For a line of 64 electrodes, 62 potential measurements are made every second for a selected current (source and sink) combination. This allows for extremely quick data acquisition and a vast increase in the spatial resolution of the survey. The system allows for two survey modes, a 'Quick Survey' that can collect 15,151 data points within 9 minutes, and a 'Normal Survey' mode that can collects 64,424 data points within 40 minutes of survey. Each survey can be processed as a full 'tomographic' dataset or can be decomposed into conventional array geometries that can then be combined together as conventional overlays. In previous examples (Fry *et al.*, 2011; Fry *et al.*, 2012), the system has shown to be a great aid to archaeological detection in 2D and semi-fully 3D collection methodologies. This paper will introduce and assess the viability of the instrument to undertake a fully three-dimensional survey methodology, using examples from both lab tests and fieldwork across England.

2. FLASHRES64 3D METHOD

The FlashRes64 system is designed to collect data simultaneously in many array types, and collect data at a much faster speed than traditional ERI survey instruments. This is due to the novel 62 channel collection method explained in Fry *et al.* (2011). Using this data collection technique, as many potential measurements are made as possible, providing a rich and detailed high-resolution resistivity point cloud beneath the ground surface. An extraction software program developed at the University of Bradford (Pope-Carter, 2012) is able to extract conventional array datasets (consisting of pseudo-Wenner, Wenner-β, Wenner-Schlumberger and Double-Dipole) as well as a non-standard optimized dataset which can be combined together as one mixed array. This software outputs data straight into the format used by Res2D/3DInv and BERT inversion software.

Due to the unique way the system collects data, full 3D methodologies are now possible by positioning electrodes in a grid system over the archaeological target. This results in data being collected in a three-dimensional data cloud beneath the surface, which can provide a more accurate 3D inversion to visualise the archaeological target beneath. Previous studies (Berge and Drahor, 2011) have shown that data collected in this manner reflect subsurface resistivities more accurately.

3. ELECTROLYTIC TANK EXPERIMENTS

Comparison tests between semi-fully three-dimensional and fully three-dimensional data collection methods were carried out in a deep water tank at the University of Bradford with promising results. A highly resistant 'Segmented Donut' feature (consisting of gravel held together with duct-tape) was suspended beneath the surface over which the electrode arrangements were tested.

Semi-fully three-dimensional data was collected using six traverses spaced at 25 mm with probes spaced at 12 mm. Fully three-dimensional data was collected using an 8 by 8 grid with probes spaced at 24 mm. Data was extracted from both the semi-fully three-dimensional and fully three-dimensional datasets using the array based extraction program and inverted using RES3Dinv. The resultant inversion data was then exported to Paraview for visualisation. From the resultant inverted datasets, the fully three-dimensional data was found to more accurately model the donut shape of the feature (Pope-Carter, 2012).

4. COMPARISON OF ERI METHODOLOGIES OVER STRUCTURES – TEMPLE NEWSAM, LEEDS

A test was conducted over the area of a suspected stable block at Temple Newsam (Leeds UK). FlashRes64 and Allied Associates Tigre ERI surveys were undertaken on the same day over an area previously surveyed with a Geoscan twin probe array. Semi-fully 3D surveys at a probe separation of 0.5 m and a traverse interval of 1 m were conducted with an Allied Associates Tigre and a FlashRes64 instrument for comparison (Fry *et al.*, 2012). A smaller area was chosen for further investigation with a full-3D field setup. This involved placing electrodes in a grid position over a rectangular building seen at greater depths. Three surveys were conducted, two with a grid (7 m $\times$ 7 m) set up at 1 m probe separation and the third grid at 2 m probe separation (grid size of 14 m $\times$ 14 m). The 1 m separation surveys were combined prior to inversion to create a rectangular survey area (Figure 1).

From the data collected from the fully 3D surveys (Figure 2), it is clear that in this instance, the fully three-dimensional 1 m survey was capable of defining the discrete feature under investigation. However, the high resistivity feature is also visible in the 2 m survey. This is due to the increased spatial resolution of the smaller probe spacing at shallow depths. The fully three-dimensional surveys do not exhibit striping artefacts that were present in both semi-fully three-dimensional surveys, and the feature under investigation is considerably clearer and more defined in the 1 m fully three-dimensional survey than in the semi-fully three-dimensional surveys.

Currently, 3D data collection requires data to be collected using the full survey mode, meaning that the three dimensional dataset can be collected in 40 minutes. It is hoped that further development of the extraction software, including the ability to extract sensitivity and noise optimized datasets, will result in an even faster data acquisition time. The table below shows the results for the comparison tests taken over Temple Newsam.

5. CONCLUSION

The FlashRes64 system provides rapid data acquisition for examining changes in the electrical resistance of the earth with depth, and is the first to demonstrate the potential of a free-electrode-configuration system for archaeological prospecting. One of the biggest advantages of the system over current methods is the speed at which the system can collect data, enabling a full 2D section to be recorded in 9 minutes at its quickest configuration. Development of fully three-dimensional surveys with the system is possible and has shown to have added advantages in terms of feature definition.

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Survey	**Instrument**	**Total data points collected**	**Array selected**	**Time (per survey traverse : for entire survey)**	**Available survey solutions**
Semi-fully 3D survey	Tigre ERT	418	Wenner	47 minutes : 2.5 days	2D survey Quasi-2D survey Semi-3D survey
Semi-fully 3D survey	FlashRes64	15,151 (short survey mode)	Free configuration 'tomographic array' Wenner*, Wennerβ*,Double-Dipole*, Wenner Schlumberger*	9 minutes : 5 hours	2D survey Quasi-3D survey Semi-3D survey
Fully 3D survey	FlashRes64	64,424 (long survey mode)	Free configuration 'tomographic array' Wenner*, Wennerβ*,Double-Dipole*, Wenner Schlumberger* Square α^{*+}, Square β^{*+}, Squareγ^{*}	40 minutes	Full 3D survey

* pseudo array with extraction program $^{+}$3D surveys only

Table 1: *Comparison summary of the two systems.*

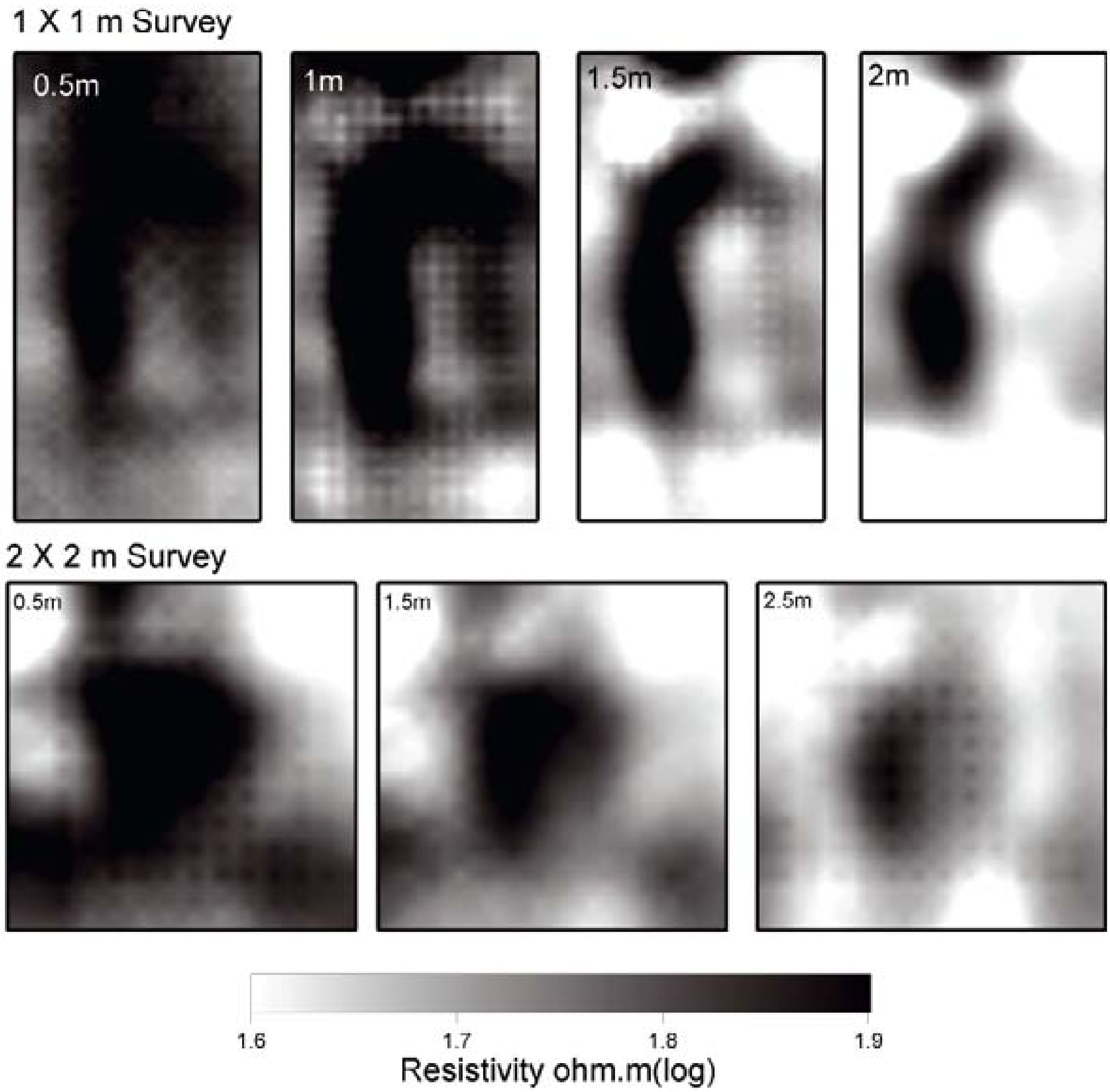

Figure 2: *Comparative plot of all the electrical imaging surveys undertaken imposed on the original earth resistance grayscale.*

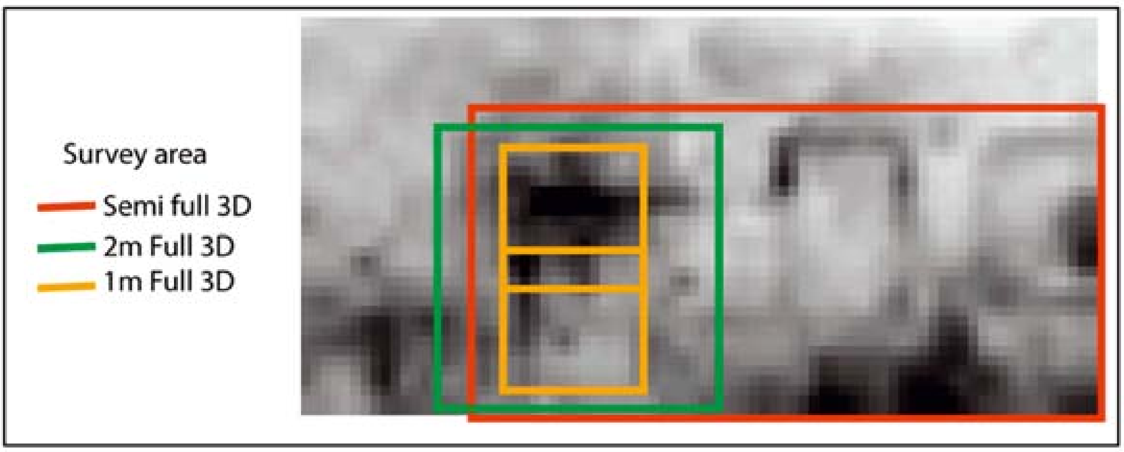

Figure 3: *Comparison of the 1 m, 2 m and Semi full 3D survey*

HISTORICAL MAPS AND ARCHAEOLOGICAL PROSPECTION

I. Kuzma, M. Bartík, M. Bielich, E. Blažová

1. INTRODUCTION

Historical maps have always been a valuable resource for historians, historical geographers and archaeologists. The documentary value that maps offer lies in possibilities for the application of several methodical approaches as well as for the search of new ones. A very significant contribution for the use of historical maps is in connection with remote exploration, with aerial prospection, ortophoto images, satellite images, LIDAR or geophysical methods. However, the criteria for research work are met only by the form and content of the maps from the first to the third Austrian military mapping. The originals of the maps from all the three military mapping campaigns are stored in the Austrian state archives in Vienna (Österreichisches Staatsarchiv, Abteilung Kriegsarchiv). Their gradual publication on DVD by the Budapest company Arcanum was a great help for research: the 1st mapping was produced in 2004, 2nd mapping in 2005, and 3rd mapping in 2007 (www.arcanum.hu).

These military maps capture not only information on respective categories of land use, settlements and objects significant from the military aspect, but also contain indirect information on archaeological objects, many of which may be confirmed by the results of archaeological prospection. They are objects of several categories, either directly visible in the terrain (prehistoric and medieval fortifications, barrows) or the objects which cannot be observed anymore. Depending on several factors, the facts/objects drawn in on historical maps can be more or less imprecise. In contrast, the aerial image is a precise proof of the existing state: imprecision comes from the interpretation of its content. In favourable cases, if objects can be identified in aerial images, data from the maps may be corrected as well. Another stage of prospection is geophysical exploration. In our case, the Fluxgate-Magnetometer made by Sensys Company (Germany) was used. Results were processed in three different software packages: Magneto software (Sensys), freeware MagPick (Geometrics), and Oasis Montaj 7.0 (Geosoft). An interpretation of the established measurements was attempted.

2. JANÍKY, PART DOLNÉ JANÍKY, DUNAJSKÁ STREDA DISTRICT, "CSILLAGVÁR"

The military maps frequently contain small medieval fortresses, which are labelled as "Sancz/Alte Schanz, Várhegy" (Figure 1, A), and some of them have been preserved until the present. One example is the earthworks of Csillagvár from the 17th century in the cadastre of the village (Drenko, 1970). It may be identified on all three mappings, but shows up best on the first one. On the second map, it is situated on the connection of map sheets, and on the third its greater part is covered by the mark of the measurement position.

The fortress has been repeatedly documented for several years through aerial prospection, and can also been seen on the images from GE (Digital Globe, Eurosens/Geodis). Csillagvár is situated approximately 50 m from the bank of the Little Danube. The fortification consists of earthworks in the shape of an irregular hexagon with dimensions of 112.6 × 102.2 m. It was protected by a moat with entrances situated on the north-eastern side towards the river. In 1968, there was an archaeological project here, during which 13 hollows in the internal area were explored. The most significant finds included silver Kreutzer of Emperor Leopold I from 1698 and silver Kreutzer of the Olomouc Bishop Charles of Lorraine of 1701 (Drenko, 1970).

In 2012, M. Bielich conducted geophysical survey on the inner area using a Fluxgate-Magnetometer from the Sensys company (Germany), with one probe 20 cm above ground level. The measured area reached 18 × 35 m with a point density of 0.5 × 0.05 m. The evaluation was done using Oasis Montaj 7.0 software. Anomalies with intensity from 3 nT to -2 nT can be distinguished on the resulting magnetic map. Anomalies correspond with the results of Drenko's research, and probably represent an inner built-up area (Figure 1, C). So far, there are no written documents about the fortification, but it can be dated to the end of the 17th century, or the beginning of the 18th century.

3. SOKOLCE, KOMÁRNO DISTRICT

Several circular objects were detected on the map of the 2nd military mapping – the map sheet Sectio 47, Colonne XXVII. Eight of such objects are recorded in the cadastres of the villages Sokolce, Brestovec, Bodza, Ižop, Holiare, Vel'ký Meder, and Zemianska Olča. They form two lines running in the N-S and NW-SE direction. They are depicted as double small circles with interruptions of no unified orientation, being oriented towards all cardinal points. (Figure 2, A). So far, only one of them, in the Sokolce – Turi village cadastre, was verified by aerial prospection. For the first time the structure of a slightly oval shape with double line of ditches reaching 65 m in diameter was detected in May 2000 (Kuzma *et al.*, 2001), and then documented as late as in June 2006 (Kuzma and Bartík, 2008). It appeared as an oval positive vegetation attribute with two lines of ditches, the outer only partially visible, and the inner one with interruption (Figure 2, C). It is situated on a low dune (110.6 m), much higher than the surrounding terrain of 1.6 m.

In February 2012, Bielich conducted geophysical measurement again using the Fluxgate-Magnetometer from Sensys, in a five probe configuration with horizontal distance of 25 cm and height of 20 cm above ground level. The measured area reached 100×100 m. The data were processed with MagPick 3.0 software. On the resulting magnetic map, it is possible to distinguish anomalies with intensity from 10 nT to – 15 nT. The given anomalies are concentrated into two closed geometrical shapes, which is a set of two ditches (Figure 2, D). The diameter of the outer ditch is 70 m, the inner one 50 m. Based on geophysical measurement, the width of the ditches fluctuates between 4 – 5 m.

Another object of this type was identified in the Sokolce – Lak cadastre during the analysis of images on GE. It is situated about 640 m away, also on a low dune (elevation 110 m) that rises high above the surrounding terrain. It is a slight oval with dimensions reaching approximately 70 m in the NE-SW

Figure 1: *Janíky, Slovakia A. Old mapping, B. Aerial photography, C. Geophysical measurement- Magnetic map of anomalies, D. Topographical model of fortress.*

and 65 m in the NE-SE direction. The interruption drawn on the map on the southern side cannot be observed.

4. ŠTÚROVO, NOVÉ ZÁMKY DISTRICT

A large fortification system has been found in Štúrovo. In 2000, aerial prospection detected an extensive medieval earthwork running for 1,900 m from its eastern end (Kuzma *et al.*, 2001). It appeared as positive crop marks. In 2005 and 2009, we also photographed the closure of the fortification in the west, so that its entire length was now 2,800 m. The fortification had been a part of the fortification system that served for defence of Esztergom during the Ottoman wars. The Ottomans conquered Esztergom in 1543 and built up a bridgehead on the other side of the Danube.

The fortification appeared solely as positive cropmarks. On photographs from 2000, 2001, 2004, 2005, 2008 and 2009 it could be seen in green corn, and on photographs from 2006 in ripe yellow corn before harvest. The whole fortification was only seen in 2009, while in other years only some sections of it were visible. For creation of the fortification plan, we therefore used oblique aerial photographs from several seasons (Figure 3, A).

The fortification is an open fortification consisting of a straight line with smaller outworks in form of redans with a straight front, with dimensions 12×25 m, placed evenly in distances of 70 to 80 m. Three further fortifications stick out from the line; they are shaped as a bicorn composed of two redans, or in two cases they have the form of pincers with dimensions 60×47 m (Figure 3, D), and they functioned as barbicans. They are placed at distances of 380 and 450 m, but are not marked on any map available. According to the fortification elements, they belong to the Dutch or French fortification school.

On the map of the first ordnance survey (and on other maps) the fortification is not included. It can be seen for the first time on Matej Bel's map of Esztergom county (Mappa Comita-

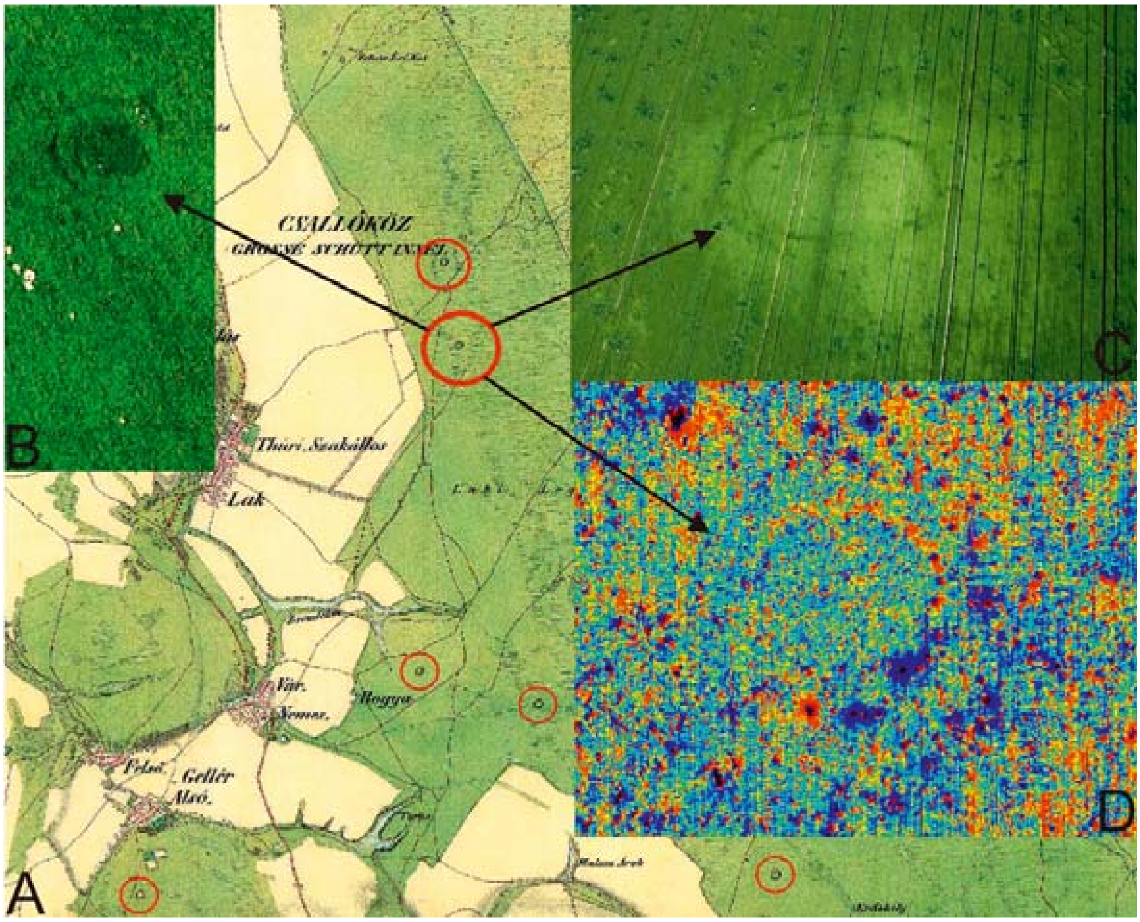

Figure 2: *Sokolce, Slovakia A. Old mapping, B. and C. Aerial photography, D. Geophysical measurement- Magnetic map of anomalies.*

tus Strigoniensis, Methodo astronomico geometrica concinnata) made around 1740 by Samuel Mikovíni, where the fortification is drawn and corresponds to our findings. Since forty years had elapsed between Mikovíni's survey and the first ordnance survey, a possible explanation could be that the fortification, which no longer fulfilled its original purpose, was levelled for use as agricultural land, and thus has not been preserved. An analogous situation is known from the north-western Czech Republic, where a 35 km long line with 35 fortifications was levelled after Napoleon's defeat at Leipzig, and was later identified by aerial survey (Smrž and Hluštík, 2007). Another map where the fortification is featured comes from the Episcopal archives of Esztergom and shows the fortification in the 16th and 17th centuries. It is marked as "Régibb sánczok" (older ramparts) together with other fortification structures and lines, representing a classical Italian system from the 16th century (Figure 3, C). However, a pulp mill and the development of Štúrovo destroyed these fortifications. The third map we have obtained is a map from 1604 made by Giowann Dominico Jaciotto (Figure 3, B). It is an interesting, and the most accurate, representation of the whole fortification system of Esztergom. Our fortification runs eastwards, and next to its eastern end on aerial photographs the map contains a small hexagonal redoubt. However, this has been destroyed by modern construction in the area, just like the continuation of the fortification in the east.

On all three maps, the fortification is drawn relatively similarly. The difference between the representation on the maps and aerial photographs is that the straight line on the photographs extends into the curved line reminding of a hexagonal redoubt with bastions 207 m in diameter, while on the maps the straight line adjoins the curved line. We assume that originally, there was a straight line, into which a curve was inserted, and the original one was then levelled. From the point where the line turns towards the Danube, its function is not clear. In this way the fortification may have been reduced, but it could also have been strengthened towards the west, so that it would have formed its second line. This could be confirmed by the data on the 1604 map, where the legend for this part of the fortification says "Secondo…", while for the section documented by us it says "Primo…".

In 2009, a ditch was cut near the road to create a channel for a water pipe. The channel profiles were cleaned and documented. The ditch was 430 cm wide and 180 cm deep to the bottom of the channel. Out of the profile character and the slope of the ditch walls, we assume a round bottom. The fill of the ditch was relatively homogeneous and no traces of repair or maintenance were recorded.

In 2012, Bielich conducted a magnetic survey using the Sensys fluxgate magnetometer in the five probe configuration with a horizontal distance of 25 cm and height above ground of 20 cm. The survey covered an area of 100 $\times$ 300 m focused on a part of ridotto with bastions on the eastern side of fortification. Data were processed by Magneto software (Sensys).

The result of geophysical measurement were linear mag-

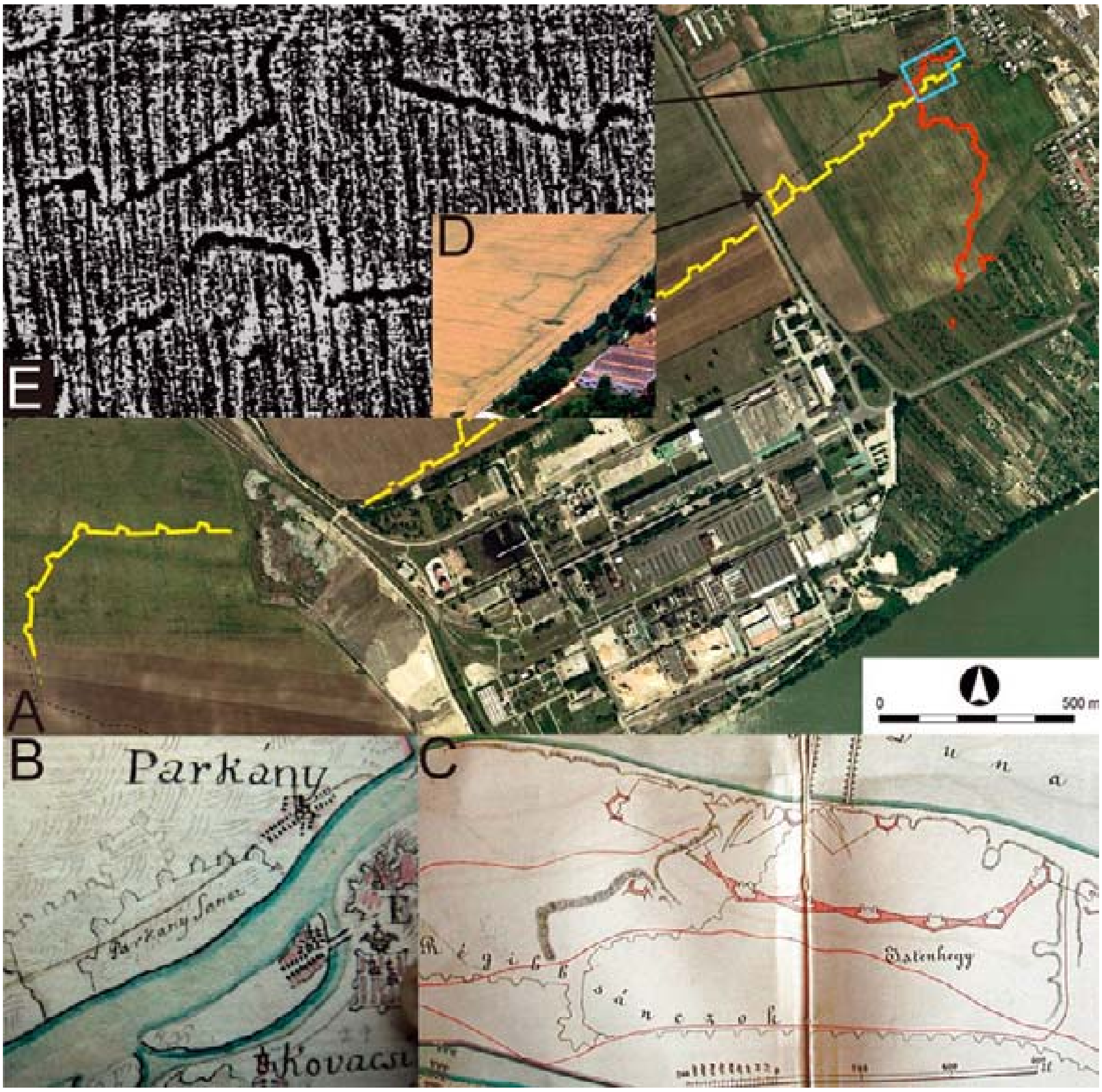

Figure 3: *Štúrovo, Slovakia A. Aerial photography of the area, B. and C. Old mapping, D. Aerial photography, detail of the part of fortification, E. Geophysical measurement- Magnetic map of anomalies.*

netic anomalies which show archaeological structures – ditches and furrows (from -2 to 2 nT/m). Magnetic anomalies show recent metal artefacts with magnitude from -550 to 770 nT/m. The rough terrain reaches magnitude from -3 to 3 nT/m (Figure 3, E).

Štúrovo is an excellent example of the usefulness of combining information from historical maps with that of aerial prospection. Yet it also shows the limits of both sources. As for historical maps, further sources may appear in the future, which may provide additional details related to the fortification. However, the possibilities of aerial prospection are practically exhausted. The only area today that is not built up, where the fortification could still be seen, is a small section by the Danube, on which there are gardens.

Based on the finds from research and surface collection, the fortification in Štúrovo and earthwork in Janíky may be dated to the period of Ottoman Wars. One cannot exclude that the ditch formation in Sokolce, which could be part of defence line, may be dated to this period. The finds from surface collection have not yet confirmed the assumption.

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CIRCULAR DITCH FORMATIONS ON THE REMOTE SENSING IMAGE

I. Kuzma

The methods of remote sensing are acquiring an ever greater significance in many fields of science and research, as well as in everyday practice. This is especially true since the 1999 launch of earth observation satellite Ikonos, when high-resolution satellite imagery became available worldwide. Imagery from this new generation of satellites opened up new research perspectives. Thus, on top of aerial photographs obtained through aerial survey, there is an increasing use in archaeology of orthophotographs and satellite images, and of LIDAR and other new techniques.

In addition to the fact that satellite images had long been secret and that access to them had been greatly restricted, there was a problem of their spatial resolution and a need of technical equipment for their interpretation and processing. The first attempts to use satellite images for archaeological purposes were also problematic for their eighty-meter graphics resolution of the first series of the American Landsat, which allowed detection of only the largest archaeological objects, such as pyramids in Giza, etc. (Fowler 2004, 119).

A turn occurred in the 1990s, when the American government made available the espionage satellite images acquired in the years 1960-1972 by the first generation of photo-observation satellites (Corona, Argon, Lanyard, Gambit, Hexagon). Similarly, the 1990s saw the declassifying of Russian images from the KVR 1000 satellite. The images from the American Landsat TM (Tematic Mapper 5, 7) or French SPOT (Spot 2, 3, 4 and 5) were specifically made available for civil purposes. Today there are several companies providing commercial images for civil purposes, such as Space Imaging Inc. (IKONOS), DigitalGlobe, Inc. (QuickBird, WorldView 1-2), GeoEye, Inc. (GeoEye-1), and others.

A really significant break in the use of vertical images of Earth for a wide public was the launching of the Google Earth (GE) application in 2004 (originally Earth Viewer from Keyhole Inc.). The program uses satellite images as well as orthophotographs (for Slovakia, for example, Google purchased photographs from the Eurosense and Geodis with 50 cm resolution). Version 5.0 made accessible the Historical Imagery archives, into which the images placed on GE in previous years were loaded again. Although they do not contain a mosaic of all territories, and the number of the image layers changes depending on location, it is always possible to compare the given territory on the images from various periods, either in the period of vegetation or without it. They are thus suitably complemented, and in a favourable case, the probability of detecting individual objects may be increased. Tens of new localities have been detected through Google Earth, and their number is rapidly increasing. Satellite images are available on various other internet addresses as well. However, if one expects a variety of images from individual applications, one will be disappointed; nearly all of them use the same images, which could be found on GE as well.

What is important for satellite images (as for orthophotographs) is geometric resolution, defined as Ground Sample Distance (GSD); that is, how the sensor is able to depict part of the earth's surface within one pixel. For example, GSD of a panchromatic image from Landsat is 30 m, GDS of the last commercial satellite GeoEye-1 is 0.41 m (for civilian use reduced by the regulations of the US government to 0.5 m, the GeoEye-2 launch is planned in 2013, 0.25 m resolution). It is important especially for the images with a 1 m and higher resolution, which became evident several times already. Therefore, it is necessary to verify findings from satellite images by a direct aerial prospection, or geophysical measurement.

An example of the premature satisfaction from the new rondell are several multiple circular objects on some orthophotographs. Dolné Saliby is one good example (Figure 1: 1), on another image from the cadastre of Mužla three such circles are found close to one another. The explanation is very prosaic. It is an effect caused by the processing of images, acquired by analogue technology and converted into digital format (Newton's Rings).

Today, a version with a 0.25 m resolution is available for the whole of Slovakia from the companies Eurosens and Geodis, and for selected areas (Bratislava, etc.) a version with 0.10 m resolution is also available. These resolutions are quite comparable with oblique photographs from aerial prospection, with distinguishable postholes and other details.

The gauge at which images are viewed is important as well. In the case of GE and other search engines, graphical gauge is available, though there is no numeric gauge (1: M). We can, however, use data for GE and other search engines marked as "view height". If we want to look for objects in a possible connection to archaeology, thus not only circular ditches, but also various smaller ones, such as fortifications, barrows, ground plans of buildings, or lines of Roman camps, among others, one of the determining factors in addition to resolution and markedness of an object is view height. In case of very marked objects, they could be detected during common viewing, which corresponds to the view height roughly from 8 km. For a more detailed viewing, the view height of approximately 2000 to 1000 m is usually enough; for a detailed viewing, the view height of about 300 m or less is preferred. Allowing for certain impreciseness, the numeric gauge may be calculated from view height, with approximately the following values: 1:10000 = 4 km, 1:5000 = 2 km, 1:2500 = 1 km, 1:1250 = 500 m.

To a certain extent, the date, or the period when the images were taken, is also important. This principle also applies to normal aerial prospection. In case of rondells, it is not so striking, since they can be detected as soil marks as well as crop marks. So far, the soil marks have undoubtedly been more frequent, and they are more distinctive, which was confirmed on the images from GE as well.

SUMMARY

During the viewing of images through GE, tens of circular ditch formations have already been detected. They are various kinds of

circles from 5-6 m in diameter, naturally with various functions as well as dating. The smaller ones, reaching 5 to 25 m in diameter, may be associated primarily with funeral purposes (barrows or graves with circular channels). With regard to the extent of the paper, I will touch only on those that could be potential rondells of the Lengyel Culture, and within these, only some of the most marked ones. I use the term rondell despite the objections of researchers from German speaking countries, though I agree with W. Neubauer (Neubauer, 2010, 66) that for the future it will be necessary to introduce not only a unified term, but also an unequivocally accepted definition, since the opinions about it are not unified either (Petrasch, 1990; Trnka, 2005; Stäuble, 2007).

Of the 16 so far verified circular formations in Slovakia (Kuzma, 2005), which correspond to the term rondell from the period of Lengyel Culture in the sense of G. Trnka's definition (2005, 12), eight may be viewed on GE. They are the rondells in Bajtava, Borovce, Cífer, Demandice, Golianovo, Prašník, Ružindol-Borová and Svodín. Bučany and Šurany-Nitriansky Hrádok have already been destroyed.

It is possible to speak of formations detected on images from satellites, or ortophotographs, as potential rondells in many cases. They include circular ditches in Brestovany (Figure 3: 4) - Eurosense/Geodis, Budmerice (Figure 2: 3, 4) - DigitalGlobe, Čermany - DigitalGlobe, Ducové (Figure 1: 2) - DigitalGlobe, Klčovany (Figure 1: 4) - DigitalGlobe, Kočín - DigitalGlobe, Košolná - DigitalGlobe, Kuzmice - Eurosense/Geodis, Lok (Figure 3: 1) - Eurosense/Geodis, Lukáčovce - DigitalGlobe, Modrovka (Figure 1: 5) - DigitalGlobe; GeoEye, Pastuchov (Figure 3: 2) - Eurosense/Geodis, Ratkovce (Figure 3: 3) - DigitalGlobe, Santovka - Eurosense/Geodis, Senica (Figure 2: 2) - DigitalGlobe; GeoEye, Suchá nad Parnou (Figure 2: 1) - DigitalGlobe, Svätoplukovo (Figure 3: 5) - DigitalGlobe, Šarkan - GeoEye (Figure 3: 6), Šelpice - Eurosense/Geodis, Šterusy (Figure 2: 5) - Eurosense/Geodis; GeoEye, Šurany - (Eurosense/Geodis), Vel'ké Kostol'any (Figure 1: 6) - Eurosense/Geodis, Vrbové (Figure 1: 3) - DigitalGlobe, and Zvončín - DigitalGlobe.

The mentioned circular ditches meet several conditions that allow them to be considered potential Lengyel Culture rondells, including territorial extent, position and location in the terrain as well as the dimension and number of ditches. The existence of a dark stain in the middle is a very important indication as well. So far almost all circular formations detected through aerial prospection in Slovakia, which may be unequivocally included into Lengyel Culture, showed evidence of this dark stain. We do not yet know how to explain its origin, since even in the rondells which were measured geophysically no extraordinary anomalies occurred. Similarly, the stain also occurs on circular ditches in Austria, including Friebritz 1, Glauberndorf 2, Immendorf, Pranhartsberg 2, Simonsfeld, Steinabrunn (Hinterleitner et al., 2010, Taf. 6, Taf. 22, Taf. 42, Taf. 90, Taf. 106, Taf. 114). Naturally, it cannot be excluded that the assumed objects may in many cases be just geologic manifestations, recent or coming from other period, as has already been confirmed several times. As an example can be cited potential rondells in Haslau an der Donau, where it was geology, or Jedenspeigen which proved to have been a medieval fortification (Hinterleitner et al., 2010, 381, 398).

Territorial extension

As for the territorial extension of circular ditch formations detected on GE, they fully correspond with the areas in which the verified ones are situated. They include three main geographical groupings – on Trnavská tabul'a' and pahorkatina (Brestovany, Budmerice (in previous publications mistakenly labelled as Štefanová), Ratkovce, Suchá nad Parnou, Šelpice, Klčovany, Košolná, Šterusy, Vel'ké Kostol'any, Vrbové, Zvončín), on Pohronie (Lok, Šarkan), and in the Nitra River basin (Čermany, Pastuchov, Lukáčovce, Svätoplukovo). Outside these areas in Považie there are Ducové and Modrovka, in Topol'čany basin Kuzmice. The only potential circular ditch was detected in Záhorie (Senica) where no rondells have been registered so far. It cannot be excluded that it will be closer to the Moravian-Austrian group of rondells than to the remaining ones situated in the territory of south-western Slovakia. The formation which is closest to it is a triple circular ditch in Ringelsdorf-Niederabsdorf (48 33 52 12, 16 51 39 91), in the Weinviertel area in Niederösterreich, situated about 36 km away. If this is confirmed, it may be said that circular ditch formations occur in the whole territory of south-western Slovakia. It is thus a considerably greater territorial extension than in Austria, where they are restricted to Niederösterreich, with focal occurrence in the Weinviertel (Neubauer 2010, 73).

Position and location

Neolithic rondells in Slovakia are situated in altitudes ranging from 125 to 320 m. This also applies to the ditch formations detected on GE. The highest situated rondell, at 322 m amsl, is the one in Prašník, closely followed by Šterusy at 280 amsl. They are situated especially on the slope or ridge of the hill. A very frequent position is on the edge of a steeper cliff, or on a more or less marked terrain edge, so that the difference between the highest and lowest part of the ditch is several metres (at least on one side of the rondell). In some cases it is even impossible to have a direct view of the opposite side of the ditch (Žitavce, Horné Otrokovce), which contradicts theories about astronomical orientation. They are found, however, also on terrain elevations/dunes in a generally flat relief (Cífer, Lok, Klčovany). If they are situated on the slope, or a slanting down terrace or elevation, the exposition of the slope is, with certain deviations, mainly in the southward direction, which applies also to the rondells detected on GE. Of the 24 potential rondells, 7 are oriented to S, 9 to SE, the remaining to SW, W, E, NW, and NE (Table 1).

The concentration of circular ditch formations in Slovakia does not reach the density of the Austrian ones. With regard to this, of importance is the find in Šterusy, which is situated in the vicinity of the rondell in Prašník (Kuzma/Tirpák, 2006). The centres of both rondells are only 670 m apart (Figure 2: 6). It is thus the shortest distance between two rondells in Slovakia. What is probable is mutual direct visual contact between them (analysis on a terrain model has not been done so far). With greatest probability, however, as in the case of Prašník, the direct visual contact with the double ditch in Borovce, distant 4.8 km (Kuzma – Lieskovský, 2007) as well as Vrbové (2.3 km) will be possible, which would mean the first visual linking of as many as four circular ditches lying in an almost straight line. This direct visibility should also be the case for Svodín and Šarkan, 6 km distant from each other.

Shape and dimensions of ditches

The shape, number of ditches, or the construction of rondell on GE images, is not, in most cases, possible to detect without geophysical measuring. A similar situation is, however, also in aerial prospection, unlike Austria, where in most cases the number of ditches or a type of rondell may be determined. As soil marks, three ditches in Golianovo (Kuzma/Tirpák, 2001) appeared at least as a double circle, the same as crop marks. Two ditches may be observed in Bajtava, Šterusy, Budmerice, and perhaps also in Lok. An exception is Suchá nad Parnou where double ditch may be clearly distinguished, as the Lochenice-Unternberg type (Podborský, 1988, 244), or Type 61 according to Řídký (2011, Obr. III.12). With the exception of Ružindol-Borová, it is thus only the second case wherein it was possible to clearly distinguish the construction of the rondell from soil marks on GE.

The dimensions of the circular ditches verified so far in Slovakia are in all cases between 60 and 300 m, with the prevalence of medium-large to large ditches based on the distinction of J. Kovárník (1986, 157). Even though the number of ditches is not necessarily related to diameter, it is clear that in the category of medium and large there is a majority of the double (being most numerous) and multiple (3 to 6) ditches, simple being just the Ružindol-Borová and Šurany-Nitriansky Hrádok. Findings on GE, by comparison, show the prevalence of the single ditch rondells. However, the situation may be considerably changed after conducting magnetometric measurements, since the verified ones also appeared on the images mostly as single-ditch enclosures. A good example is Budmerice, where geophysical measurement confirmed five ditches (or four and a palisade), with diameters of 160, 136, 98, 72 and 62 m (Figure 2: 3, 4); it cannot be ruled out that they are two building phases (Lieskovský – Pastirčák – Šebesta – Tirpák in press). The dating to Lengyel Culture is confirmed also by surface collection. It thus appears that, with certain reservation, the double and multiple circles with the diameter over 60 m in Slovakia may be considered Lengyel immediately after their detection on the images of remote sensing.

So far, the circular ditches detected on GE were verified by aerial prospection in Čermany, Košolná, Lukáčovce, Modrovka and Suchá nad Parnou. However, aerial prospection does not have to be an unequivocal confirmation, since it may only be a better quality documentation of the state known already from GE. Geophysical measuring is clearly needed; it has so far been done only in Budmerice. It will be thus interesting to monitor how many of the rondells mentioned here (and potentially others as well) may be, after a consistent verification, included unequivocally into the Lengyel Culture rondells.

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	Village	**No, of ditches**	**Dating**	**Ditch diameter**	**Verification**	**Altitude in m**	**Position**	**Exposition**	**Entrances**	**"Entrance orientation"**	**GE Co-ordinates**
1	**Bajtava**	2	188×185/130×124	LgK	CM	216	5	SW	4	NW, SE, NE, SW	47°51'25.52" N, 18°43'09.15" E
2	**Borovce**	2	70-80	LgK	CM	196	1	NW	1>	SW, S	48°35'01.44" N, 17°41'48.40" E
3	**Bučany**	2	45,5/70	LgK	E	155	4	0	4	N, S, E, W	48°25'11 27" N, 17°42'03 69" E
4	**Cıfer**	4	71×78/ 80×84/ 97×105/114×127	LgK	CM	148	6	0	4	NE, SE, SW, NW	48°17'58.65" N, 17°29'24.21" E
5	**Demandice**	1-2?	120	LgK	CM	184	3	NE	4?	N, E, W, E?	48°08'09.17" N, 18°47'07.40" E
6	**Golianovo**	3	178×210/ 58×182/ 148×167	LgK	CM	190	1	SSW	6	E, W, SW, SE, S, N	48°15'40.31" N, 18°12'58.75" E
7	**Horné Otrokovce**	2	125×95/150×120	LgK	PM	223	1/2	SE	4	NE, SW, NW, SE	48°28'30.86" N, 17°52'49.47" E
8	**Hosovce**	2	280×300	LgK	CM	252	1	S	1>	SEE	48°24'36.92" N, 18°22'11.56" E
9	**Kl'ačany**	2	60/40	LgK	CM	166	1	SE	4	N, S, W, E	48°22'56.49" N, 17°53'13.39" E
10	**Podhorany-Mechenice**	2	92×85/120×110	LgK	CM	200	1	NE	4	NNE, SSW, NNW, SSE	48°22'54.29" N, 18°07'46.98" E
11	**Prašnık**	1	130×130/94/74	LgK	CM	322	1	SW	4	N, E, W, E	48°37'30.58" N, 17°40'46.60" E
12	**Ružindol-Borová**	1?	116	LgK	PM, CM	217	5	SW	2	N, NW	48°22'41.81" N, 17°27 00.39" E
13	**Svodın 1**	1	60	LgK	E	199	4	SE	4?	NE, SW, NW, SE	47°54'38.55" N, 18°30'29.50" E
14	**Svodın 2**	2	110/160	LgK	E	199	4	SE	4	NE, SW, NW, SE	47°54'38.55" N, 18°30'29.50" E
15	**Šurany-Nitriansky Hrádok**	1	70	LgK	E	125	4	0	4	N, S, W, E	48°04'05.70" N, 18°12'35.26" E
16	**Žitavce**	6	132/118/ 108/75/ 60/40	LgK	CM	190	5	NW	4-6?	SW-NE	48°11'04.41" N, 18°18'30.05" E
17	**Brestovany**	2?	180	LgK?	0	161	1	SW	?	?	48°23'43.03" N, 17°40'03.76" E
18	**Budmerice**	5	160/136/98/72/62	LgK?	FM	195	1	S	4	NNW, SSE, SWW, NEE	48°22'37.82" N, 17°23'59.68" E
19	**Čermany**	1	150	LgK?	AP	160	1	E	?	?	48°28'12.23" N, 18°02'33.13" E
20	**Ducové**	1	160	LgK?	0	220	1	W	?	?	48°37'41.11" N, 17°52'27.34" E
21	**Klčovany**	1	120	LgK?	0	170	1	E	?	?	48°26'49.23" N, 17°30'41.63" E
22	**Kočın**	1	150	LgK?	0	230	1	SW	?	?	48°35'49.31" N, 17°40'01.74" E
23	**Košolná**	1	85	LgK?	AP	198	1	S	?	?	48°25'19.12" N, 17°27'37.79" E
24	**Kuzmice**	1	250	LgK?	0	230	1	SE	?	?	48°35'20.11" N, 18°05'14.24" E
25	**Lok**	1-2 ?	210	LgK?	0	165	6	S	?	?	48°10'01.52" N, 18°28'14.67" E
26	**Lukáčovce**	1	120	LgK?	AP	160	1	NE	?	?	48°23'05.60" N, 17°57'26.18" E
27	**Modrovka**	1-2?	145	LgK?	AP	230	1	NW	?	?	48°38'24.42" N, 17°51'56.32" E
28	**Pastuchov**	1	160	LgK?	0	210	1	S	?	?	48°29'46.71" N, 17°54'35.13" E
29	**Ratkovce**	1	160-180	LgK?	0	160	1	SE	?	?	48°21'16.62" N, 17°42'48.08" E
30	**Santovka**	1	230	LgK?	0	170	1	SE	?	?	48°09'47.94" N, 18°43'53.95" E
31	**Senica**	1	140	LgK?	0	208	1	S	?	?	48°41'44.79" N, 17°19'22.65" E
32	**Suchá nad Parnou**	2	140/	LgK?	AP	134	1	NW	4	N, S, W, E	48°24'28.07" N, 17°08'32.15" E
33	**Svätoplukovo**	1	160	LgK?	0	150	1	SE	?	?	48°13'57.72" N, 18°03'58.59" E
34	**Šarkan**	1	85	LgK?	0	172	5	SE	?	?	47°52'17.96" N, 18°33'43.07" E
35	**Šelpice**	1	120	LgK?	0	225	1	S	?	?	48°25'55.42" N, 17°30'15.02" E
36	**Šterusy**	2	185	LgK?	0	280	1	SW	?	?	48°37'09.48" N, 17°40'55.58" E
38	**Šurany**		240	LgK?	AP	128	1	SE	?	?	48°06'21.87" N, 18°10'10.95" E
39	**Vel'ké Kostol'any**	1	240	LgK?	0	240	1	SE	?	?	48°29'46.72" N, 17°42'53.11" E
40	**Vrbové**	1	230	LgK?	0	230	1	SE	?	?	48°36'21.85" N, 17°41'29.08" E
41	**Zvončín**	2	200	LgK?	0	160	1	SE	?	?	48°23'41.94" N, 17°30'29.62" E

CM - Cäsium magnetometer, PM - Proton magnetometer, FM - Fluxgate magnetometer, E - excavation, AP - Aerial prospection,

1 - slope, 2 - terrain edge, 3 - top of the hill, 4 - terrace, 5 - ridge of the hill, 6 - dune, 7 - table land

Table 1: *Circular enclosures in Slovakia. 1-16 verified enclosures, 17-42 potential enclosures on Google Earth.*

1. Dolné Saliby, Newton ring's, GE.

2. Ducové, GE.

3. Vrbové, GE.

4. Klčovany, GE.

5. Modrovka, GE .

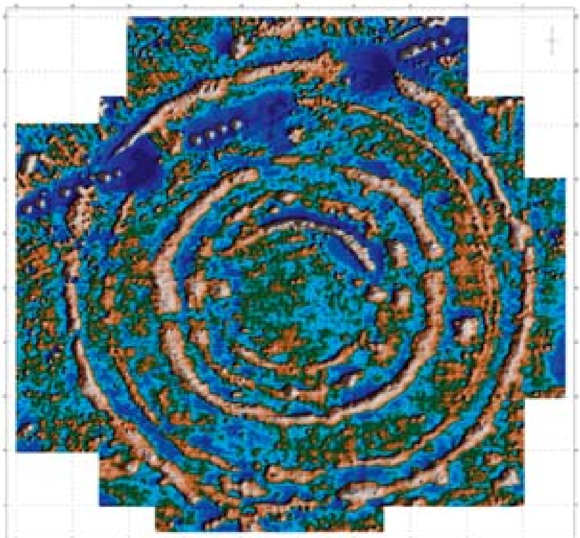
6. Veľké Kostoľany, GE.

Figure 1

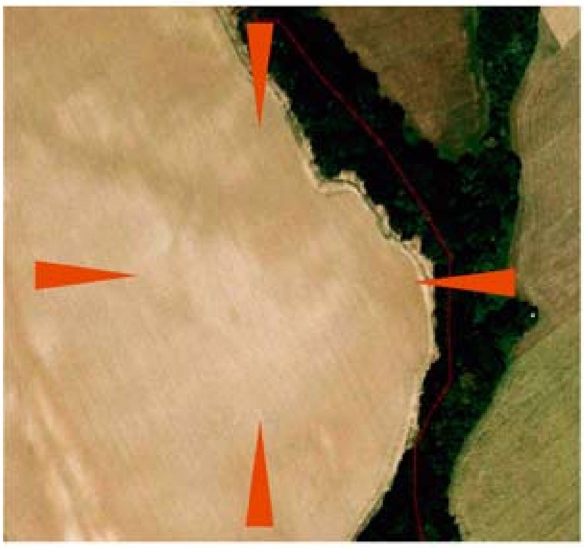
1. Suchá nad Parnou, GE.

2. Senica, GE.

3. Budmerice, GE.



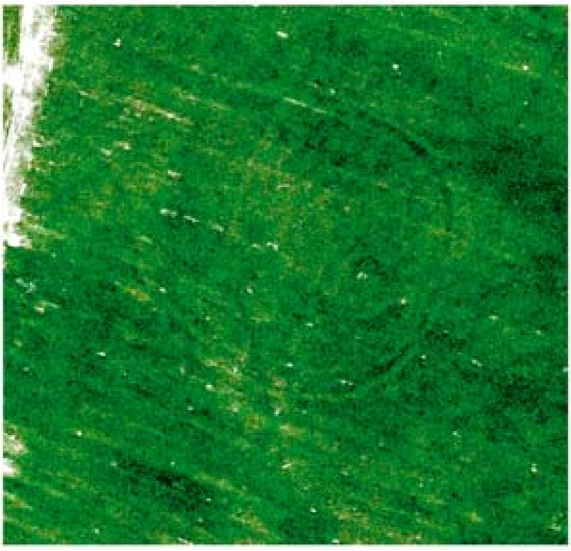
4. Budmerice, Magnetogramm (J. Tirpák).



5. Šterusy, GE.

6. Šterusy and Prašník, distance 670 m.

Figure 2



1. Lok, GE.

2. Pastuchov, GE.

3. Ratkovce, GE.

4. Brestovany, GE.

5. Svätoplukovo, GE.

6. Šarkan, GE.

Figure 3

USING AIRBORNE LIDAR TO MAP FIELD SYSTEMS – METHODS, CHALLENGES AND EXAMPLES

R. Hesse

Field systems are the most extensive traces of former human activities. For thousands of years, humans have modified their environment by clearing, subdividing and digging or ploughing the land to grow crops. The intentional or unintentional redistribution of soil creates distinct and recurring field system patterns which can survive as relief features for many centuries. Such patterns include ridge-and-furrow, terraces and lynchets, celtic fields, raised and sunken fields as well as headlands and alignments of clearing cairns. They record agricultural practices as well as their spatial distribution and extent and are therefore an important source of archaeological information.

Using appropriate visualisation techniques, high-resolution digital elevation models derived from airborne LIDAR are an ideal basis for the mapping of historic and pre-historic field systems. Based on case studies from several countries and encompassing periods from the Iron Age to modern, the scientific potential as well as the challenges encountered in detecting and mapping field systems are highlighted.

RELOCATION OF A PARTLY EXCAVATED ROMAN VILLA RUSTICA BY GEOPHYSICAL PROSPECTION

W. Neubauer, S. Flöry, T. Zitz, E. Nau, K. Löcker

The most prominent local Roman site in Satteins, situated in the province Vorarlberg in the western part of Austria, is the Villa Rustica "uf der Rühe", partly excavated in 1934 by A. Hild. The excavation results have been subsequently published, including a map of the excavated walls. Only a few rooms have been excavated completely, the walls mainly trenched from two sides.

The Austrian National Heritage Board together with the municipality of Satteins was interested in presenting the Roman site to the public. Therefore, the area in the vicinity of the excavation was to be investigated to search for further Roman buildings and an expected Roman road. In 2009 and 2010, the ZAMG ArcheoProspections® team conducted geophysical prospection measurements in collaboration with the municipality of Satteins. For the magnetic prospection, a Foerster gradiometer array consisting of four probes was used in a measurement raster of 0.1×0.5 m. The GPR measurements have been carried out using a Sensors & Software PulseEkko^{Pro} system with 250 and 500 MHz antennas in a raster of 0.5×0.05 m and 0.5×0.02 m respectively.

From the first inspection of the excavation map and the initial attempt to georeference it, it soon became clear that not only were the parcels indicated incorrectly, but the orientation of the map was also misleading. Therefore, the objective of a second investigation was the collection of high-resolution GPR data from areas that are now forested, as well as to relocate the partly excavated structures. Besides the geophysical prospection, a terrestrial 3D laser scanner survey was conducted to document both the walls that are still partly visible in the topography and the changes caused by the excavations, and to place the villa in context with the surrounding landscape. The initially pure prospection project developed into the reinvestigation of the former excavation and a contextualisation of the combined results.

The Villa Rustica is situated on a protruding hillock forming a 3,000 m^2 plateau in a strategically perfect position, providing a good overview of what was, at the time it was built, mainly swampy valley bottom dominated by the meandering river Ill. Hild excavated a main building with hypocausted rooms and a smaller adjacent building. The GPR survey located the last remains of a former enclosing wall in the north and northeast of the site. Most stones from this boundary wall have been robbed, as can be proven by historical documents. Toward the southeast, the site is delimited by a narrow valley cutting 16 m into the soft bedrock. A spring is located at the end of the valley. During Roman times, the valley seems to have been used as a pathway from the villa to the spring, located in a distance of 50 m from the main building, as became visible in the digital terrain model.

The small adjacent rectangular building with a base area of 64 m^2 size is still visible in the topography. Neither the excavation nor the GPR survey showed any internal walls. According to the excavation report, a strongly reflecting anomaly detected by GPR measurements is due to a terrazzo floor. This building is interpreted as a storage house or workshop; a function as a stable can be excluded due to the finds made within the building.

As the result of the combined geophysical prospection and the terrestrial laser scanning, it was possible to relocate the earlier excavated main building of the Roman Villa Rustica below the excavation deposits, to geo-reference the old excavation map and to detect additional archaeological structures. Room 3 of the building, as indicated on the excavation map, is partly uncovered still today and has been hypocausted. The main building covered an area of approximately 270 m^2 . The massive walls, partly reinforced by foundations, indicate at least two former storeys for the two tower-like risalits of the villa. As shown by the excavation, the plastered walls of the building have been painted in white. The roof was covered with typical Roman tiles, and most of the rooms had massive terrazzo floors. Three of the rooms could be heated. Many fragments from frescos proved the high status of the owners of this remote Villa Rustica. The finds date the construction of the villa to the early second century AD. In the late third century, the villa was destroyed by fire, an event that is possibly related to the invasion of Germanic tribes. Situated near the important Roman road (which has not yet been completely relocated) conneting the Rhine valley with the Arlberg region, the Roman villa obviously had a function.

By combining the digital terrain model created from the laser scanning with the results of the geophysical prospection, including the now correctly geo-referenced excavation map and the excavation report, it was possible to reconstruct the Roman Villa Rustica in the form of a virtual reality model set into the surrounding landscape.

Figure 1: *Based on the archaeological excavation and prospection results a possible model of the Roman Villa Rustica in Satteins was generated in Virtual Reality and embedded into the digital terrain model obtained from terrestrial laser scanning.*

AUTOMATIC CLASSIFICATION OF NEAR SURFACE MAGNETIC ANOMALIES – AN OBJECT ORIENTED APPROACH

M. Pregesbauer, I. Trinks, W. Neubauer

ABSTRACT

Magnetometer prospection is commonly used in archaeology for the non-invasive detection, mapping and investigation of buried prehistoric sites. The recorded data can contain numerous anomalies caused by archaeological structures in the ground. State-of-the-art geomagnetic data processing results in geo-referenced maps that are conventionally interpreted within Geographical Information Systems (GIS). With the continuously increasing size of surveyed areas, the manual outlining and classification of magnetic anomalies becomes a highly time consuming process. Possibilities for automated classification of the magnetic prospection data prior to the actual archaeological interpretation would considerably enhance the productivity of the archaeological interpretation process regarding magnetic data. Therefore, object oriented image processing methods known from remote sensing applications offer a large spectrum of readily available procedures for the automatic and semiautomatic analysis of raster data sets. Suitable algorithms have been utilized in order to exemplary analyze a magnetic archaeological prospection data set with the goal to automatically map magnetic features facilitating further archaeological interpretation.

1. INTRODUCTION

Magnetic prospection (Aspinall *et al.*, 2008; Neubauer, 2001) is the most widely used geophysical archaeological prospection method (Gaffney and Gater, 2003; Scollar, 1990). Recent developments in the setup of motorized multi-sensor magnetometer systems, employing up to 10 gradiometer or total field sensors mounted with a horizontal spacing of 25 cm, permit the coverage of more than 20 hectares per day. The collected data is presented in the form of geo-referenced greyscale map images, showing local variations of the magnetic field.

The first step towards an archaeological interpretation of geophysical prospection data is the delineation and classification of anomalies contained in the data. While it is feasible to conduct this step manually in the case of traditional small-scale survey areas, for large-scale archaeological prospection surveys, resulting in data covering square kilometres rather than hectares, novel and efficient means for data analysis and archaeological data interpretation are required.

Techniques and concepts derived from the research fields of Geoinformation and Earth Observation Science have led to the emerging field of Object Based Image Analysis (OBIA). OBIA offers a methodological framework for machine-based classification, and to a limited extent the interpretation of complex classes, defined by the measured data values, spatial, structural and hierarchical properties (Lang, 2008).

Figure 1: *Raster image of the magnetic field survey of the Neolithic circular ditch system at Kleinrötz in Lower Austria.*

2. METHODOLOGY OF THE OBJECT ORIENTED CLASSIFICATION

The methodology has been developed on an exemplary data set from a multi-sensor caesium magnetometer survey conducted over a near surface structure of a Neolithic circular ditch system (Kreisgrabenanlage) at Kleinrötz in Lower Austria (Figure 1). The classification of magnetic features follows a hierarchical iterative approach:

- Starting with a single image object of one pixel, pixels that are homogenous in terms of geometry and spectral similarity are grouped together as object primitives, who then serve as unclassified initial objects for the following classification step.
- Starting the classification, point-like and linear features with significant dynamic values are classified. Areal features whose dynamic range appears smaller than that of the point-like and linear features are classified in the final iterative step.
- Finishing the classification, a cleanup procedure is per-

formed in order to reduce small classified image objects related to data noise classified image objects (< 4 Pixel) with a minimum distance (> 10 Pixel) to other small image objects are reclassified as *"unclassified"*. Finally, the magnetic feature classification is exported as a vectorized data set (shape files) for use in GIS.

- The accuracy of the classification results is estimated by using an error matrix as introduced by Story and Congalton (1986).

3. DATA PROCESSING EXAMPLES

As described above, the workflow starts with an initial segmentation. The aim here is to obtain step object primitives that have a universal high-quality, applicable and adaptable shape for the future image classes.

After the segmentation, all objects are assigned to an initial class called "unclassified". As described above, the classification of the magnetic features follow a hierarchical iterative approach. Beneath the magnetic value range, for each class certain homogeneity criteria like geometry features or semantic features have been defined.

Prior to the start of the classification, the field data statistics are calculated, taking into consideration the dynamic range of all so-far unclassified objects. For each iteration step, the amplitude threshold in nT regarding corresponding the 5-quantile (lower border) and the 95-quantile (upper border) is calculated. All segments with values between the upper and the lower border are input for the next iterative steep. Values above and below the border are classified as positive or negative features.

A final "clean up" step to eliminate small, classified objects that tend to be data noise, like small iron parts in the topsoil, concludes the classification.

The reliability of the classified data is demonstrated by using an error matrix (Story and Congalton, 1986). An archaeological interpretation conducted manually by an archaeologist experienced in the interpretation of magnetic archaeological prospection data has been used as a reference for the accuracy analysis.

An overall accuracy of 92.97% of correctly classified segments for the classes "magnetic feature" and "unclassified" was finally obtained.

4. CONCLUSIONS AND OUTLOOK

Object oriented image processing methods are suitable to efficiently classify magnetic field data from magnetic archaeological prospection surveys. It is emphasized that this classification procedure is not to be confused with an archaeological data interpretation, which is subject to the archaeological expertise. Features that are more or less recognizable to the human perception can also be recognized automatically by a computer. The object orientated approach provides the necessary tools for the formalization of the procedure.

The archaeological data interpretation itself is the challenging follow-on step building on the data classification. Based on the experience and knowledge of an expert archaeologist, the formalization of this knowledge and experience into an object-oriented set of rules will be the focus for future methodological advancements. The capability to formalize not only geometric, radiometric and class related feature to an object class, but to exploit also semantic relationships of classified object will be of crucial importance.

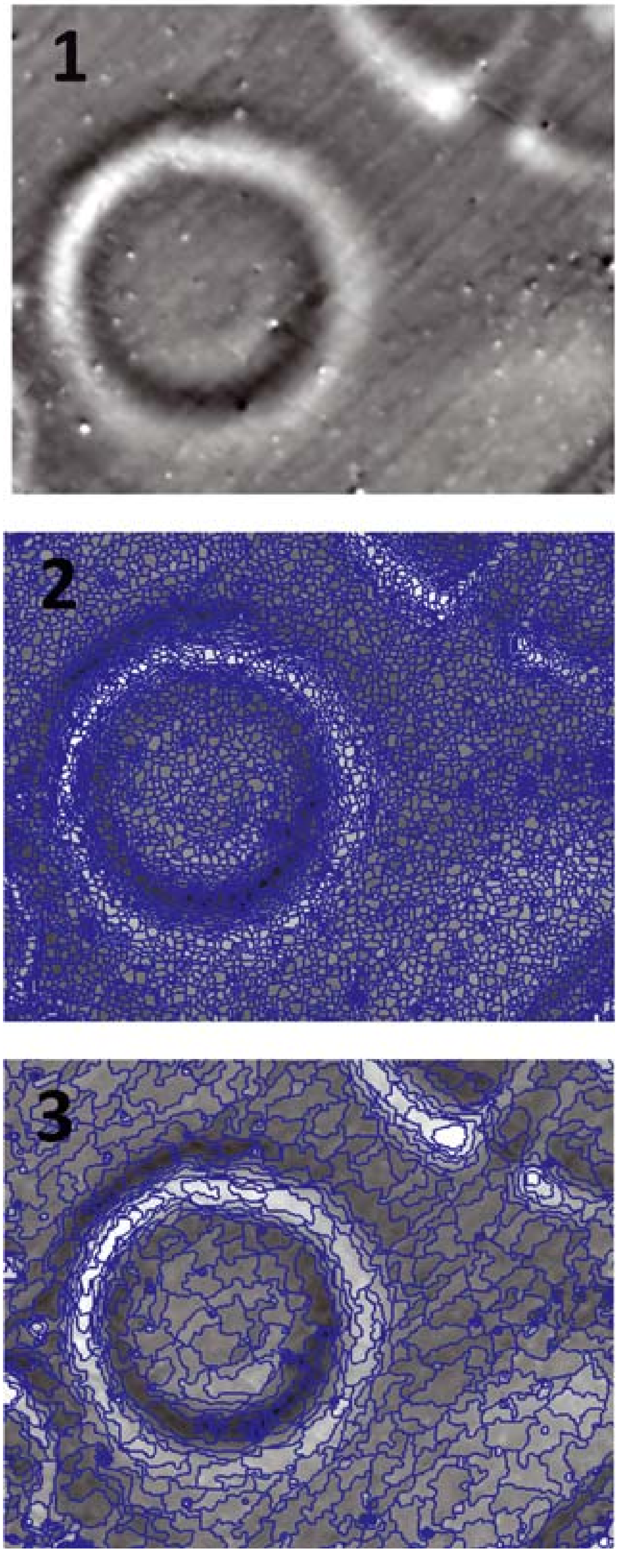


Figure 2: *From the raster image of the magnetic data (1) to the initial base objects (2) and finally to the object primitives (3).*

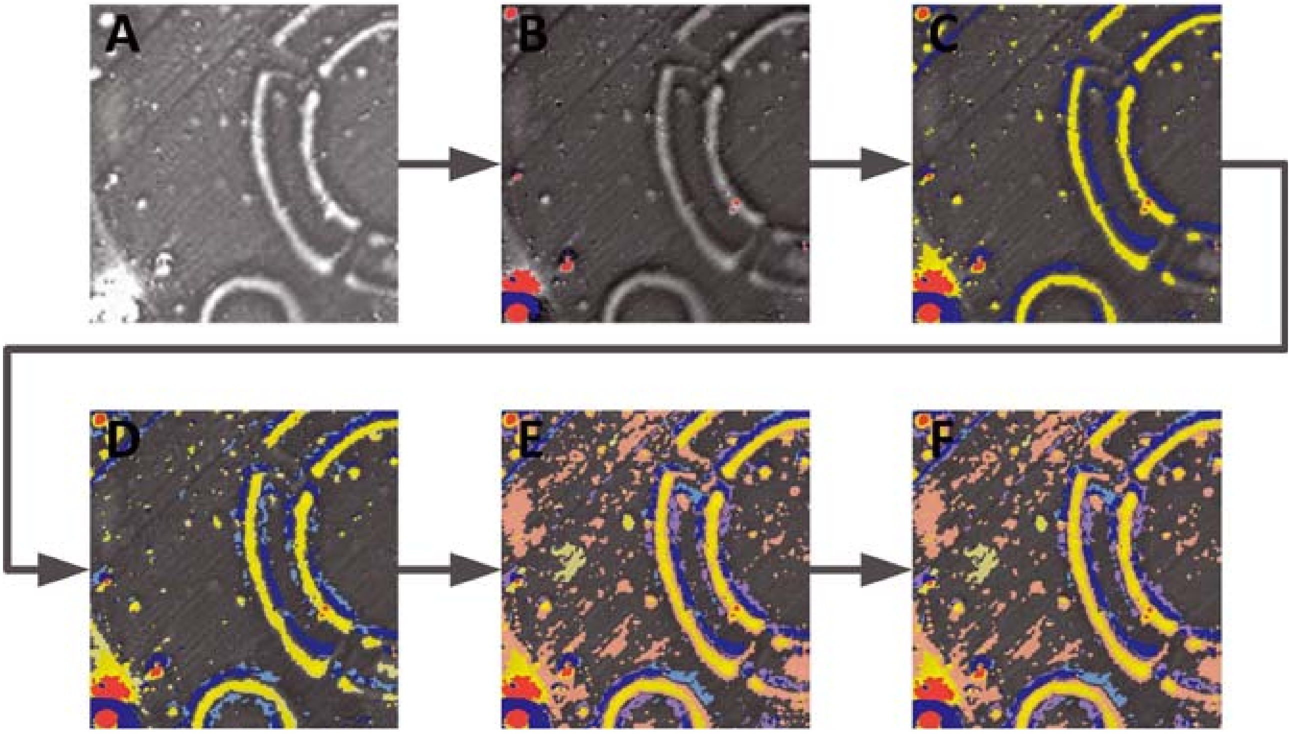


Figure 3: *Classification results: (1) Visualization of the magnetic field data, (2) Objects segmented, exceeding the dynamic range of ± 15 nT, (3) 1st iteration result, (4) 2nd iteration result, (5) 3rd iteration result, (6) final classification result after "cleanup".*

ACKNOWLEDGEMENTS

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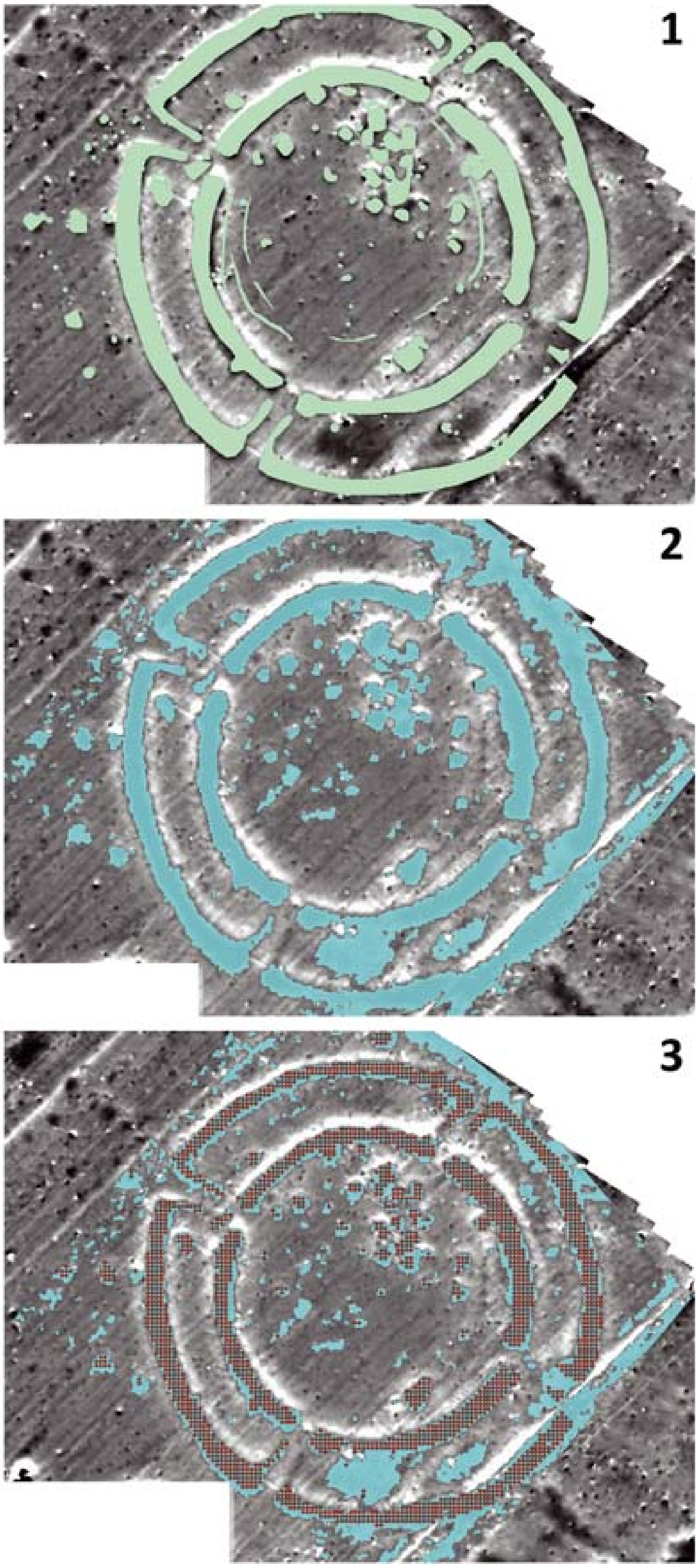

Figure 4: *Accuracy Assessment comparing a manual interpretation (1) and the automatic classified results (2). The red dots symbolize the matches between the manual interpretation and the automatic classification on a 0.5 meter sampling raster.*

ELEMENTS FOR THE CONSTRUCTION OF 3D-MODELS FOR ARCHAEOASTRONOMICAL ANALYSIS

G. Zotti, W. Neubauer

During the ASTROSIM project, supported by the Austrian Science Fund (FWF) under grant number P21208-G19, we aimed for a thorough investigation of the archaeoastronomical potential of the Neolithic circular ditch systems (Kreisgrabenanlagen; KGA) which had earlier been prospected in Lower Austria (Melichar and Neubauer, 2010). No trace of these early monumental buildings is visible today on the surface, except for soil and crop marks. Therefore we aimed for the use of virtual models which were to be constructed in a digital terrain model (Zotti *et al.*, 2009).

All archaeological data and a digital elevation model (DEM) were collected in the Geographical Information System ArcGIS 9.3. A part of the DEM was then exported, together with aligned textures showing the magnetograms, a modern map, and feature outlines for the main ring and palisade ditches into Google (now Trimble) SketchUp. In this simple-to-use 3D modelling program, the ditches were cut into the soil and palisades were erected. The model building at that stage did not aim at photorealism with lots of graphical accessories and gadgets, but at a geometrically plausible model. A very helpful property of SketchUp models is the geolocation capability, so that solar illumination and shadow effects can be simulated inside SketchUp, at least for modern dates.

The imported terrain section cannot be so large as to include distant mountains, so a diagram was developed which includes diurnal paths of the stars derived from the Bright Star Catalog (Hoffleit, 1991) for the KGA epoch (including effects of proper motion and precession) and characteristic diurnal paths of the sun at solstices and the cross-quarter days (exactly between solstices and equinoxes), the Moon at its standstill positions (lunistices) and a plot showing the measured horizon line, against which a panorama photo taken on each site had carefully been aligned. All celestial lines show the effects of atmospheric refraction, and the star lines indicate the brightness dependent angles below which the respective star is generally invisible due to atmospheric extinction, to allow an estimate of whether a star can be observed when it is crossing the elevated landscape horizon. Optimally, such a background panorama should be included in a translation invariant background node like a sky box. However SketchUp does not have such an element, and so this diagram was mapped onto a spherical ring which encloses the rest of the model and which is created by a loader plugin developed for that purpose. Care must be taken in this diagram and in the model to account for the difference between geographical/astronomical north and grid north of the archaeological data caused by the meridian convergence, which SketchUp labels as "North Angle". The ring has to be *attached* to the current view camera, so that it is always centred on the viewer to avoid visual errors caused by parallax effects. Standing or walking through the virtual model in SketchUp now always shows the distant mountain backdrop with astronomical information ready for evaluation (Figure 1). The same panorama photograph can be used as landscape background in a desktop planetarium program.

Several available desktop planetarium programs provide nice simulations of the night sky. We selected Stellarium for our purposes: it is free and open-source, so its accuracy can be verified by examining the source code, and with exchangeable constellation patterns and landscape backgrounds it seems very useful for applications in the fields of archaeo- and ethnoastronomy. For added realism, atmospheric refraction and extinction have been contributed (Zotti and Neubauer, 2012a). The biggest innovation, however, was the development of a new plugin, Scenery3D, which allows the combination of a 3D model foreground with an appealing and believable night sky simulation. The simulation also includes shadows cast by the Sun, the Moon and the planet Venus. The geometric accuracy of the simulation has been thoroughly tested with a model of an astronomically oriented modern building (Zotti and Neubauer, 2012b).

The KGA models can be exported into OBJ format and loaded in the Stellarium plugin. Here, the user can move around in the scenery and select standpoints and viewing axes from where to observe celestial processes (Figure 2), or also select an observing location for shadow effects (Figure 3). It had been envisioned to present and demonstrate the expected stellar alignment results of the ASTROSIM project. Although these could not be confirmed after the horizon surveys, we are sure similar research will welcome this plugin as useful tool.

For presentation of some project results to a wider audience in a visually more attractive system, a virtual environment including the two adjacent Kreisgrabenanlagen at Pranhartsberg is currently being developed with the Unity3D game engine, which allows the inclusion of, and motion along, larger virtual landscape areas derived from a DEM, but where the astronomical components have to be developed from scratch.

The Multimedia presentation will be based on videos exported from ArcGIS and SketchUp and screen captures from Stellarium and Unity3D.

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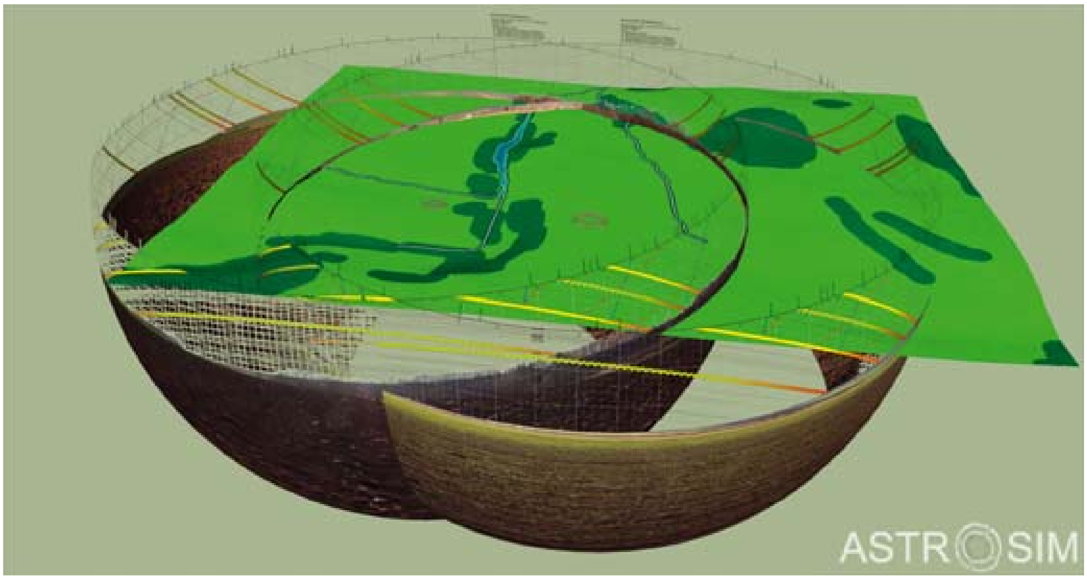

Figure 1: *Spherical rings textured with panorama photographs taken on site, enriched with diagrams of astronomical information, are used as horizon backdrops for each KGA in the SketchUp models. Such a ring is usually attached to the view camera and so encloses the scene without causing parallax errors.*

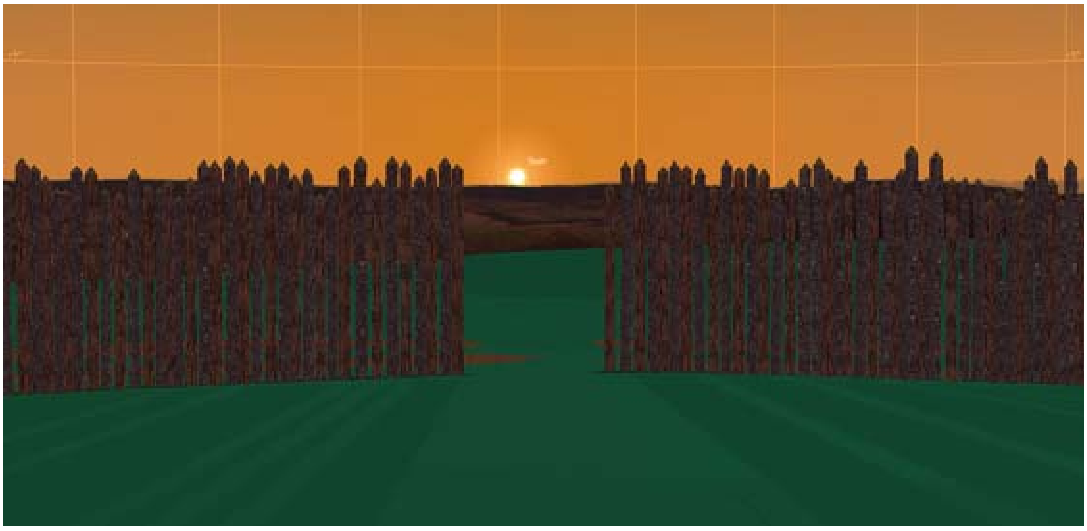

Figure 2: *Summer cross-quarter sunrise in KGA Puch, simulated in Stellarium with the Scenery3D plugin. Although the azimuths of this and the opposing entrance fit to the astronomically defined dates just between solstices and equinoxes, they represent at the same time the direct downward slope line and thus fit to most of the other KGAs for which no astronomical connection could be confirmed.*

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Figure 3: *Shadow simulation in Stellarium with the Scenery3d plugin. The sun, rising over a nearby ridge, casts its first rays into the centre of KGA Pranhartsberg 1 around the winter cross-quarter day. However, the ridge may have eroded over the last few millennia, so the applicability of this observation as date mark cannot be given with any certainty. On the other hand, again, the orientation of the entrances seen to the right and left here seem to be closely related to the terrain slope.*

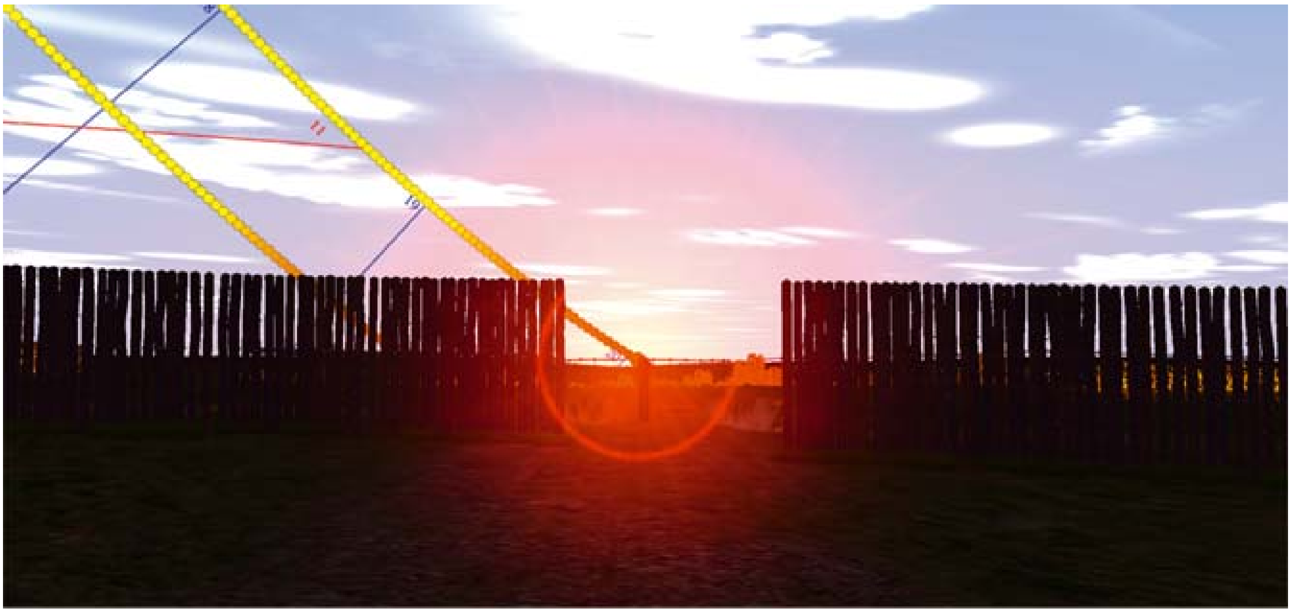

Figure 4: *A sunset simulated in Unity3D. The sun sets in the direction of the northwestern entrance path of the KGA Pranhartsberg 2 on the day of summer solstice. The magnetogram hinted at two postholes for posts which may have further enhanced the orientation aspect. However, this is the only KGA with such a clear solar orientation which is not co-aligned to the terrain slope. The diagram of solar paths (showing the tracks for summer cross-quarter and summer solstice) is similar to that of Figure 1 but has been reprojected and attached to a skybox, and the various diagram elements (alt-azimuthal grid, declination lines, and solar, lunar, and stellar tracks) can be switched on and off to allow interactive demonstrations and a more natural look of the sky.*

TOWARDS THE RAPID DOCUMENTATION OF THE TANUM LANDSCAPE: DEVELOPING AN INTEGRATED WORKFLOW USING 3D LASER SCANNING AND IMAGE BASED MODELLING TECHNIQUES

M. Kucera, C. Sevara, I. Trinks, J. Ling

The Tanum World Heritage Area, located in northern Bohuslän ca. 150 km north of Gothenburg, Sweden, is a multifaceted landscape containing remnants of human activity from the Neolithic to Modern Historic times. This area is particularly famous for its well-preserved rock art, with no less than 1,500 recorded localities containing thousands of images (Ling, 2008, 5) dating mainly from the Bronze Age, covering over 1,200 years (ca. 1700 – 500 BCE). To date, documentation efforts in the area have focused primarily on the recording and preservation of these rock carvings, and while other components of the landscape have certainly not been neglected, a byproduct of this action has been that in some ways the carvings themselves have become divorced from the larger cultural and physical context of the region. Therefore, a prime goal of any new research in the region should be to focus on the documentation of the area from a landscape perspective, including the recording of all presently surviving elements of past land use at all scales. No less important is the need to develop an effective way to monitor the condition of archaeological recourses in the Tanum area in order to assess the true impact of accelerated degradation due to exposure, pollution and high visitor traffic. Recent advances in 3D documentation technologies, including 3D laser scanning and image based modelling techniques, can provide solutions to these issues by offering integrated and complementary ways to rapidly record, process, archive and share data from a landscape to a feature level, making them ideal tools for the recording of all facets of the Tanum region.

A complete documentation and analysis of the Tanum area has to be seen at different scales. Firstly, a topographic model based upon airborne laser scanning (ALS) data forms the basis of any further spatial analysis. High-resolution terrain models constructed from ALS data can be used for the detection of past land use at an intersite to site scale, and can also be used for the effective estimation of shoreline displacement due to glaciations and land uplift. Secondly, terrestrial laser scanning (TLS) techniques can be used at a site to intrasite level to provide detailed recording of individual archaeological features in the landscape, such as rock cairns, rock carving panels, and even individual carving outlines (Figure 1). Finally, image based modelling techniques such as structure from motion (SfM) and multi-view stereopsis (MVS) as well as high-resolution handheld laser scanning can be used to record individual features and provide detailed documentation of feature elements including the precise (50 µm) reproduction of structure within the features. This might shed light on the initial creation processes. All these datasets can then be combined to form a multiresolution model of the Tanum landscape, providing rapid access to information at varying scales and for various purposes.

Figure 1: *Application of a hand-held laser scanner to record rock art in the Tanum World Heritage Area.*

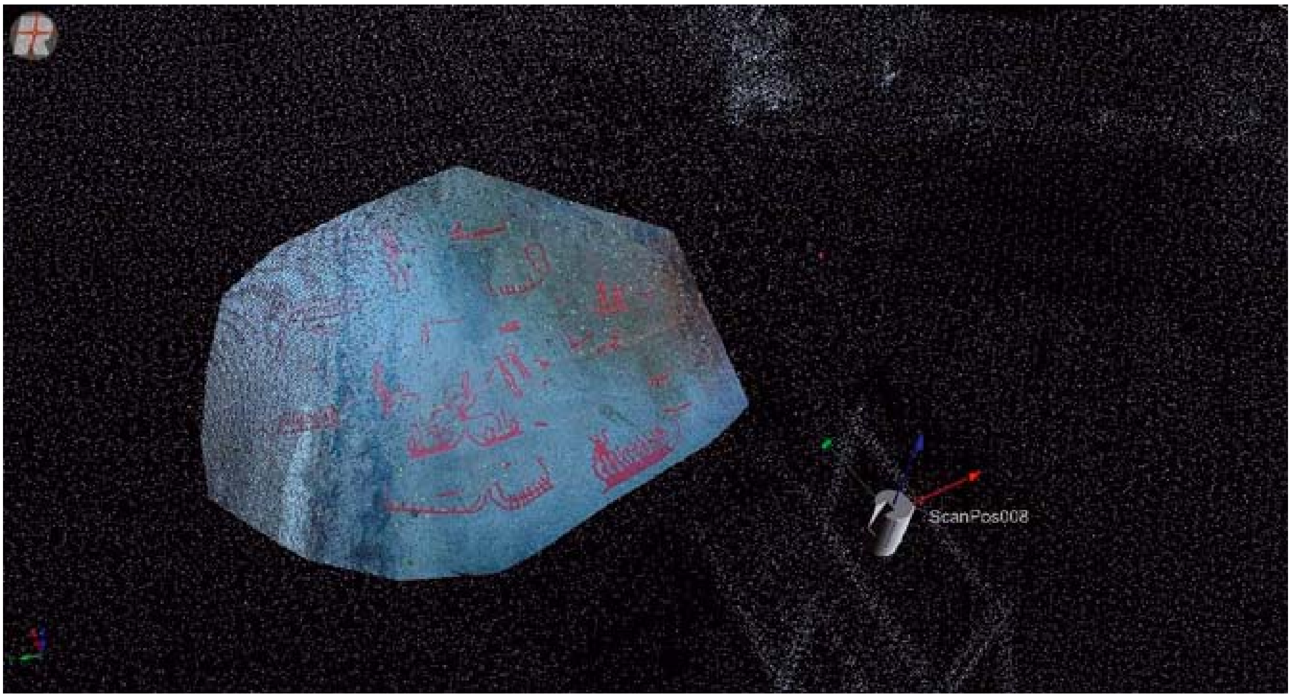

Figure 2: *Rock art in the Tanum areas as depicted in reults from the Z-Scanner 700 CX.*

In order to assess the applicability of these methods as components of an eventual large-scale recording project, the individual methodologies required initial testing to determine their suitability with regard to specific parameters, such as the reflective composition of rock surfaces. In May of 2012, a pilot study was conducted at a number of locations in the Tanum landscape in order to further develop a comprehensive workflow based on these concepts and to evaluate different parameters for the use and integration of the various techniques. A Riegl VZ400 was used for the TLS applications, providing scans of the landscape at a distance of up to 250 m as well as detailed recording of upstanding monuments. Individual features such as rock cairns and rock art panels were recorded in fine detail, with fine scans of panel areas providing detailed capture of rock art image outline and depth. The full-waveform capabilities of the VZ400 also proved to be extremely useful with regard to the efficient filtering of dense vegetation surrounding the monument areas, and this feature could be of great use for the detection and recording of monuments in heavily vegetated parts of the landscape in the future. A Z-Corporation, Z-Scanner 700 CX was tested for the detailed documentation of the petroglyphs. With a 50 µm resolution, this scanner was able to capture elements of individual rock carvings at far greater detail than the TLS scans. The main question here was whether the composition of the bedrock would be suitable for this technique. A dense distribution of reflecting particles embedded in the stone might have caused an inappropriate amount of noise in the scan, which would prohibit the use of this specific device in this context. However, we encountered no problems of that sort when using the Z-Scanner on the types of rock specific to the Tanum area (Figure 2). In addition to the laser scans of the areas, rock carving panels were documented using SFM and MVS techniques. A Nikon D7000 with a 35mm lens was used to capture images, which were processed using Agisoft Photoscan. Prior application of such techniques in similar contexts (Plets *et al.*, 2012; Sevara and Goldhahn, 2011) have demonstrated the applicability of image based modelling approaches to the documentation of rock carving panels, and both image based modelling and laser scanning techniques proved to be highly complementary in this context. All collected datasets were georeferenced using a total station and RTK GNSS sensor, allowing for subsequent post-processing, integration and analysis in a GIS environment.

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FOLLOWING THE TIMELINE – AIRBORNE IMAGING SPECTROSCOPY TO MAP VEGETATION FEATURES AND CROP MARKS

M. Pregesbauer

ABSTRACT

Hyperspectral imagery is a suitable tool to detect and to document the ongoing process of vegetation growth and the development of crop marks and vegetation features. To gain more knowledge about their development and the dynamics of vegetation with regard to crop marks, a multi-temporal data acquisition over a complete vegetation period was carried out. A modern hyperspectral airborne data acquisition platform, equipped with the latest high-resolution hyperspectral imaging sensors was utilized to acquire a time series of datasets.

To study the development of crop marks during a vegetation period, repeated test flights over a known archaeological site, a buried roman villa next to Zillingdorf in the province of Lower Austria, have been carried out. The acquired data form the basis for a multi-temporal analysis of the development of crop marks.

1. MOTIVATION

Hyperspectral remote sensing is a weather sensitive data acquisition method. For all hyperspectral campaigns, the best suitable weather (no clouds, no flock, low humidity) should be guaranteed during the data acquisition (Schläpfer and Richter, 2002). The definition of an exact moment during a vegetation period for the data acquisition is not that well defined. One aim is to develop recommendations for which periods during a vegetation period are best suited for data acquisition to ensure the best data quality regarding the archaeological interpretation. However, prior to this, a framework for the multi temporal data analysis has been developed.

2. DATA ACQUISITION

In total, 19 data sets ranging from March 2012 until July 2012 have been acquired. On all campaigns, a SPECIM Eagle II visible near infrared (VNIR) senor with a spectral range from 400 to 970 nm has been utilized. Additionally, a HYSPEX system with the spectral range from 400 to 2500 has been used for tree data acquisition. All together, these data sets have been georectified and radiometric corrected for the subsequent data processing (Figure 1).

3. CONCEPT OF DATA ANALYSIS

On each temporal data layer, the visible crop marks have been mapped and subsequently linked hierarchically. All visible crop marks are classified and attributed with additional vegetation indices. Each classified data set is regarded as a layer in a multi-temporal data cube. All overlapping segments of a classified crop mark are synchronized and linked together. Figure 2 describes the concept, which is known as a map concept in the world of object oriented image analysis.

The so classified and linked objects are now subject to the ongoing multi temporal analysis.

4. OUTLOOK AND FUTURE DEVELOPMENTS

The concept described here to deal with multi-temporal data sets is the first of two issues regarding the analysis of multi-temporal hyperspectral data. The framework on the multi temporal data analysis has a further relevance because it is transferable to the problem of multi-source data sets. Multi-temporal data analysis has to deal with data from one sensor source acquired over a certain period of time, whereas multi-source data sets are acquired with different sensors, measuring different physical properties, and probably over a certain period of time.

The second and future issue will deal with the analysis of the multi temporal changes in the shape of the crop marks and the spectral properties that have to be analyzed. As a consequence, recommendations on suitable data acquisition time frames, to obtain certain information on vegetation parameters regarding archaeological crop marks shall be given.

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Figure 1: *Detail of tree multi temporal data sets of the project area, acquired on April 26th, Mai 18th, June 18th (from left to right).*

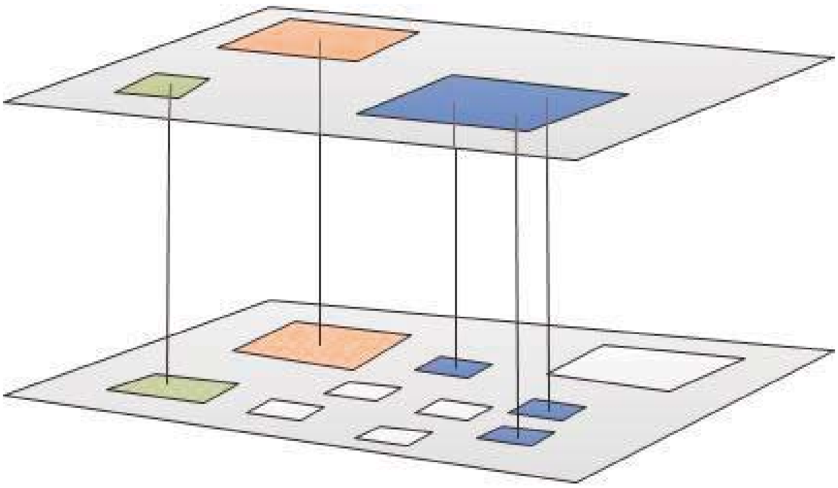

Figure 2: *Map concept to link overlapping classified feature in a multi temporal data cube.*

TRANSDIMENSIONAL INVERSION METHODS FOR ELECTRICAL RESISTIVITY TOMOGRAPHY IN ARCHAEOLOGY

B. Thierry Hildenbrand, K. Gallagher, F. Nicollin, D. Jordan

Historically, the non-destructive electrical resistivity method is the oldest of the archaeo-geophysical prospecting techniques, having been introduced in the mid-1940s by Atkinson (Aitken, 1974). Today, the ERT (Electrical Resistivity Tomography) is widely used for detecting buried archaeological structures and for monitoring the evolution of several physical and chemical properties of soil. The aim of the work presented here is to develop new inversion tools to improve the interpretation of substructures from resistivity data.

Inversion methods aim to estimate the distribution of subsurface resistivity using measurements of the distribution of electrical potential from a set of electrodes at the Earth's surface, for example in the form of a geo-electrical pseudosection. In order to infer the resistivity structure of the subsurface, a Poissonian partial differential equation has to be solved, allowing for the fact that the conductivity is not constant in the soil.

Numerical methods for solving partial differential equations require some form of spatial discretization, or mesh of nodes, at which the solution is specified. The nature of the mesh is an important factor in determining the accuracy and the stability of the method. In general, most commonly used geoelectrical inversion methods are based on regular grid geometries, with either square or rectangular cells in 2D (Figure 1a). Furthermore, in order to obtain stable inversion algorithms, regularization (or damping) techniques are often adopted. In addition to providing numerical stability, regularisation methods produce a smooth resistivity structure. However, the smoothness is determined from the regularisation parameters, which themselves need to be chosen.

We have developed a regularisation-free, non-regular grid based approach, which also leads to smooth models. In this case, the smoothness is effectively determined from the data themselves and so inferred subsurface structure can be complex if the data contain information on such complexity. The method follows from that described by Bodin *et al.* (2009) in the context of seismic tomography. In this approach, a 2-D model is defined by a number of irregularly distributed points which themselves define a geometric structure known as Voronoi tessellation (Okabe, 1992).

Each point is the centre of a polygonal Voronoi cell, and the boundaries of a cell are defined as the perpendicular bisector between the centre and other centres close to the current centre, so called natural neighbours (Sibson, 1981) (Figure 1b). The number, and distribution, of neighbours about each node vary with the density of the nodes. Their density is a compromise between being 'close to' and 'surrounding' a node', and yet this is uniquely determined by the nodal distribution. The great advantage of using such a natural neighbour method is its geometric flexibility for solving complex problems on highly irregular evolving grids without compromising accuracy.

In our context, this Voronoi tessellation defines the resistivity structure, and so each cell has a resistivity assigned to it (much like any grid-based numerical method). As the electrical flux is conservative, the Finite Volume method has been chosen

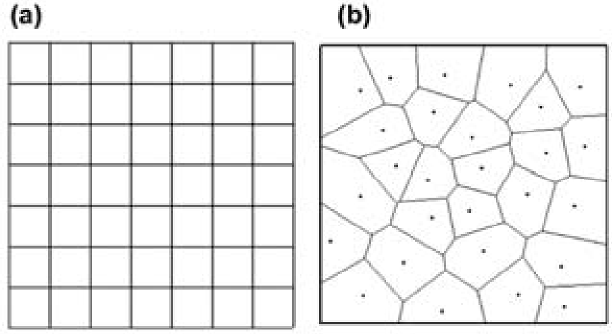

Figure 1: *Two examples of grid geometries for geoelectrical inversion methods. (a) A regular and square mesh, and the grid points for the numerical solution can be in the centre of the cell or at the corners. (b) A Voronoi diagram, showing the polygonal cells and their centres (black dots). These centres are the grid points for the numerical solution.*

to solve for the electrical field numerically. In addition, the Finite Volume method is easily adapted to an irregular grid. Using this approach, we can make a prediction of the electrical potential we would expect to measure at the surface for that particular resistivity structure, i.e. we solve the forward problem.

For the inversion, we avoid matrix based gradient methods, and use either fixed dimension or transdimensional Markov Chain Monte Carlo (MCMC) (Green, 1995), a stochastic sampling method. Transdimensional is the case in which the number of parameters is itself can be treated as an unknown. Thus, the total set of parameters is the locations of the cell centres, the resistivity in each cell and the number of cells (for transdimensional). The inversion procedure is iterative, in which a randomly generated starting model is perturbed to produce a proposed new model. This proposed model is compared to the current model according to some simple probabilistic rules, including how well we fit the observed data. The proposed model can be rejected, and we retain the current model, or it is accepted and the proposed model becomes the current model. At any iteration, the four possible modifications to the current model are defined as: move a cell centre, change the resistivity in a cell, delete a cell or add a new cell. The whole process is repeated many times (tens of thousands) and the output is an ensemble of accepted resistivity structure models which are consistent with the observed data to varying degrees.

Below we show an example comparing results using different inversion methods using perfect synthetic data generated from a known subsurface structure (Figure 2a). One approach uses a typical regular grid cell structure for calculating the electrical potential. The synthetic data were inverted using typical matrix inversion methods, with 400 regularly distributed grid cells and required regularisation for a stable solution. While the general structure is recovered, the resolution is poor and the im-

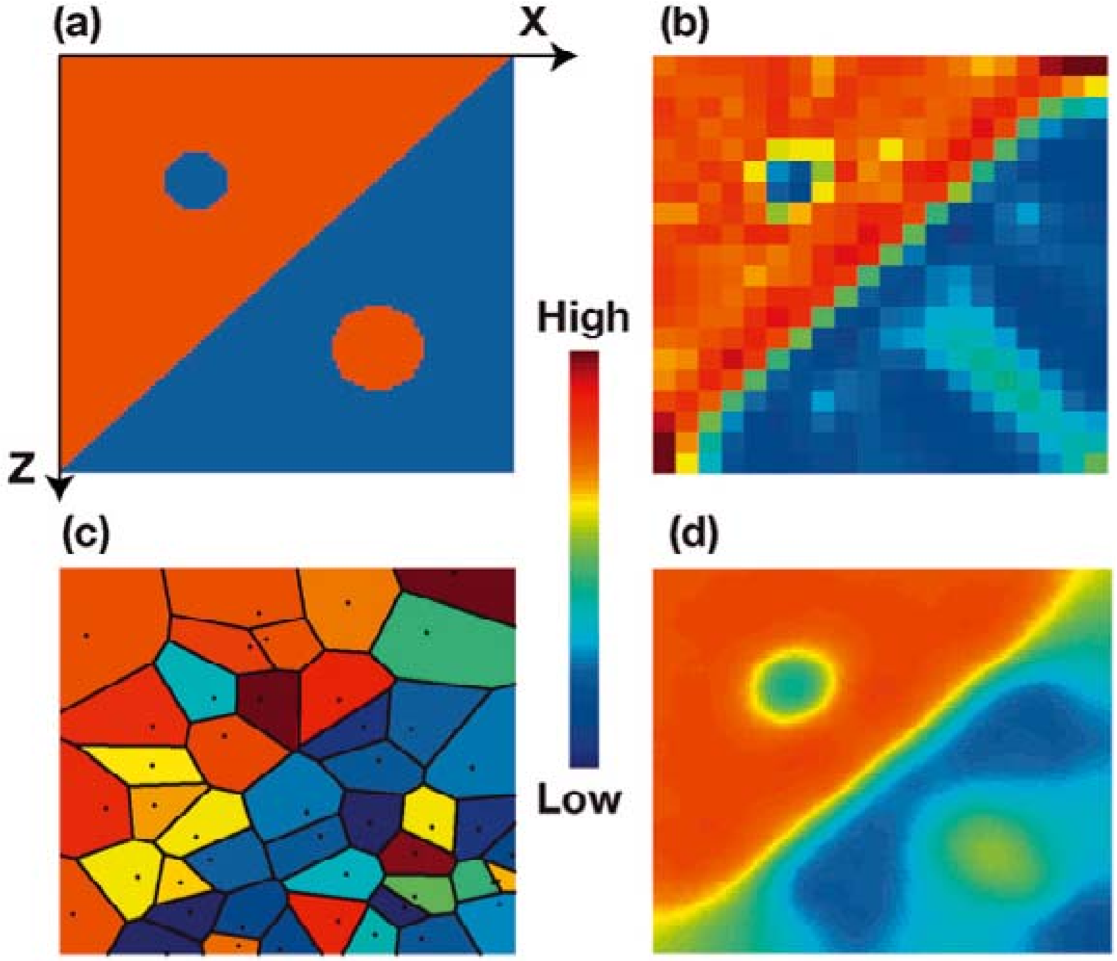

Figure 2: *An example of the irregular grid cell inversion approach (adapted from Bodin et al., 2009) to infer 2D (X-Z) structure. The colours reflect the physical property such as resistivity, as shown in the colour bar in the centre. (a) The true 2D subsurface structure. (b) A best data-fitting solution from typical inversion methods using 400 regular grid cells and regularisation. (c) A single irregular grid cell model, parameterised with Voronoi cell centres (the black dots in each cell). There are 45 cells in this model. (d) The expected (or average) model of 50,000 irregularly distributed cell models.*

age is blurred (Figure 2b). The next approach uses the Voronoi cell structure and MCMC for the inversion, running 50,000 forward models. An individual irregular grid cell model, generated as described above, is shown in Figure 2c. Each individual model tends to have a relatively coarse resistivity structure. Taking the average of all the accepted models, however, we have a parameter-free smoothed model, as shown in Figure 2d. The interesting feature of this is that although averaging is inherently a smoothing process, the average model retains sharp features in the subsurface structure (e.g. the discontinuity running from the bottom left to the top right). This is because the data require this feature and so most of the individual models, although coarse, contain something approximating the discontinuity (this can be seen in Figure 2c). By taking the average, such common features tend to be constructively reinforced, while other less well resolved structures that appear in only a few models tend to disappear.

This new method requires many models to be run, but has the advantage that we avoid choosing a simple regular cell parameterisation and requiring regularisation in the inversion. Both of these can influence strongly the inferred subsurface structure and introduce artefacts in the interpretations.

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EVALUATION OF DIFFERENT SOFTWARE PACKAGES FOR ALS FILTERING

A.M. Klimczyk, M. Doneus, C. Briese, N. Pfeifer

High quality digital terrain models (DTM) and digital surface models (DSM) are very important information sources for archaeological interpretation. This is due to the fact that the terrain structures represented in the models give not only knowledge about the contemporary world but include also features remaining in the topography of past landscape.

During the last decade, airborne laser scanning (ALS) proved to be very useful for generating dense and accurate DTMs and DSMs (Kraus, Pfeifer, 1998; Kraus, 2004). Point clouds collected by ALS systems represent the whole landscape in a very detailed manner: vegetation, terrain, buildings etc., which are components to create a DSM. In order to generate a DTM, the point cloud must be filtered. The aim of the filtering is to separate all man-made objects and vegetation from the terrain, by a classification of the point cloud into terrain and off-terrain points. This step is usually done automatically using various filtering algorithms implemented in numerous software packages.

Currently, many ALS data processing software packages, which are able to perform the automatic ground-points extraction, can be found on the market. The goal of the presented research is to evaluate the available software packages by comparing the filtering procedures used by the software, the accuracy of the results and the difficulties that occurred during the work. This experimental comparison is based on three reference point clouds, which have been filtered in a manual way. The information gathered during the research will be available on a webpage, where it will be modified and kept up-to-date.

Comparison of various filtering methods is an ongoing research since commercial use of ALS systems began. First comparisons can be found in Huising *et al.* (1998), and continued by others (Haugerud *et al.*, 2001; Tao 2001; Zhang *et al.*, 2005). The most quoted comparison is the ISPRS report from Sithole *et al.* (2004), in which the authors distinguished four main filtering methods: slope-based filters, block-minimum, surface based methods and clustering/segmentation. A detailed overview of filtering methods and references for the algorithms is presented in Kobler *et al.* (2007). These four different filter concepts are still widely used. Recently, a group of scientist from Texas A&M University prepared a new review of critical issues in ALS filtering (Meng *et al.*, 2010). In the field of archaeology, that kind of comparison has not been done until now, although the filtering concept itself plays an important role in archaeological research (c.f. Doneus *et al.*, 2006, 2008; Masini *et al.*, 2011).

As far as the software comparisons are concerned, only one report giving an overview of ALS processing software was found (Fernandez *et al.*, 2007).

The idea behind the project is to perform regular comparisons and evaluations of ALS filtering software packages. Each year, new filtering algorithms are created and the existing ones are very often refined. It is important to follow those changes and document them in order to have an overview of which software might be useful for archaeological purposes. To do so, an experimental approach was used and three test areas, interesting from the archaeological point of view, were chosen in the Leithagebirge, Lower Austria (Figure 1). The full-waveform ALS data set was collected over this region using a Riegl Airborne Laser Scanner LMS-Q560 on the 8^{th} of April 2006 (Table 1).

The proposed workflow for the comparison of the various software packages includes five steps:

1. Gathering information about software packages (filtering algorithms, prices, system requirements etc.).

   Based on scientific publications and internet webpages, a preliminary list of currently available software was created. This list is modified on a monthly basis.

2. Preparation of the reference data set using a manual classification method. In this step, each point cloud was manually classified into terrain and object points. For this task, the DTMaster (INPHO, 2012) software was used. It allows performing the manual classification in a profile view in 3D, or in 2D based on hillshade view of the surface, contour lines etc. After the filtering, a field control was preformed to verify the results. The remarks from the control were used afterwards to refine the classification (the resulting statistics are presented in the Table 1).

   For each terrain class, a DTM (Figure 2) was generated in the software package SCOP++ (INPHO, 2012). The settings for the areas were the same: 20 cm grid size and interpolation method called classic prediction.

3. Tests of the filtering parameters. Working with each software package involved testing the settings available for the filtering process, in order to get the optimal outcome. Some packages performed more automatically, other needed more interaction. In few cases, the algorithm worked not on the point cloud but on a rasterized data set. Nevertheless, as a resultant set of points in *.xyz or *.las format was always obtained. This output was used to generate the resulting DTMs using SCOP++ (the settings for each model were the same as for the reference data).

4. Qualitative and quantitative comparison of the results.

   The results of the automatic filtering were compared with the reference data sets (Figure 3). In the first place, the visual quality of the models was examined based on hillshade views of the models (in 2D and 3D), profile lines and height differences maps. Secondly, in the quantitative part, the histograms of the height differences and commission/omission errors were investigated. The table of commission and omission errors gathers statistics concerning the amount of ground and object points that were correctly or incorrectly classified. This comparison was only possible when the result of the filter was a part of the original point cloud (without any shifts between points).

5. Adding additional remarks, e.g. quality of the software documentation, problems while running the application, straightforwardness.

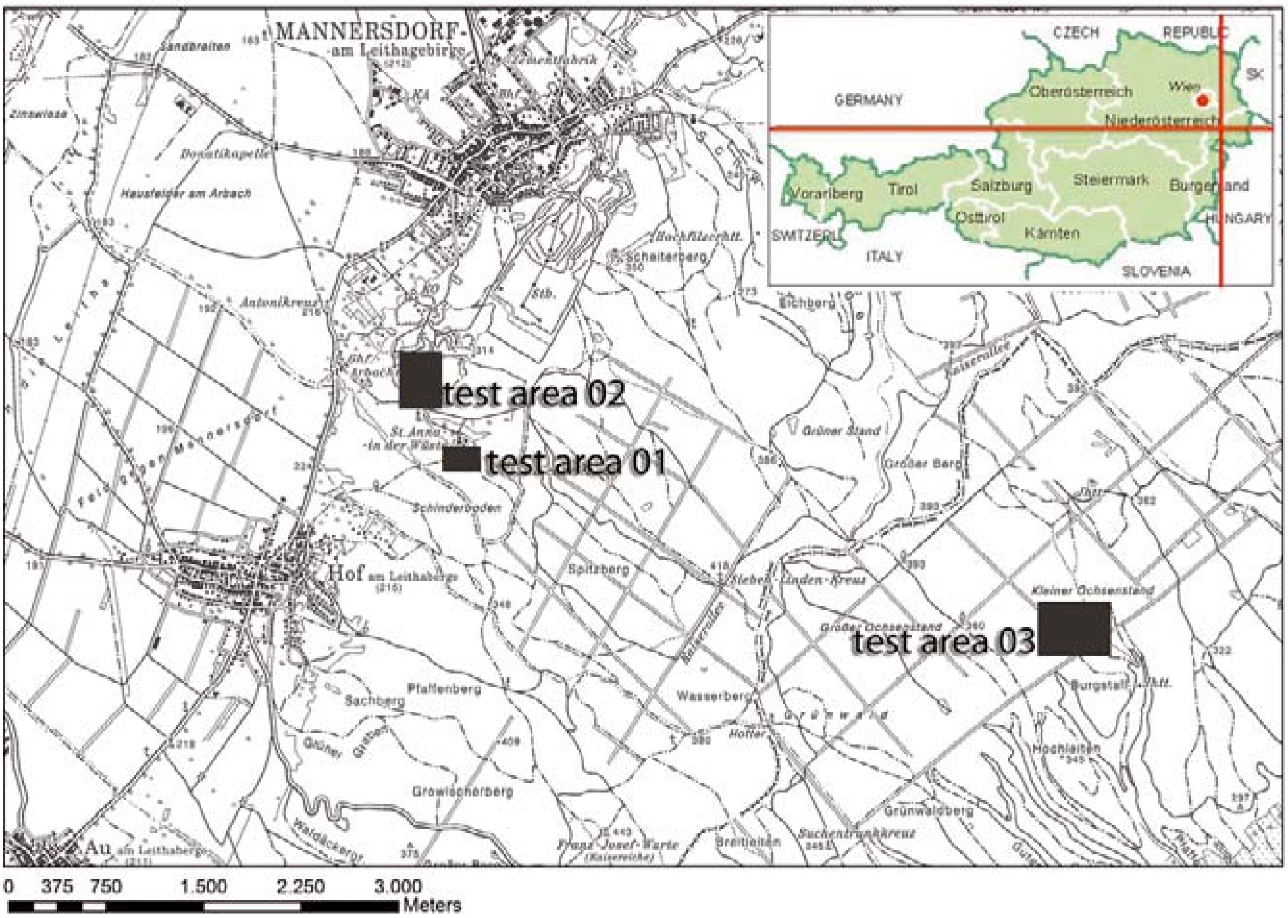


Figure 1: *The location of the reference data sets in Lower Austria.*

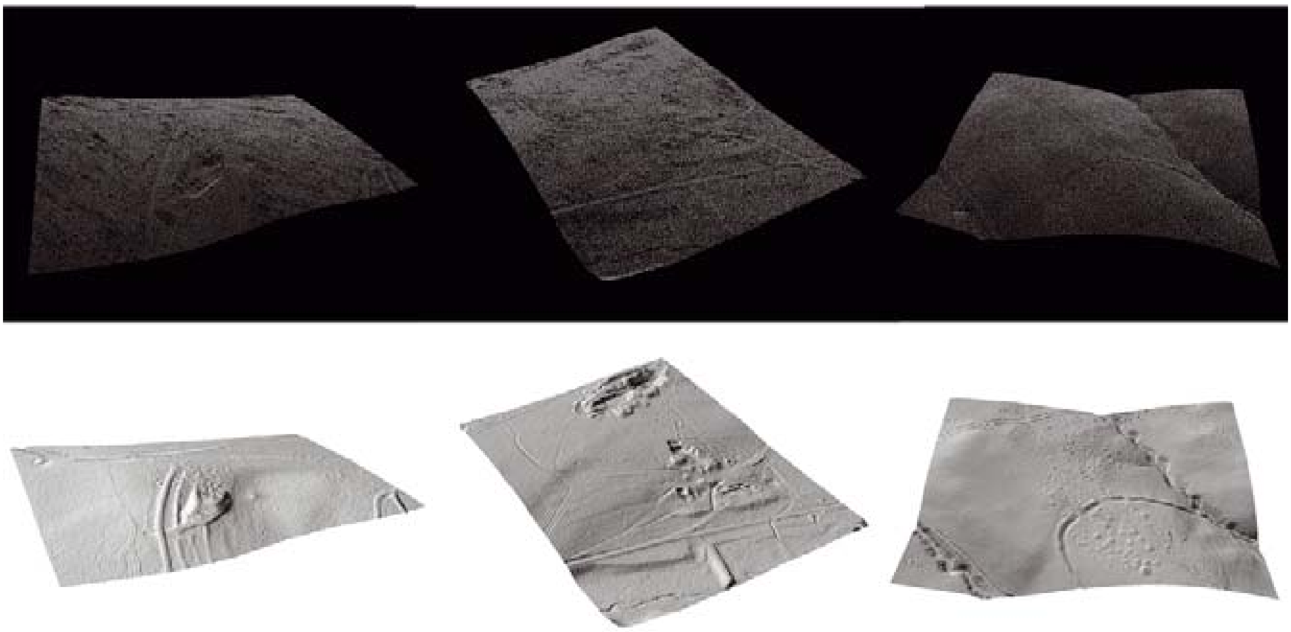
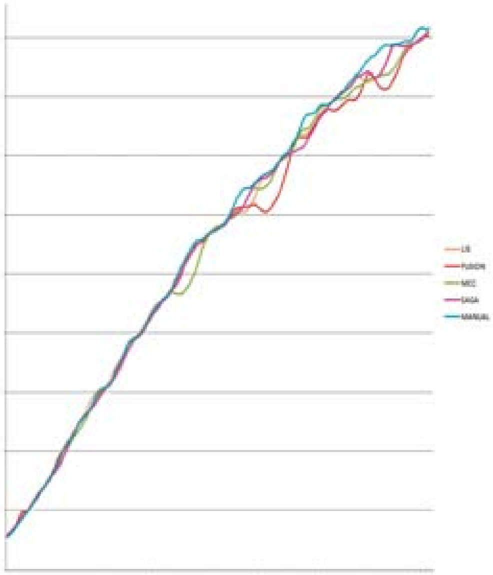
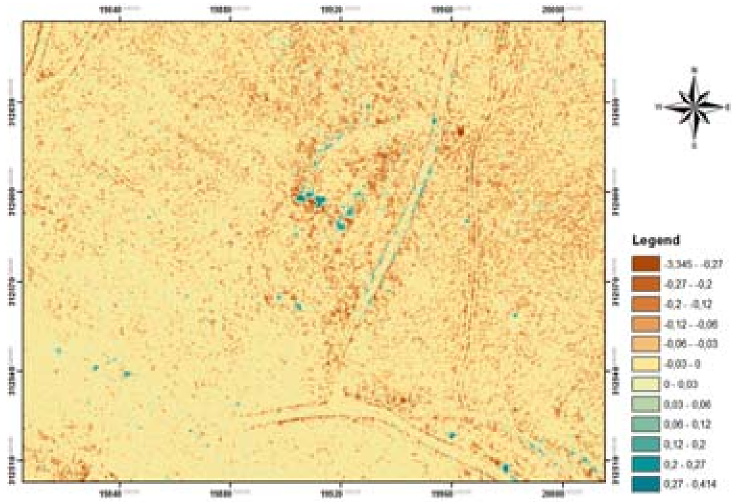


Figure 2: *The point clouds (upper part) and the DTMs (hillshade view, lower part) of the three reference data sets (from left: area01, area02, area03).*





LIS							
		Filtered					
		BE	Object				
Reference	BE	207628	65434	273062	45,84%	Type I	0,240
	Object	8521	314088	322609	54,16%	Type II	0,026
		216149	379522	595671		Total	0,124
		36,29%	63,71%		7,68		

MCC							
		Filtered					
		BE	Object				
Reference	BE	200147	72915	273062	45,84%	Type I	0,267
	Object	10453	312156	322609	54,16%	Type II	0,032
		210600	385071	595671		Total	0,140
		35,36%	64,64%		6,98		

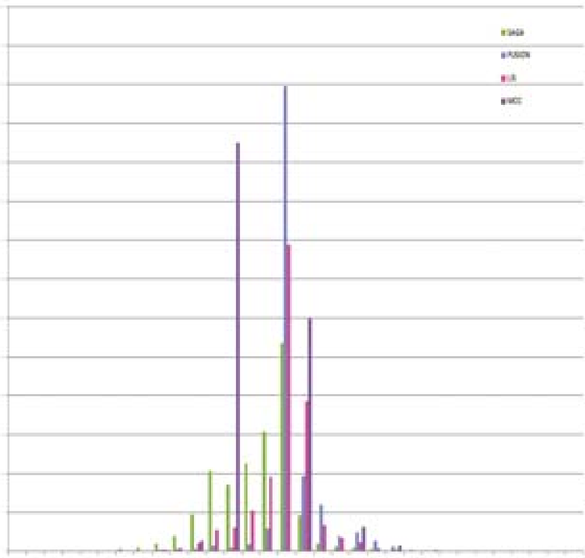


Figure 3: *Analysis of the results (upper row from left: profile view on the bank, difference model; lower row from left: omission and commission errors table; histogram of the height differences).*

Data specification			
Test area	ONE	TWO	THREE
File format	*.las		
Area size	220m × 160m	300m × 400m	520m × 400m
Ground points	273062	894583	1992396
Object points	322609	1217542	2829990
Total points	595671	2112125	4822296
Instrument	Riegl LMS-Q560		
Date	08.04.2006		

Table 1: *Reference data set specification*

The result of this project should be published in a dynamic way by creating a webpage (Figure 4), which would gather all important information gained during the research like the description of the software packages, the best parameters settings for chosen test areas, the difference models and other comparisons.

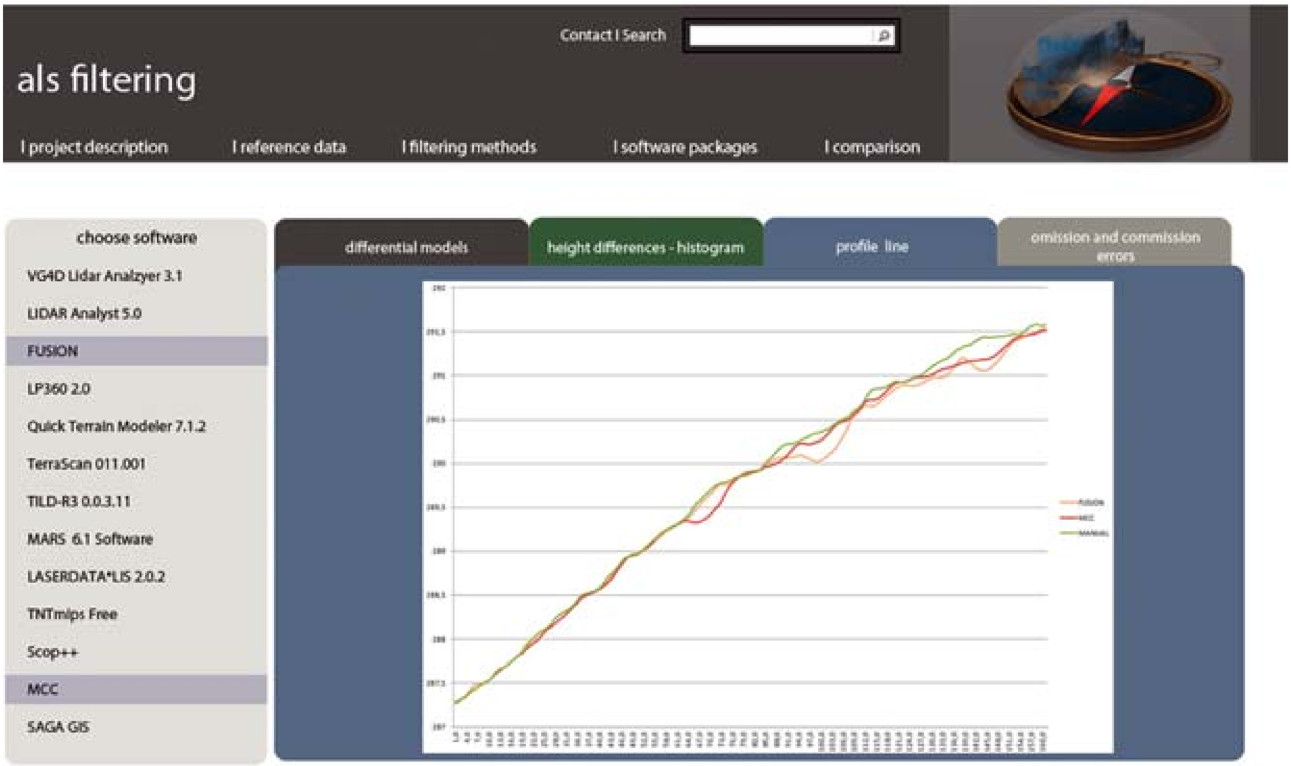


Figure 4: *Project of the webpage. Comparison example.*

Currently the research is in its preliminary phase. A chosen group of software packages has been tested, and the results of the software performance vary in respect of quality. However, more tests must be done in order to present detailed remarks and conclusions.

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THERMOMETRY AS AN ADDITIONAL GEOPHYSICAL METHOD IN ARCHAEOLOGICAL PROSPECTION

R. Křivánek

1. INTRODUCTION

Thermometry, geothermal or thermometric measurement is geophysical method based on a detailed monitoring of changes in temperature or heat flux. Today, the method is commonly used in several areas and specific conditions, such as complex geophysical measurements in boreholes, volcanology, pyrotechnology and industry. In archaeology, this simple geophysical method has been used rather sporadically and complementarily. Thermometric measurements over the last decade were a component of many archaeo-geophysical surveys in Czech archaeology. We can generalize the results of experimental measurements to summarize several common features concerning the methods and options as used in archaeology.

2. METHOD OF SURVEY

Thermometric measurements is possible with different types of thermometers. In Bohemian archaeo-geophysical measurements, we use two types of simple instruments. Common thermometers with sensitive sensors (e.g. GTH 1160, Greisinger electronic GmbH) allow contact-point thermometric measurements of flat surfaces and/or also specific measurements in paving tile joints or under a few centimetres of soil. To monitor changes in temperature conditions we use also a second thermometer for reference measurements on a fixed point. Infrathermometers (e.g. GIM 1840 - ST 60 XB, Greisinger electronic GmbH) offers thermometric measurements of small circular area with diameter of a few centimetres, depending on the distance of the object. Infrathermometric measurement can monitor horizontal solid (tiles, floor), or vertical (wall) surfaces. During measuring, it is worthwhile to use a second thermometer on the reference point. The density of measurement is dependent on the extent of the area of interest. It is normally measured in the network 0.5x0.5 m. Experience from repeated observations of in the Cathedral of St. Vitus (see Mrlina, Křivánek and Majer, 2005; Mrlina, Kivánek and Maříková-Kubková, 2005) indicates that in addition to the need to ensure stable temperature conditions and density of measurement, the result of thermometry also depends on the season when measurements are taken. Rectangular positive thermal anomaly observed in the tomb in winter (Figure 1a) may not be identified in the spring (Figure 1b) or autumn. In summer, the floor can even produce a contrary negative thermal anomaly.

3. EXAMPLES OF RESULTS

3.1. Measurement inside of historical buildings

The most common archaeological use of thermometry is in prospecting unfilled spaces, such as cavities, tombs and crypts inside historical buildings (churches, sacral architecture). In most cases, there are several geophysical methods used and several physical parameters monitored. In the case of a survey on the floor of Romanesque rotunda of St. George at the top of the mountain Říp, cadaster Mnetěš, district Litoměřice, the results of thermometric and electromagnetic measurements were compared (Křivánek, 2011; Nováček, 2011). Places where positive temperature anomaly were detected (Figure 2a) showed lower apparent conductivity in the electromagnetic results (Figure 2b). Based on the combined results, we can assume that under the floor of the rotunda there is a small cavity, tomb, or other space filled with material other than bedrock.

Thermometric measurements can also be used in other specific situations, including those where most other geophysical methods cannot be effectively applied. One such situation, for example, is a previously researched Early Medieval situation now laying under the stone paving of the third courtyard at Prague Castle in cadaster Prague-Hradčany, district Prague 1. High levels of electromagnetic interference (Figure 3b) are caused by buildings, reinforced concrete structures, paving of the third courtyard, distribution of electrical infrastructure, etc. In this complicated situation, it is not possible to employ other electromagnetic, resistivity or magnetometric methods. Positive temperature anomalies (Figure 3a) cut across under the floor of the buried church, identifing a subsurface disruption of St. Bartholomew church around which existed in the past, according to the written sources, a water source and also tectonically faulted bedrock.

3.2. Experimental measurement in open terrain

Survey of cairns or burial mounds

Thermometric measurements with positive results are usually carried out in the temperature-stable environment of closed buildings, but we also held several thermometric test measurements at open-field archaeological sites in the Czech Republic. The results of several experimental thermometric measurements, during the use of several geophysical methods, suggest that, in conditions of varying temperature, it may be appropriate under certain conditions to distinguish temperature changes of subsurface archaeological situations. In the case of complex geophysical monitoring of a cairn on cadaster Kostomlaty pod Řípem, ditrict Litoměřice, we can observe some correlation of several measured physical parameters (Figure 4; see also Křivánek, 2004, 68-69). Negative temperature anomalies (Figure 4a), compared with a range of low values of apparent conductivity (Figure 4b) apparently also indicates the extent of cairn stones below the surface.

Thermometric measurements in open terrain were also tested in other specific situations, like the subsurface remains of ditch or rampart fortifications.

4. CONCLUSION

Thermometric measurements in archaeology do not belong to the usual methods of geophysical surveys of sites. This sim-

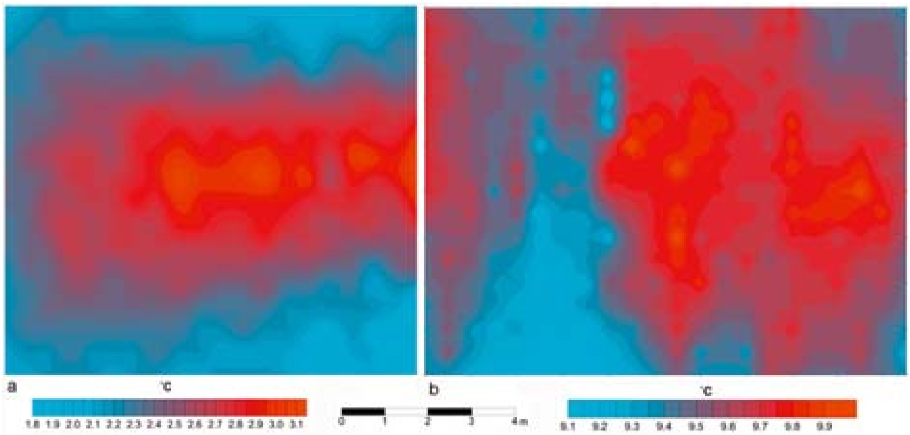

Figure 1: *Prague-Hradčany, district Prague 1. Comparison of results of thermometric measurements in winter 2003 (1a) and spring 2002 (1b) on the tile floor in front of the main altar in the Cathedral of St. Vitus. Verification of different temperature anomalies and the possibility of detection of two-piece rectangular tomb depending on the season of measurement (surveyed area: approx. 10 × 8 m; geophysical survey: Křivánek 2001-2003).*

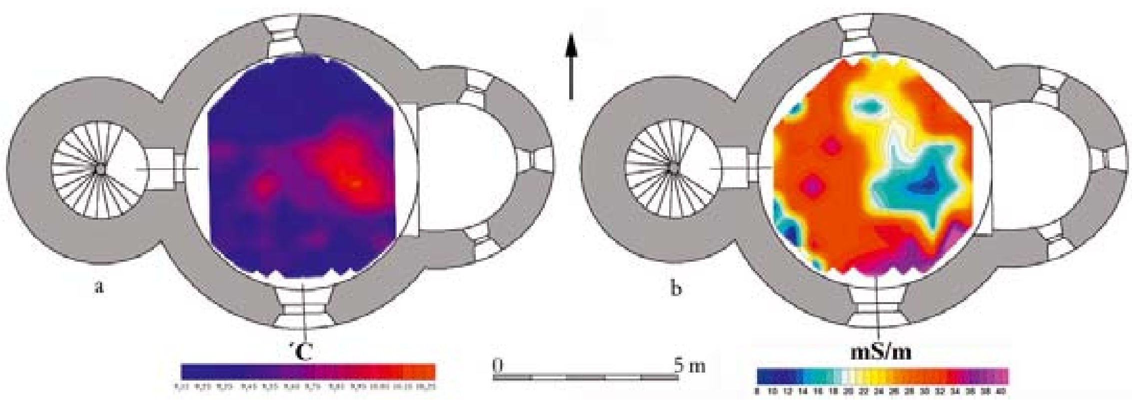

Figure 2: *Mnetěš, district Litoměřice. Combination of results of thermometric (2a) and electromagnetic conductivity (2b) measurements inside of St. George's rotunda on the hilltop of Říp. Identification of probable small tomb, cavity or space filled with other material than bedrock (surveyed area: approx. 5 × 5 m; survey: Křivánek 2009 – 2010).*

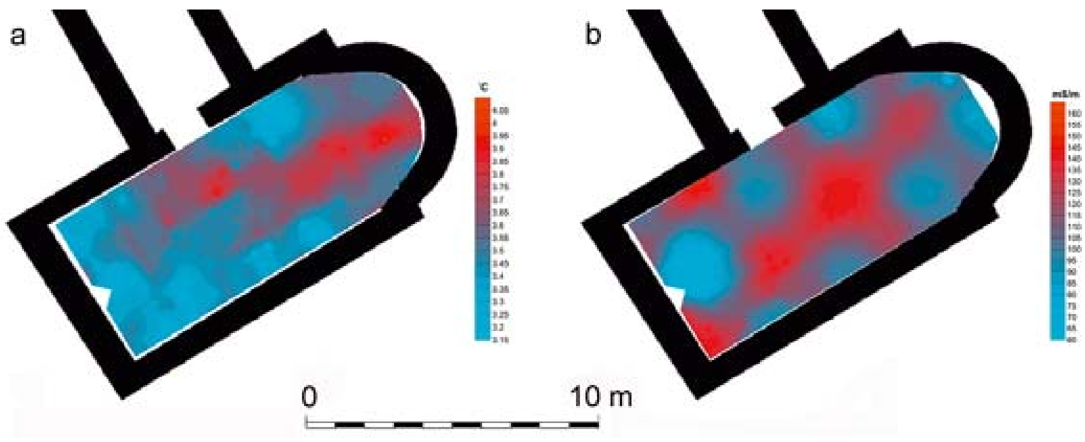

Figure 3: *Prague-Hradčany, district Prague 1. Combined results of thermometric (3a) and electromagnetic conductivity (3b) measurements on the tile floor inside the former church of St. Bartholomew, today buried below the third courtyard of Prague Castle. Identification of high electromagnetic interference caused by buildings and positive temperature anomalies cut across under the floor of the church (surveyed area: approx. 6 × 12 m; geophysical survey: Křivánek 2006).*

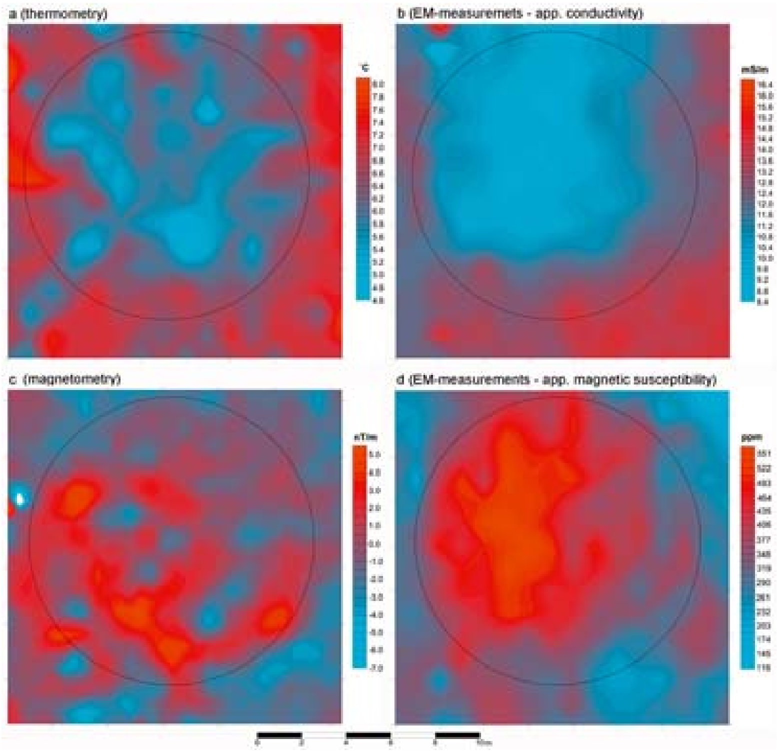

Figure 4: *Kostomlaty pod Řípem, district Litoměřice. Comparison of thermometric (4a), electromagnetic conductivity (4b), magnetometric (4c) and electromagnetic apparent magnetic susceptibility (4d) measurements over a forested cairn. A negative thermal anomaly seems to reflect stony concentrations from the cairn (surveyed area: 15 × 15 m; geophysical survey: Křivánek 2001).*

ple method may be used additionally, within the application of geophysical prospection methods, especially when searching for unfilled spaces (tombs, crypts, cavities, corridors) inside of historical buildings. Measured temperature contrasts with the surrounding environment, however, also depend on the season of survey, fill or closure of the space. Results of thermometric measurements can also be valuable in places where, due to a larger share of disturbances (metals, electromagnetic sources, recent buildings, etc.), is not possible to effectively use other geophysical methods.

The possibilities for thermometry in archaeological situations in the open field will probably remain very limited by current climatic conditions (sunlight, wind, rainfall, etc.), but some results suggest that the measured surface temperature changes may also reflect changes of differently thermally conductive materials (stone, soil, clay, sand, etc.) below the surface. In thermally more stable conditions (for example misty autumn days or dense forest), thermometry applied in smaller areas in short measurement periods can identify these subsurface changes. However, more areal measurements in the field have difficulty with conditions of temperature stability in time and space, introduce measurement errors, and are not probably cost-effective.

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EXPERIMENTS WITH TRAPEZOIDAL ARRAYS FOR ARCHAEOLOGICAL EARTH RESISTANCE SURVEY

J.C. Harris, C. Gaffney

Earth resistance is a well-established method for detecting and delineating subsurface archaeological features. Currently the twin-probe array, a collinear configuration with two probe pairs separated by a distance, is favored for archaeological prospection, due to its accuracy in resolving archaeological targets. However, twin-probe surveys are slow compared to other prospection techniques, due to the manual insertion of electrodes into the ground surface at set intervals. The requirement for constant tethering between the two probe pairs also impedes the flexibility of survey strategies. Within the past few decades, earth resistance arrays have been adapted to mobile platforms to increase the rate of data collection. Non-linear arrays, such as square and rectangular arrays, are particularly suited for adaptation to mobile units because they are easily configurable to self-contained platforms.

The square array has proven effective for archaeological prospection. Its compact form facilitates easy mobility and the collection of three individual configurations (alpha, beta and gamma). Unfortunately, the square array's relatively shallow depth of investigation and orientation-dependent resistance measurements limits its effectiveness for archaeological prospection (Aspinall and Saunders, 2005).

Over the past couple of decades, trapezoidal arrays have been explored for near-surface resistivity survey. The mobile trapezoidal systems designed by the GEOCARTA company shows promising results for archaeological prospection (Dabas, 2009; Tabbagh *et al*., 2000; Panissod *et al*., 1997; Panissod *et al*., 1998). However, further investigation is required to understand the general properties of the trapezoidal array, and how these properties can be used effectively for archaeological applications.

This poster presents research into the trapezoidal array's general properties. The research included a series of experiments, which investigated the array's resolution of features, depth of investigation, and apparent anisotropy. Results of these experiments show many similarities between the trapezoidal array and the square array. Yet, the individual trapezoidal configurations produce unique results, especially the trapezoidal gamma configuration, which may provide additional interpretational value for resistance survey. Overall, this research demonstrates the effectiveness of the trapezoidal array for archaeological prospection.

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IN PURSUIT OF THE PAST

S. Hay, S. Kay, A. James, M. Berry

The regular application of geophysical and topographical survey techniques to evaluate archaeological sites has been the most recent addition to landscape surveys in Italy, carried out by a partnership between the British School at Rome (BSR) and the Archaeological Prospection Services of Southampton (APSS), a unit within Southampton University.

The creation of a focused team based at the BSR providing a service of geophysical and topographical surveys, draws upon the specialised skills and expertise of experienced researchers. The service also benefits from the academic support and resources provided by the BSR and the University of Southampton.

The initiative has been extremely successful since its inauguration in 2001 and has participated in a vast range of chronologically diverse projects, most notably the Portus Project, as well as projects of Italian and foreign research institutions within Italy. The wide distribution of the geophysical work over much of Italy is testimony to the variety of the commissioning bodies which include Soprintendenza, Italian and foreign universities, Province, Regione and local Comune. More recently, the BSR and APSS have begun to extend the geographical spread of their surveys across the Mediterranean, with ongoing work commissioned by partners in Spain, Libya, Sudan, Tunisia and Montenegro.

The poster presents an overview of the research that has been undertaken, the results achieved, and the range of techniques that are used in the field.

PRODUCTS OF NEW CZECH HYPSOGRAPHY BASED ON ALS TECHNOLOGY AND THEIR POTENTIAL FOR ARCHAEOLOGICAL RESEARCH: EVALUATION OF LIDAR DATA AND INTERPOLATION TO DTMS

L. Holata, J. Plzák

In this study, we will introduce and evaluate the potential of official ALS map products, which are provided by the Czech Office for Surveying, Mapping and Cadastre (COSMC) for archaeological purposes. These maps will be available for the whole of the Czech Republic, and will be frequently used by archaeologists because of their relative low cost. Therefore, we will discuss the processes of their acquisition, subsequent elaboration, and their transformation to resulting digital terrain models (DTM). All these steps in evaluation of LiDAR data can significantly influence the recording of relief structures.

The method of ALS was chosen for productions of new and superior hypsography in the Czech Republic. This project, a co-operation between several institutions, is taking place in the period from 2009 to 2015. The collection of data is planned for the end of 2012, whereas the final map products are gradually generated; these are called DTM of the 4^{th} generation and DTM of the 5^{th} generation (DTM-4G and -5G respectively). These products are generated after pre-processing of raw data and their consequent modifying by a robust filtration, which will remove the majority of measurements from non-ground features.

DTM 4G is created by the regular network of points (GRID) with distance 5×5 m (Figure 1). It is a result of preliminary automated elaboration of LiDAR data. The full middle error of altitude is 0.3 m in the open terrain and up to 1 m in woodlands. The terms of finalization is planned for the end of the year 2012. The area is at first divided to the squares of 25 m^2 and one node point with a lower altitude is chosen in every square to represent the relief. In the case of anomalous values, another node point is selected. This irregular point network is consequently transformed to S-JTSK coordinate system, and through interpolation algorithm is formed into regular network with 5 m points distance.

DTM 4G utilizes only a small part of the overall number of points. Therefore, only large topographic objects in relief are recorded. All less perceptible objects, including anthropogenic earthworks, are left out. It is not possible to use this source for prospection of unknown sites. However, this map product is more detailed than the actual hypsography of the Czech Republic. That is why DTM 4G can be applied as a high-quality basis for inter-site spatial analysis or predictive modelling.

DTM 5G is provided in the form of the irregular points network (Figure 2). It is the result of semi-automated elaboration of LiDAR data. The full middle error of altitude is 0.18 m in the open terrain and up to 0.3 m in woodlands. The release is planned for 2015, but the processed models are continuously updated. The lower node points are chosen from squares with extent of 25 m^2 only in agricultural areas without relief edges, while the rest of territory is divided into squares with extent 1 m^2. This solution causes the elimination of unsubstantial relief irregularities. The areas without measured points are filled in by interpolating values from the values of surrounding points. Resulting data were consequently rarefied because of small errors elimination (especially inclusion of vegetation) whereas maximal altitude error is preserved. Consequently, they are transformed to the S-JTSK coordinate system.

DTM 5G constitutes a sufficiently detailed base that can be used in archaeological prospection, although it is still not accessible for the majority of the Czech Republic. After it has been

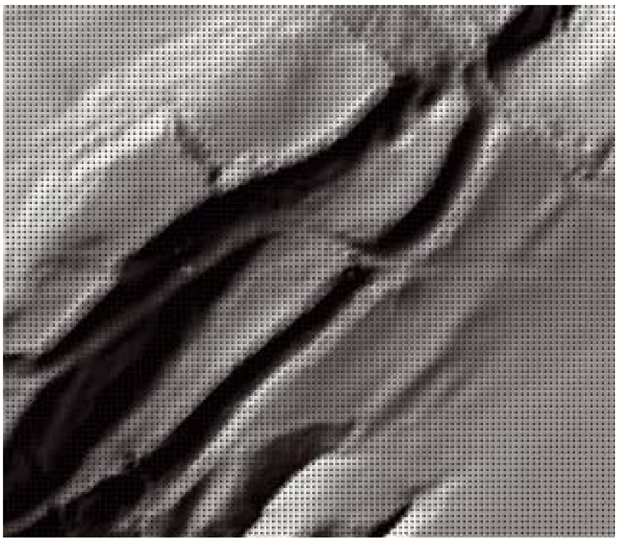

Figure 1: *DTM 4G.*

Figure 2: *DTM 5G.*

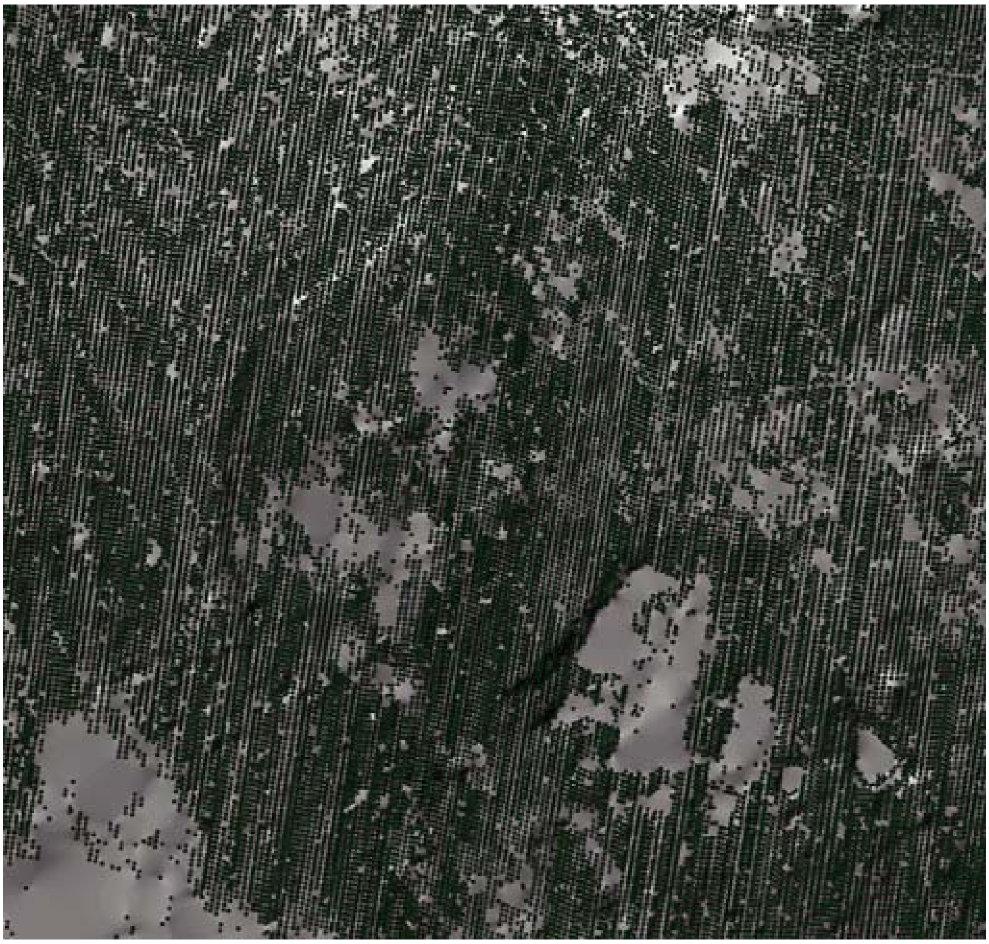

Figure 3: *Data modified by robust filtration.*

released, it will be widely used by archaeologists. It is necessary to keep in mind that these data are not primarily for archaeological purposes. Even if many earthworks are recorded by this date, average density of points is only 0.25/m^2 and less perceptible relief structures might be completely missed. The same situation can arise in areas with absence of real points of relief, where factitious points are interpolated. In the case that some type of site actually occurs only in such an area, it will not be recorded. DTM 5G should be always compared with the raw data and the data modified by robust filtration.

The empty areas can be clearly visible just in the data modified by robust filtration. These are created by a greater amount of points (the average density is 0.9/m^2) but include also more errors and anomalies (Figure 3). Nevertheless, these can be partially overcome by the choice of interpolation algorithms (cf. below). Therefore, it is possible to use this kind of data in archaeological research as well, when DTM 5G is not fully worked up. All kinds of ALS map products have to be critically reviewed and verified by the precise ground-truthing before any final conclusions can be formulated.

In the second part, we would like to discuss the problems of interpolation algorithms that transform the disconnected points to continual relief in elevation DTM. We have tested six interpolations in ArcGIS 10 for DTM 4G, DTM 5G and also for the data modified by robust filtration. Transformations direct from points (IDW, Kriging, Natural Neighbour, Spline) together with interpolations flowing from TIN (Linear, Natural Neighbour) were included. We purposefully used only the basic setting of particular parameters because we assume a similar workflow by other archaeologists.

In the case of DTM 4G, the best results are provided by Kriging and both Natural Neighbours. The calculation of Kriging was slower and it can be used in smaller areas than Natural Neighbour. In addition, the edges of slopes are better recorded by Natural Neighbour. DTM created by Spline is mostly smooth and it looks best from an aesthetic point of view, but it can evoke the presence of false objects. Linear interpolation reflects the structure of the TIN, and hence it is not really acceptable. The worst DTM was generated by IDW; the striking structure of source points largely complicates the discernment of relief formations.

The most suitable interpolation for DTM 5G are Linear interpolation and both Natural Neighbours. All of them exactly record the earthworks. Inconsistent situation is registered in the case of Spline algorithm. This reflects the finest of relief curvature but without precise surface survey, we are not able to consider if the small earthworks really occur in relief or if some anomalies are recorded. The false earthworks are generated by Kriging in the areas with lower density of points (Figure 4). This situation is accented by IDW, which reflects the structure of points again. Both these algorithms are unsuitable for DTM 5G.

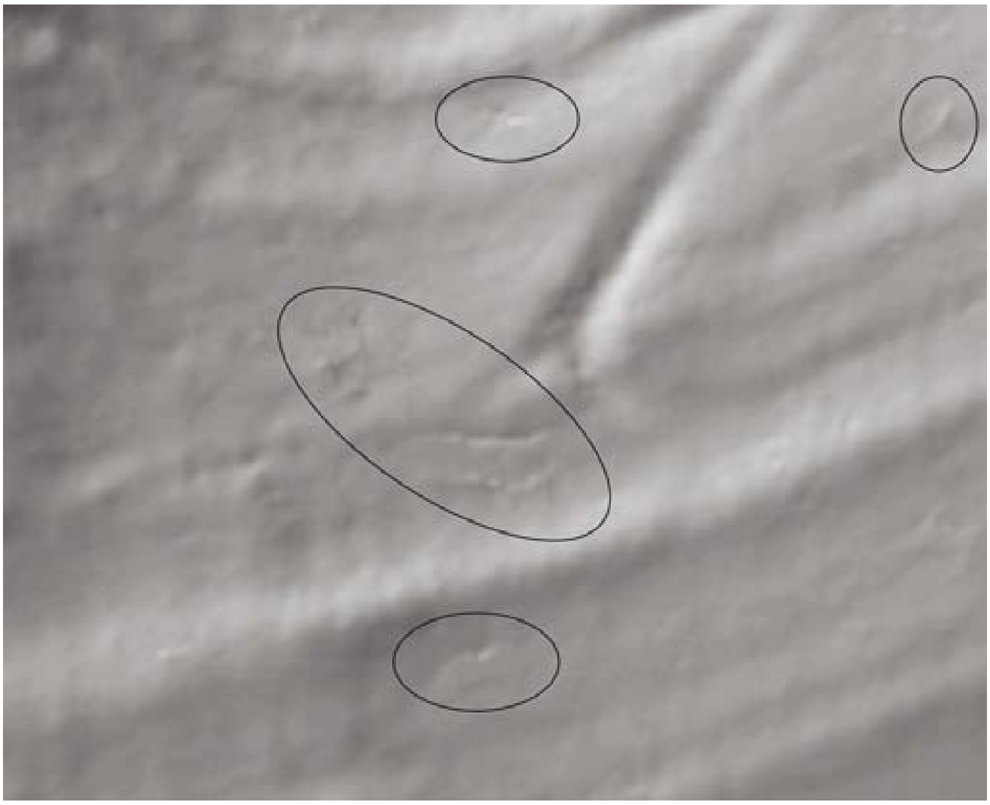

Figure 4: *Kriging interpolation of DTM 5G; pseudo-structures are marked.*

Creating of pseudo-objects in empty areas is further manifested in the transformation of the data modified by robust filtration to DTM. These problems occur in the case of IDW, Kriging, Spline and Linear interpolations. The latter two interpolations also reflect the anomalies in source points and generate false earthworks in places with higher point densities. In addition, we find that Natural Neighbour calculated from points generates a DTM that is slightly displaced. Therefore, all these interpolation are unsuitable for DTM 5G. In the case of Kriging, it is raised by its exacting and time-consuming calculation of DTM. The best results are provided by Natural Neighbour calculated from TIN.

The comparison of various interpolations on different kinds of data has brought very inconsistent results. Some general patterns can be derived from the tested sets. The pertinence of IDW increases with an increase in the density of source points. Kriging is not so acceptable for LiDAR data because it creates pseudo-structures in empty areas, and time-consuming calculation limits its usage with huge amount of points. Spline is dependent on the quality of input data. It can record the slight earthworks, but we must be sure that source points include any anomalies. Linear does not work well with the irregularities of data that are represented by the abnormalities in measuring or lower density of points. Both Natural Neighbours are generally suitable for LiDAR data, but the algorithm calculated from points generates a DTM that is slightly displaced in the data modified by robust filtration and also for DTM 4G.

Every interpolation algorithm generates specific DTM and its choice has to be determined by the character of source data. We prefer the realization of several methods in evaluating of LiDAR data in order to exclude false structures in DTMs. To achieve the correct interpretation of DTMs, a critical approach is necessary; we must realise the limits of source points and we must ensure the correct transformations to elevation DTM before the visualization of anthropogenic earthworks is realized.

ACKNOWLEDGMENT

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REVEALING THE INVISIBLE: EVALUATION OF MODERN REMOTE SENSING TECHNIQUES IN THE LIGHT OF ARCHAEOLOGICAL PROSPECTION

M. Ruš

1. INTRODUCTION

Archaeological prospection nowadays employs several remote sensing techniques e.g. Airborne Laser Scanning (ALS) or commonly referred also as Light Detection And Ranging (LiDAR), Airborne Imaging Spectroscopy (AIS), multispectral, panchromatic and true colour satellite imagery, Air Photography (AP), and Synthetic Aperture Radar (SAR). Because of its potential to show archaeological sites, the field of Remote Sensing has greatly influenced archaeological prospection over the last few decades. Especially modern techniques have called the archaeologist's attention on the one hand due to a dramatic increase of spatial and spectral resolution, and on the other hand due to a lowering of prices. Networks have been built sharing RS data for free with other academics like e.g. the open science approach by the DART[1] project. Therefore, archaeologists have a broad range of RS tools available to non-invasively detect and interpret archaeological sites. Especially airborne laser scanning and hyperspectral scanning systems – which will be the focus of the proposed dissertation – are very young techniques, employing sensors with high spatial and spectral resolution.

With the arrival of every new sensor, data filter, or algorithm, archaeologists are able to visualize features prior invisible to the human eye. Once made visible, the huge amount of data has to be manually processed and interpreted. This approach has proven to be very effective, but has its limitations. There are basically two problems attached to this approach: (1) scale and (2) complexity.

(1) Today, a multitude of RS datasets (especially aerial photography and ALS) are available on country-wide scales. Therefore, using these data, archaeological features can be searched for in these large scaled areas (federal states or countries). However, systematic visual based interpretations are only rarely financed, because of the enormous time and personnel costs involved. Here, a development of tools for (semi-) automatic image interpretation is needed.

(2) The integration of all sensor data into a complex project output will open again new possibilities where trained archaeologists are able to recognize new and more detailed information. Especially AIS and ALS data are being used to enhance the limits of a human eye in the process of image analysis and interpretation. But data from modern sensors are highly complex, especially when fused with each other in an integrated approach. Both technological knowhow as well as archaeological background knowledge are required with the interpretation of such complex RS data. This has distracted archaeologists from using fused datasets. A workflow and tools to derive "readable" images from the complex datasets and to (semi-) automatically detect these features of interest are needed.

[1] http://dartproject.info/WPBlog/, accessed 10.4.2012

2. AIMS

According to the introduction, current research in the field of archaeological RS is in need of investigations towards multi-sensor integrative approaches. Therefore the proposed dissertation will focus on ALS and AIS data fusion for the purpose of archaeological prospection. There is a strong need for better understanding of AIS potential as this data source might be both over- and underestimated. Another novel approach, which is especially desirable for the increasing number of large-scaled datasets, is the development of (semi-)automatic detection techniques for crop- and soilmarks. The project will focus on the fused AIS and ALS datasets, which have a high potential for reliable results.

The main aim of this study can therefore be described as the investigation, how ALS and AIS can enhance our understanding and identification of buried archaeological and palaeonvironmental features indicated by cropmarks and soilmarks? To follow this aim, the whole process of ALS and AIS data processing, visualization and interpretation has to be investigated to assess its potential for the detection and interpretation of archaeological cropmarks and soilmarks. This will lead to the development of an optimal workflow to derive and use fused datasets.

3. CASE STUDY

This research study will focus on a case-study area of Carnuntum in Austria, where large-scaled datasets of all mentioned prospection techniques are already available, due to the work of the Ludwig Bolzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro[2]), the Vienna Institute for Archaeological Science (VIAS[3]), and the Aerial Archive of the Department for Prehistoric and Medieval Archaeology (UFG[4]).

4. RESEARCH QUESTIONS

Based on the aims and the state of art, the following research questions will have to be investigated:

- What is the methodological workflow needed to fully extract the rich archaeological information out of AIS imagery? Which spectral bands are most sensitive to pick up the specific signatures of crop marks? Which vegetation indices might enhance cropmarks visibility and detection?
- How can high resolution ALS and AIS imagery support the detection of cropmarks and soilmarks using data fusion? What is the best workflow mix of spectral and spatial enhancement for the data fusion of used RS data? Is ALS alone helpful in detection of crop/soilmarks? How

[2] http://archpro.lbg.ac.at/, accessed 10.4.2012
[3] http://vias.univie.ac.at/, accessed 15.4.2012
[4] http://ufg.univie.ac.at/, accessed 10.4.2012

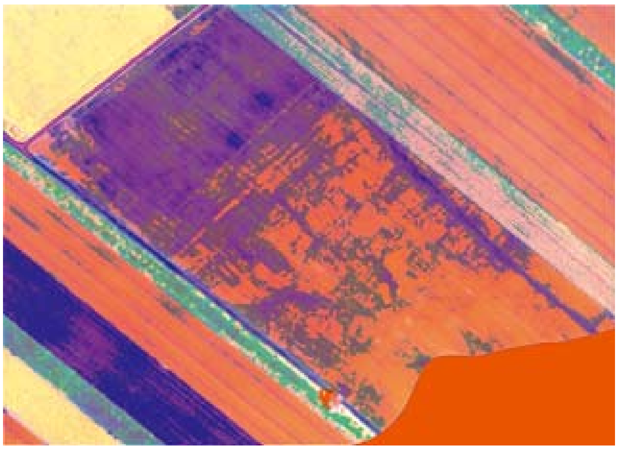

Figure 1: *Modified AIS data with ND-filtering, Z-smoothing and REIP (bands 10-90). Crop marks appear more sharply divided with negative (blue) and positive (orange) features.*

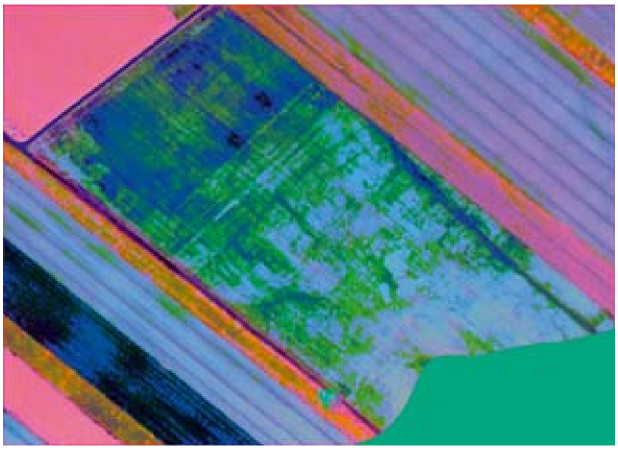

Figure 2: *Modified AIS data with ND-filtering, Z-smoothing, REIP (bands 10-90) and PCA (RGB of all 3 components). Features appear not so sharp but in more numbers and smaller scales that were previously invisible.*

much more information are we getting when adding AIS data?

- What is the interpretation of cropmarks and soilmarks out of this fused ALS and AIS datasets? How much new knowledge can they provide to the overall picture of archaeological landscape of Carnuntum?
- How can semi-automatic detection of cropmarks and soilmarks from fused datasets support the interpretation and analysis of large landscape of Carnuntum? Is OBIA method the right answer to get the best results in terms of both quantity and quality?

5. RESEARCH DESIGN AND METHODOLOGY

The complex methodological workflow is divided into several main steps:

5.1. Step 1: ALS and AIS data pre-processing

The first step involves ALS and AIS data preparation. This means correct data georeferencing, orthorectification and radiometric calibration. The data are already provided according to the table above with some degree of pre-processing but they have to be corrected to match more accurately. A selection of suitable, small, and representative test-areas will be used for the systematic investigations and tests of the other working packages. This data subdivision is necessary because whole dataset is too large to test various analyses in the first run. Later a base data elevation layer (DSM) is derived out of ALS first echo points. This layer will be used in the data fusion process as described in step 3.

5.2. Step 2: AIS evaluation

The purpose of this step is to find the workflow needed to get maximum archaeological information out of available AIS data. The goal is to enhance cropmarks and soilmarks visibility within the pre-defined test-areas. Both the software ENVI and a new developed toolbox for Matlab are provided by the UFG. They comprise all necessary algorithms for band mixing, edge detection, contrast enhancement, band animations, red edge inflection point (Figure 1), band elimination, noise filtering, principal component analysis (Figure 2), distribution fitting, image similarity, spectral profile and histogram, and vegetation indices e.g. NDVI. Comparing and quantifying the results to the already available results from air-photo interpretation and geophysical prospection, the value of AIS will be discussed and recommendations for its archaeological application derived.

5.3. Step 3: ALS and AIS data fusion

The purpose of this step is to define a methodological workflow for ALS and AIS data fusion applied to the selected test-areas. Data fusion is a popular approach which combines data from multiple sources to improve the potential values and interpretation performances of the source data and produce more readable representations of the targeted data classes. Data fusion can be performed in 3 different levels: Pixel, Feature, Decision (Solberg, 2006). There are 3 major fusion methods used at feature and decision level: Bayesian Inference, Dempster–Shafer Evidence Theory, Neural Networks (Zeng *et al.*, 2006). However there are many other methods available, each has its own advantages and careful decision will be made to get the most information out of ALS and AIS data fusion for the purpose of cropmarks and soilmarks enhancement and detection. As discussed earlier in this expose previous research proved that data fusion is the method for target RS data enhancement. Therefore the archaeological expectation of this step is to aid in the identification of more positive results using higher rate of accuracy when compared to single sensor approach. This is valid for both cases – visual and automatic classification.

5.4. Step 4: Fused data evaluation and interpretation

A proposed data fusion workflow will be applied to the whole dataset. After initial evaluation additional corrections might occur. Then a range of visual interpretations will take place starting from pure ALS and AIS data up to fully fused dataset. Existing knowledge about the Carnuntum landscape in the form of cropmarks and soilmarks extracted from APs and geophysics will then be compared with newly interpreted information (Figure 3). The results from this step will be the base for the comparison with the results from the next one and will act also as a validation source.

Figure 3: *Modified AIS data with ND-filtering in RGB mode and underlying vertical AP from the same flight. Direct comparison with interpretations based on previous AP research proves that new AIS data may reveal more cropmarks previously unseen.*

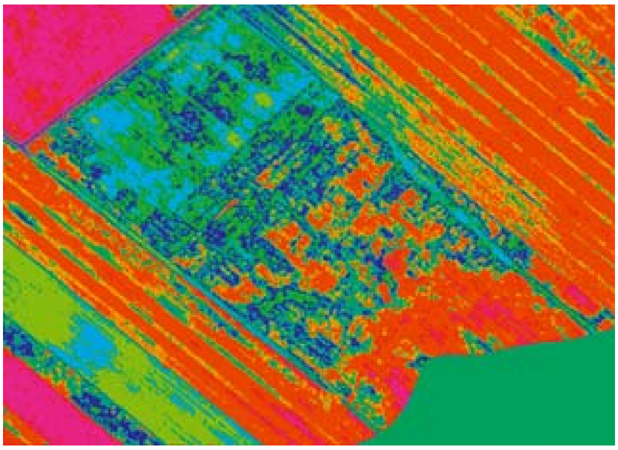

Figure 4: *Modified AIS data with ND-filtering, Z-smoothing, NDVI (bands 90-50) and classification into 10 classes. This PBIA example shows a rather complex image with all its limitations. To make image more readable, OBIA method with data fusion should provide better distinction between positive/negative cropmarks and surrounding environment.*

5.5. Step 5: Semi-automatic detection

The final step involves the most challenging task. It is important to stress that the purpose should not be perceived as a substitute of human visual interpretation, but rather as a support tool when dealing with processing and interpretation of large amounts of data. The principle is the extraction and automation of human cognition when applied to large volumes of data. Semi-automatic detection of cropmarks and soilmarks from fused ALS and AIS datasets might improve the speed of discovery and test the hypothesis about validity of this tool for such a purpose. The results will quantify the rate of success when compared to previous visual interpretations from fused data, AP and Geophysics. A methodological workflow will be tested against selected test-areas and later on the whole dataset. Automatic target detection in image analysis is using two main approaches – object and pixel-based. Pixel-Based Image Analysis (PBIA) contains several algorithms for analyzing individual pixels, e.g. supervised and unsupervised (Figure 4) classification. Object-Based Image Analysis (OBIA) gives more weight on pixel groups or objects by comparing pixels to their neighbors. This approach is more close to the human way of making sense of images and we can see a number of papers that use this method more effectively as the old one. The OBIA approach is rule based and usually contains two basic steps – segmentation to group pixels of common value (e.g. blue pixels are water) and classification to separate segmented pixel groups into target classes (e.g. lake, forest, road, cropmark, soilmark). Both image analysis methods will be tested and quantified.

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AN UNIFIED MAGNETIC DATA ACQUISITION SOFTWARE FOR MOTORIZED GEOPHYSICAL PROSPECTION

V. Sandici, D. Scherzer, A. Hinterleitner, I. Trinks, W. Neubauer

The efficient coverage of large areas through archaeological magnetic and GPR prospection requires a transition from manually operated carts to motorized survey systems. This transition is not straight-forward, but requires elegant technical solutions for the challenges posed by real-time navigation of the survey equipment over the measurement area and the exact positioning of the acquired data. In the case of motorized surveys, the speed of data acquisition and the size of the area surveyed daily increases 10-fold. Therefore, a positioning method using odometers and distance markers or guidance lines placed on the ground is no longer feasible. The solution to overcome these challenges lies in high-precision real-time kinematic differential GPS (RTK-GPS) tracking of the survey system. Along with the new hardware available for motorized multi-channel GPR and magnetometer measurements, developed by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro), a new software solution for real-time navigation had to be developed. In addition, motorized survey requires a magnetic data logging software in order to ensure the efficient use of the newly developed systems independent of the sensor platform.

The requirements for the motorized magnetic prospection data acquisition software were to record the measured, digitized data and to correctly distribute the GPS tracking positions, as recorded in parallel, among the data, and to continuously display the current position of the system and the surface area already covered graphically in the field. The basic idea was to develop a visual data logger. As it turned out in practice, although this core functionality may be sufficient, it is not completely satisfactory. Subsequently, the specification for the data acquisition software had to be extended and a new concept developed.

Our interpretation of this concept resulted in the development of the LoggerVis data acquisition and navigation software (Figure 1). It extends the previous concept with a third core feature: the monitoring of the measurement system for real-time quality control. Considering the rough environmental conditions that the hardware is exposed, in terms of terrain, weather conditions, dirt, etc., frequent hardware failures have to be taken into account. An entire section of the user interface is dedicated to the important task of displaying all system components so that the operator can insure they are working correctly.

The main purpose of this feature is to avoid recording corrupted data, and thereby avoid losing valuable time in the field. The sensors and GPS data connection status are displayed using an intuitive green/red colour based warning. Using text displays, the current sensor readings, received RTK-GPS position in UTM coordinates and GPS position quality are being displayed. The data-rate gauge acts as a second indicator for the sensor input and shows the received sensor readings for the last second.

Another concern is the quality of the received sensor data. For quality control, the following two features were implemented: firstly, a chart visualisation of the received sensor data, displaying it as a time series in order to permit the quick identification of abnormal amplitudes or frequency content of the data; secondly, the possibility for online visualisation of the recorded data. The online visualisation displays the recorded magnetic data values directly on the navigation map in form of greyscale colours (Figure 2). This visualisation permits the operator to instantly determine the quality of the acquired data.

Another issue for the user interface is the variable lighting conditions in an outdoor operating environment. In order to account for the different visibility conditions, the user interface colour scheme is completely customizable by the user for maximum readability in the field.

Motorized surveying implies a whole range of different equipment. For magnetic measurements, for example, we have two different types of sensors, the Caesium magnetometers and the fluxgate gradiometers. Different digitizers exist for the fluxgate gradiometers, each communicating with the data logging computer using their own protocols. Several receivers exist for GPS positioning and tracking (Leica, JAVAD, ALTUS), each communicating with the data logging computer using different types of GPS strings. The software should work with all the equipment available in the inventory, and expose the unique abilities of each system to the user. A uniform interface for all of the different measuring systems relieves the operator from having to learn to operate software solutions specific to each system.

A crucial advantage of a unified software system resides in the fact that the field computer becomes an interchangeable part of every measuring system, especially important with the near experimental composition of the LBI ArchPro systems. A uni-

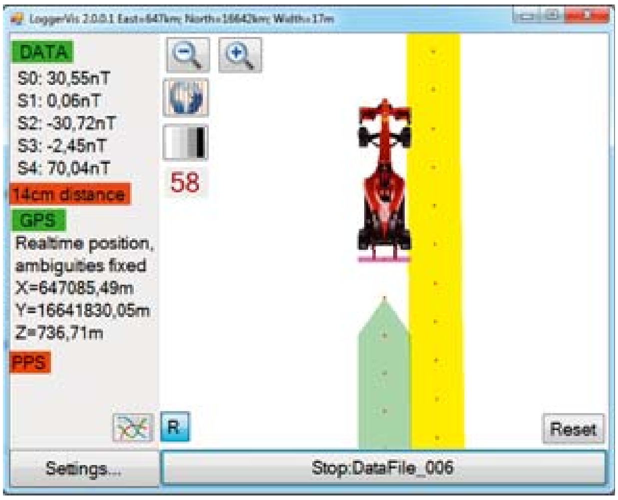

Figure 1: *LoggerVis navigation and system overview user interface. Magnetic sensor readings and the RTK-GPS data quality are displayed on the left. The surveyed area is shown as coloured band behind the survey vehicle. GPS positions are shown as red dots.*

Figure 2: *Example of LoggerVis online visualisation of magnetic prospection data values.*

form software concept also enables standardization of the format of the recorded data, facilitating data processing. The xml standard was chosen for the output data format, because it combines recorded data and metadata and is readable. The meta-data describes the data formats and structures used in the file for storing the measurement data, as well as information on the survey area, date, time, weather and ground conditions, operators and system components. LoggerVis manages the output files in conjunction with each survey site: choosing the storage location of the output files implies the description of the survey area, including weather and ground condition information. A separate section in the meta-data is the description of the equipment used. This additional information gains value in the perspective of automated data processing that enhances the output quality in relation to the data acquisition hardware and survey site conditions. This extra information gathered also permits the evaluation of various configurations of hardware in terms of the measured data quality, and for the identification of possible problems.

Summing up, the combined features of the developed software system provide an operating system for measurement equipment, rather than being just another data-acquisition software. Besides logging data, LoggerVis uses the data input to guide the operator, providing an intuitive real-time system control and online navigational information, leading to a maximization of the measuring system's productivity. Future developments planned by the LBI ArchPro certainly will encompass the concept of a dedicated operating system.

TOWARDS AN AUTOMATED GEOREFERENCING AND ORTHORECTIFICATION OF ARCHAEOLOGICAL AERIAL PHOTOGRAPHS

M. Doneus, G. Verhoeven, W. Karel, C. Briese, N. Pfeifer, C. Ressl

1. INTRODUCTION

Aerial photography is one of the oldest archaeological prospection methods. Although it is highly efficient in detecting sites, its full potential (i.e. the detailed mapping of archaeological and palaeoenvironmental structures) can only be used when the photographs are georeferenced, (ortho)rectified, interpreted and mapped. Georeferencing, also known as image orientation or registration, assigns spatial information to the imagery to explicitly define their location and rotation in respect to a specific Earth-fixed coordinate frame. This enables their transcription to a map, a process that obviously involves the archaeological interpretation of the detected structures and/or features in relation to other available georeferenced data sets (Palmer, 2000). When executed repetitively, several multi-temporal observations can be mosaicked into an extensive overall view of an archaeological region, which will be used as basic information for further prospection, excavation, protection measures, and spatial analysis.

Irrespective of the method applied, the georeferencing of the images is commonly determined with ground control points (GCPs), whose measurement and identification is a time-consuming operation (that is only partly reduced in photogrammetric packages by using automatic tie points and a block adjustment for multiple images). Especially in large-scale archaeological projects with thousands of images, this is currently considered to be the biggest bottleneck. Along with specialised software, reference data, photogrammetric skills and experience are required. Therefore, aerial archaeology often does not go beyond the data acquisition stage. As a result, millions of aerial photographs (APs) are currently stored in archives that often only allow a very limited geometric access of the imagery. These archives contain an enormous amount of valuable optical information for detecting and documenting archaeological landscapes, which cannot be exploited efficiently.

2. THE PROJECT

Hence, automated techniques for the georeferencing of archaeological APs are highly desirable. In order to allow an absolute georeferencing, this approach can be based on the available georeferenced reference data (orthophoto and digital terrain model or DTM). Within this workflow, however, several issues of typical archaeological APs have to be considered:

- both vertical and oblique images are acquired
- different non-metric (uncalibrated) cameras are used
- oblique photographs often lack a high number and/or good distribution of possible ground control points
- oblique APs are often shot from an extremely oblique viewpoint
- often, even rough georeferencing is missing [e.g. position information by a hand-held GNSS (global navigation satellite system) receiver].

Since March 2012, the Austrian Science Fund (FWF) is supporting the project "Automated Georeferencing and Orthorectification of Archaeological Aerial Photographs (ARAP)". Three international partner organisations (Vienna Institute of Archaeological Science of the University of Vienna, LBI for Archaeological Prospection and Virtual Archaeology based on an international partnership, and Research Groups of Photogrammetry and Remote Sensing of TU-Vienna) are co-operating within the project. They have long-term experience in archaeological prospection, especially aerial archaeology and photogrammetry. The general aim of the proposed project is to create solutions for the automated georeferencing and orthophoto generation of archaeological APs. The resulting workflow should allow the efficient processing of both newly generated and previously acquired aerial images based on available reference data.

In order to fulfil these requirements, the project will (1) evaluate a calibrated digital still camera (DSC) with an attached positioning and orientation system (POS) for archaeological prospection and automated orthophoto production = "hardware approach"; (2) develop a workflow including software for automatic orientation of APs without accurate initial positioning and rotation information = "software approach".

Both approaches will be implemented in the conventional aerial reconnaissance work from a small aeroplane as well as in an innovative method using an unmanned aerial vehicle (UAV) to acquire aerial imagery completely autonomously and being independent of conventional aircrafts.

3. HARDWARE APPROACH

This approach aims at creating a hand-held calibrated DSC with an attached positioning and orientation system (POS). By combining a low-cost IMU (inertial measurement unit) and a GNSS receiver, the POS observes the external orientation parameters as input for the previously outlined software approach. Currently, several affordable IMU solutions (prices around €200) are being tested for their accuracy, tendency to drift and consistent performance. In addition, they should allow easy integration with low-cost GNSS receivers, enable sub-second camera synchronisation and data logging (on the same board or using a third hardware component) while featuring low power consumption. Finally, the integrated POS solution must be robust enough to be taken in the air and small enough to fit in a case that is easily mountable on a camera's hot/flash shoe (Figure 1). Within the outlined software workflow (during the bundle block adjustment), the POS data will be used as initial values resp. as weighted observations of the exterior orientation of the photograph. This will allow reducing the effort for estimating these initial values. However, in order to increase the absolute accuracy of the final georeferencing, the usage of available high quality DTM and orthophotos will be essential.

Figure 1: *The first prototype of a hot/flash shoe-mounted case which holds the integrated POS solution.*

4. SOFTWARE APPROACH

In the initial phase of the project, the software approach is vital, as it is the only method that can be used for the millions of vertical and oblique APs that are in archives waiting to be processed. Furthermore, researchers who do not have the hardware necessary for the second integrated solution could employ this software. This approach is primarily based on image matching and orthorectification algorithms, a given set of orthophotos and a digital terrain model to georeference the oblique images to existing orthophotos of the respective area.

Developments in recent years have made it possible to compute the relative orientation of photographs of a static scene in a fully automatic manner, even without initial values. Algorithms based on stable keypoints found in the combined image and scale spaces (Lowe, 2004), and the matching of corresponding image points by finding nearest neighbours in the descriptor (feature) space defined by statistics of their local neighbourhoods, have proven to cope with moderate geometric and radiometric discrepancies between corresponding image regions. Together with the relative image orientation, a sparse reconstruction of object space is generated that, however, lacks scale, position, and attitude with respect to an Earth-fixed coordinate frame.

These unknown parameters shall be determined by help of existing orthophoto maps. However, APs (to be georeferenced) and georeferenced orthophotos are generally taken at largely different calendar dates with different vegetation and infrastructure (and sometimes even different terrain elevation). As a result, the discrepancies between homologous image regions are generally too large for these algorithms to succeed. To cope with this challenge, and to keep computation times reasonable, a priori knowledge must be used that narrows the search both in image and parameter spaces. For example, the external orientation parameters from the hardware approach can be used as direct input, while vegetated areas yielding unreliable keypoints may be masked out, or the principal components of the sparse point cloud may be used to estimate the rotations about the horizontal axes for flat terrain. As the number of possible combinations of information known beforehand is large, the software approach must be adaptable to various levels of processing. Thus, it will use a scripting language on the higher levels, and a flexible database scheme that supports 3-dimensional spatial geometries and queries.

5. CASE STUDY

The aerial archaeology unit at the Department for Prehistoric and Medieval Archaeology of the University of Vienna (UFG) houses more than 110,000 vertical and oblique APs in its aerial archive (Doneus *et al.*, 2001). The metadata of all photographs, including their footprints, are stored in a GIS-based database (Figure 2). Since 2001, the total archive is being systematically digitized using a professional photogrammetric scanner (Vexcel Ultra Scan 5000). At the moment, roughly 60% of all aerial photographs have been digitised with a resolution of 10 µm (for B&W images) and 15 10 µm (for colour infrared images). From this dataset, an archaeological case study will serve to test and evaluate all proposed solutions for automated image orien-

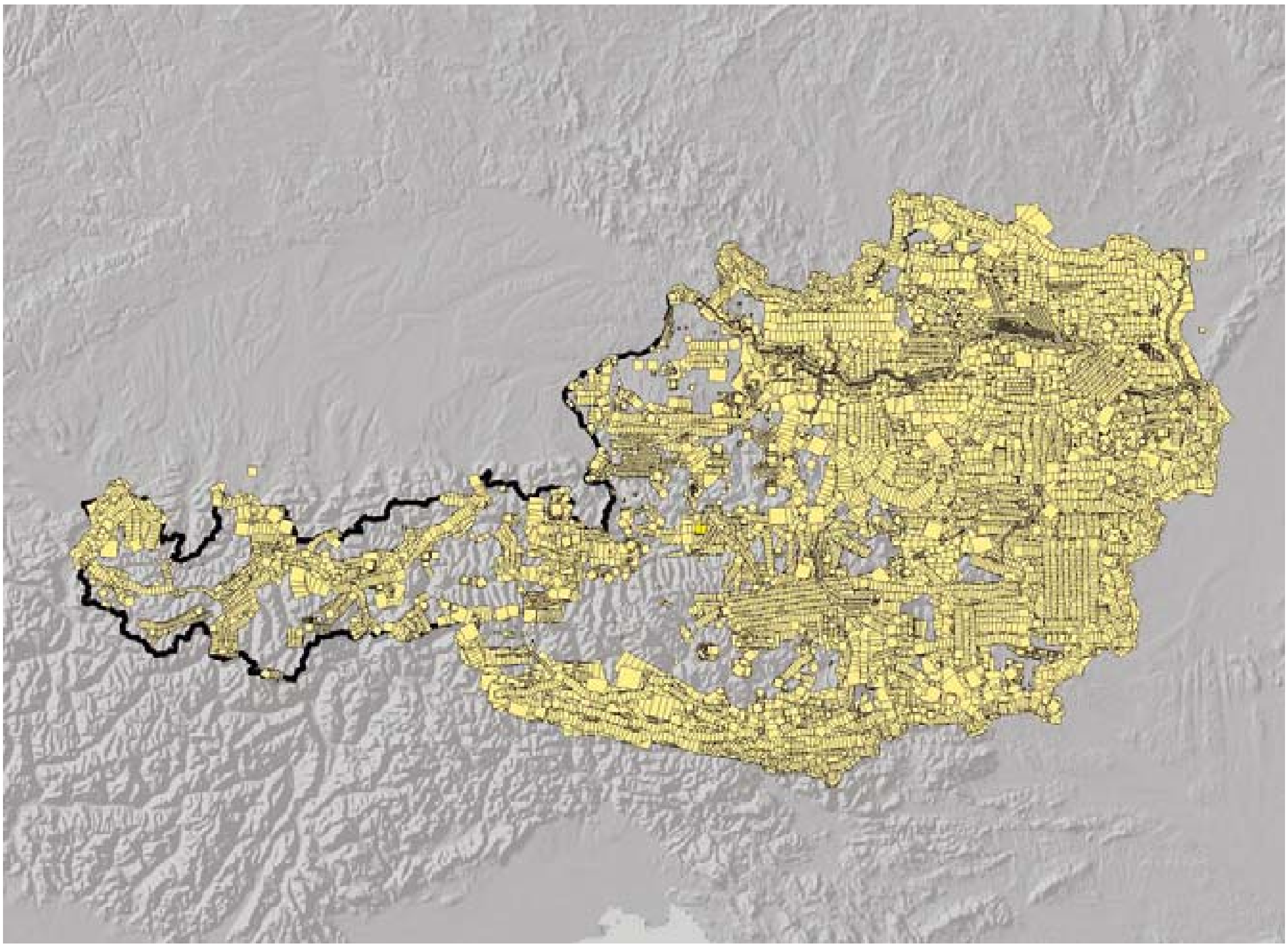

Figure 2: *Map of the approximately determined footprints of more than 110,000 aerial photographs stored at the aerial archive of the Department for Prehistoric and Medieval Archaeology in Vienna.*

tation and orthophoto generation. The proposed 250 km^2 area is largely covered by vertical and oblique APs from various years and seasons, with scales ranging from 1:25,000 to 1:5,000. The evaluation should identify problems and improve our approach, both using conventional aeroplanes as well as UAVs. The case study should also result in written guidelines about the methods of proper aerial data acquisition and georeferencing.

ACKNOWLEDGEMENTS

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AERIAL PHOTOGRAMMETRY - FROM THE KITE TO THE OKTOKOPTER. EXPERIENCE IN USING KITE, BALLOONS AND OKTOKOPTER FOR PHOTOGRAPHIC AND PHOTOGRAMMETRIC ARCHAEOLOGICAL DOCUMENTATION

M. Bogacki

This presentation will introduce experiences and results of archaeological aerial prospection using various low-altitude aerial platforms such as kites, balloons and multi-rotor craft. First attempts were made in 2005, and from that time, the author has had the opportunity to work in many projects, both in Poland and abroad. Aerial documentation has been conducted at excavations in Russia, Ukraine, Libya, Lebanon, and Peru, among other places.

Early efforts were made with helium balloons. After one year of these experiments, kites were added, then hot air balloons and finally multirotors. Multirotors are radio-controlled aircraft with more than two rotating blades. They are relatively easy to build and to control, and offer an efficient, low-budget alternative for aerial prospection.

Oblique and vertical photos were georeferenced as preparation for inclusion with other data, such as geophysical maps and geodesic maps in GIS applications. The photographs were also processed in photogrammetry software and were transformed into orthophotomaps and Digital Surface Models. The author also has experience with ultra light planes and helicopters, but these are often too expensive for smaller archaeologists projects, especially in developing nations. The large amount of collected photographic data and experience in the field or aerial photography provide the opportunity to compare different methods of aerial documentation by showing their advantages and disadvantages. In addition, the author will show differences in the quality of documentation based on various method of data processing.

REMOVING THE INFLUENCE OF VEHICLES USED IN MOTORIZED MAGNETIC PROSPECTION SYSTEMS

A. Hinterleitner, W. Neubauer, I. Trinks

When investigating archaeological heritage on the scale of landscapes with the help of magnetometry, it is necessary to conduct high-resolution magnetic measurements very efficiently, covering large areas in a short time. It is not feasible to cover more than a few hectares per day of fieldwork with traditional manually operated magnetometer systems. On the other hand, magnetometer arrays towed by motorized vehicles, such as Quad bikes, offer a dramatic increase in survey speed as well as in the size of sensor arrays that can operated. While magnetic sensor arrays are generally mounted several metres away from any motorized tow-vehicle – in our case the tow bar has a length of five metres (Figure 1) – the vehicle still exerts a strong but variable influence on the magnetometer sensors, thereby causing disturbances in the data.

The magnetic influence of the motor-operated tow vehicle on the data measured by the magnetometer arrays consists of several components. These are the permanent magnetic field of the vehicle, the induced magnetic field of the vehicle when moving through the Earth's magnetic field, and the temporal magnetic field caused by the engine and electrical components, such as the lighting dynamo. The total magnetic effect of the vehicle varies depending on the driving direction in regard to magnetic north, the velocity the system and the rotation speed of the engine. Moreover, the influence of the vehicle on the sensor array is dependent on the relative, varying position of the motorized vehicle to the sensors. Additionally, there is a small magnetic influence caused by the slightly closer positioned digitizer and the DGPS rover antenna, which communicates via radio with the base station.

The way to cover a large area efficiently with a motorized magnetometer system, towing the sensor array with a stiff tow-bar several metres behind the drawing vehicle, is to drive in shifted O-shaped loops with straight line segments between the turns. In contrast to the traditional zigzag operation along parallel profile lines with turns at the end of each profile, this procedure permits a non-stop operation at high speeds without any turnarounds and without the need to interrupt and restart the data measurement. We are continuously recording the magnetic data values (Foerster gradiometer vertical component data or Caesium total field data) along very long swaths covering many loops. This implies that all possible orientations of the measuring system relative to magnetic north, as well as relative to the orientation of the motor-driven vehicle, can occur and thus affect the data.

In order to eliminate the variable magnetic effect of the entire motorized system, we have developed a statistical method that estimates the influence from the recorded data. This method works independently of the sensors used, the sensor position, the digitizer employed, the positioning system, the drawing vehicle and the archaeological site. In particular, shifts of orientation-depending sensors are removed as well.

Figure 1: *LBI ArchPro motorized magnetic prospection system consisting of 8 Foerster gradiometer probes pulled by a Quad bike.*

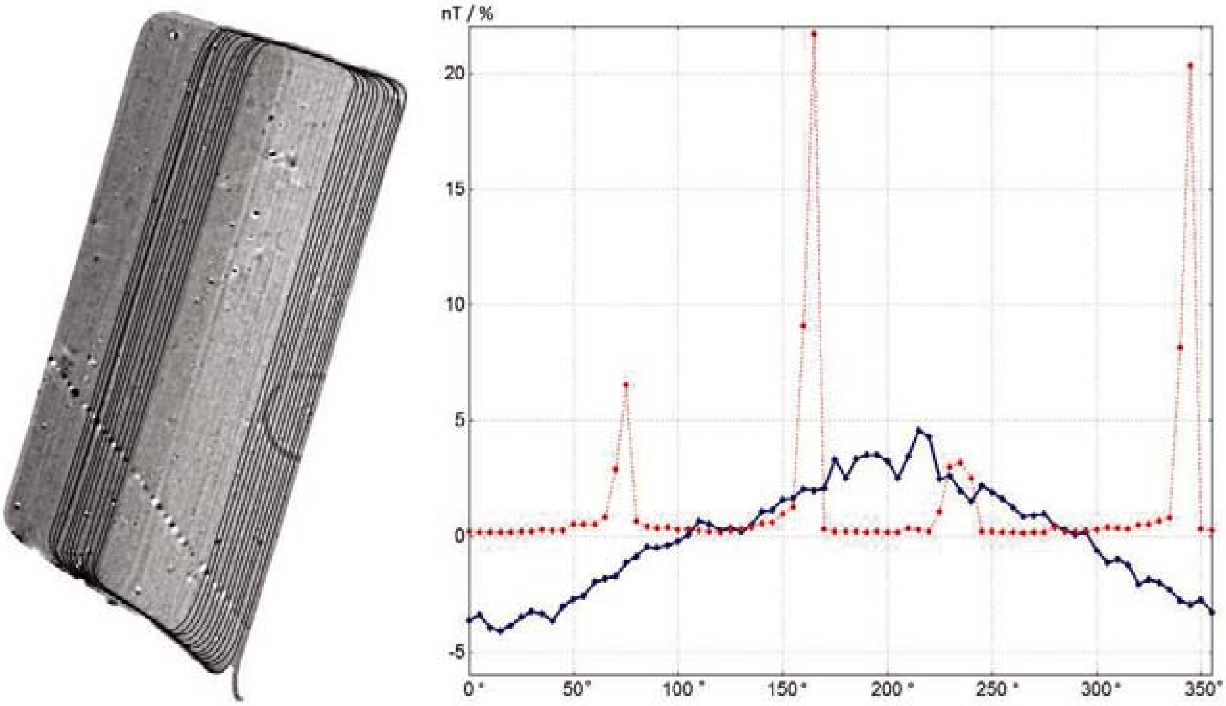

Figure 2: *Magnetic influence on one sensor (blue, [nT]) as function of the system orientation (5°sectors) and percentage of magnetic data used for the computation of the influence (red). Left: Track used to calculate this example surveyed in Strettweg/Austria.*

For each sensor, the measured magnetic data are spilt according to the current driving direction relative to magnetic north into sectors of 5°width, resulting in 72 sectors covering the entire 360°circle. For each sector, we compute the median of the magnetic data values, which is an estimate for the influence for the respective sector. We use sectors of 5°ranges because these constitute an optimized size in regard to two opposing requirements. On the one hand, the range should be small enough to provide a representative estimate of the magnetic effect for a large number of different orientations. On the other hand, the range should be sufficiently wide to contain a large number of magnetic values permitting a reliable calculation of the estimate.

Figure 2 illustrates the magnetic influence on one sensor depending on the orientation and the percentage of magnetic data values used for the calculation of the median. This figure clearly illustrates an advantage of this method: we have a large number of magnetic values for the calculation of the median for the four main directions of driving, resulting in a robust estimate of the magnetic influence.

In order to remove the influence of the vehicle for each sensor and measuring point we calculate the exact orientation of the measuring system and interpolate between the two dedicated 5°sectors accordingly. Figure 3 shows magnetic prospection data acquired with a motorized 8-channel Foerster gradiometer systems using a Quad bike at Strettweg/Austria before and after the removal of the vehicle influence.

Magnetic anomalies caused by archaeological structures very often have only very small amplitudes of few nT or even less. On the other hand, magnetic anomalies of modern object, such as fences, power masts etc. often possess amplitudes of several hundred nT or more. To render the algorithm robust against the effect of such huge anomalies we calculate the median of the magnetic values instead of the arithmetic mean for each sector. However, even this solution is sometimes insufficient. Therefore, in this calculation we use only magnetic data values in a range of ±60 nT around the median of all magnetic values for each sensor. Furthermore, we only use sectors if they contain at least 0.1 percent of the magnetic data. If there are fewer data values in that sector, we interpolate that estimate from the neighbouring sectors. This approach is necessary because we often drive close to field borders that are lined by strongly magnetic fences, masts or other strongly magnetically disturbing objects. Therefore there are often very high data values encountered in sectors where we have only a small number of magnetic data, for example in turns or in the relatively shorter base lines, compared to the swaths measured across the field. Unstable estimations in individual sectors can, when they are very large, badly affect the estimation of the influence of the vehicle for many magnetic data due to interpolations including these outlier sectors.

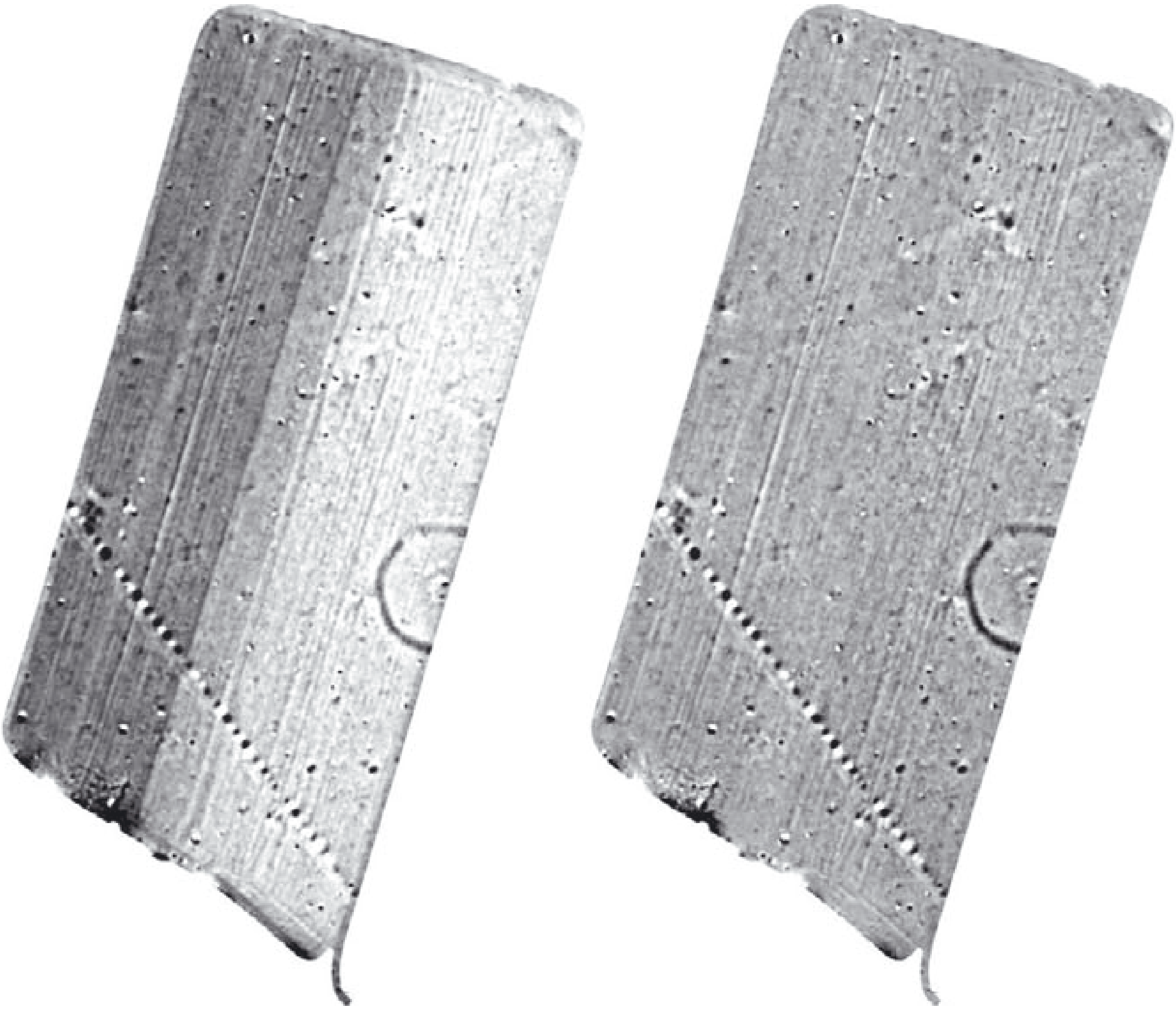

Figure 3: *Left: raw data acquired by motorized magnetic prospection in Strettweg/Austria prior to the removal of the vehicle influence; right: the magnetic prospection data after removal of the vehicle influence; gray scale range (white –4 nT to black +6 nT).*

FROM RADIO WAVES TO LANDSCAPE ARCHAEOLOGY

P.M. Barone, C. Ferrara, E. Pettinelli

1. INTRODUCTION

The capability to detect subtle changes in soils as well as generate substantive responses from buried structures and features have made Ground Penetrating Radar (GPR) a non-intrusive investigation method of growing interest to archaeologists. More and more reports of blanketing dig sites with GPR are appearing. Evaluation of historical sites is always hampered by the lack of factual information. While excavation is permitted in some cases, many sites do not permit intrusive investigations of any sort, since exposure may lead to rapid site and artifact degradation. Further, the time and cost of extensive excavation is large. The need for techniques that provide rapid area coverage and detailed imaging of the subsurface naturally leads to exploiting the power of GPR.

In this paper, we present the results of some radar surveys aimed at reconstructing the ancient buried targets of different archaeological sites at shallow subsurface, thanks to multi-profile data acquisition and to the use of a three-dimensional software package. Such results show the potential of this approach, not only as an informative tool to reconstruct the ancient past, but also as a reconnaissance method before performing any restoration plan or destructive tests.

2. THEORY AND METHODS

GPR is the general term applied to techniques which employ radio waves, typically in the 1 to 1000 MHz frequency range, to map structures and features buried in the ground (or in manmade structures). Historically, GPR was primarily focused on mapping structures in the ground; more recently, GPR has been used in non-destructive testing of non-metallic structures.

The concept of applying radio waves to probe the internal structure of the ground is not new, in particular for archaeological purposes (Pettinelli et al., 2011). Archaeological applications of GPR are limited only by the imagination and availability of suitable instrumentation.

Exploration depth is site specific; soils absorb radio waves in different ways depending on the chemical and physical soil characteristics (e.g. sands and gravel are favourable for GPR, in contrast silt and clay are not).

"How deep can you see?" is the most common question asked of GPR. While the physics is well known, there are fundamental physical limitations. Many people think GPR penetration is limited by instrumentation. This is true to some extent, but the material itself primarily governs exploration depth, and no amount of instrumentation improvement will overcome the fundamental physical limits. Radio waves decrease exponentially and soon become undetectable in energy absorbing materials (Annan, 2003).

In order to obtain a XY image of the subsurface, the radar data should be collected in multi-profile mode, where the profiles are acquired parallel to each other, at a fixed distance. This technique allows creation of XY time (or depth) slices, in which the lateral geometry of the targets can be identified (i.e. Jol, 2009). A further processing of the data collected on a XY grid allows a pseudo-3D visualization of the subsurface through the countering of the anomalies generated by the electromagnetic contrast between the target and the background material. The result is a three-dimensional representation of the subsurface using the isosurfaces to display a surface of constant data value in three dimensions.

3. EXAMPLE 1

Much part of the ancient and famous city of Pompeii (Italy) was excavated, but there are some areas where the archaeological features are just partially exposed, and where remains are obliterated by volcanic deposits. Recently, GPR results highlighted several buried structures (Barone *et al.*, 2011; Pettinelli *et al.*, 2011), but the buildings thus identified present some problems in terms of diagnostic and restoration planning.

This GPR survey was conducted using a TR1000 system (Sensors and Software, Inc.) equipped with 1GHz antennas. The use of this frequency is intended to detect the inner structures of walls and pavements in the ancient Roman *domus* (private villa) of *Marcus Fabius Rufus*.

This villa is one of the largest and best-preserved villas in Pompeii, and a restoration was planned; GPR data was acquired in order to understand not only whether vertical or horizontal static problems exist, but also if there are internal structures not mentioned in the architectonic history of the villa.

Figure 1 shows GPR results on a pavement inside a room of this villa. Based on archaeological information, this room was heated using a typical Roman engineering system, the hypocaust (*hypocaustum*). This was an ancient Roman system of subfloor heating, used to heat houses with hot air. The word derives from the Ancient Greek hypo meaning "under" and caust-, meaning "burnt" (as in caustic). Hypocausts were used for heating hot baths (*thermae*), houses and other buildings, whether public or private. The floor was raised above the ground by separated pillars made by square bricks (about 20 cm $\times$ 20 cm $\times$ 40 cm), called *suspensurae* (architectural term given by Vitruvius); and, also, spaces were left inside the vertical walls so that hot air and smoke from the furnace would pass through these enclosed areas and out of flues in the roof, thereby heating but not polluting the interior of the room.

The GPR investigation allowed confirmation of this information, detecting this typical heating structure below the pavement with three fundamental layers: i) the grouting material, ii) the *suspensurae*, and iii) the foundation.

4. EXAMPLE 2

The second case shows a particular GPR investigation conducted inside an extended archaeological area partially excavated in an ancient Messapic city in Southern Italy, Cavallino (Lecce, Italy).

The *Messapii* (English Messapians) were an ancient pre-Roman tribe that inhabited, in historical times, the south-eastern

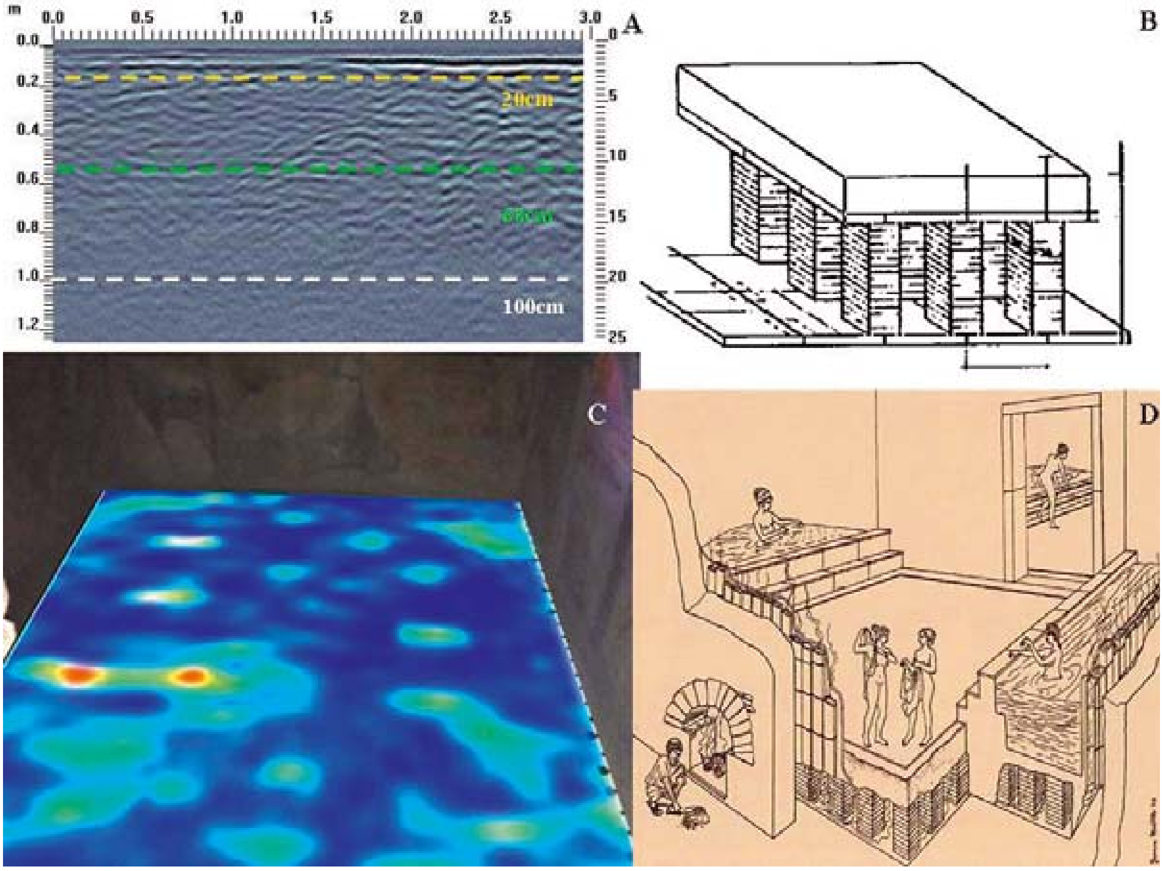

Figure 1: *In the radargrams (1A) it is evident the presence of three layers (0-20 cm: grouting material layer; 20-60 cm: suspensurae layer; 60-100 cm foundation layer), as schematically depicted in 1B. 1C shows a map (at a depth of approximately 20 cm) of the anomalies below the pavement: the circular and dotted electromagnetic evidences could be interpreted as the top of the suspensurae. 1D is a general reconstruction of the hypocaust system.*

peninsula or "heel" of Italy (Salento, modern Apulia), and probably arrived in Italy from the other side of the Adriatic Sea about 1000 BC. They spoke an Indo-European language, Messapic, and, in 266 BC, the *Messapii* were conquered by Rome, and they rarely appeared in history after that.

The aim of the GPR survey was to understand the geometry and the position of buried structures in connection with some test-pits bringing to the light several archaeological remains. Due to a time lapse in the geophysical investigations during a year, two different radar systems were used: the Noggin Plus and the Pusle Ekko pro (Sensors & Software, Inc.), both equipped with 500MHz antennas.

Figure 2 shows a general overlap of the GPR depth-slices (about 0.55m depth) on the areas investigated. The presence of regular anomalies in connection with the partially visible archaeological remains is clear.

5. EXAMPLE 3

The last case shows a preliminary result of a GPR survey tested in a large archaeological area at Gabii (Italy), close to Rome, within a long-term international project. The Gabii Project was launched in 2007 with the objective of studying and excavating the ancient Latin city of Gabii, a city-state that was both a neighbour of, and a rival to, Rome in the first millennium BC. The Gabii Project is an international archaeological initiative under the direction of Prof. Nicola Terrenato of the University of Michigan, and will extend through at least 2014.

Located in the region of Italy once known as Latium, the site of Gabii was occupied from at least the 10th century BC until its decline in the 2nd and 3rd centuries AD. Amazingly, the site of Gabii was never developed in subsequent centuries, or even substantially occupied, nor has the urban area ever been the site of major, stratigraphic excavations. As such, the site provides a unique opportunity to study the development and structure of Archaic urban planning in Central Italy, both monumental and civic architecture, domestic space, and all other corollary studies.

The first GPR results shown in Figure 3 were collected close to the excavated area across the Prenestina street, using a Pulse Ekko pro GPR system (Sensors & Software, Inc.) equipped with 500 MHz antennas.

The maps highlight the presence of several archaeological features linked to the partially known urban planning of the ancient city of Gabii. In fact, between 2008 and 2009, a magnetometry survey was acquired in the same areas, providing evidence of strong anomalies due to buried streets (Becker *et al.*, 2009). The GPR survey in 2011 shows not only a high consistency with the magnetometry results (even here the streets are strongly detected), but also some particular anomalies related to archaeological urban structures.

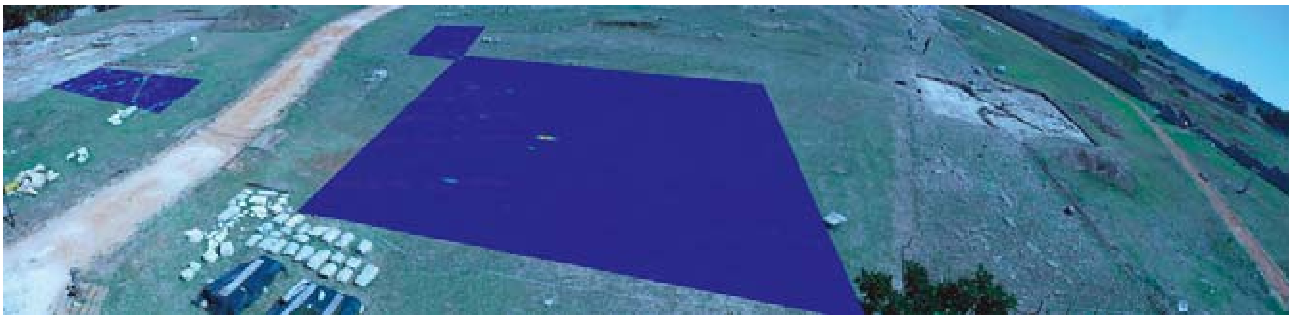

Figure 2: *This figure depicts three areas in which the GPR was performed; overlapping the depth-slices (about 0.55 m depth), regular structures beneath the soil, and linked to previously excavated archaeological features, are clearly visible.*

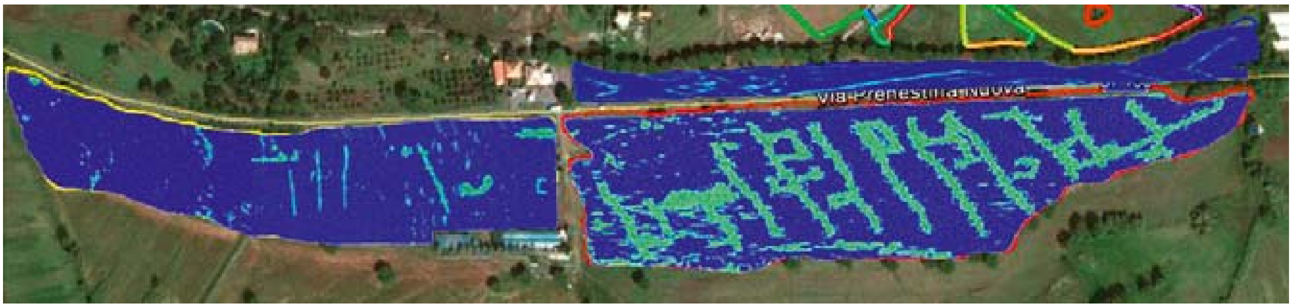

Figure 3: *The figure illustrates the extensive GPR survey collected in the archaeological area of Gabii (Rome, Italy); the maps show clearly both linear anomalies due to the orientation of the streets (SE-NW), and other features probably due to ancient buildings.*

6. CONCLUSIONS

The above examples demonstrate the value of GPR for archaeological investigations, particularly with regard to structures buried beneath the soil and inside buildings. GPR detects a wide range of potential targets, but ground truthing is critical to ascertain the proper explanation of the GPR data, and rough surface conditions demanded slower step mode data acquisition.

The analyses of the radar sections and depth-slice maps highlighted not only peculiar internal characteristics of ancient buildings, but also the geometry of the buried ruins, allowing us to interpret, understand and correctly reconstruct the ancient development of the sites.

These results show that the GPR technique is particularly suitable both in architectonical and archaeological conditions, producing good results in term of signal penetration and vertical resolution.

The application of non-invasive geophysical techniques, such as GPR, has the potential to precisely map the layout of an ancient city (like Gabii or Cavallino), and also to discover architectonic hidden structures inside ancient buildings (e.g. Pompeii), producing important historical, archaeological and ancient urban planning information without compromising the physical integrity of these unique sites.

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ELECTRICAL RESISTIVITY TOMOGRAPHY AS A TOOL TO RECONSTRUCT THE PALAEOENVIRONMENT OF NEOLITHIC SITES

N. Papadopoulos, A. Sarris, W. Parkinson, A. Gyucha, R. Yerkes

1. INTRODUCTION

Neolithic and Bronze Age settlements have been successfully prospected using magnetic surveying techniques in the past (e.g. Schier, 2006). Although they are crucial for spatial mapping, in the case of tells, magnetic methods are not able to resolve the various features that belong to different strata. Thus, other techniques, such as Ground Penetrating Radar (GPR) and electrical resistivity tomography (ERT) are carried out in order to provide more information regarding the stratigraphy of the tells. ERT method has been mainly used as a complementary tool within large geophysical prospection campaigns in terms of isolated lines to explore the stratigraphy of the recent sediments (Maillol, *et al.* 2004).

The archaeological site of Szeghalom-Sebes-Körös Mente is located at the agricultural area to the north of the Sebes Körös River at the central-east part of Hungary (Figure 1a.). Szeghalom is a representative Tisza settlement with some intrusive Bronze Age finds (Ecsedy, *et al.* 1982). The predominant Late Neolithic character of the site was confirmed by a recent reconnaissance of the site through the application of geochemical, magnetic susceptibility measurements and soil texture analysis (Salisbury, 2010).

Since 2010 an extensive surface and geophysical survey has been undertaken at the Middle Neolithic Szeghalom-Kovácshalom tell. Surface and geophysical surveys indicated that the area was probably the locus of a "flat" farming settlement, together with other dispersed architecture. The goal of the geophysical research was to map the subsurface architectural remains in areas on and around the tell, to provide additional information regarding the extent of the sites and the evolution of habitation patterns of the region. More than 35 hectares have been covered with the magnetic method, while GPR has been used in an experimental mode in overlapping regions covering an area of more than 2.5 hectares.

This work will focus on the experimental ERT measurements that were completed in the site during the 2012 field expedition. The ERT survey was carried out along a number of transects which were laid out in the area on and around the tell. The purpose of the ERT survey was to investigate the stratigraphy of the tell and confirm the passage of the palaeochannels around the tell.

2. FIELD STRATEGY

The Pole-Dipole electrode configuration was used to complete the ERT survey along the twenty-eight individual transects (Figure 1b). All of the lines (except one) were arranged along the west east direction and parallel to each other with an inter-line spacing of 10 meters, and having varying length. A similar field strategy was utilized to collect the data. The unit electrode distance along the lines was one meter (a =1) and the N separation (ratio of the distance between A and M electrodes to the M-N dipole length) ranged from 1 to 8. In order to increase the investigation depth and the recorded signal additional data with unit electrode spacing "2a" with N=4-8 and "3a" with N=5-9 were also measured. More than 140,000 field data were collected from the lines that had a maximum length of almost 5 km, rendering the specific ERT survey the largest known in the exploration of a Neolithic site in Europe. The Syscal Pro resistivity meter was used to capture and store the field data employing the roll-along technique to survey long lines.

3. ERT DATA PROCESSING

The topography along each line was extracted from the Digital Elevation Model and used to correct the data for the topography effect. Then each line was processed with a standard two-dimensional (2-D) resistivity inversion algorithm (Tsourlos, 1995). This original algorithm was appropriately modified to calculate only the part of the Jacobian matrix, which is actually essential to the inversion procedure based on the idea proposed by Papadopoulos et al (2006, 2011) and extended for long 2-D ERT sections by Tsourlos (2008). The new 2-D algorithm was further and appropriately modified to account for non-standard electrode configurations with multiple "a" spacing and N-separation. It is based on the simple observation that in the case of large 2-D problems, the majority of the Jacobian matrix elements, which correspond to a measurement are practically zero, reflecting the fact that most of the parameters are so far away from the measurement that they do not affect it. The inversion procedure is based on an iterative least-squares smoothness constrain algorithm utilizing the augmented system (Papadopoulos et al., 2011). The search radius to define the rectangular area in order to calculate only the significant part of the Jacobian was set to 2d (*d is the maximum distance between the A and M electrodes*) for the case of the new algorithm.

All the ERT lines were processed with both the original algorithm (*which involves the full Jacobian calculation*) and the new one (where only the significant part of Jacobian is calculated) using similar inversion parameters. Both algorithms converged to a final 2-D resistivity inversion model for each line after eight iterations. The new algorithm proved to be 2.8 to 8.4 times faster than the original algorithm depending on the geometry, the parameters and the measurements that were involved in the inverse problem formulation for each different line. The inverted resistivity models exhibiter error less than 1% for the majority of the lines signifying the high quality of the collected data.

4. ERT RESULTS

The inverted resistivity data were processed through a kriging interpolation algorithm and visualized as 2-D vertical cross-sections. The mean relative difference of the models resulted

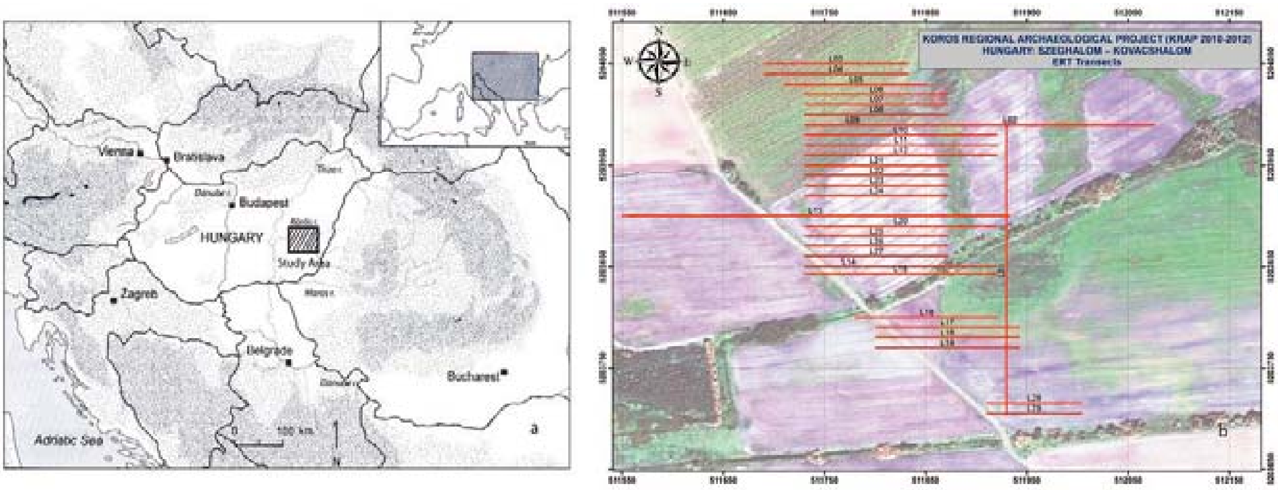

Figure 1: *(a) Map of the Carpathian Basin indicating the locus of the Körös Regional Archaeological Project. (b) Layout of the ERT transects covering the area on and around the Szeghalom-Kovácshalom tell.*

by the original and the modified algorithm was 2.7%, which enhances the comparable accuracy of the models resulting from both algorithms (Figure 2a, b). The results of the inverse modelling were used as a basis for the geological interpretation of the data. The resistivity values vary between 3 to 100 Ωm with an average of 30 Ωm signifying a clayey environment with sandy materials and scattered anthropogenic material (Figure 2c). The values were classified in four categories, which from the shallowest to the deepest units are: 1) Top Soil and Anthropogenic Layer (45-100 Ωm), 2) Silty Clay (16-30 Ωm), 3) Silty Clay with Sand (30-45 Ωm), 4) Blue Clay (3-16 Ωm).

Then an effort was made to integrate the individual 2-D resistivity models to compile a 3-D representation of the subsurface geology of the site around the tell. Each line was given exact X and Y coordinates based on the reference system and afterwards they were all combined to a single data set. An inverse distance interpolation algorithm was employed in order to create volumetric 3-D representations, including the topography of the site. In all these representations an area of high resistivity values is identified that is prominent on the tell, signifying the cultural and anthropogenic material. The palaeomeander, which flowed around the tell, is registered with low resistivity values due to the fine clayey material that fills the old river bed and generates a large resistivity contrast with the surrounding materials (Figure 3).

In the final processing stage, an effort was made to model the elevation variation for the different geological units that were recognized through the ERT survey. To this end, each geological interface was digitized using the geological/geoelectrical models extracted by the inversion procedure as base maps. The top soil and anthropogenic layer is mainly registered on the area of the tell having a maximum depth of almost 3.2 meters below its centre. The thickness of the cultural material gradually decreases reaching about 0.5 meter at the edges of the tell. Outcrops of top soil and anthropogenic material are also registered at the south, north and east of the tell with depth that does not exceed the 2 meters (Figure 4a). The ERT survey was quite successful in outlining the shape, direction and thickness of the palaeomeander that flowed around the tell, at least in the areas that were covered with ERT lines. This palaeochannel formed a V-shape resistivity anomaly and exhibited strong low resistivity values which were more prominent at the east of the tell. The palaeochannel is deeper at the east of the tell, with a maximum depth of 2.5 meters, while its depth does not exceed 1.7 meters at the north and west of the tell (Figure 4b).

The formation of silty clay and silty clay with sand covers the whole region that was surveyed with the ERT. It appears to have an average thickness of 5.5 meters and seems to be thinner in the north-eastern corner of the area (~0.5-0.7 m). The thicker deposits of this formation are evident at the north (~10 m) and at the central-southern part (~8-8.5 m) of the area. Finally, the formation of the blue clay, that can be considered as the "bedrock" in this specific survey, is buried in an average depth of about 7 meters below the ground surface. It exhibits its largest burial depth (~10-10.5 m) below the tell and the sites located at the north and at the south of the tell. In contrast, at the north-east of the site the blue clay is overlaid by relatively thinner deposits of no more than 4 meters.

5. CONCLUSIONS

Electrical resistivity tomography was employed on the tell and around its vicinity in an effort to image the deeper strata of the tell and the palaeochannels surrounding it. The results of the ERT survey were particularly successful in mapping the stratigraphy of the tell and the palaeoenvironmental characteristics around it. In general, this work showed that ERT is a powerful tool in the detailed reconstruction of the palaeoenvironmental conditions of Neolithic sites.

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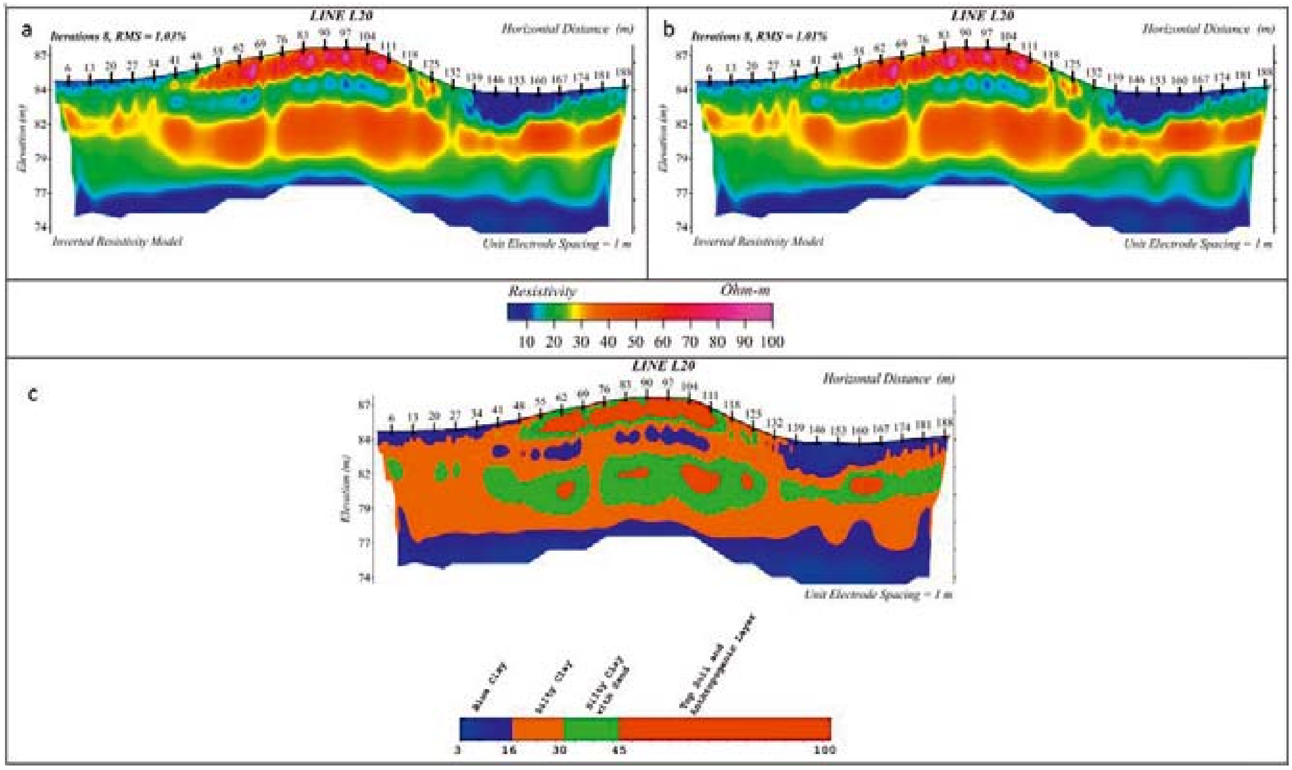

Figure 2: *Resistivity inversion results along a specific line using the original (a) and the new (b) algorithm. c) Geological model along the same section resulted by the interpretation of the inversion results.*

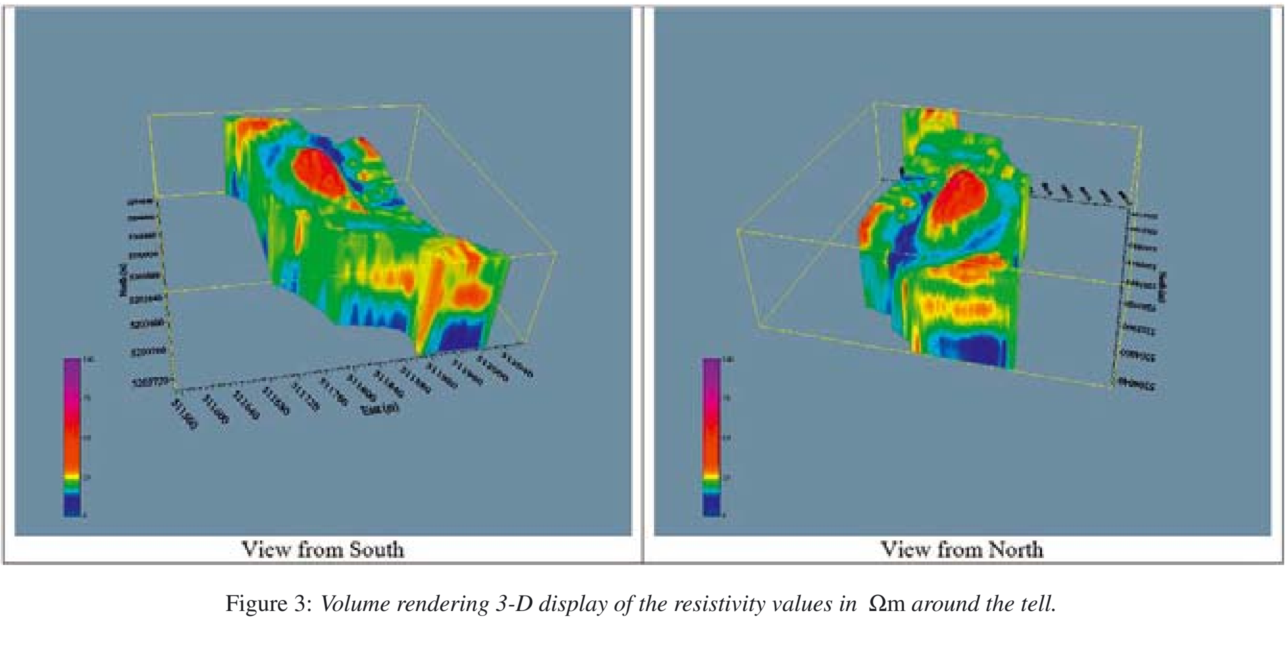

Figure 3: *Volume rendering 3-D display of the resistivity values in* Ωm *around the tell.*

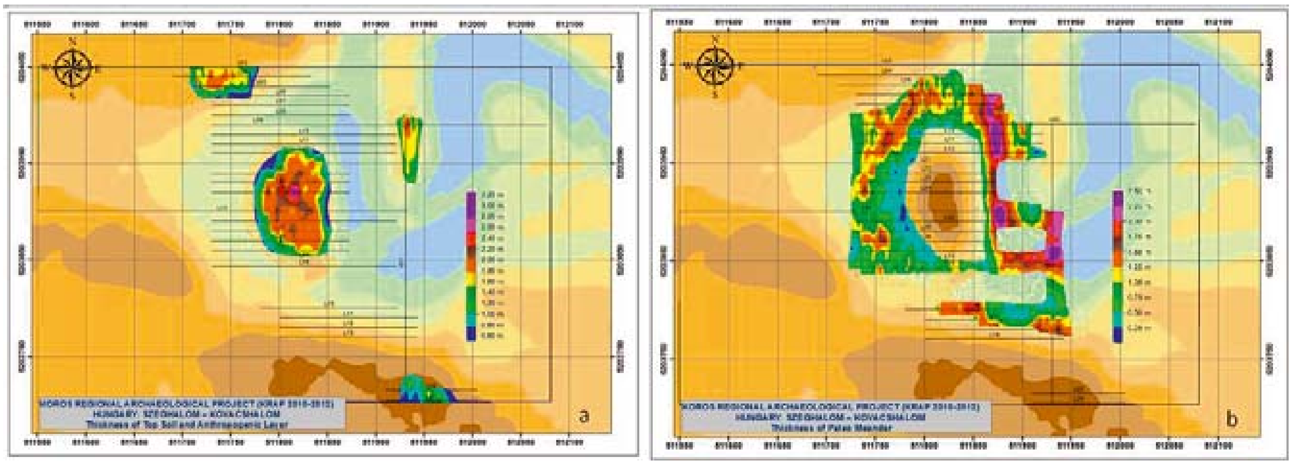

Figure 4: *Thickness of the top soil and anthropogenic layer (a) and the palaeomeander (b) extracted by the ERT results.*

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UNDERSTANDING THE SETTLEMENT PATTERN OF ANGKOR (CAMBODIA) IN THE LIGHT OF ALS DATA

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The northern part of the Tonle Sap basin in North-west Cambodia (South-east Asia) witnessed dramatic changes in occupation patterns from Iron Age to 19th century AD. The location of the site made it the regional centre of agriculture and trade. What caused rapid population growth in pre-Angkorian and Angkorian era? Situated on fertile soils, Angkorean farmers were able to practice intensive rice cultivation, supported by extensive an water management system, to feed the population. Their location on the land, trade route linking modern South Vietnam and Thailand, and direct access to Eurasian trade through South China Sea, Mekong and Tonle Sap yielded vast income for the local rulers. These circumstances enabled the formation of Angkor, the biggest low-density urban complex of the preindustrial world, and rise of The Khmer Empire, which, at its largest extent, stretched across modern southern Vietnam, Thailand, southern Laos and the northern margins of Malaysia. This period of prosperity was brutally interrupted by the so-called "abandonment of Angkor" in AD 1431/32. In the romantic vision of 19th and early 20th century researchers, Angkor fell under swords of Thai conquerors, but recent research by international research teams, inter alia Greater Angkor Project (University of Sydney, EFEO, APSARA Authority) revealed that the decline was long process in which several factors contribute, including climatic changes, environment degradation and a new geopolitical situation. In the first half of 15th century, the population of Angkor rapidly fell but there is no evidence of abandonment of the site. Both the archaeological and historical evidence prove that still some communities were living in Angkor after AD 1432.

Archaeologists who resumed research after the end of the civil war in the early 1990's had to deal with the vast area that should be investigated to understand Angkor. Estimations show that this site is as big as the modern Baltimore-Washington agglomeration. To answer those questions, GAP researchers used AirSAR radar for mapping the area, which is now partly covered by dense tropical vegetation. Limitation of this technique was offset by supplementing with airborne laser scanning done in April 2012. LiDAR survey was conducted by Khmer Archaeology LiDAR consortium (8 international partners from Australia, France, USA, Cambodia, Hungary and Japan) and covered approximately 300 km^2 of Angkor and Phnom Kulen in Siem Reap province and Koh Ker in Preah Viher province. This helicopter mounted survey resulted in a billion reflections. Point density is 10-15 points per meter with vertical and horizontal error margins lower than 15 cm. ALS is supplemented by over 5000 high-resolution vertical images.

One of the goals of doing LiDAR survey in Cambodia was to understand the settlement pattern of Angkor. Theoretical outlines are based on climatic factors and important information from written sources. Cambodia lies in the monsoon zone, which causes division into dry and wet season, so through the year ancient Khmer had to face problems of both not enough and too much water. To deal with that issue, Khmers developed a vast water management system, which, with the exception of huge reservoirs called baray (e.g. Western Baray 8×2 km), consisted of numerous smaller features like water cistern. The crucial role of these cisterns as water reservoirs for household use is known due to Chinese written sources, so they could potentially provide data about the number and density of the population. Chinese text sources clearly indicate that one cistern was in use by one to three families. High-resolution ASC survey, done in April 2012, allowed us to trace the small depressions under the canopies of modern jungle. Geostatistic elaboration of the cisterns is now an ongoing research issue. The first step in this research was creating tools able to automatically detect features of interest. The easiest and most efficient way for GIS software to detect them was to consider the role of cisterns as deposit basins able to catch water, and to query the raster DEM for features surrounded by pixels with higher Z values. This simple calculation revealed all depressions within the DEM. The second step was filtering by size to eliminate bigger water reservoirs like temple moats and sacral ponds. The output is a map presenting all features that a) were able to contain water b) have the correct dimensions. The present issue, currently under elaboration, is advanced geostatistical analysis to test theories about population distribution within Angkor. This research could be supported by a theoretical framework used in Mesoamerican archaeology. In early 2013, the GAP research team will conduct field survey to ground-truth the ALS results.

In conclusion, ALS has great potential in understanding rainforest civilization and its low-density urban complexes, known from South-east Asia, Mesoamerica and potentially Sri Lanka. Landscapes modified by ancient societies, previously hidden beneath tropical forest, is now available for researchers dealing with concepts of the city that are radically different from those known from Mediterranean and European civilizations.

BIPARTITE DIVISION IN A MIDDLE WOODLAND "MOUNDBUILDER" SOCIETY: EVIDENCE FROM ARCHAEOLOGICAL PROSPECTION

M. Schurr

During the Middle Woodland period (ca. 200 BC to AD 350), burial mounds and other types of ceremonial earthworks were built across the Eastern Woodlands of North America. Mounds from different sub-regions share common characteristics that define them as part of the widespread Hopewell phenomenon, a set of burial practices that were shared across many otherwise different local groups. Once a prominent feature of the landscape, but now virtually destroyed by cultivation and other human activities, the Middle Woodland mounds of eastern North America still play a prominent role in the minds of archaeologists and the public. However, the remnants of these structures are often detectable only through archaeological prospection.

From 200 BC to AD 350, people of the Goodall tradition of northwestern Indiana (Mangold and Schurr, 2006; Schurr, 1997) built numerous burial mounds near the southern end of Lake Michigan (Figure 1). Goodall tradition mounds are found singly or in groups ranging in size from 2 to 22 mounds. At the larger sites, such as the Goodall type-site, the mounds are grouped into clusters, suggesting that some social divisions existed in Goodall society. However, the social organization(s) of Middle Woodland "Moundbuilder" societies are not well understood, and were probably quite variable.

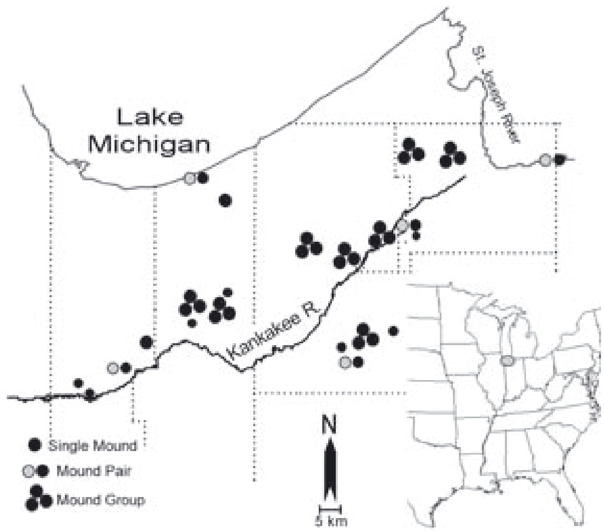

Figure 1: *Distribution of Goodall Tradition Hopewellian mounds in northwest Indiana, USA.*

Goodall tradition mounds were relatively simple constructs. Their builders first removed the topsoil (O horizon) from the area where the mound was to be constructed. A square or rectangular pit from with a surface area ranging from 4.5 to 12 m^2 was then excavated into the subsoil, to a depth of approximately 1 m, to form a shallow sub-surface tomb. Sometimes the soil from the pit was heaped on two sides of it to form flanking berms. One or more burials were placed in the tomb along with the elaborate Hopewell artefacts that are such a distinctive part of the mortuary treatments of this period. The tomb was covered with a relatively flimsy, perishable covering (such as hide, woven vegetable mats, or bark) supported with poles or held in tension by log weights or bone pins. The tomb was probably covered but remained accessible for some period of time, until it was considered "full" and a mound was built to cover it. Often the tomb was first covered with a 10 – 20 cm thick layer of distinctive soil, usually a wetland soil such as muck (a black peaty soil), marl (a white carbonate-rich clay), or a mixture of both. The final mound cap or mantle was composed of soil scraped up from the surrounding area and usually contained local habitation debris. The finished structure could range from 1.2 – 8 m in height and 7 – 30 m in diameter. Sooner or later (and probably sooner) the flimsy tomb covering partially collapsed under the weight of its overburden and the tomb gradually filled with fine-grained sediments.

In the nineteenth century, American pioneers settled the region that had been occupied by the Goodall Hopewellians almost two millennia earlier. Throughout the last two centuries, artefact collectors dug into most or perhaps all of the Goodall mounds, and many have been almost obliterated by erosion and ploughing. Today, even identifying some of the mounds remains a difficult task, as many have been reduced so badly that they are not even recognizable from surface observations. However, the original sub-surface tombs still exit, and even those that were looted contain substantial intact archaeological deposits because of the unsystematic nature of the looting excavations. The presence of subsurface deposits opens the possibility that the mound remnants can be detected by archaeological prospection.

As noted above, Middle Woodland mounds frequently contain a layer of wetland soil that was placed directly over the sub-surface tomb. The portion of the wetland soil layer over the tomb is often preserved when it subsided below the original surface level and is detectable by shallow prospection methods such as gradiometry or resistivity survey (Schurr, 1999). The muck lens is easily detected by soil resistivity with a twin probe array as it produces a pronounced low resistance anomaly because the peaty muck soil usually retains more moisture than the background (Figure 2). The same soil configuration also produces a clearly defined magnetic anomaly (Figure 3) because the muck contains large amounts of iron, often in the form of flecks or even lumps of bog iron. A looted mound produces a clear toroidal anomaly (Figure 3). Much has been made of the use of mucky soil in mound construction as a symbolic representation of a gateway to the underworld (Hall, 1979).

When viewed within the context of variation within a mound group, the different soils used in mound construction can provide clues about the social organization of the societies that built the mounds. Gradiometry and resistivity surveys at the Goodall and Mud Lake sites provide evidence that some mound groups were constructed so that paired or alternating mounds had different kinds of soil caps. At Mud Lake, a muck-capped mound appears to have been paired with one having a marl cap. At

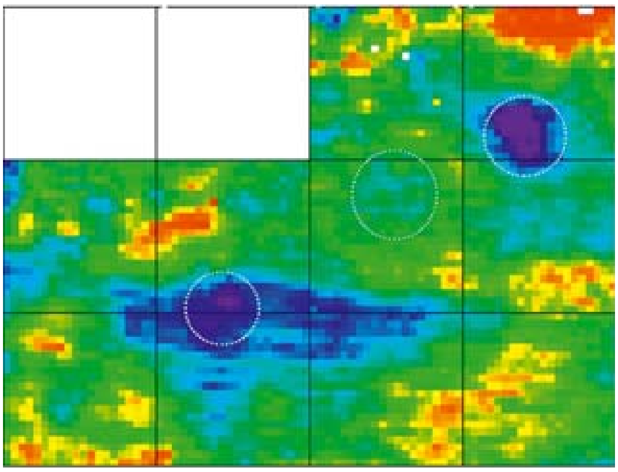

Figure 2: *Resistivity survey of alternating muck- and marl-capped mounds, 20 m grid lines. RM 15 with twin probe array, 0.5 m probe spacing, 1 m survey interval, color ramp from 284 Ω (blue) to 900 Ω (red).*

Goodall, muck-capped mounds alternate with marl-capped ones in a linear mound group. The Goodall tradition is an eastern extension of the well-known Havana Hopewell of the Illinois Valley. Linear arrangements of Havana mounds have usually been interpreted to have chronological significance (King *et al.*, 2011). The alternation of construction materials in the linear group at Goodall, an eastern extension of Havana Hopewell, indicates that principles other than chronology may have been used to structure Goodall (and perhaps other Havana) mound groups. The alternation of muck and marl caps at Goodall tradition sites suggests that some sort of bipartite division played a fundamental role in Goodall social organization, perhaps in the form of two lineages or moieties. The relatively simple bipartite organization contrasts with more complex systems such as a possible triple-lineage system proposed for Scioto (Ohio) Hopewell sites (Greber and Ruhl, 2001).

Middle Woodland mounds are protected by State and Federal laws and are considered to be sacred sites by many Native Americans because they contain human burials. The further development of non-destructive methods for the identification, investigation, and interpretation of such sites without excavation is clearly an important goal for archaeological prospection in eastern North America. This paper provides an example of how archaeological prospection can be used to determine methods of mound construction that can provide evidence of ephemeral topics such as the principles used to organize the unique and interesting societies that built the mounds.

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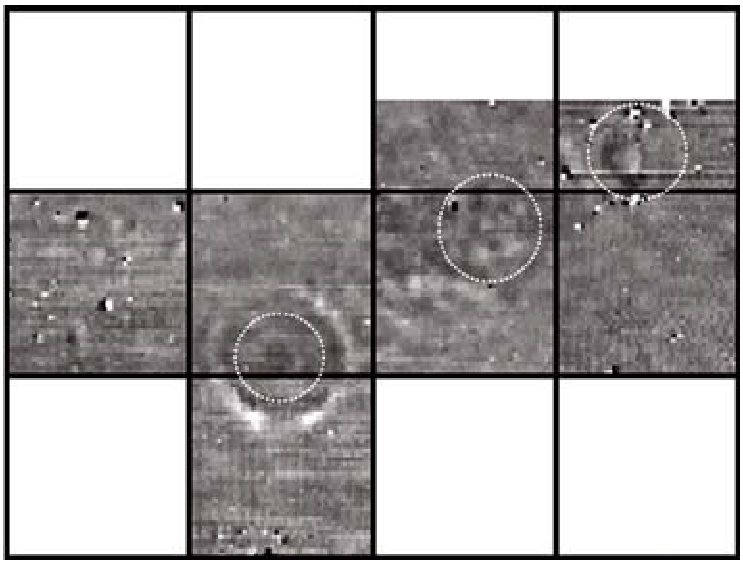

Figure 3: *Magnetic survey of alternating muck- and marl-capped mounds, 20 m grid lines. FM 36, sample interval of 0.25 m, 0.5 m transect interval, 256 shade grey-scale map, ±10 nT.*

INVERSION AND ANALYSIS APPROACHES OF SQUID GRADIOMETER DATA MEASURED ON LARGE ARCHAEOLOGICAL AREAS

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The ground-based SQUID (Superconducting Quantum Interference Device) gradiometer system for geo-magnetic prospection was developed jointly at IPHT Jena and Supracon AG. The system represents a passive measurement system that acquires both the single magnetic field components and components of the gradient tensor of the Earth's magnetic field by means of SQUID-based magnetometers and gradiometers, respectively. The magnetometer signals are used to enhance the suppression of the homogeneous Earth's magnetic field in the gradiometer measurement and hence provide a first step of motion noise compensation.

Different system configurations enable the system to measure one or more components of the gradient tensor as well as the full tensor information of the five independent tensor components at the same time. Hence, it is possible to adapt the system layout to the actual requirements of the measurements and the expected magnetic anomaly distributions.

The system could be equipped with up to three different cryostats (Figure 1). They are evacuated Dewar vessels, which hold the magnetic sensors within the bath of liquid helium to ensure the sensor working temperature of 4.2 K at normal pressure. Besides the magnetic sensors and their readout-electronics, the system involves a differential GPS (Global Positioning System) with base station for the positioning of the measured data points with high precision and an inertial unit that provides the angle information of the system attitude. The precise knowledge of the system attitude is used for further motion noise reduction for geo-referencing of the full tensor as well as to enhance the accuracy of the spatial localization and orientation of the sensors during operation. All the above mentioned processing steps aim for maximized signals caused by magnetic anomalies in the subsurface and try to minimize the influence of surrounding sources for disturbances like the pulling vehicle, traffic besides the measuring field or close power lines for example.

The different sensor data are collected all together in an inhouse developed data acquisition unit and is stored in a measurement computer. The whole system – cryostats, data acquisition, GPS and inertial unit – are mounted on a non-magnetic measurement cart normally pulled by an all-terrain vehicle. The cart was developed to ensure the steadiness and functionality of the system under real field conditions, to suppress the influence of surface roughness and finally to realize a pulling speed over ground

Figure 1: *SQUID measurement system crossing a bank structure covered with aeolian silt deposit and accumulations of graminaceous plants of the Mongolian Steppe. The all-terrain vehicle pulls the non-magnetic measurement cart holding three different cryostats (orange/black), the data acquisition system and the rover part of a differential GPS (white cover box).*

Figure 2: *Measured SQUID magnetogram with a couple of point-shaped anomalies which represent regions of interest as a result of the automatic segmentation and pattern recognition. Shown lines illustrate the calculated relations between different connected regions (Here: local maxima and minima in the signal amplitude) during the inversion using the "point shaped" model.*

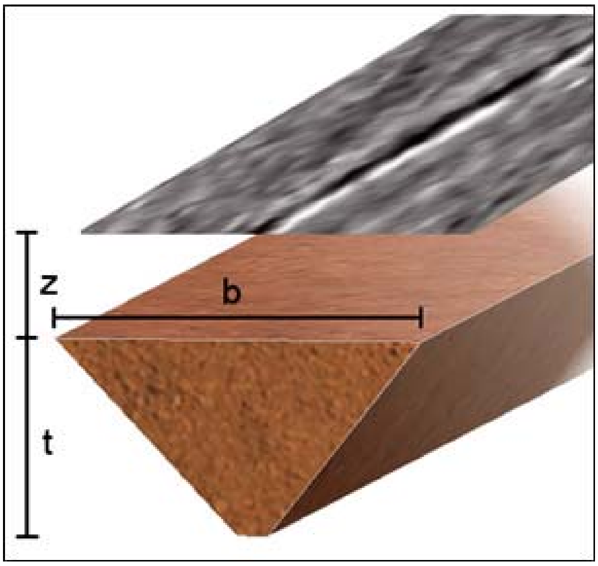

Figure 3: *Illustration of an example of minimization of three free parameters during the inversion using the "polyhedral source" model of a ditch structure: z is the covering depth, t the lateral depth of the structure and b the breadth of the upper surface. The data set is a cut-out of the magnetogram of Figure 4.*

of up to 50 km per hour. With respect to the data sampling rate of 1 kHz and the described measurement speed, an area of 10 ha (105 m^2) per day is typically investigated. That way, the complete system provides an effective, fast and sensitive tool for geo-physical investigations in fields like geology (Stolz, 2006), detection of unexploded ordnances (Linzen *et al.*, 2009) and especially archaeology (Meyer *et al.*, 2009). The combination of all sensor data allows the generation of magnetic maps with high resolution in localization and orientation. These magnetograms are geo-referenced and they give a first overview of the buried and anomaly causing objects in the investigated area.

The possibility of an area-wide and detailed prospection with the discussed system offers new data quality and hence a potential for various inversion methods. One of the most important points regarding the application of this system is that it generates more information about the subsurface situation in areas of interest, without losing the advantage of a non-invasive investigation method. The selected inversion method of a structure in the magnetogram depends on the appearance of the anomaly. There are two principal types of appearances. These are, on the one hand, side separated or overlapped dipole-like source distributions coming from localized inhomogeneities in the soil, like pieces of bricks, furnace slag or post holes. On the other hand are broad anomaly structures stemming from distributed inhomogeneities like hidden ditches, banks or edges.

The first inversion approach is called "point-shaped source" model and it is based on the combination of image processing techniques and an advanced physical model of a general dipole. Segmentation and pattern recognition algorithms identify the regions of interest and the relations between them allow the separation of overlapped sources and the calculation of the position or depth and orientation of a point-like source causing the anomaly as shown in an example in Figure 2. The spatial dimensions and amplitudes of the anomaly signal are used for an inversion using the underlying physical model of a point source that involves detectable parameters like distances, angles and symmetry lines within the characteristic appearance in the magnetograms. With this approach, it is possible to get information even about complex scenarios with many overlapping structures or objects.

The second approach is based on a so-called "polyhedral source" model proposed in an approach of P. Furness (1994). Here, the physical idea is the reduction of the magnetic description of a convex homogeneous body to the magnetic influence of its surfaces and edges. Our implementation of this approach was made to overcome the inaccuracies that appear at linear expanded anomaly structures in the magnetograms, by trying to invert these appearances with the "point-shaped source" inversion discussed above. At this point the physical description of the influences of a broad structure to a homogeneous magnetic field allow the inversion of such scenarios to get information about the covering, the surface shape and an idea of the susceptibility contrast between the inner and outer material of the structure, assuming a homogeneous magnetic filling of the body. The application of this approach is a combination of the description of geometrical structure and the analytical field together with numerical minimization algorithms to adapt the body and its anomaly to the measured appearance in the magnetogram. One possible set of minimization parameters is shown in Figure 3.

In contrast to the differences in the source description and field analysis, both approaches have in common the fact that they work with at least one tensor component of the Earth's magnetic field, but accuracy of the inversion could be increased by using more tensor components that are consistent with each other.

In this work, we want to demonstrate these inversion methods by analyzing a variety of examples from real field measurements. Along with many field excursions in Germany and Central Europe, the system showed its applicability across large scanned areas in a wide range of different archaeological sit-

Figure 4: *SQUID magnetogram measured on a 350 × 350 m² area in the Orkhon-Valley in Central Mongolia. The gray colours represent a vertical gradient component in the range of ±14 nT/m. Different linear and rectangular structures point to buried remains of a large settlement structure. The different accumulations of point-shaped sources with high gradient amplitudes may reveal the technical usage of this area.*

uations in the steppe at the Orkhon-Valley in Central Mongolia. One example of a magnetogram is shown in Figure 4. In this magnetic map, a distribution of long ranged linear structures as well as sharply bounded dipole-like anomalies is visible. With this magnetogram, it is clear that both of the described approaches are necessary to get a more or less comprehensive description of the situation and distribution of the underground sources.

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THE UTILISATION OF REMOTE SENSING DATA FOR THE INVESTIGATION OF IRON AGE SITES AND LANDSCAPES – A CASE STUDY FROM AUSTRIA

M.D. Fera

1. RESEARCH AIMS

The aim of this research is to examine the potential of data derived from remote sensing for the investigation of Iron Age settlement patterns and associated land use in the first millennium BC in Eastern Austria. Along with a new qualitative assessment of sites identified by preceding research, the development of techniques and methods for the placement of sites in a broader landscape context is intended to form the basis of a PhD project in progress by the presenting author.

2. BACKGROUND AND CONTEXT

Remote sensing methods have become an indispensable part of archaeological research, not least because they allow us to survey archaeological surface remains and underground structures in large areas in relatively short time. Aerial imagery has an especially long tradition in this field (Crawford, 1929) and has proved to be a very effective tool for the detection of archaeological structures at both the landscape and site scale (Doneus, 2003).

The main research institution for aerial archaeology in Austria is the Aerial Archive of the University of Vienna, situated at the Department of Prehistoric and Medieval Archaeology. The archive holds a set of 120,000 aerial images covering around 6,000 archaeological sites all over Austria, mainly collected since the 1970s, and deriving from various research projects conducted by university faculty and staff (Doneus *et al.*, 2007).

The traditional way of investigating and interpreting the imagery is through a visual interpretation of georeferenced and rectified oblique and vertical images, deduced by applying a photogrammetrical workflow (Doneus, 1996) in a GIS-environment. Additional ground based surveying and the incorporation of complementary prospection methods adds to the qualitative evidence of the interpreted structures of archaeological sites which are aggregated and administered in a GIS-based database at the Aerial Archive (APIS).

An additional method for large-scale prospection that overcomes limitations of aerial imagery in forested areas is airborne laser scanning (ALS), which is capable of delivering data for digital topographic models (DTMs) of areas under dense vegetation (Kraus and Pfeiffer, 1998; Briese *et al.*, 2002; Doneus *et al.*, 2008). Particularly the use of full-waveform airborne laser scanning (FW ALS) and sophisticated filtering and classification algorithms provide DTMs that preserve subtle structures and allow the identification of archaeological features on the scale of sites, as well as remnant historic landscapes (Doneus, Briese and Kühtreiber, 2008).

For the detection of archaeological features, different visualization methods have been developed. For visual interpretations, analytical hillshades of the DTM are mainly used, and further development led inter alia to the use of Local Relief Models (LRM) (Hesse, 2010) and the application of sky-view factor (Kokalj *et al.*, 2011; Stular *et al.*, 2012). All of these visualization methods are aimed at a visual interpretation and expert based classification, mainly working in a 2D-environment.

Another potential of ALS-derived high-resolution digital elevation models (DEMs) is the use of geomorphometric approaches for geomorphological maps. Such maps can be used to predict and interpret the location of archaeological sites (De Reu *et al.*, 2011) and first tests with object-based image analysis (Verhagen and Drăguţ, 2012) show the usefulness of this approach on landform objects at the landscape scale. Efforts to identify archaeological features provide some results, especially on distinctive features like barrows (de Boer *et al.*, 2008), but the method still faces problems due to the multitude of diachronic surface structures.

3. CASE STUDY - EARLY IRON AGE SITES IN EASTERN AUSTRIA

The study area is located south of Vienna and comprises 2.5 km^2. Previous research on settlement patterns in the first millennium BC in Eastern Austria has indicated that there are regular patterns for the spatial and hierarchical distribution of settlements for Early Iron Age and Late Iron Age (Kaus, 2006; Rebay, 2002; Nebelsick, 1997). For the Early Iron Age, the area is assigned to the regional Kalenderberg group of the Hallstatt culture, for which hilltop settlements seem to be the most significant category of settlement. These settlements are often associated with barrows from the same time, which seem to play an important role in structuring the landscape. In addition, some settlements on flat areas are known (Griebl, 2004); whether there were also burials without a mound remains undetermined (Rebay, 2002), since many mounds have been flattened through agricultural use. Some of the hilltop settlements were fortified, whilst others do not show recognisable fortification structures. Generally, knowledge about the structure and surrounding of these settlements is deficient; nevertheless it was thought that all of the hilltop settlements of this cultural phase are already known (Rebay, 2002).

The Aerial Archive and the Ludwig Boltzmann Institute for Archaeological Prospection (LBI ArchPro) have provided the data sets used in this study. Besides incorporating data from publications to the current state of research, the results of two projects at the University of Vienna (Doneus *et al.*, 2007; Doneus and Griebl in press) form the basis of the site database. While one project stressed the use of systematic aerial reconnaissance in the core region of the study along the Leitha River, a follow-on project used ALS in the forested mountainous ridge of the Leithagebirge (Figure 1). While many flattened barrows in agriculturally used areas were detected by aerial archaeology, the systematic investigation with the use of ALS revealed many additional barrows in the forested areas.

The workflow for processing aerial images and ALS data as proposed in this paper involves the following steps. The aerial images of the selected areas are rectified by the use of a digi-

Figure 1: *3D representation of ALS data using a filtered DSM for elevetation information and sky-view factor as a texture showing an area of a fortified Iron Age hillfort with associated burrows and younger surface structures in the area of the Leithagebirge. (Rotate page clockwise.)*

tal surface model (DSM) derived from ALS-data, which was not available at the time of the preceding project, and which can increase the accuracy of the rectification of oblique and vertical aerial images and provide an improved basis for visual interpretations.

To utilize the full potential of the ALS data for the study region, different processing steps are done on multiple scales. Different visualisation methods at the site scale are compared and refined for interpretation of surface structures, while ways of investigating and interpreting the data sets in a three-dimensional (3D) environment are explored. Additionally, geomorphometric analyses are used to produce maps on a landscape scale for further research on the placement and distribution of sites. While the resulting maps and models offer possibilities for targeted investigations with the help of predictive modelling, they might also allow a qualitative assessment of the data pool as related to a possible methodological bias or being a result of varying preservation conditions, to improve deduced models of Iron Age landscape structures.

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WHOSE FORT? INVESTIGATING THE REMAINS OF AN ENIGMATIC ENCLOSURE IN SOUTHERN NEPAL

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1. INTRODUCTION

The Terai area of southern Nepal has a large number of archaeological sites and monuments that have only recently received attention (Coningham *et al.*, 2011; Schmidt *et al.*, 2011). Best known is the World Heritage Site of Lumbini, birthplace of Gautama Buddha. Twenty kilometres west are more sites related to Buddha's life (e.g. Tilaurakot and Kudan) as well as pillars erected by Emperor Asoka for some of the earlier Buddhas, at Gotihawa and Niglihawa. While all these sites are part of the Terai's sacred Buddhist landscape, there is one site that stands out by being very different and wholly unexplored.

The site of Araurakot lies 1.3 km southeast of Niglihawa. It is a large, nearly square structure (Figure 1) ramparts up to 4 m high and sides approximately 240 m long. The southern and eastern ramparts are a massive tapered brick construction, ca. 17 m wide at the foot and 2–3 m at the top, with several bastions on the corners and sides. Two 15 m wide ditches are located outside the eastern ramparts, and one ditch outside the southern. The northern and western ramparts are much lower earthen constructions (1-2 m high), probably reduced in height by continued erosion. The inside appears to be empty, apart from a platform-like elevated area (ca. 1 m high) in the southeast quadrant of the site. The platform is not entirely at right angles to the rampart. Hardly anything is known about this impressive site, and even its dating on stylistic grounds has not yet been confirmed, although a construction during the Kushan period (ca. 2*nd* century AD) seems likely. Our team explored the site in January 2011 and 2012 using magnetometer and GPR surveys, undertook a detailed earthwork survey and mapped the topography of the site with an auto-tracking Total Station.

2. MAGNETOMETER SURVEY

A fluxgate gradiometer survey of 1.6 ha covered the majority of the south-eastern platform. A Bartington Grad601-2 was used to measure 40 data grids of 20 m size, resulting in a final survey resolution of 0.25 m $\times$ 1.0 m. The platform shows several small mounds that were recorded in the detailed earthwork survey. In addition, a large mound is visible in the south-western part of the survey area, abutting onto the rampart. In the southeast of the area, a pronounced depression could be of more modern origin, possibly used as a quarry by local villagers, who seem to have adopted the site as their cricket ground.

The magnetometer data (Figure 2) show several pronounced positive magnetic anomalies. Most notable is a rectangular anomaly to the north of the platform (ca. 20 nT), probably caused by a buried brick structure forming an enclosure. Only the northern wall seems to create a pronounced negative anomaly. The size of this structure is 35 m $\times$ 20 m and it seems to enclose a smaller structure of 8 m $\times$ 14 m, located in its centre and extending south from the northern edge of the enclosure. This smaller structure is marked by small mounds on the surface on its northern and southern end. It is likely that these are piles of brick rubble from the destruction of this structure. A possible explanation for the fact that these small mounds are only found to the north and the south could be that the structure was higher there.

A second feature inside the enclosure manifests itself as a cluster of localised anomalies (ca. 3 m square overall) west of the internal structure. A string of bipolar magnetic anomalies runs along the northern edge of the platform. These could be caused by a brick facing of the platform, or the whole platform could be made of brick, although the latter is less likely. At the southern edge of the survey area lies a rectilinear strong (ca. 80 nT) anomaly, directly underneath the large mound that abuts onto the brick rampart (see above). It is likely that the anomaly is caused by a brick construction with internal subdivisions that forms this mound. It could be a purpose-built part of the rampart, forming either an access ramp or an internal buttress (it lays exactly between two of the outer buttresses). The remaining magnetic anomalies are difficult to associate with individual structures, although alignments of positive anomalies are discernible, especially in the eastern part of the survey area.

3. GPR SURVEYS

Ground Penetrating Radar (GPR) surveys were undertaken with a 500 MHz Mala Ramac system (Figure 3) to cover the rectangular enclosure detected in the magnetometer survey. The readings were recorded in data grids of 20 m size along parallel transects spaced 0.25 m apart. The data were resampled to an in-line spacing of 0.05 m and processed with band-pass filtering and background removal. The electromagnetic velocity was estimated from the signal hyperbolas and was found to be 0.075 m/ns, which was used for the depth migration of the data and to calculate depth-slices of 0.1 m thickness. Since the investigated area is fairly level, no topographic corrections were necessary. The depth slices are displayed as relative greyscale images where black indicates strong reflections.

The enclosure shows clearly in the GPR data (Figure 4), extending most prominently from 0.4–0.8 m depth. The northern and western sides even extend down to approximately 1.1 m, which explains the negative magnetic halo created by the more substantial northern wall. While the internal structure is only vaguely defined in the magnetometer data, it shows clearly in the GPR results over a depth range of 0.4–0.6 m. The feature is mainly identified as a 1–2 m wide band of demolition rubble; only the eastern wall can still be discerned on the inside of this rubble band. Combined with the reduced depth range it therefore appears that this internal structure was far less substantial than the enclosure itself. The data confirm that there is more demolition rubble at the northern end of this internal structure with some pronounced anomalies located in the small mound on the surface.

At a depth range of 1.1–2.1 m a circular arrangement of isolated anomalies (ca. 1.5 m each, arranged in a circle of 4 m di-

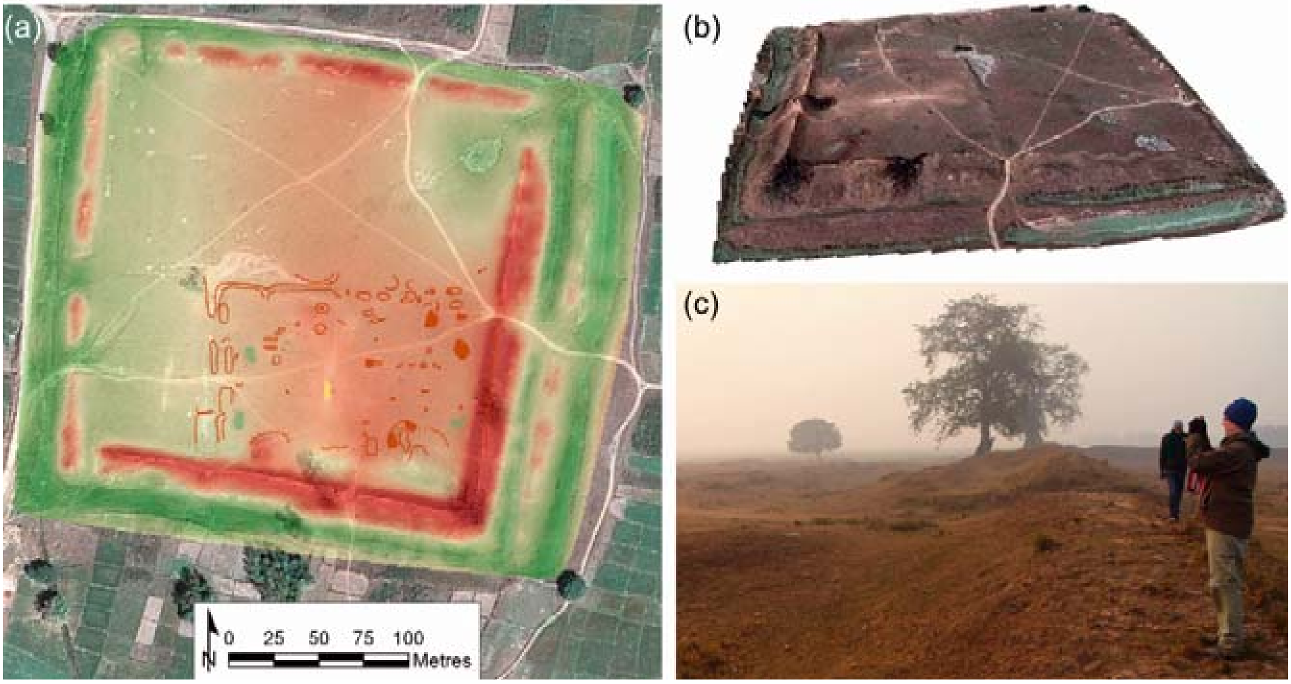

Figure 1: *The ramparts of Araurakot: (a) topographical model and earthwork survey (red) overlaid on satellite image; (b) 3D model of the site, viewed from east; (c) on top of the rampart, photographed from north.*

ameter) is visible in the centre of the internal structure. It is far deeper than any of the other anomalies associated with this structure, and its origin is unclear. The other magnetic anomaly inside the enclosure and west of the internal structure is also more clearly defined in the GPR data. It shows as a square block of 2.3 m width that has its best definition at 0.4 m depth, where a string of small circular anomalies (ca. 0.5 m) run along its western and southern sides while bigger anomalies run along its north. These are possibly stone-packed pits, maybe to hold a wooden construction that would have been open towards the internal structure. This feature is rotated approximately 20° relative to the enclosure and the internal structure and it only disappears in the GPR data at a depth of 2.2 m. South of the enclosure is another GPR anomaly (ca. 1.2 m wide) that coincides with a strong magnetic bipole (ca. 50 nT). The GPR signal extends from 0.4-1.0 m. Beneath it, from 1.1-1.9 m, are two thin (ca. 0.5 m wide) straight anomalies at a right angle to each other, as well as some further linear anomalies, all at different angles to the enclosure.

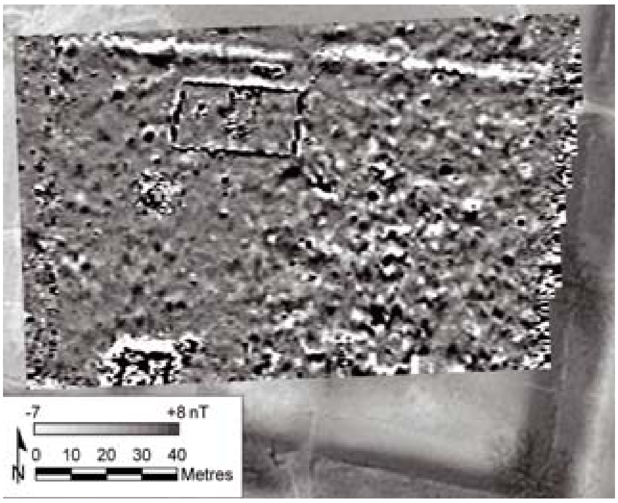

Figure 2: *Magnetometer survey over the platform in the south-eastern quadrangle.*

4. INTERPRETATION AND DISCUSSION

The investigated platform seems to have been purpose-built in the south-eastern corner of the enclosed site, either made entirely of brick, or, more likely, as a brick enclosure filled with earth. In South-Asia, the use of a brick-lattice is common to create platforms, whereby the resulting cells are filled with earth. However, no such internal subdivisions of the platform were found in the data, only the big mound in the south abutting the rampart seems to have been built in this way. The magnetometer survey already highlighted the most prominent features on the platform: a rectangular enclosure at its northern end with an internal rectangular structure in its middle and a smaller structure to the west. These features were imaged in even greater detail by the GPR data. They showed that the enclosure wall is fairly substantial, reaching to a depth of 1.1 m, approximately the level of ground in the interior of the main site, north of the platform. The square block in the western half of the enclosure extends even deeper, to 2.2 m. At that depth, a circular arrangement of features is visible in the centre of the enclosure and another block outside to the south. Underneath this outer block are further linear features. By contrast, the internal structure in the middle of the enclosure is shallow and confined to a narrow depth range.

All these depth estimates were derived from the GPR slices and have to be evaluated critically. Ringing often produces anomalies below the original features, and depth-slices can show

Figure 3: *GPR survey over the enclosure on the platform.*

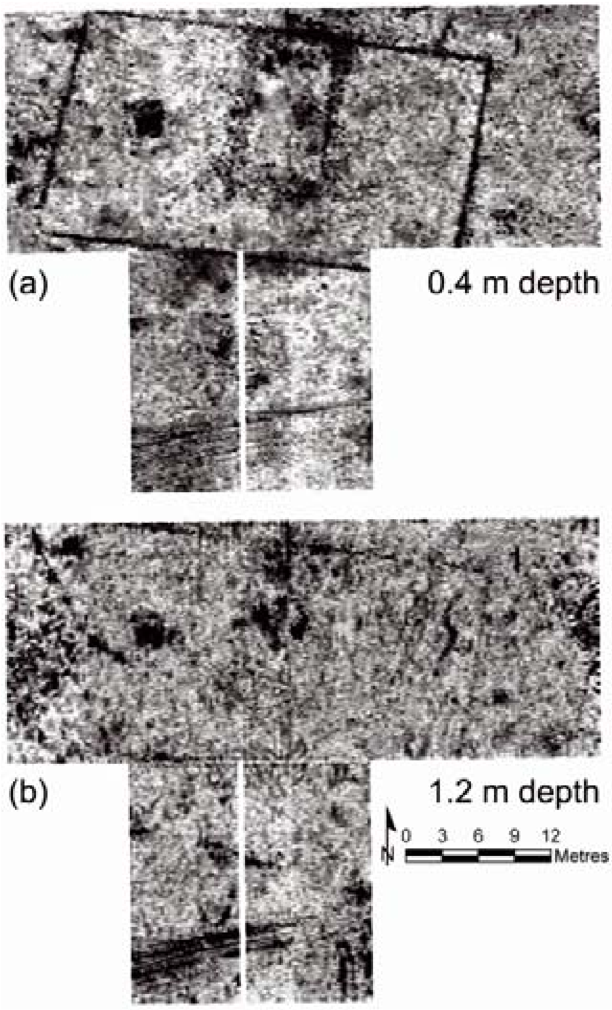

Figure 4: *GPR depth slices at 0.4 and 1.2 m depth.*

'ringing-ghosts' from higher anomalies at depths where other strong anomalies have dissipated. However, after careful analysis of the data these effects were ruled out. For the migration of the data a constant electromagnetic velocity was selected, which is an oversimplification and the true depth range of the calculated slices may hence be slightly different. The relative stratigraphy, though, would not be affected by a recalibration of the velocity values.

Based on these results a three-layer stratigraphy can be hypothesized.

- Linear structures, a circular arrangement of small features (4 m in diameter) and a square block (2.3 m side length) initially existed just below the current outer ground level.
- The circular arrangement of features and the square block were then enclosed by a rectangular structure, built on the current outer ground level.
- Eventually, the platform was built, filling in the enclosure wall, but leaving the square block to protrude. The internal structure inside the enclosure was a very marginal construction on the upper levels of the fill in this late phase.

It is conceivable that the central circular arrangement and the square block were the initial focus of this site, with a subsequent enclosure wall and eventually a ceremonial platform that formed the nucleus of the large ramparts, with the southern and eastern brick ramparts built to flank the platform.

The magnetometer survey was essential for the identification of important structures on the platform. However, only the very good spatial and depth resolution of the GPR data allowed the construction of a comprehensive archaeological stratigraphic narrative. The details of this can only be fleshed out through excavations and the dating of key layers. The interpretation of depth from GPR data remains challenging and ringing effects have to be identified to derive useful depth information.

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AUTO-EXTRACTION TECHNIQUES AND CULTURAL HERITAGE DATABASES – ASSESSING THE NEED, EVALUATING APPLICABILITY AND LOOKING TO THE FUTURE

D. Cowley, V. De Laet, R. Bennett

1. INTRODUCTION

This paper discusses the opportunities for the creation of national mapping and heritage databases presented by semi-automatic extraction techniques applied to emerging resources like Airborne Laser Scanning (ALS), hyperspectral and very high-resolution satellite (VHRS) datasets. Such techniques raise many issues, including philosophical objections and the necessity to understand appropriate contexts in which they can be applied.

Databases or inventories of archaeological features and heritage assets are crucial to effective management and underpin reliable research. However, the mechanisms by which such inventories are created vary enormously, and their utility for heritage management and research is likewise highly variable. In countries with long traditions of heritage records, inventories may draw on over a century of work in different frameworks, including antiquarian observations, fieldwork, aerial photograph interpretation and excavation. Such datasets are of course very valuable, but as products of cumulative and sometimes unsystematic processes they are generally biased by many factors, including intellectual traditions, funding and modern and recent land use (e.g. Cowley, 2011; Rączkowski, 2011; Risbøl, 2013). Moreover, these databases are produced in human timescales, depending on observation and record creation by a human actor, and this is essentially limited by resource and the speed at which a person can walk the ground, collect surface artefacts or map from an aerial photograph. Thus, even where significant bias in databases can be seen, reflecting, for example, differing intensities of field observation, addressing the unreliability of the data is seen as desirable, but ultimately a long-term objective dependent on resourcing. The situation can be acute in the many parts of the world that do not have long-established heritage inventories, and the existence of all but the most basic of heritage records is rare. This is a difficult problem to resolve, as traditional approaches to creating heritage databases provide important data, but require time and significant resource to create. We argue that a balance of traditional recording with a willingness to explore more automated approaches to feature identification in digital data sources is required to facilitate the rapid creation of systematic baseline heritage records.

There is a paradox here between the ready and increasing availability of extensive data sources, such as aerial and satellite imagery, and the ability of the heritage community to effectively exploit them to inform the understanding of the past and the management of its material remains. At the centre of this paradox is the almost wholesale reliance in archaeology on traditional means of extracting data – that is visual inspection or a physical presence in the field – in essence a 'manual' approach. This is a fundamental limiting factor on the scale and speed at which new data can be assessed or biases in existing heritage databases addressed. We argue that an exclusively manual approach to the creation of heritage datasets is a major limitation to the fuller exploitation of existing data sources (i.e. aerial/satellite imagery) and will fail to fully engage with the potential of complex 3D and multi/hyperspectral datasets. However, such developments require careful assessment and consideration of approaches and contexts, based on a full understanding of the different types of data that may be created and the processes by which this is undertaken.

2. RETHINKING APPROACHES TO NATIONAL-SCALE MAPPING

Archaeologists may choose to research relatively small areas that can be inspected in detail. However, dealing with development threats in large areas that have a poor record, variable in coverage and quality, is problematic for cultural resource managers as databases may not support prioritisation and protection. Addressing this problem is one of the key objectives of English Heritage's National Mapping Programme, a unique project that has been underway since 1992/3 primarily using aerial photographs to map extensive areas and create heritage records (Horne 2011; Winton and Horne 2010). With a variable number of staff (averaging 15-20 for long periods), by 2011 about 52,000 km^2 had been examined, recording over 100,000 archaeological sites at an average coverage rate of 1 km^2/day. This far-sighted project has created records that underpin effective heritage management and support better understanding of the past, and is based on a 'manual' approach operating on human timescales with significant financial resource.

A very different approach to large area mapping has been developed in Baden-Württemberg using ALS data (Bofinger and Hesse, 2011; Hesse, 2013). This relies on a heavily automated data processing workflow, including the routine use of local relief models (LRM), to allow 35,751 km^2 to be mapped in six years by a single operator, identifying an estimated 600,000 sites. This approach is important for a number of reasons. Firstly, it exploits the potential of digital 3D data, working from the simple postulate that archaeological features often have low relief relative to the rest of the landscape, to use the LRM algorithm to extract features of potential interest. Secondly, by facilitating rapid analysis of spatially extensive data, it allows the creation of a consistent dataset in a timescale that is an order of magnitude quicker than exclusively 'manual' approaches. Thirdly, it provides another way of looking at the data that is not entirely dependent on the experience, knowledge and skills of a human interpreter – factors that can introduce their own limitations as observers will routinely see what they expect and are familiar with, and will more rarely recognise the unexpected or the anomalous (i.e. confirmation bias).

It is vital, however, to recognise the type of information produced by different approaches. Thus, while the English approach should produce records that are archaeologically reliable, the Baden-Württemberg data contains a presently unquantified balance of definite/potential sites. It is important to note that the two approaches produce different types of information, with different levels of reliability and different roles in heritage management. However, the scale of the difference in coverage rates demonstrates that if rapid assessment of large areas is required to create baseline datasets, then semi-automatic techniques as aids and guides are essential. This does bring with it a need to define purpose and to manage expectations (Opitz and Cowley, 2013, 6-7). With rapidity comes less certainty, and a need to accept that a significant percentage of sites identified may not be 'real'. Nevertheless, in circumstances where databases are poor, perhaps this is a better option than slowly progressing the creation of traditional site databases over many centuries when these too will never achieve a total record, especially when threats to heritage assets are real and present. Moreover 'manual' and 'auto' methods are not mutually exclusive, but ideally are complimentary. Therefore, in Baden-Württemberg the ALS-based feature detection provides an indication of potential interest that can be followed up in a variety of ways as required, adding detail and enhancing the record. This involves a key conceptual shift, from a fixation on individual identifications being correct to overall patterns being descriptive. Much remote sensing archaeology has focussed on detailed recording of sites (even if these are large enough to be called landscapes), with less emphasis on broad-brush inventories of large areas. In the many parts of the world where even basic archaeological inventories are lacking, there is a strong case for prioritising rapid, broad-brush characterisation of the archaeological resource to support heritage management, over the detailed understanding of tiny parcels of land. Here, the explicit definition of the purpose at hand is vital, as this will define the appropriateness of techniques applied.

3. ESCAPING SILOS AND DEVELOPING COMPLEMENTARY METHODS

While automatic 'feature' extraction is now a routine in many fields from car number plate recognition to medical applications, auto-extraction, or more accurately, semi-automated extraction of features in archaeology has generated mixed, sometimes highly polarised views. This has been evident in discussion of the utility of automatic (or semi-automatic) feature extraction at the conferences of the Aerial Archaeology Research Group (AARG) and others (De Laet and Lambers, 2009). Meanwhile, in print the effectiveness of auto-extraction of circular marks on satellite imagery (Trier *et al.*, 2009) has been questioned because of the balance of false/true detections (Hanson, 2010), while Parcak (2009, 110-111) is overtly critical of automatic approaches, stating, for example, that 'computers' will never have the same ability as human eyes to identify features. However, these critiques miss four key points: firstly the implication these methods have for rapid coverage of large areas to provide baseline datasets; secondly the ability of 'computers' to interrogate complex datasets in ways that allow us to see beyond the visual and familiar; thirdly the need to distinguish between the processes of detection of (potential) sites and the archaeological interpretation of those features; and fourthly that the archaeological applications using these kind of data are at an early stage (with a heavy reliance on methods developed for environmental purposes rather than in specifically archaeological contexts).

Failure to distinguish the contexts in which particular approaches are appropriate probably lies at the heart of concerns that heavily automated procedures for feature extraction might be seen as a substitute for knowledge-based expert interpretation (Palmer and Cowley 2010). However, while uncritical application of any data-processing techniques may produce poor information and is undesirable, so too the limitations of traditional modes of interpretation must be recognised. Confirmation bias is an ever-present danger, since archaeologists will tend to see what they know, unconsciously ignoring features that do not fit and observations will always be biased towards the familiar. On the other hand, semi-automatic techniques such as LRM may identify monuments not expected by the archaeologist. Indeed, the accountability and replicability of algorithms such as LRM is a challenge to the often highly subjective work practices of traditional archaeological interpretations from aerial imagery. This identifies the necessity of integrated applications of semi-automatic extraction and traditional observation, such as the recent work in Norway that combines automatic detection and visual interpretation followed by field observation. This is an iterative process, where the role of archaeological specialist is not lost from the processing chain (Trier and Pilo, 2012).

Thus, we argue that oppositions between knowledge-based expert interpretation and (semi) automatic techniques are false (Cowley, 2012). Surely, the real issue for debate is how automated and manual approaches can be used in appropriate complementary contexts, recognising, for example, the different demands of extensive mapping where site detection is paramount or detailed understanding of a landscape where archaeological experience and knowledge are important. There is some progress towards a balanced position, which has moved beyond simple extremes ('auto-extraction can do everything' vs 'only the archaeologist can interpret imagery') to discussion of the appropriate contexts for differing techniques. In addition, there is now a body of material on feature extraction in specifically archaeological contexts (De Laet *et al.*, 2006, 2007, 2008), and experiments with semi-automatic feature extraction to detect circular marks on satellite imagery (Trier *et al.* 2009) and more recently pits in ALS data (Trier and Pilo, 2012). It is vital to recognise that this research is still at an early stage, reflected, for example in the balance between true/false detections in the satellite imagery experiments (Trier *et al.*, 2009), drawing heavily on approaches developed outside archaeology. Indeed, data processing in archaeology is probably still under-developed, and De Laet and Lambers (2009) have commented on the divides between aerial archaeologists and airborne/satellite remote sensing specialists in their differing willingness to use algorithms and other transformations of the basic data. The development of feature-extraction in specifically archaeological frameworks is a positive development and one that is vital if archaeologists are to engage with complex and extensive datasets efficiently. These approaches have demonstrated their utility for ALS data, and they will be vital for fuller exploitation of hyperspectral and VHRS data to generate heritage records.

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ELECTRICAL RESISTIVITY OF STONE BUILT STRUCTURES. APPROACHES TO TECHNIQUE, INTERPRETATION AND MODELLING

P. Brengel, D. Jordan, B. Thierry-Hildenbrand

1. INTRODUCTION

Electrical resistance (ER) survey is widely used in archaeological prospection. It has a long history, developing from the use of simple DC ER meters in the 1950s to modern fast multi-electrode systems (Clark, 1990; Scollar *et al.*, 1990; Gaffney and Gater, 2003). Software and hardware improved significantly during the 1990s, and today electrical resistance tomography (ERT) is one of the most efficient and informative prospection methods at the archaeologists' disposal (Papadopoulos *et al.*, 2006, 2011; Wake *et al.*, 2012).

Electrical resistance survey is commonly used in two ways:

- Horizontal 2D ER survey, most commonly of sites where the bulk resistivity of stone-built archaeological remains contrast with that of the surrounding soil.
- 2D or 3D ERT to more fully describe the structure of buried archaeological remains.

The interpretation of ER data depends on the appearance of recognizable patterns of ER anomalies describing buried archaeological remains. Horizontal 2D ER survey can, as with ERT, make it possible to calculate values of apparent electrical resistivity in the soil, if the geometry of the electrode array in use is taken into consideration. Such apparent resistivity values could be used to refine the interpretation of ER anomaly patterns, but only if the way in which archaeological structures determine the bulk resistivity in the ground is understood. However, the bulk resistivity of archaeological remains has only very rarely been determined by direct measurements or by laboratory experiments. Thus, the interpretation of ER anomaly values is based largely on presumptions of their likely values rather than on empirical evidence. Therefore, the reasons why ER surveys sometimes fail to detect remains, or give only partial detection, are poorly understood. We do not know enough about how electrical resistivity distributions form in the soil and in archaeological remains (Jordan, 2009). This is particularly significant for stone-built structures, since these are often targeted by ER survey because of the strong ER contrasts they can create with the natural soil.

In order to more fully use the potential of archaeological ER survey, it is necessary to improve our understanding of the resistivity of archaeological remains and their soil contexts, by direct measurement in the field, by laboratory analyses and by seeking appropriate numerical modelling approaches, applying methods adapted from soil science and geology.

This paper explores the structure and electrical resistivity behaviour of stone-built archaeological remains. It considers how data collected by fieldwork and laboratory experiments can be used as a basis for realistic numerical models describing the bulk resistivity of such remains.

2. FIELD AND LABORATORY METHODS

2D ER and ERT survey is carried out over stone-built structures using simple electrodes, as over any other remains, unless the ground surface consist only of stone, where special arrangements are required to ensure sufficient electrode contact.

In archaeological remains consisting largely of fine soil material, the electrical resistivity of specific strata can be determined by direct measurement, by placing electrodes around undisturbed samples in plastic tubes and boxes (Figure 1a, 1b). The origins of these resistivity values can be explored by measuring their chemical and physical properties in the laboratory, including water content, texture (especially clay content), salinity and temperature, since these directly control electrical conduction. By varying these factors under controlled laboratory conditions, using undisturbed soil samples, it is possible to simulate the variation of bulk resistivity in the field and explore, for example, the effects of changing water content.

This approach works well for fine soils with only small inclusions (such as stones) in low concentrations. Stony materials, such as those forming the Donnersberg wall, however, require that the laboratory measurement system be sufficiently large so that a representative bulk resistivity can be measured (Rey *et al.*, 2006).

Figure 1: *Cylindrical PVC tube for undisturbed soil samples with predefined electrode positions (a) and soil box with four fixed electrode positions (b).*

3. MODELLING

Archaeological features can be depicted numerically as 2D or 3D networks of points, each representing a volume of soil with a specific resistivity (Jordan, 2009). Such models make it possible to calculate the resistance measured in ER surveys, for example by applying finite elements methods. By varying the resistivity values of each point, changes in the soil physical and chemical properties within archaeological remains can be simulated in order to understand the effect of these variations on ER survey results.

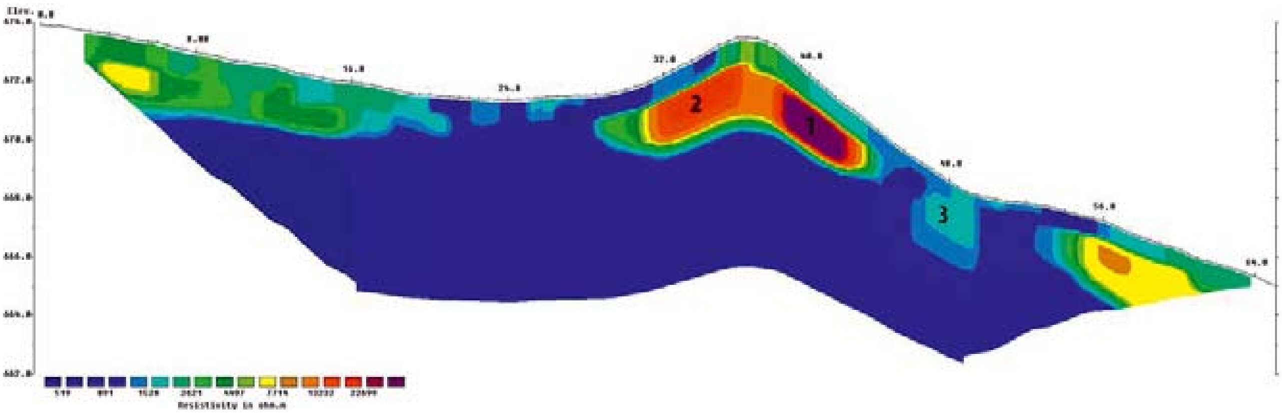

Figure 2: *ERT profile crossing the south-eastern wall of the Celtic settlement on the Donnersberg.*

The weakness of such models is that they required the input of resistivity values, which must either be estimated or known from previous surveys. An alternative is to calculate values of resistivity from underlying properties using empirical relationships established by experiment (such as transfer functions). One such function is that of Rhoades *et al.* (1999), which describes three pathways of electric current flow in soil through pore water and porous, partly saturated peds. This approach can be adapted to stony soils and archaeological remains built partly of stone by combining it with finite-element methods. However, remains consisting largely or entirely of stones are better represented by alternative approaches that may be based on adaptations of Archie's law for soils with stone inclusions (Rey *et al.*, 2006) or on pathway or percolation models (Jordan, 2009).

4. CASE STUDIES

The paper describes two contrasting case studies that illustrate the challenges of understanding ER behaviour on stone-built remains. ERT has been used to explore the internal structure of stone-built monuments standing above the ground surface (Tsokas *et al.*, 2008; Tsourlos and Tsokas, 2011) and, more frequently, those that are completely buried.

Many structures survive both above and below the ground surface. For example, the city walls of proto-urban Celtic settlements are mostly collapsed, but remain visible as banks crossing the landscape. In south-western Germany, these wall structures can be found surrounding hill-top settlements such as the Donnersberg. This 8.5 km wall encloses an area of 240 ha, one of the largest Celtic settlements in central Europe (Zeeb-Lanz 2008).

Before the excavation of an inward-turned gateway in the eastern part of the city wall, ERT was used to map distributions of resistivity associated with the wall's internal structure. From earlier excavations, it was known that the face of the wall was constructed using very accurately-fitted dry–stone construction, without mortar. To ensure stability, wooden poles were built into the wall at regular intervals. The back of the wall consisted of an embankment of rock mixed with soil intended to support the wall face from behind.

Figure 2 shows a 64 m ERT section crossing the wall orthogonally, close to the gate. The range of apparent electrical resistivities is between 500 and 23,000 m. As expected, the structure of the front side of the wall (1) makes it highly resistive. The lack of mortar or fine soil material between the stones (Figure 2) means that there are few electrical pathways through which a current can flow. The resistivity of the rear embankment (2) is considerably lower, presumably because the fine material between the stones provides a pathway for electrical conduction both through continuous water-lines pores and through water and clay within the soil matrix. An area in front of the wall with a resistivity of approximately 1,600 m (3) is associated with a ditch filled with collapsed stone material from the wall.

The constructions and collapse-debris exposed in the excavated front of the wall (Figure 2) show the origins of the bulk resistivity of the structure. The wall consists of three different phases which indicate that it was rebuilt at least twice. The front of the wall was constructed with larger stones, whereas the inside of the wall is filled with smaller stones. Finer soil material is almost completely absent. Electrical conduction pathways, which determine the bulk resistivity of the structure, can therefore only exist where the solid stones touch each other or where there is a continuous film of water on the surface of the stones providing a conductive pathway between them.

This may be contrasted with the stone build structures of the Roman town of Amiternum in the Aterno valley in Italy. Amiternum is located in the Abruzzi, 10 km north of L'Aquila, and was occupied from the early Roman period of the third or second century BC. Since 2006, it has been the subject of a multidisciplinary research project involving the universities of Köln, Mainz and Bern with the cooperation of the Soprintendenza Archaeologica per l'Abruzzo (Heinzelmann and Jordan, 2012).

During fieldwork in 2008, the soil surface above two Roman walls was first surveyed with 2D ER and ERT measurements and then excavated rapidly in order to sample soils and make ER measurements in the excavated sections. A small area of 6×6 m above the walls was surveyed with a dense net of ERT lines at regular intervals.

These stone-built walls contrast with that of the Donnersberg (Figure 3) because they are closely-fitted and tightly bound by solid mortar.

Magnetic susceptibility, moisture (by FDR) and ER were measured within the excavation and samples were taken within the soil and archaeological features for further analysis. These physical and chemical analyses were then used, in combination with ERT data, to model the distribution of electrical resistivity, and the way it is represented in surface ER surveys, under changing soil moisture conditions.

Figure 3: *Excavated front side of the wall with three wall phases. Source: GDKE RLP, Dir. Landesarchäologie Speyer.*

Figure 4: *Excavated Roman wall structures at Amiternum during the campaign in 2008.*

5. CONCLUSIONS

Our limited understanding of the origins of electrical resistivity within stone-built archaeological structures limits our ability to plan and interpret archaeological surveys. To address this, we are exploring new approaches to field survey, laboratory analysis and numerical modelling, and establishing a research workflow from empirical field data to realistic models:

- 2D ER, ERT and excavation at many, varied stone built structures.
- Detailed measurement – during excavation – of bulk ER, water content and associated properties within archaeological strata and stone-structures.
- Laboratory analysis of soil and stones sampled from excavations to explore the origins of their bulk resistivity.
- Laboratory experiments exploring the influence of varying chemical and physical factors on the bulk resistivity of stone structures.
- Development and testing of numerical models representing stone built structures using structural concepts and direct measurements of resistivity values in the field and laboratory.

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MAGNETIC SURVEY IN DAHANEH-E GHOLAMAN, SISTAN-IRAN

K. Mohammadkhani

The work presented here is a part of my thesis research program at the University of Lyon 2 (France), carried out between 2007 and 2012 with the support of UMR 5133 Archéorient laboratory, Maison de l'Orient et de la Méditerranée, Université Lyon 2, IFRI (Institut Français de Recherche en Iran) and Zahedan and Zabol offices of the ICHHTO (Iran Cultural Heritage, Handcrafts and Tourism Organization). This project aims to better understand urbanism during the Achaemenid period in the eastern part of Iran.

Dahaneh-i Gholaman (The Gate of Slaves) is located east of Sistan-Baluchistan (Iran), some 40 km southeast of Zabol. The site was first recognized by Umberto Scerrato, who conducted surface surveys and undertaken excavations there between 1962 and 1965 (Scerrato, 1962, 1966a, 1966b, 1970). Between 2000 and 2006, the area was re-investigated by S.M.S Sajjadi in cooperation with a team of ICHHTO (Sajjadi, 1997, 1998, 2004, 2007). The first excavations have shown that the site would have been occupied only during the 6th and 5th centuries BC (Scerrato, 1962): these results were confirmed by more recent works of Sajjadi. Because the site was never reoccupied, Dahaneh-i Gholaman has produced evidence and particularly well-preserved data for a city centre founded during the Achaemenid period. The site is located on a natural terrace, 11 m above the surrounding plain and on the northern foot of marl hills that overlook the site from 30 m above. Thanks to the research of Scerrato, 27 buildings have been identified; among theses, Scerrato and Sajjadi have excavated 11 buildings. The buildings are aligned on both banks of a large canal, which is divided into two branches on the eastern part of the site. All of the buildings are made with fired brick and mud brick. The buildings recognized in Dahaneh-e Gholaman are of different nature and size: the largest must have had administrative and/or religious purposes, smaller ones certainly correspond to private housings and finally several craft workshops are visible. Two km towards south, there are also the traces of large walls of one squared structure (190 m per side). The width of walls is between 5 and 8 m. Based on its size and its isolated location, away from the main group of buildings, Scerrato and Sajjadi believed that this is a military structure, maybe a garrison quarter (*Padegan* in Persian). Regarding the width of the site, the presence of large buildings and the extent of the irrigation works, Dahaneh-e Gholaman was undoubtedly an important city during the Achaemenid era. Scerrato argued that these remains correspond to the ancient city of Zarang, capital of the Drangiana satrapy mentioned in Achaemenid inscriptions (Scerrato, 1966b) ruled by a vassal of the Achaemenid Empire.

The climate of region of Sistan is arid, as the only water comes from the perennial Helmand River and some seasonal rivers. There are 120 days of wind in this region (between June and September every year). For this reason, there are many moving sand dunes that each year cover the remains and cultivated land around. To provide water for the Zahedan and Zabol region, four artificial lakes have been built (named Chahnimeh in the regional dialect) around Dahaneh-e Gholaman. The artificial lakes number 1, 2 and 3 were natural depressions that were filled with water about 30 years ago. Lake 4 is a new artificial built to the west of site in 2007-2008 and filled in 2008. Those lakes obliterated a part of site in south to the east and west. The east of Dahaneh-e Gholaman is further disturbed by a road, a modern canal and electricity lines.

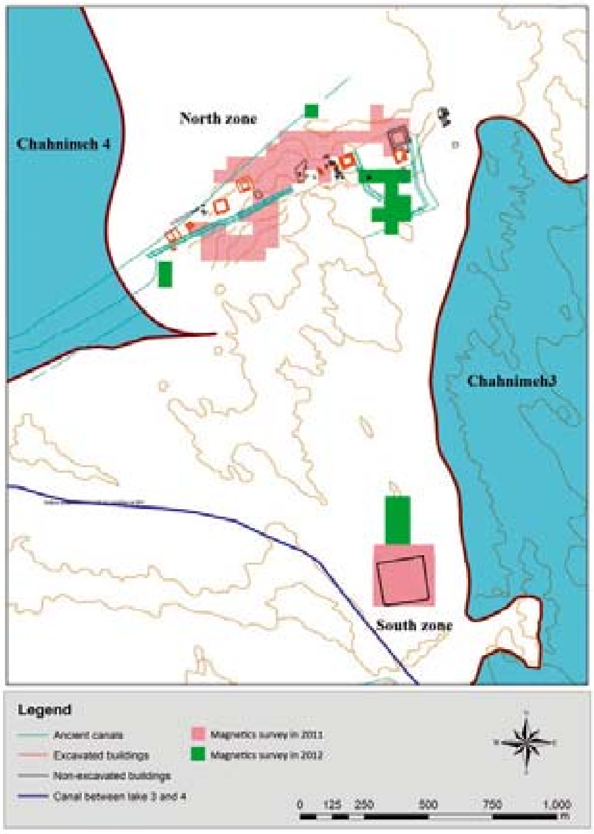

Figure 1: *Map of Dahaneh-e Gholaman. Location the northern and southern zone, and the surveyed surface (Map adapted from a document signed by L. Mariani, a member of the Italian mission, preserved in the archives of the research center of Shahr-e Soukhteh and Dahaneh-e Gholaman).*

In this research, we used different method for study: field walking, geophysical surveys (magnetic method) and aerial photo interpretation. At the beginning of our work in Dahaneh-e Gholaman, we carried out geophysical testing using a caesium gradiometer (G-858 Geometrics) in the north zone where most of the buildings are concentrated. Four places were selected for this test, between some excavated buildings, on some non-excavated buildings visible on the surface and across the Achaemenid canal in the centre of the site. The results of this survey were positive, as the maps showed anomalies of some buildings walls and of the banks of the Achaemenid canal (Figure 3).

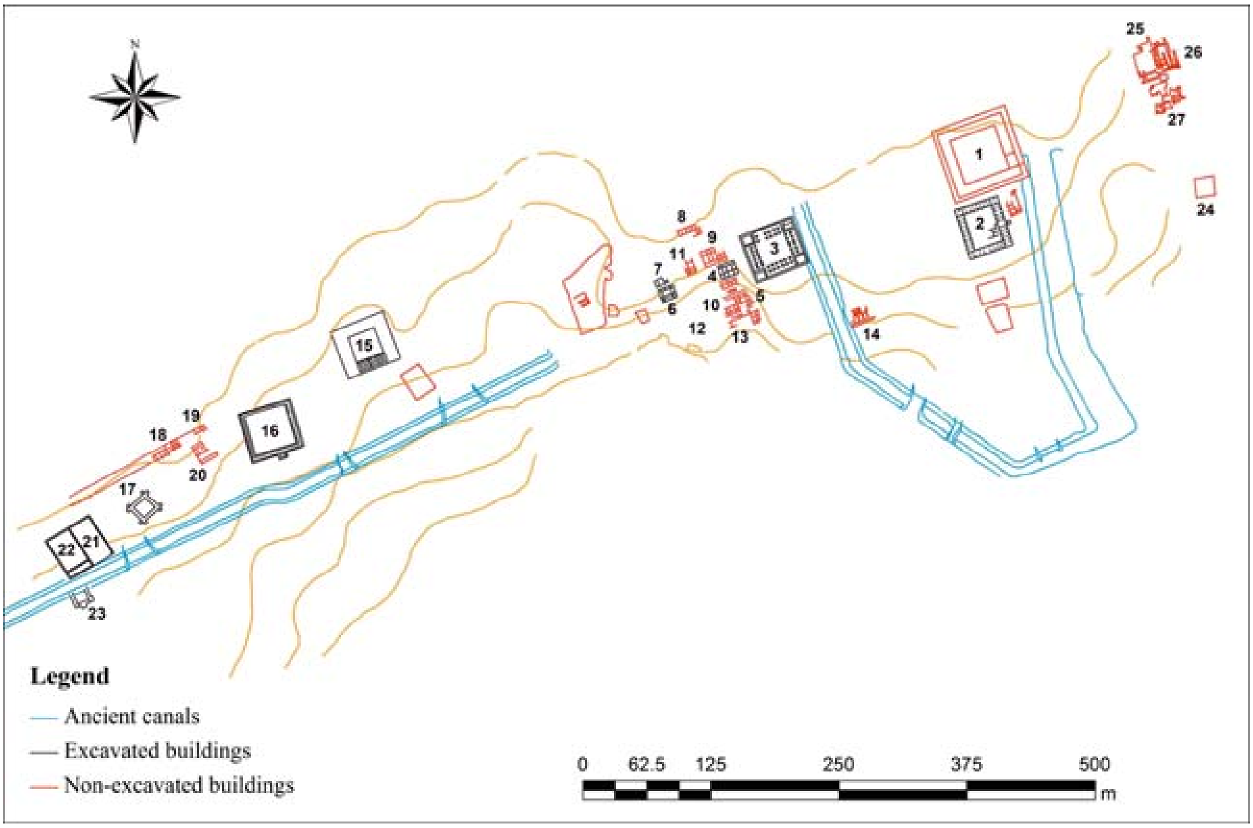

Figure 2: *Map of the remains at northern zone of Dahaneh-e Gholaman (After Scerrato, 1966b, Fig. 2).*

After this magnetic survey, field walking surveys were carried out from the south of the site (*Padegan*) north to the excavated buildings. As a result, a distribution map of pottery has been drawn. The highest densities of pottery are located in two specific places in the southern part of the site, at the exact place of the remains of large walls, and around and between the buildings to the north. These results suggest that there may not have been any buildings between these two locations. In the northern zone, this survey has also allowed us to find 13 new traces of buildings shown on the surface between the excavated ones, one of which was found 200 m further east near the bank of the artificial lake 3.

There is one main ancient canal in south of the buildings in north zone. According to the study of aerial photos (1/2000, 1965 NCC of Iran) and satellite images (Landsat and Google Earth), two new canals have been found in the north zone. One of these new canals joined the main ancient canal near the end of canal in the western part of the site, and another is in the middle of site south of the buildings. The direction of the main canal is west-east until its source of water (Sanaroud River). The Sanaroud was a relict branch of the Helmand River in the Achaemenid period. The length of main ancient canal was 11 km; today, after the construction the artificial lake 4, 10 km of this canal have been destroyed.

Besides archaeological surveys, magnetic exploration has been completed in two zones: one zone in the north and one in the south. Magnetic survey covered the space between the excavated buildings, on the un-excavated buildings that were shown on the Scerrato map, on the Achaemenid canal, on the hill in the central northern zone and south of the main Achaemenid canal. The topsoil in Dahaneh-e Gholaman is eroded by seasonal rains, which have destroyed many archaeological structures. The anomaly of this erosion is visible on the site and appears on the magnetic map. Thus, study of urbanism in Dahaneh-e Gholaman has proved difficult. Nonetheless, the anomalies representing walls of the un-excavated buildings are clearly visible. The results obtained by magnetic method in the northern zone indicate some buildings and structures. Futhermore, an anomaly representing a pottery kiln is shown on the magnetic map of the central part of north zone. This sector also has many slags on the surface.

In the southern zone, we carried out magnetic survey on the structure named *Padegan* (Figure 4). The results show one square inside the big square that was visible on the surface. In the magnetic map, we founded the anomaly of one building (50×55 m) that is similar to the Achaemenid royal residences in Fars. Regarding the isolated position of the building, 2 km away of the other buildings, and with the sole information of its plan, it is impossible to specify its function. This question is still debated for many of the well-known hypostyle halls of Fars, which are sometimes called palaces or pavilions based only on their stone structure and not according to their plan. In any case, the model transferred from Persia would be a further indication of the importance of Dahaneh-e Gholaman in which we generally see the location of the capital of the satrapy of Drangiana. The presence of such a building south of Dahaneh-e Gholaman may also show links between the heart of the empire and the periphery, whether through political influence (building construction by royal order) or cultural influence (local monarch's decision to build on the model of Pasargadae and Persepolis), or the presence of Persians in the region.

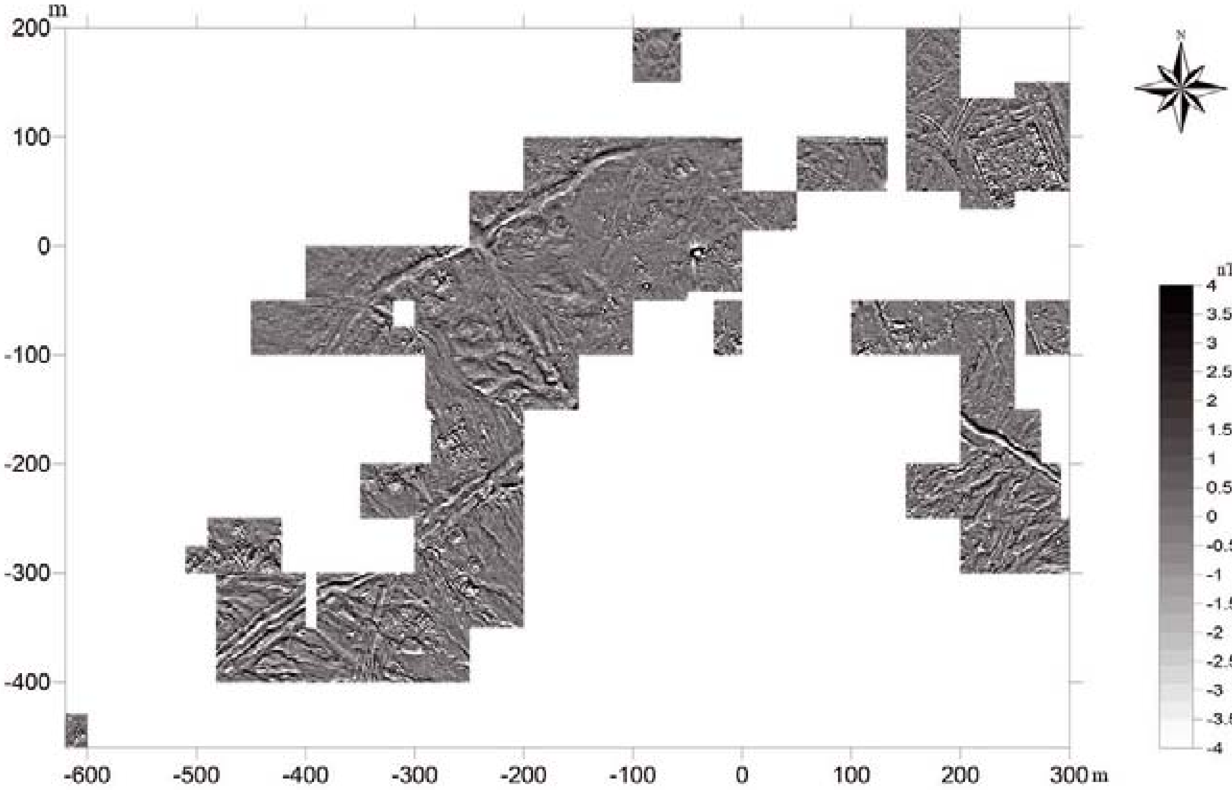

Figure 3: *Magnetic map of northern zone at Dahaneh-e Gholaman.*

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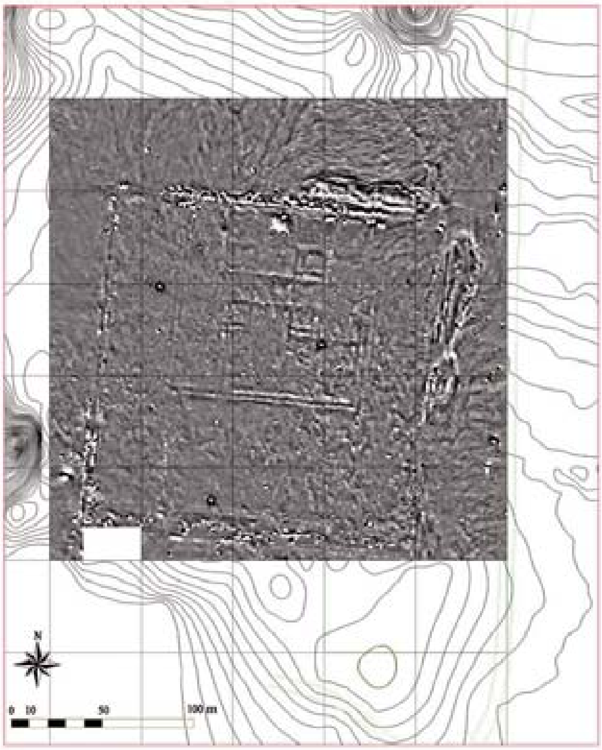

Figure 4: *Magnetic map of southern zone at Dahaneh-e Gholaman.*

THE IMPACT OF ENVIRONMENTAL DYNAMICS ON MULTIPLE SENSOR RESPONSES OVER ARCHAEOLOGICAL FEATURES, EXAMPLES FROM THE DART PROJECT

D. Boddice, R. Fry, A.R. Beck, C. Gaffney, N. Metje, A. Schmidt

1. INTRODUCTION

The DART Project (`http://www.DARTproject.info`) has been running for over two years. The fifteen month data collection program has completed, with monthly geophysical, spectroradiometry, and hourly in-situ weather, Time Domain Reflectometer (TDR) and temperature recordings captured on both clay and free draining sites at Harnhill (Cirencester, UK) and Diddington (Cambridgeshire, UK). The main goal of the DART Project is to understand further the dynamics of archaeological feature detection using these techniques, especially over soils that are traditionally considered to be difficult, such as clays. It is envisioned that the project will aid the future detection of archaeological features by providing a better insight into optimal detection times and techniques.

The DART project is examining four specific locations in great detail so that we can identify how environmental changes impact on soil conditions. Such aspects greatly affect the success of archaeological prospection (both geophysical and optical techniques). The project has collected in situ measured water content, electrical conductivity, temperature and weather readings and will compare these values with results from monthly geophysical and spectrometry surveys.

This paper will examine the effects of differing buried archaeological ditch sediments and the adjacent undisturbed soils and changes in water content (derived from apparent permittivity measurements) on the changing geophysical response, recorded throughout the survey period (June 2011–Sept 2012).

The summer of 2011 was one of the warmest British summers ever recorded, and was followed by an equally record-breaking dry winter. However this unusual dry weather was also followed by extreme precipitation from April until August 2012, making the survey year unusual in terms of seasonal variation. Hence, the project has collected a varied dataset indicative of both drought and saturation conditions on both fine grained and freely draining soils.

2. TIME-DOMAIN REFLECTOMETRY (TDR) MONITORING STATIONS

Time-domain Reflectometry is a well established electromagnetic technique used to monitor soil moisture in environmental, engineering and soil science research. The TDR unit sends a pulse of high-frequency EM energy from the TDR down a coaxial transmission line consisting of a coaxial cable and a probe (waveguide) embedded in the soil. Due to changes in impedance, at the start (t_1) and at the end of the probe (t_2), the pulse is reflected back and the reflections can be identified on the waveform trace. The time between these two reflection points is used to determine the apparent permittivity (ε_a) of the sample using Equations 1 and 2.

$$L_a = c(t_2 - t_1)/(2L_e) \quad (1)$$

$$\varepsilon_a = (L_a/L)^2 \quad (2)$$

Where L_a is the apparent length of the recorded waveform, t_1 and t_2 correspond to the start and end reflections, c is the speed of light, L_e is the electrical length of the probe determined through calibration in known materials and L is the physical length of the probe. The sensors can also be used to take measurements of conductivity by measuring the energy lost from the pulse over a longer time period and over subsequent reflections. The reflection coefficient after a long period is read from the trace and multiplied by a probe constant (which is determined experimentally during calibration) to give the conductivity.

The sensor takes bulk readings, with the results being influenced by all material in the wave's path, including soil gas, organic and non-organic solid particles, and bound and free water, which all have very different dielectric properties (Table 1). Readings are also affected by loss mechanisms due to conductivity and dipolar relaxation. Due to these effects on the readings, relative dielectric permittivity readings taken with TDR equipment are usually referred to as apparent permittivity.

As there is no significant temporal change to the volume of dry soil particles, Table 1 shows that apparent permittivity is most sensitive to changes in the free water content (which displaces soil gases from the pore spaces) due to its relative high value, and water content can be determined by fitting a curve to data derived from calibration measurements. Several relationships exist for linking the apparent permittivities to volumetric water content, such as the Topp model (1980) and Ledieu model (1986). However the relationship between water content, apparent permittivity and the bulk permittivity of the soil is conditioned by the particle sizes, bulk density, temperature, chemical composition of the soil (which affect the ratio of bound to free water), and the frequency of the signal used to measure the properties. Many of the available models do not provide globally applicable relationships, particularly in fine-grained soils. Further details on the TDR method can be found at `http://dartproject.info/WPBlog/?p=1512`.

Figure 1 shows the relationship between both apparent permittivity and conductivity data from one of the study sites (Cirencester Quarryfield) for the monitoring period so far for probes at depths of roughly 0.3 m and 0.7 m below the ground level. Several gaps are present in the data due to technical reasons, particularly near the start of the monitoring periods.

Several observations can be made from these data. Both the apparent permittivity and conductivity follow similar trends with peaks and troughs in both of them occurring at the same time. However, the soil within the archaeological feature seems to show a greater range of variation for each wetting and drying event, particular at the 0.3 m deep probes. At the deeper probes (0.7 m), the archaeological sediments display generally higher values for both permittivity and conductivity, suggesting higher water content in the ditch throughout most of the year. Minimum values of permittivity, for both the ditch sediments and adjacent undisturbed soils occur at the end of summer (August 2011 until the start of December 2011) for 0.3 m depth, showing

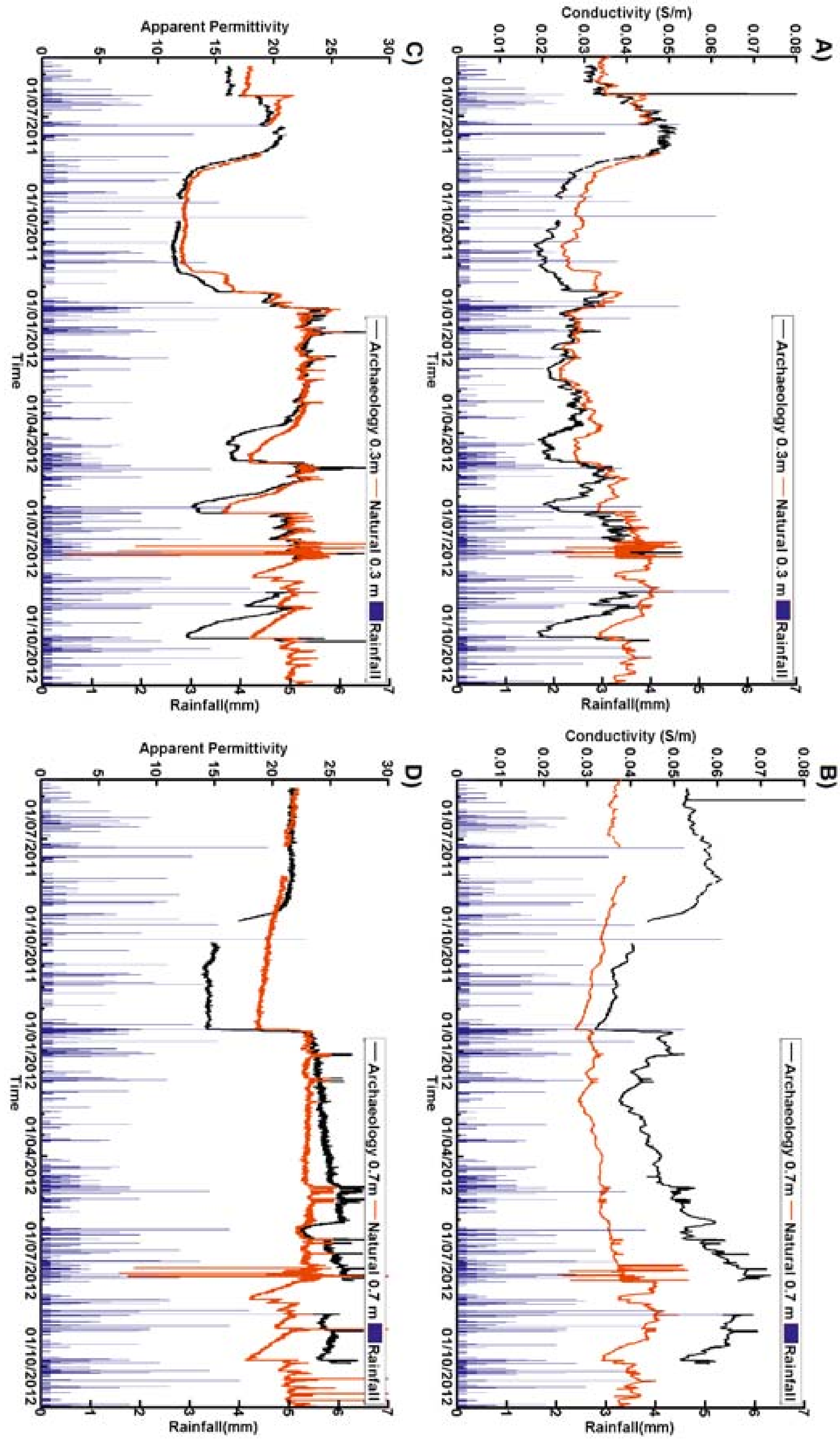

Figure 1: *TDR data from Cirencester Quarryfield A) Bulk Electrical Conductivity 0.3m B) Bulk Electrical Conductivity 0.7 m C) Apparent Permittivity 0.3 m and D) Apparent Permittivity 0.7 m.*

Material	Relative Dielectric Permittivity	Approximate Percentage for Loam Soil
Mineral Fraction	3-5	45%
Organic Matter	4	1-5%
Soil Gas	1	10-40%
Free Water	80-81	10-40%
Bound Water	3-5	Dependant on soil texture and chemistry

Table 1: The Dielectric Permittivity of the Different Constituents of Soil (EU Soils, 2012; Jones *et al.*, 2002).

a lag between the long dry summer weather and the response of the soil at depth. At 0.7 m depth, the lag is even greater with the minimum values being recorded between September 2011 and January 2012. At the deeper 0.7 m probe, both the permittivity and conductivity within the ditch continued to rise during spring and summer 2012 whereas the surrounding profile slowly fell over the same period. At the shallower depth probe (0.3 m), contrast between the feature and surrounding soil remains very small throughout the majority post-drought period, highlighting the difficulties faced with geophysical detection on clay soils.

3. GEOPHYSICAL SURVEY

A 10×10 m geophysical survey grid was established at each site, with measurements taken at a monthly interval using earth resistance (twin probe electrode array with several different electrode separations, measured with a Geoscan RM15 earth resistance meter and MPX15 multiplexer), ERT (ZZGeo FlashRes64 Electrical Imaging equipment) and EM (CMD Mini Explorer) (more details on the geophysical methodology can be found at `http://dartproject.info/WPBlog/?p=861`).

The readings from TDR measurements have a great influence on the success of geophysical detection of archaeological features. For example, Earth resistance measurements vary greatly depending on the properties of moisture content and conductivity, as well as environmental conditions such as precipitation and temperature. To illustrate the variation of response from the same feature a year apart, a scheme was developed to examine the lateral feature response between June 2011 and June 2012 over our free draining survey site (Cirencester Cherry Copse). The responses over the ditch (transects running approximately perpendicular a ditch feature) were taken to delineate lateral variation. To determine heterogeneity in feature response these transects were added together and averaged. The results, along with the associated box and whisker diagram for each averaged data point can be seen in Figure 2.

The difference in response from the two surveys is rather dramatic, the hot summer of 2011 showing a clearly marked ditch response, although a much higher (noisier) spread of data. Some of this variation can be explained by variations in the feature width and orientation. The background response decreased by around 55-60 ohms (Ω) between the two dates, suggesting that the soil composition (a mix of solid particles, moisture content and gas) altered significantly over the course of the year. The magnitude of the anomaly caused by the ditch also reduced significantly. Although still visible in the dataset, the difference between the ditch and background readings were only around 5Ω in the latter survey, compared to a contrast of around 18Ω in June 2011. Given the extreme weather between April and June, it is likely that the 2012 readings show the soil in a state of near saturation, wherein both the ditch fill and the surrounding bedrock have become so similar in their moisture content as to leave little trace of the anomaly (Carr, 1982; Cott, 1997; Hesse,

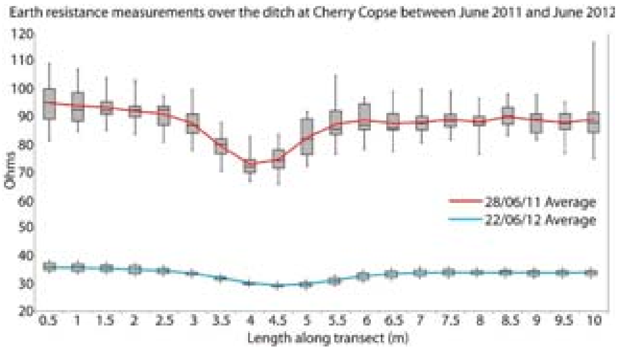

Figure 2: *Graph showing the differing earth resistance response caused by the ditch at Cherry Copse over the same area at different times of the year.*

1966; Scollar *et al.*, 1990).

A few of the earth resistance greyscale datasets collected from the fieldwork season at Quarry FIeld are shown below (Figure 3). The earth resistance data collected with a twin-probe separation of 0.5 m (shown) have an estimated depth of investigation of between 0.25–0.5 m, and prior to analysis, were minimally processed (de-spiked to remove erroneous measurements caused by poor ground contact). It is clear that the response from the ditch in Quarry Field (the dark, high resistance linear feature running NNW-SSE on the right of the geophysics area) changes throughout the fieldwork season, and is best defined in November 2011. As can be seen in Figure 1, this coincides with a period where the permittivity (and probable water content) in the ditch was at a minimum, and the most significant contrast exists between the archaeological sediments and surrounding soil, particularly at greater depths.

4. CONCLUSION

Further analysis, which will be presented at the ISAP 2013 conference, will aim to assess the impact of environmental conditions on the geophysical response. It is clear that there is a potential to predict 'best' times for geophysical survey, based on the TDR readings, and TDR Data will be taken the same dates as the geophysical surveys to further analyse this relationship. Links will be drawn between the volumetric water content derived from the apparent permittivity readings using the Topp model and results presented from ongoing research into the links between the physical nature of the soils and the seasonal geophysical response. Improved understanding of the dynamic relationship between environmental factors and archaeological feature contrast will improve sensor deployment. This is crucial in environments where the signals exhibit periodicity and are therefore marginal from a prospection point of view.

Figure 3: *Changing response from Quarryfield ditch over fieldwork season.*

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THE INTEGRATED APPROACHES ON GPR AND MAGNETIC GRADIOMETER SURVEYS FROM SOME ARCHAEOLOGICAL SITES IN ANATOLIA, TURKEY

M.G. Drahor, C. Öztürk, B. Ortan

1. INTRODUCTION

The aim of integrated geophysical surveys is to give more detailed information to archaeologists for fast and effective excavations, by providing the probable architecture of the settlement and locations of buried archaeological relics. Both magnetic and GPR methods are widely used for archaeological prospection, as they are fast and provide data which are apt to obtain an image of investigated site and to give detailed information about 3D representation of buried structures (Gaffney *et al.*, 2004).

Magnetic methods are very sensitive to the magnetic susceptibility changes within the soil. Furthermore, burnt archaeological structures that include thermoremanent magnetization, such as kiln, pottery deposits, etc. are very common on archaeological sites and are other important magnetic features. Magnetic scanning by fluxgate gradiometer is quite practicable, and gradiometers quickly collect data in archaeological prospection. Today, this technique is extensively used to obtain reliable information from an archaeological site for subsurface planning (Clark, 1996; Drahor, 2006).

Ground penetrating radar (GPR) is a very fast and cost-effective technique for investigating archaeological sites, and has been applied for 30 years in archaeological prospection to map shallow subsurface targets. It is sensitive to variations in three physical parameters (dielectric permittivity, electrical conductivity and magnetic permeability) of the subsoil (Davis and Annan, 1989). This method can thus detect all materials located in the subsurface, including those that are non-magnetic, plastic and wooden. In addition, it has a higher resolution than other geophysical techniques for the localisation of shallow structures; the depth of related targets can also be sensitively obtained. GPR provides 3D volumetric images of the subsurface to obtain information about buried archaeological structures (Drahor *et al.*, 2011).

Anatolia is among the archaeologically richest areas in the world. Many archaeological sites contain well-known and important archaeological relics, which extended from the earliest Neolithic to the Ottoman Period. In this study, integrated GPR and magnetic surveys were carried out at three different archaeological sites having a range of archaeological characteristics. This abstract presents the integrated approaches of GPR and magnetic results performed at these archaeological sites in Anatolia.

2. DATA ACQUISITION AND PROCESSING

The present work was carried out to determine the buried archaeological structures and the architectural plan of a Roman Rustic Villa, a höyük and a Hittite empire city. The aim of the surveys was to perform combined geophysical surveys — magnetic and GPR measurements – to investigate the archaeological structures at the sites. Integrated magnetic and GPR studies were fulfilled in a Roman Rustic Villa site in Göksun-Maraş and a höyük site in Batman in the south-eastern part of Turkey, and an important Hittite empire city (Şapinuva) in the central part of Turkey. Magnetic scanning surveys were carried out using Geoscan FM36 and 256 gradiometers, while the GPR investigations were performed with a GSSI SIR 3000 with 400 MHz antenna. The line and measuring intervals of magnetic data were 0.5 m and 0.25 m, respectively. Whole GPR data were collected in two perpendicular directions (N-S and E-W). Line intervals in GPR surveys were 0.5 m in every measuring direction (Figure 1). Magnetic data were processed using Geoplot software, while the GPR data were processed using GPR slice software. Magnetic results were

Figure 1: *GPR and magnetic gradiometry surveys in some archaeological sites in Anatolia, Turkey.*

displayed as gray-scale images. GPR results were also presented colour depth slices and 3D volumetric representations.

3. INTEGRATED INTERPRETATION

For the first study, magnetic and GPR results from Gre Amer höyük (Batman-Turkey) are combined. The magnetic surveys were executed in an area of approximately one hectare. GPR surveys were performed in areas where the magnetic survey indicated interesting results. Two interesting results of magnetic and GPR surveys are presented in Figure 2. Processed magnetic images for area I and II are located on the top left side of the figures. Colour depth slices show the processed GPR results. Positive (dark) and negative (white) colours of magnetic images depict the traces of archaeological relics with both magnetic and non-magnetic properties. Magnetic images are very complicated to obtain sufficient information and to make a powerful interpretation about the subsurface structures, even though the general extension (NE-SW and NW-SE) of archaeological structures is visible on the images. GPR results are more distinct than the magnetic images and they clearly show the buried archaeological structures in the subsurface. Some structures are displayed in both magnetic and GPR images. According to the GPR results, buried archaeological structures are generally concentrated in western and southern parts of area I and in the north-western and eastern parts of area II. In fact, this result is also seen in the magnetic images, but it is very difficult to make an exhaustive interpretation due to the complicated images obtained from magnetic surveys. This situation is probably caused by the soil type and properties, although the effect of burnt materials should also be considered. The integrative approach of GPR and magnetic has helped us avoid such negative interpretive complications. These examples clearly demonstrate the usefulness of a combined methods approach.

The second study integrating magnetic and GPR data was carried out on a Roman Rustic Villa in Göksun region of Maraş, Turkey. Detailed and large-scale magnetic prospection study was performed in an area of one hectare. GPR surveys were also carried out in three different sites, which were determined after the extensive magnetic gradiometer surveys. Magnetic and GPR results of area III are presented in Figure 3. According to magnetic data, some NE-SW and NW-SE extensions are clearly visible in the images, although the magnetic image is very complicated in terms of the interpretation of archaeological relics. Particularly, the important negative extensions in the magnetic image should be related with wall structures made of limestone. The first GPR depth slice (13–27 cm) is not compatible with the magnetic image except for some positive anomalies in the western part of the area. However, the second GPR slice (55–68 cm) is very compatible with the magnetic image in terms of negative magnetic data. High radar reflections correspond to negative magnetic anomalies in the area. However, radar reflections in shallow depths are not compatible with positive magnetic anomalies. In this study, only negative magnetic anomalies are clearly evident as archaeological relics in the magnetic image, while the GPR slices directly displayed the buried archaeological remnants. GPR slices are mostly interrelated with each other, and they clearly show the extensions of archaeological relics depending on the depth.

The third and last study was performed in a Hittite Empire city in Ortaköy region of Çorum, Turkey. Şapinuva was one of the most important Hittite cities during the empire period. The ruins of the city are spread out over 9 km^2 and include many building foundations. The city was an important military and religious centre due to being in a strategic and politically important geographic location in the Hittite period. The city was razed by fire during the Middle Hittite period, and many mud-brick constructions were physically alternated due to this fire. Magnetic and GPR surveys were performed in two different parts of the city. Results presented belong to magnetic and GPR studies performed in a cult area related to the Hittite empire period. Figure 4 presents the magnetic image and GPR depth slices obtained from this cult area. In the magnetic image, the archaeological remains generally extend in NE-SW and NW-SE directions. In addition, there are important magnetic anomalies in the eastern part of the investigated area. These anomalies should be related to the burnt structures due to their high magnetic character. Some other structures with high magnetic values might also be related to the burnt structures and materials. GPR slices obtained from shallow depths mostly support the magnetic image. In the first slice (21–43 cm), some radar anomalies correspond to magnetic anomalies. This is also the case for the second and third GPR depth slices. The integration between these methods is clear, given the successive interpretation of the subsurface archaeological relics at the Şapinuva archaeological site. Therefore, we can determine the buried subsurface walls with GPR, while the burned materials, walls and other remnants are identified using the magnetic method. The result of these integrated methods is significant improvements in the archaeological interpretation, as is seen from this example.

4. RESULTS AND DISCUSSIONS

The integrated results of magnetic and GPR investigations performed on three different archaeological sites can be summarized as follows. The studies prove that the integrated usage of magnetic and GPR techniques can provide greater information about the characterisation of archaeological relics. Therefore, we can obtain sufficient information to make powerful interpretations about subsurface archaeological remains. The goal of the combined magnetic and GPR surveys was to determine the various archaeological findings buried at different depths and to image the plans of archaeological vestiges. These investigations show that GPR produces results that are mostly compatible with the magnetic images. Particularly, GPR results are especially important when attempting to improve interpretations of complicated magnetic images. In addition, the depth-slice images of GPR provide enhanced 3D interpretation, as the volumetric representations add support to the exhaustive interpretation. Consequently, the result of the integrated approach, combining GPR and magnetic gradiometry, gives us more useful interpretations about subsurface archaeological remains.

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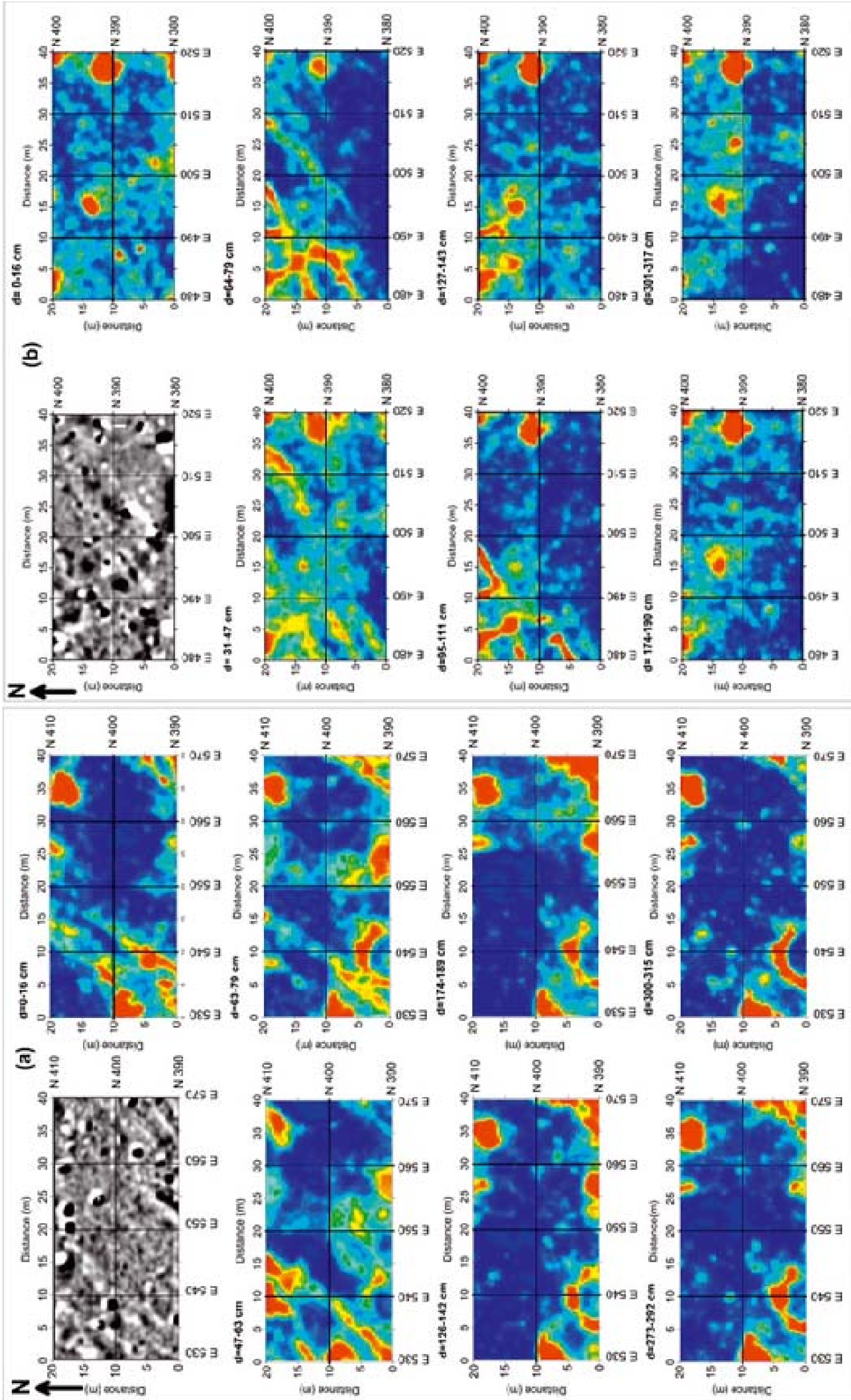

Figure 2: *Magnetic gradiometry images and GPR depth slices of Gre Amer höyük, Batman, Turkey. (a) Area I and (b) Area II.*

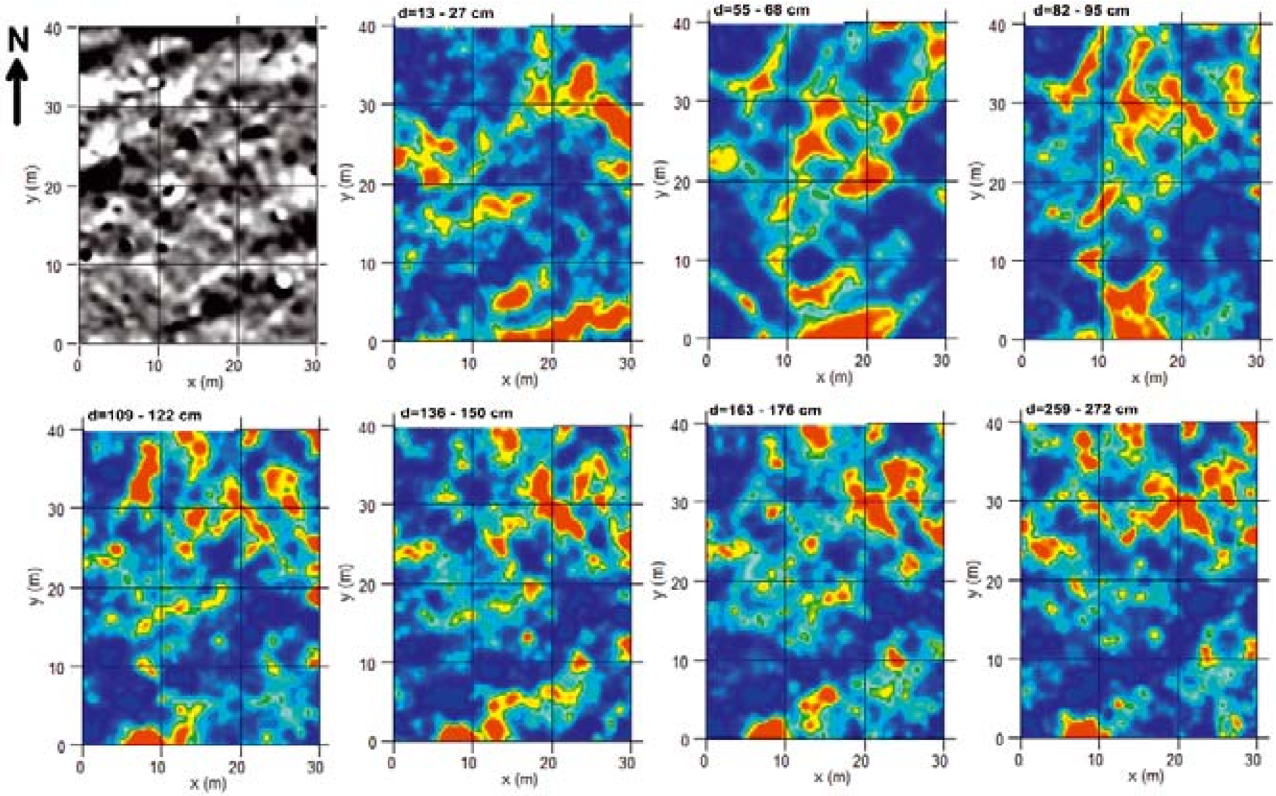

Figure 3: *Magnetic gradiometry image and GPR depth slices of a Roman Rustic Villa, Göksun, Maraş, Turkey.*

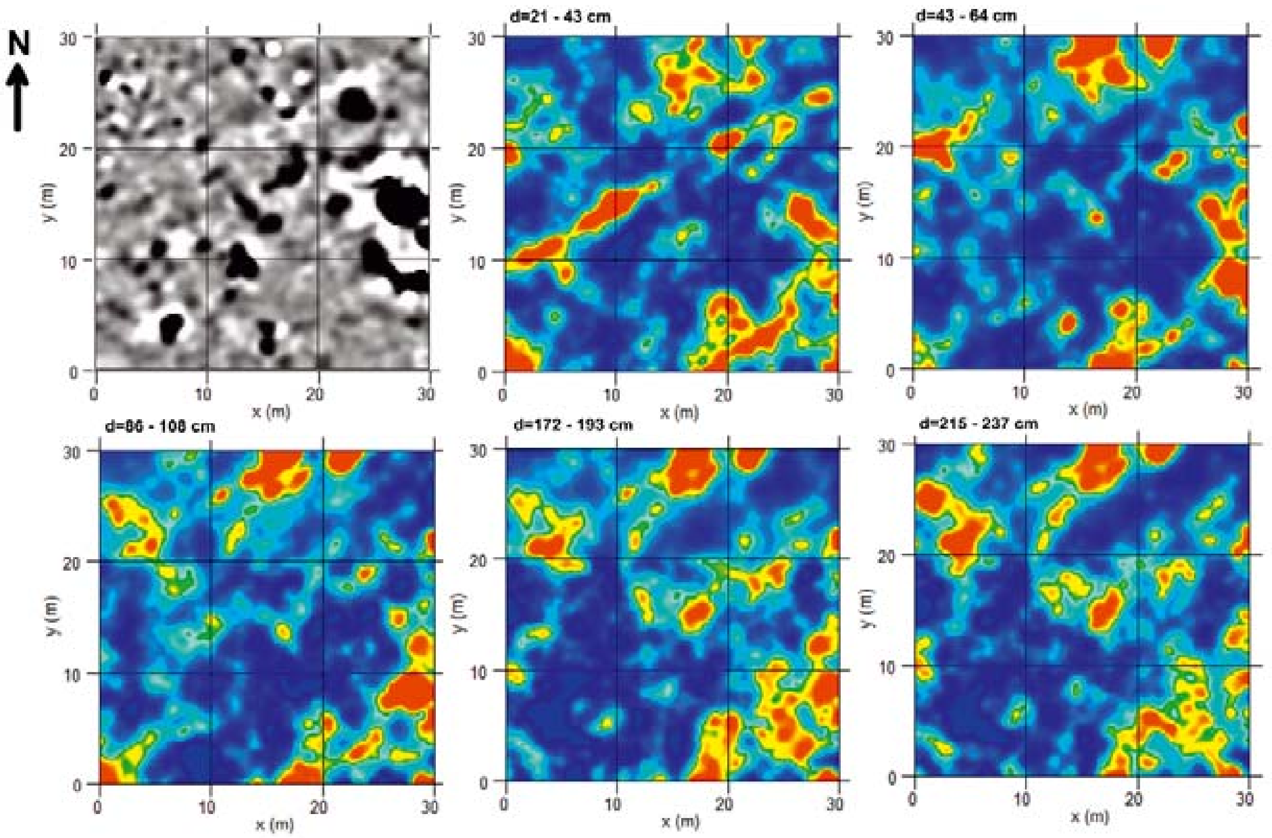

Figure 4: *Magnetic gradiometry image and GPR depth slices of Şapinuva Hittite Empire City, Ortaköy, Çorum, Turkey.*

THE DISCOVERY OF A GLADIATORIAL SCHOOL AT CARNUNTUM

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E. Nau, M. Pregesbauer, M. Kucera, G. Verhoeven

The Roman town of Carnuntum is located on the southern bank of the Danube River 40 km southeast of Vienna, at the former border of the Roman Empire. The landscape is characterised by the river cutting through the foothills of the Carpathian mountain ridge to the east and is situated on gravel terraces forming a flat to slightly hilly terrain. As the Roman capital of the province Pannonia, Carnuntum was an important town during the first four centuries AD. Roman Carnuntum consisted of a large legionary camp with associated auxiliary camps and an extended surrounding civilian settlement, the so-called canabae legionis, in the eastern part. The western part was dominated by the civil town, the autonomous municipium Aelium Karnuntum raised to this status by Caesar Hadrian in 124 AD.

Today, the archaeological remains are spread over an area of approximately 10 km^2 within the modern communities of Bad Deutsch Altenburg and Petronell. For more than 15 years, this archaeological landscape has been the focus of a large-scale archaeological prospection project (Neubauer *et al.*, 2012) applying and developing the latest non-invasive remote sensing and geophysical near-surface prospection methods and technologies. This project was initiated by the team ZAMG Archeo Prospections® and the University of Vienna (Doneus *et al.*, 2001; Doneus and Neubauer, 2005; Eder-Hinterleitner *et al.*, 2003) and continued in 2010 by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro). Only a few monuments from the Roman period survive as above-ground monuments, such as the Heathen's Gate, an originally 15 m high quadrifons. Some remains are still visible in the topography, such as the western of the two known amphitheatres at Carnuntum.

The western amphitheatre south of the civil town was erected outside of the Roman Civil Town in the first half of the second century AD and was modified many times during later phases, as excavations in 1923–1930 showed. The Roman amphitheatre, hosting up to 13,000 spectators, was credited by contemporary inscriptions to have been the fourth largest amphitheatre in the Roman Empire. It was intensively used for gladiatorial games, as documented and illustrated by many finds. Despite the earlier excavations, the surroundings of the amphitheatre were mostly terra incognita. First indications on significant structures around the amphitheatre came from aerial photographs showing a main Roman road leading towards it from the town, with shops and tabernas towards its eastern side. In the west, however, no structures at all were visible.

Figure 1: *The 16-channel 400 MHz MALÅ Imaging Radar Array surveying the field containing the school of gladiators. In the background some of the remains of Carnuntum's western amphitheatre can be seen.*

Figure 2: *GPR depth-slice of the high-definition GPR data acquired with the MIRA system from ca. 60 cm depth. Note the point-anomaly belonging to the pole that pressumably had been been placed in the centre of the training arena.*

In September 2011, the LBI ArchPro and its international partner consortium announced the discovery of a gladiatorial school (Latin *ludus*) west of the amphitheatre. This unique discovery, rated amongst the top-ten archaeological discoveries of 2011 [1] , was made possible by systematically applying a multidisciplinary prospection approach based on remote sensing and high-resolution near-surface geophysical prospection during the last decade (Neubauer, 2011; Neubauer *et al.*, 2012).

Repeated aerial reconnaissance flights over Carnuntum in the 1990s vaguely indicated buildings west of the amphithe-

[1] http://archive.archaeology.org/1201/features/topten_austria.html (accessed 28.3.2013)

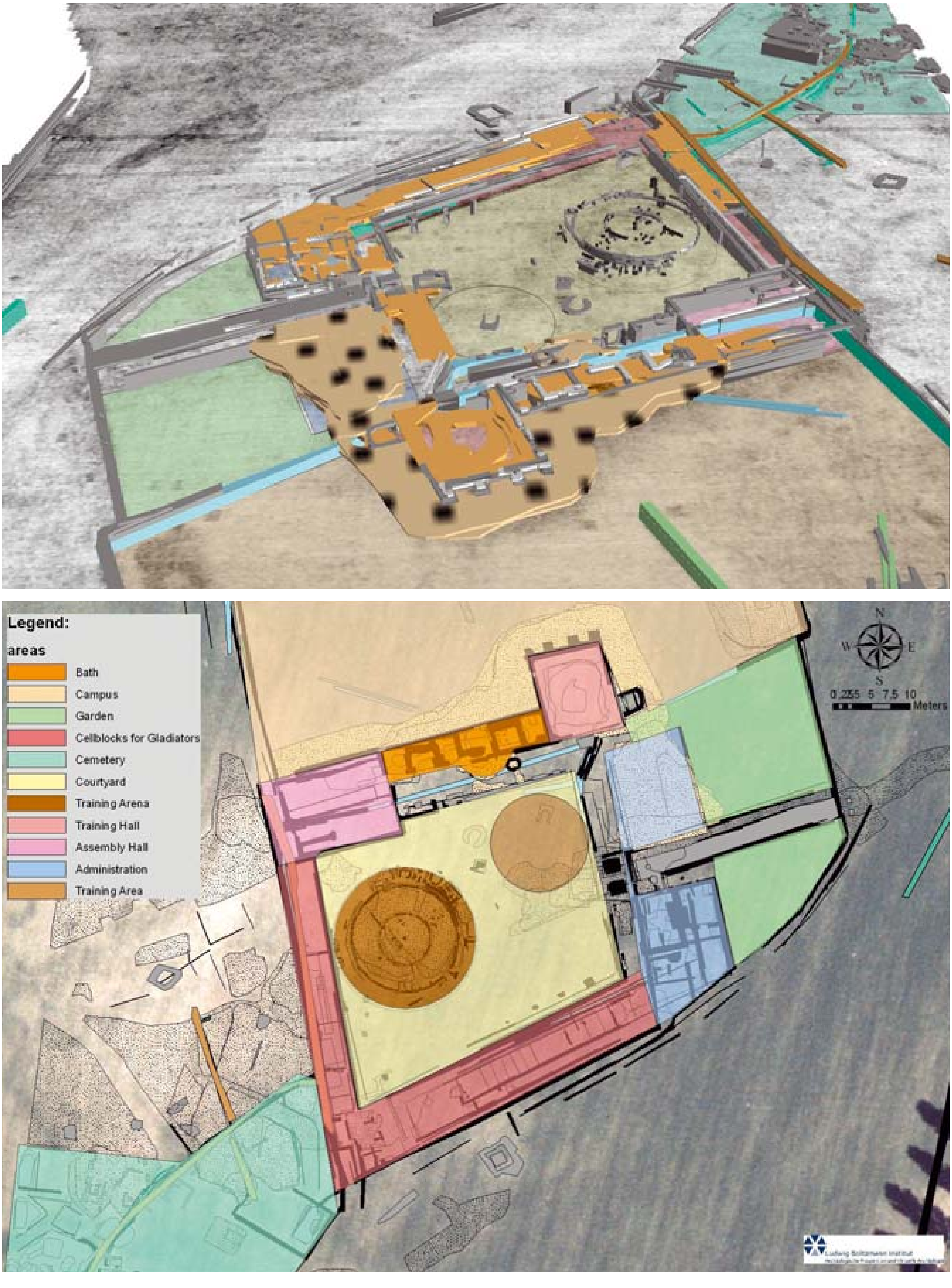

Figure 3: *3D interpretation of the magnetic and GPR prospection data (top) and plan view presentation (bottom).*

atre, based on a large anomaly consistently showing up as soil and crop marks. In 2000, a magnetic survey using a manually operated five sensor PICODAS MEP750 Caesium magnetometer was carried out in the respective field to verify these findings. The magnetometer data, sampled with a spatial resolution of 12.5×50 cm, revealed traces of the foundation walls of a large trapezoidal building complex, as well as associated infrastructure, such as a main canal belonging to the water supply system of the Roman town. A subsequent ground penetrating radar (GPR) survey conducted in 2000 using a Sensors & Software PulseEkko^{Pro} 900 MHz antenna manually towed in a sledge with 5 cm inline GPR trace spacing and 50 cm cross line spacing resulted in GPR depth-slices showing more details of the large building complex. Animations of the depth-slices revealed circular structures in the building's courtyard and indicated an uncommon function of the large complex.

Recent technological and methodological developments leading to increased efficiency of near-surface magnetometry, GPR, electromagnetic induction surveying, airborne imaging spectroscopy and laser scanning formed the background for an additional integrated investigation of the area by an international team of archaeologists, geophysicists, soil scientists and IT experts from the LBI ArchPro and its international partners. In spring 2011, the team started with a high-definition GPR survey of the school of gladiators using a MALÅ Imaging Radar Array (MIRA) system in motorized configuration (Figure 1). The array consists of 16×400 MHz antennae with 8 cm channel spacing and possibilities for 4 or 8 cm inline GPR trace spacing using a trace stacking factor of 4 and operation speeds of 12-15 km/h (Trinks *et al*., 2010). Using a real-time kinematic GPS with centimetre accuracy at data rates of 5 Hz or more and smart navigation solutions, the acquisition of 3D archaeological prospection data volumes has become possible, imaging buried Roman structures in unprecedented resolution. The measured GPR data were processed into depth-slice images (Figure 2) using special software developed in close collaboration with ZAMG Archeo Prospections®. Subsequently, the new GPR results have been complemented with magnetometer data acquired using a novel motorized 10-sensor Foerster fluxgate gradiometer array, extending the initial Caesium magnetometer survey area. In collaboration with the research group ORBit at Ghent University, high-resolution electromagnetic induction (EMI) data were acquired in autumn 2011 using a novel motorized four-coil DualEM-21S sensor. The EMI data provided complementary information about the magnetic susceptibility and electrical conductivity of soil volumes with different depth extent.

All geophysical measurement devices were equipped with the latest differential GPS technology permitting exact geopositioning of the measurements. Since GPS readings were stored five times per second with an accuracy of approximately 2 cm, data collection could be performed at speeds between 8 and 30 km/h. The integration of the individual survey methods in combination with a detailed digital terrain model obtained through airborne laser scanning puts the discovered Roman remains in context with their topographic position and the associated infrastructure and environmental settings. Combining all data permitted an integrated GIS-based site analysis of the revealed archaeological stratification in relation to the underlying geology, the hydrological settings and the geomorphological situation considering the palaeorelief and the pedological context.

The detailed geophysical and archaeological interpretation of the data (Figure 3) resulted in a 3D interpretation model of the detected remains of the ludus. The outstandingly well-preserved architecture was revealed through virtual excavation within an integrated 3D data volume produced by high-resolution, non-destructive prospection methods. The foundations of the building complex including a circular training arena surrounded by basements of former wooden stands, cell blocks, training and assembly halls, infrastructure, practice fields, a bath complex and an administrative wing were mapped in three dimensions in unprecedented detail and virtually reconstructed (Figure 4). The completeness of preservation of this gladiatorial school at Carnuntum is considered to be unique in the former Roman Empire.

The main building complex of the ludus at Carnuntum covers 2,800 m^2 located within a walled parcel of about 11,000 m^2 just outside of the Roman town. The main buildings at the south-eastern end of the parcel are arranged around a central inner courtyard. A single, easily controlled entrance to the complex can be seen on its eastern side, facing the amphitheatre. Inside the school's courtyard, the separate circular training arena in which the gladiators practiced, 19 m in diameter, was surrounded by wooden spectator stands founded on stone basements. In the centre of this arena clear evidence for the foundation of the palus, a wooden pole used to exercise blows with the sword and body slams with the shield (Futrell, 2006), was recorded.The importance of this pole can also be deduced from the names given to the best gladiators: primus palus, secundus palus etc. (Futrell, 2006; Mejer, 2007). A building complex including a 100 m^2 heated training hall, an extensive bathing complex and an assembly hall has been identified around the closed courtyard. The gladiators were accommodated in small cells of approx. 5 m^2, arranged within an elongated cell block. The administrative wing and living quarters of the school's owner, the lanista (Bomgardner, 2000; Meijer, 2007) can clearly be discerned in the prospection data to the right and left of the main entrance of the ludus. The barracks of the school and the lanista's buildings were at least two stories high, as indicated by typical stairway corridors. The lanista was head of his familia gladiatoria with all legal power over the life and death of the gladiators.

To the northwest, and within the walled compound, an extended open campus adjoins the school, which most likely held further practice areas for chariot races, stables and enclosures for wild animals. The animals – remains of bears and lions were found inside the amphitheatre – were put into the arena together with specialized venationes, the beast hunting and bestiarii, the beast fighting gladiators. In the immediate vicinity of the ludus, distinctly separated from other burial fields of Carnuntum, the separate cemetery of the gladiators was discovered. We are convinced that we found the cemetery of the gladiators' right behind the building, with large burial monuments, stone sarcophaguses and other more simple graves.

Aside from foundation walls of the main building complex and the enclosed campus, the geophysical prospection data revealed a major part of the public water and drainage network, hypocaust floor-heating systems, portals, the foundations of memorials, paths and gateways. Given its state of preservation, dimensions and type of architecture, the discovered ludus is considered to be internationally unique. Although it is estimated that over one hundred ludi must have been built throughout Roman history (Meijer, 2007), most of them have been destroyed or covered over. The only known existing building directly comparable to the find made in Carnuntum is the partly excavated Ludus Magnus behind the Coliseum (Amphitheatrum Flavium) in Rome (Colini, 1962). Unlike the new discovery, the Ludus Magnus is only partly accessible today and fewer details have been preserved.

This unique archaeological find exemplifies the tremendous amount of highly-detailed information that can be gathered by

Figure 4: *Virtual reconstruction of the school of gladiators. ©M. Klein | 7reasons*

following the latest multidisciplinary, entirely non-invasive and hence archaeologically sustainable, non-destructive, prospection approach promoted by the LBI ArchPro. During the 19th century, Carnuntum was called the "Pompeii at the doors of Vienna" due to the good preservation of the Roman ruins. Since then, the situation has changed drastically. Both aerial photography and geophysical data show that the archaeological heritage has suffered severe damage.

The presented case study exemplifies a long-term interdisciplinary archaeological prospection approach to the survey of Roman archaeological landscapes, initially presented at the Archaeological Prospection Conference 2001 (Doneus *et al.*, 2001; Doneus and Neubauer, 2005). Invoked by the discovery of the ludus, the archaeological landscape Carnuntum will now be mapped in a large-scale prospection project over the next three years, directed by the LBI ArchPro. Through the combination of aerial archaeology and modern remote sensing with high-resolution geophysical subsurface mapping and a GIS-based archaeological interpretation and spatial analysis, the project will develop a foundation for sustainable cultural heritage management.

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RADIOMETRIC CALIBRATION OF ALS DATA FOR ARCHAEOLOGICAL INTERPRETATION

C. Briese, M. Doneus, G. Verhoeven

1. INTRODUCTION

Airborne laser scanning (ALS, resp. airborne LiDAR) is a widely used data acquisition method for topographic modelling. Due to its ability to accurately and densely sample the terrain surface, it became a commonly used technique for the generation of digital terrain models (DTM). In archaeology, this potential has revolutionised prospection of forested areas (Doneus and Briese, 2006). For the analysis and classification of the topography, geometric criteria derived from the acquired 3D point cloud are typically used. Next to the widely used geometric information, ALS systems typically provide additional information about the recorded signal strength of each echo.

In order to utilize this additional radiometric information for the study of the point-wise backscatter characteristic of the sensed surface, radiometric calibration is essential (Briese *et al.*, 2008; Wagner, 2010). As a result of this radiometric calibration (Briese *et al.*, 2008; Lehner and Briese, 2010) physical quantities (the backscatter cross section σ [m^2], the backscattering coefficient in γ [m^2 m^{-2}] and the diffuse reflectance measure ρ_d [m^2 m^{-2}]) that describe the backscatter characteristic of the sensed object at the specific laser wavelength are available.

This publication focuses on the radiometric calibration of ALS data for archaeological interpretation. After the presentation of the radiometric calibration workflow, a full-waveform ALS data set from the case study area Carnuntum (Austria) is investigated. Based on the ALS trajectory and the observables estimated from the decomposition of the full-waveform data set (namely the range, amplitude and echo width per detected ALS echo) the complete ALS data set is calibrated radiometrically. Subsequently the results for the case study area are presented and discussed. This section includes the archaeological interpretation of the resulting radiometric image that can be estimated from the calibrated diffuse reflectance measure ρ_d of the ALS point cloud. The final section provides a conclusion and outlook into future work.

2. RADIOMETRIC CALIBRATION OF ALS DATA

The physical basis for the proposed radiometric monochromatic calibration of ALS data is the radar equation (Jelalian, 1992). The practical workflow for absolute radiometric correction based on full-waveform ALS data and in-situ reference targets consists of the following steps (c.f. Figure 1 and Briese *et al.*, 2012):

1. Selection of the in-situ reference targets based on the ALS flight plan
2. Determination of the incidence angle dependent reflectance ρ_d of the reference surfaces utilising a spectrometer or reflectometer (cf. Briese *et al.*, 2008) that operates at the same ALS wavelength
3. Recording of meteorological data (aerosol type, visibility, water vapour, etc. for the estimation of an atmospheric model) during the flight mission in order to estimate the atmospheric transmission factor
4. Full-waveform decomposition (echo extraction and estimation of echo parameters)
5. Direct georeferencing of the ALS echoes and maybe strip adjustment in order to get an advanced relative and absolute georeferencing of the ALS data
6. Estimation of the local surface normal in order to consider the local incidence angle
7. Estimation of C_{cal} based on the ALS echoes within the in-situ reference targets (e.g. defined by a polygon area)
8. Radiometric calibration of all echoes based on the determined value of C_{cal}

At the end of this workflow, which can be realised with the program package OPALS (OPALS, 2012), each ALS echo has assigned the additional calibrated diffuse reflectance measure that can be used in the further radiometric analysis of the ALS data.

3. STUDY AREA

In order to study the process of radiometric calibration of ALS data for archaeological interpretation of the scene the case study area Carnuntum (Austria) was selected. The ALS data were collected on the 5^{th} of June 2010 (ALS sensor: RIEGL LMS Q-680i). This ALS sensor utilises a laser source for the active illumination and signal detection at a wavelength of 1550 nm. Simultaneous to the aerial data acquisition campaign, in-situ radiometric ground control measurements with a reflectometer (can be seen as a single band spectrometer; the instrument was provided by the company RIEGL) were acquired. The resulting point density (last echo) of the ALS data was higher than 4 points per m^2. The radiometric processing of the full-waveform data set was performed with the software OPALS.

4. RESULTS AND DISCUSSION

Figure 2 illustrates the result of the generation of a radiometric image (diffuse reflectance measure ρ_d) of the complete case study area, while Figure 3 provides a detailed view of the calibrated radiometric information over an archaeologically interesting area near Roman Carnuntum's military amphitheatre.

In the lower right part of Figure 3, a first result of an archaeological interpretation of the radiometric information provided by ALS data is presented. It clearly shows that the delineation of different archaeological features is possible with the help of the estimated radiometric information.

5. CONCLUSION

This contribution provides first archaeological results for the usage of calibrated radiometric information derived from full-

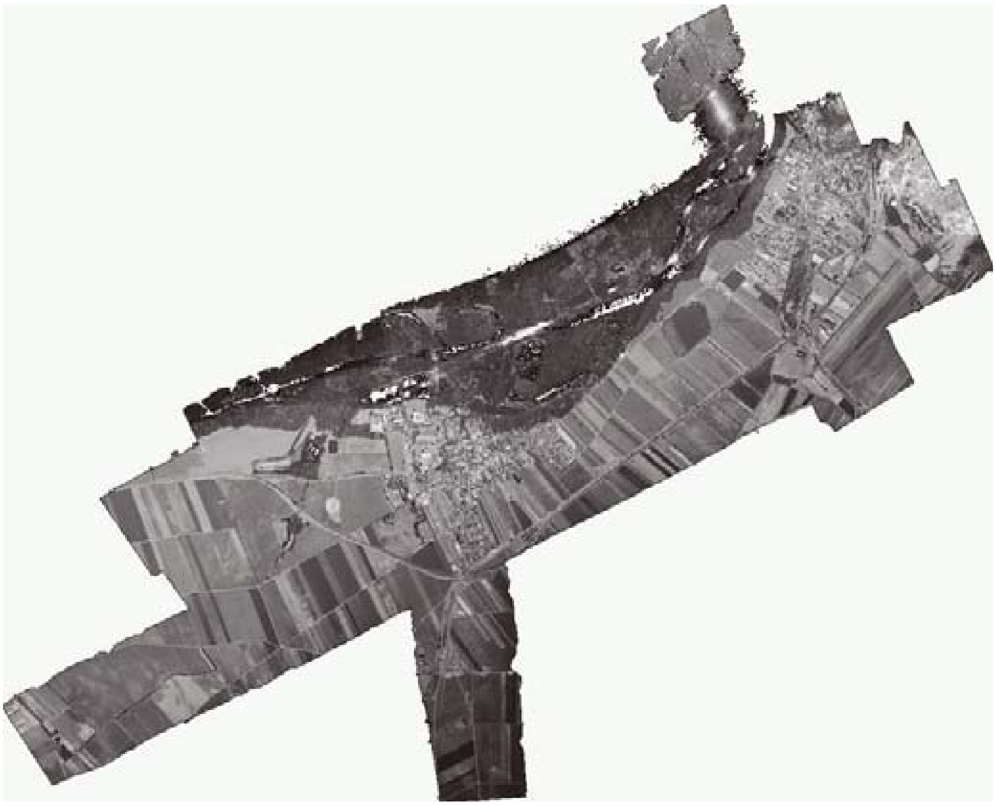

Figure 1: *Calibrated radiometric information (diffuse reflectance measure ρ_d) from ALS data for the case study area Carnuntum (approx. 8.2 km × 6.5 km).*

waveform ALS data. In contrast to passive imagery, the calibrated information from ALS (which utilises a laser source for the active illumination of the sensed surface) is not altered by shadows caused by sun light. Furthermore the resulting images are true-orthophotos due to the fact that the radiometric information is derived for each 3D point and therefore can be located on its correct position.

However, although the first results for ALS radiometry look promising, further research in the application for archaeological interpretation is necessary. Besides a detailed study of the measurement noise and radiometric accuracy, the analysis of further case study areas and the study of multi-temporal behaviour of the ALS radiometry are planned. Additionally, the monochromatic ALS imagery will be compared to simultaneously acquired passive imagery.

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Figure 2: *Detailed map of the calibrated radiometric information from ALS data (0.25 m raster size) with archaeological features; the lower right image of the same area displays an archaeological interpretation of the radiometric ALS data.*

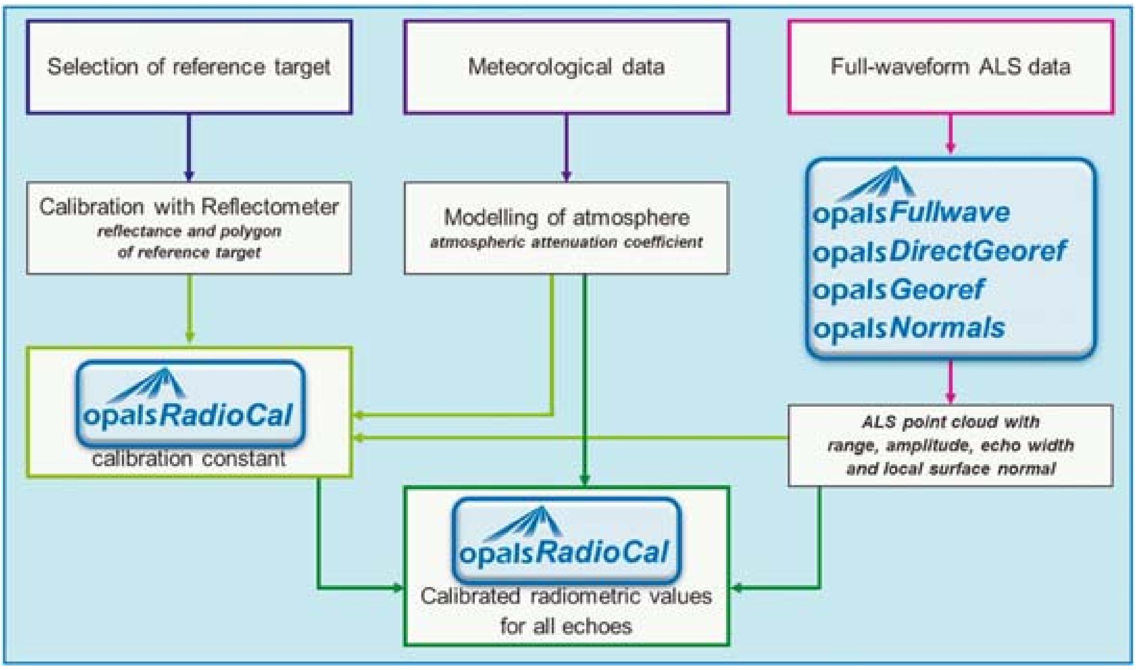

Figure 3: *Radiometric calibration workflow (Lehner and Briese, 2010).*

INTEGRATING MULTI-RECEIVER EMI MEASUREMENTS TO CHARACTERIZE THE SOIL-LANDSCAPE AROUND THE SCHOOL OF GLADIATORS, CARNUNTUM

T. Saey, M. Van Meirvenne, I. Trinks, P. De Smedt, G. Verhoeven, W. Neubauer

ABSTRACT

Recently, the foundations of a school of gladiators were discovered by employing a combination of non-invasive prospection techniques in the Roman town of Carnuntum, 40 km south-east of Vienna (Austria). Although the well-preserved remains of the school were revealed using high-resolution geophysics, some questions about the surrounding soil landscape remained unanswered. Therefore, a proximal soil sensing procedure based on a single electromagnetic induction (EMI) survey with a multi-receiver EMI instrument was applied to map the school of gladiators and its surroundings covering a 5.6 ha area. We investigated both the complementarity of the apparent electrical conductivity (ECa) and apparent magnetic susceptibility (MSa) measurements for mapping the school and its soil landscape. As a result, an integrated visualisation of the school in its soil landscape was obtained. This study proved the huge potential of EMI soil sensing to interpret the soil landscape and to discern small-scale natural and archaeological features without any invasive practice.

1. INTRODUCTION

Over the past years, the use of geophysical methods in geoarchaeological studies have increased substantially (Brown, 2008; Van Dam, 2012). In such studies, magnetometry and ground penetrating radar (GPR) were used most frequently (Gaffney and Gater, 2003). Much less common is the use of low frequency electromagnetic induction (EMI) methods. However, the latter is commonly deployed in proximal soil sensing and precision agriculture because measurements of the apparent electrical conductivity (ECa) allow the detailed characterization of the variability of soil properties such as texture, organic matter and moisture (Domsch and Giebel, 2004; Heil and Schmidhalter, 2012; McBratney *et al.*, 2005; Saey *et al.*, 2009b). Besides ECa, EMI methods measure simultaneously the apparent magnetic susceptibility (MSa) (Simpson *et al.*, 2010). The MSa provides additional information compared to measurements with a magnetometer.

To enlarge their applicability, some EMI instruments have multiple receiver coils creating a potential for depth investigations of the electrically conductive and magnetic features (Saey *et al.*, 2012). When such information is available over a larger area, the detailed reconstruction of the soil-landscape becomes possible, e.g. Saey *et al.* (2011) and De Smedt *et al.* (2012). Such information is highly complementary to the understanding of buried archaeological structures revealed with other methods (e.g. De Clercq *et al.*, 2012).

Recently, the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) announced the discovery of the buried remains of a gladiator school (a "ludus gladiatorius") next to the excavated amphitheatre of the Roman city of Carnuntum, Austria. This was achieved by combining high-resolution magnetometry and multi-antennae GPR measurements (Neubauer *et al.*, 2011). However, these methods did not provide information about the composition of the soil and its variability. The aim of this research is to evaluate the usefulness of an EMI survey with a multi-receiver instrument, registering simultaneously ECa and MSa, to characterize the soil variability around the gladiator school. We will especially focus on the ability to interpret the soil-landscape of this highly valuable archaeological site.

2. ROMAN CITY OF CARNUNTUM AND STUDY AREA

The city of Carnuntum was located some 40 km south-east of Vienna on the south bank of the Danube (Figure 1). As the capital of the Roman province Pannonia, it was home to an estimated 50,000 inhabitants between the 2nd and 4th centuries AD. Outside its gates, this city possessed one of the largest amphitheatres of the Roman Empire. After the invasion by the German tribes, the city was completely destroyed and today only the remains of one gate survive above ground (Neubauer *et al.*, 2002). In the beginning of the 20th century, the amphitheatre was discovered, and its foundations were excavated between 1923 and 1930. Recently Archeo Prospections® and the LBI ArchPro discovered and mapped the buried remains of the school of gladiators in an adjacent field using several non-invasive techniques (Figure 1) (Trinks *et al.*, 2010). Because the buried remains of the entire Roman town and surroundings are currently protected, no destructive prospection techniques are still allowed. Our study site represents a 5.6 ha arable field, containing the gladiator school and bordering the excavated amphitheatre (Figure 1).

Our study site is located on slightly undulating, fluviatile and gravel-rich terraces of the nearby river Danube. Near the end of the Weichselian glacial period, this area was covered by aeolian loess deposits from a variable but generally limited thickness. The study area has a slightly undulating topography with a range in elevation of 12.9 m. In general it slopes to the northwest.

3. SOIL SENSOR SURVEY

The study area was investigated with an EMI sensor with one transmitter coil and four receiver coils, the DUALEM-21S instrument (DUALEM, Milton, Canada) (Saey *et al.*, 2009a). Both transmitter-receiver spacing and orientation determine the depth and weighting response pattern of the signal. This multi-receiver EMI instrument allows measuring both the ECa and MSa of four different soil volumes.

In our mobile configuration, thee sensor was put in a non-metal sled and pulled behind an all-terrain vehicle at a speed of about 6-10 km h^{-1}, crossing the field at parallel lines 0.85 m apart. The eight simultaneous ECa measurements were recorded by a field computer at a frequency of about 8 Hz and connected to a DGPS. Within lines, measurement intervals were at about 0.1 m.

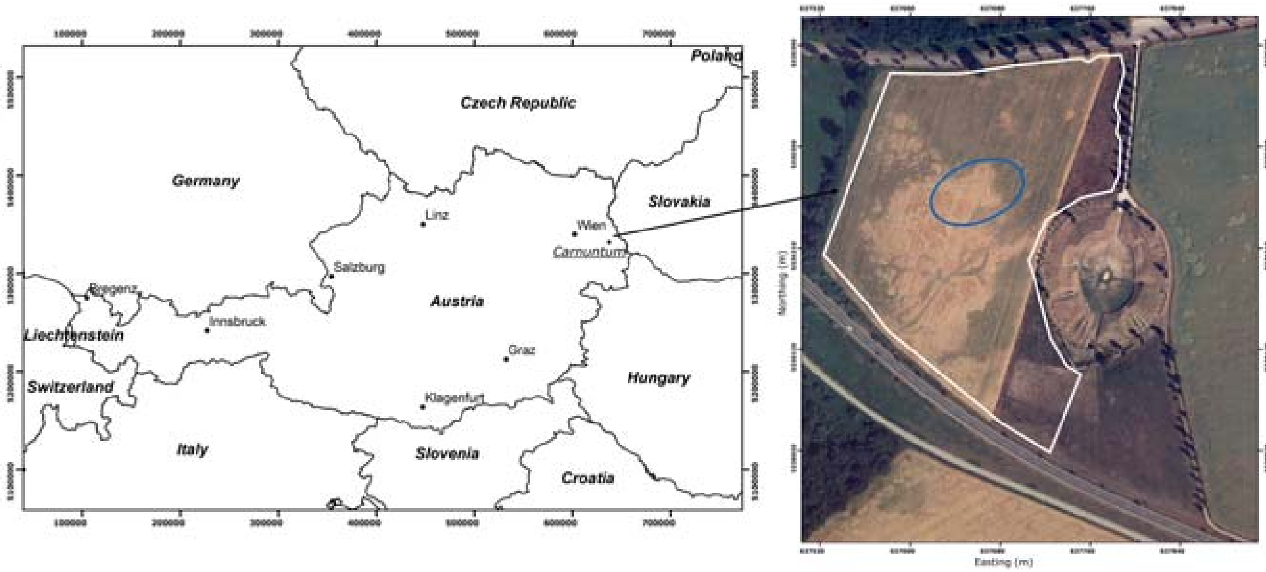

Figure 1: *Localisation of the study site in Austria and aerial photograph with indication of the study site (red) and the position of the school of gladiators (oval).*

4. ECA AND MSA SURVEY

The mean ECa increases from the shallowest to the deepest measuring coil configurations, indicating that the subsoil is on average much more conductive than the topsoil. In this case the increase is rather strong and it most likely indicates also an average increase in clay content with increasing depth.

The MSa measurements depict a general magnetic variation across the study area with strong contrasts between the northeastern part and the southern and eastern parts. These maps reveal the archaeological structures related to the school of gladiators. A curved structure, crossing the area from the southwest to the northeast, is visible on all four MSa maps. This structure is known to the archaeologists of the LBI ArchPro as one of the major water delivery canals (aqueduct) to the city of Carnuntum.

5. DEPTH SLICING

The modelled conductivity (EC) or modelled magnetic susceptibility (MS) of a particular depth interval or slice can be deduced from integrating the measured ECa or MSa values. The major advantage of isolating the contribution to EC or MS of a particular depth slice is that its interpretation can be linked to a particular depth.

On the study site, the EC-depth slicing resulted in an enhanced visibility of patterns. In the north-western part of the study site, a fine-scale polygonal network appears. Based on previous experience with EMI sensors we interpreted this network as frost-wedge pseudomorphs (Cockx *et al.*, 2006; Meerschman *et al.*, 2011). In the central and northeastern parts of the study area, traces of surface drainage patterns are clearly visible. Most of these gullies flow into the lower part of the area where the frost-wedge pseudomorphs are present. Complementary to the EC-depth slices, MS-depth slicing enhances the visibility of the archaeological traces related to the school of gladiators and its associated structures. The school itself, an outside training area for horses and grave monuments are easily noticeable after depth slicing. When EC and MS data are combined, it becomes clear that the school was constructed on an area with low EC values and outside the area affected by erosion. The builders of the school obviously selected a location near to the amphitheatre, which was situated at a higher position in the landscape with stable (gravel rich) subsoil, avoiding sloping and wet clay rich parts of the area.

6. CONCLUSIONS

The potential of multi-receiver EMI for soil-landscape research around archaeological sites is in the ability to integrate the multiple complementary signals of both the electrical conductivity and magnetic susceptibility. Combining the multiple ECa measurements allowed us to interpret the soil landscape. Moreover, the complementary MSa measurements enabled locating the buried archaeological remains.

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INTERPRETING GPR DATA IN GIS: ANIMATION TOOLS AND 3D VISUALIZATION APPLIED TO THE ARCHAEOLOGICAL INTERPRETATION OF ROMAN STRUCTURES

V. Poscetti

This paper is focused on the 3D archaeological interpretation of ground-penetrating radar (GPR) data in a GIS environment. On the basis of GPR data recently collected by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology in cooperation with its partners at the test site of the Roman Town Carnuntum (Austria), a 3D interpretation model of the area of the Forum was created by using ArcGIS software (recent version ArcGIS 10). The GPR data was collected by using a multi-channel MALÅ Imaging Radar Array (MIRA) system equipped with 400 MHz antennae. Compared to the older GPR surveys of the area, which mainly focused on the well-known complex of the Forum (Neubauer *et al*., 2002), the recent prospection also included an area west of the Forum, where other structures of the Roman Town were detected, including a big hall with apsis and hypocaust which probably belongs to a domus (Figure 1). The goal of the archaeological interpretation of the MIRA dataset was to test the potential of the GIS software in the interpretation of the data, especially related to the 3D approach. Methodological and technical aspects regarding the use of the software (such as use of attributes, 3D editing and animation tools) will be discussed in this paper.

The GPR method (Daniels, 2004; Conyers and Goodmann, 1997) is now widely used in archaeology, allowing non-destructive high resolution 3D investigation of archaeological sites. The GPR data is frequently visualized as 2D time- or depth-slices extracted from a 3D data volume, as well as in form of isosurfaces (Goodman *et al.*, 2009; Leckebusch, 2003). The depth slices represent a very suitable basis for the archaeological interpretation of the data (Leckebusch *et al.*, 2008; Neubauer *et al.*, 2002). Different series of depth-slices (with different thickness) extracted from the same 3D data block are usually analysed, in order to improve the data interpretation. GIS technology represents a powerful tool for interpreting and managing this large amount of data (Neubauer, 2004), especially in the case of high-resolution large-scale surveys with multi-antenna systems (Trinks *et al.*, 2010). By using GIS software, 2D and 3D interpretation models of the investigated structures can be performed.

In ArcGIS software, the depth slices are imported into an ESRI ArcGIS$^{\mathrm{TM}}$ project in form of 2D georeferenced TIFF images. Different series of depth slices from the same data set are generally imported into the GIS project, in order to achieve a more comprehensive analysis of the GPR data. The anomalies are mapped by creating 2D polygons that are classified and described in the related database (2D graphical interpretation; Figure 1).

The creation of 3D polygons (polygons with z values in their vertices) is also possible: this can be useful, especially for stepping further into a 3D environment, because it allows fully exploiting the potential of the 3D editing (for example sloping or irregular structures can be drawn by varying the z values inside the polygon vertices). Nevertheless, because editing 3D polygons in the 3D environment is technically quite complex (due to the different z values to be managed), 2D polygons are preferably used (for 2D as well as for 3D interpretation) for standard and more efficient interpretation of the data.

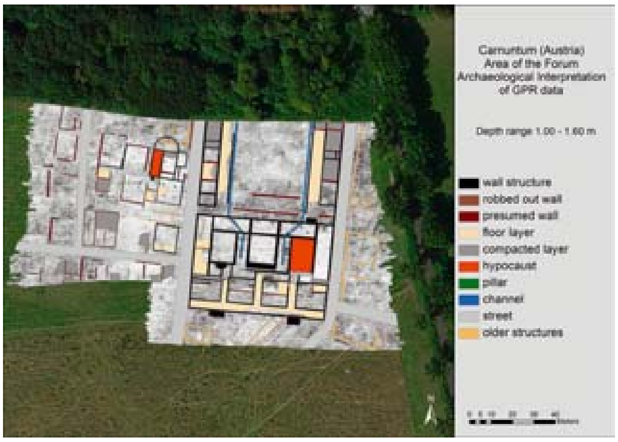

Figure 1: *2D archaeological interpretation of GPR data in ArcMap. Aerial view (Bing Maps Aerial) and GPR depth slice as background.*

By using attributes, the features are usually classified by typology (walls, floors, etc.) and phase. The elements allowing different phases to be distinguished are generally represented by the orientation of the structures (different orientation can indicate different constructing period), as well as by their depth below the ground (generally deeper structures are older). In the present work, some structures, mainly located east and south of the Forum, are distinguished from the rest of the remains, probably belonging to an earlier phase of the town ("older structures" in Figure 1). Other important aspects related to the structures such as the function, the height (related to the presumed state of conservation) and depth are also usually documented in the attributes.

By interpreting the data through the different depth levels (different depth slices), individual shape files (or feature classes in a geodatabase) can be created for the most meaningful levels (main changes in the archaeological stratification): each shape file will contain the features related to a specific depth level. Alternatively, all features can be created in a single shape file (or single feature class) and the depth information related to the single features included into the attributes. This last approach offers the advantage of an easier management of the GIS project (due to the reduction of files) and improves the interpretation process in the 3D environment, allowing direct creation of a single 3D model on the basis of the single shape file, instead of overlapping different layers (the overlapping of many features often does not offer a clear 3D view of the archaeological structures; see Figure 2).

To create the 3D model of the structures, the single shape file (or the individual shape files) is imported into ArcScene (3D

Figure 2: *3D visualization in ArcScene. Left: overlapping many features (many shape files). Right: single 3D model (single shape file).*

display environment) and the features are extruded, resulting in a 3D visualization of the buried archaeological remains (Figure 2). Taking into account the different depth levels of the interpretation, the feature extrusion can be set to correspond to the distance between two contiguous depth levels (this method is generally applied when the interpretation is conducted on several individual shape files): in this case, all features belonging to the same depth level are extruded with the same value. Alternatively, the single features can be extruded separately corresponding to the estimated height of the single structures in relation with their presumed state of conservation. The estimated height of the structures is based on the visual inspection of the sequence of depth slices (first analysis in ArcMap) that also are imported into the ArcScene project as basis of the 3D interpretation. This approach offers, in my opinion, a more intuitive concept in relation to the 3D interpretation of GPR data, and allows better imaging of the archaeological remains in a 3D environment (for example, the extrusion height of walls can be set higher than the adjacent floor giving a more "realistic" view of the structures).

During the interpretation process in the 3D environment, it is common that one needs to make corrections to a previous graphical interpretation (for example, shape and depth of features): these can be made directly in ArcScene by using the 3D editing. Along with the extrusion of the polygons, representing the typical editing in a 3D environment (extrusion by attributes), the 2D polygons in ArcScene can be edited in a similar manner as in the 2D environment, although with some limitations related to the z direction. 3D polygons allow an improved use of the 3D editing (see above) but their management is more complicated.

An important aspect related to the 3D editing is offered by the possibility of combining the use of ArcGIS software with the use of 3D modelling software, such as Google SketchUp, with the goal of improving the 3D interpretation by creating more detailed 3D models (for example in terms of texture, where the ordinary extruded shapes apparently can only use a vertically projected texture). In order to do that, the extruded polygons can be converted into 3D features (so called "multipatch"), exported into a format usable by the 3D modelling program (Collada) and reimported into ArcScene as 3D models. In Figure 3 and Figure 4, the 3D GIS interpretation of the remains of the building complex of the Forum is shown: walls and pillars (hypocaust) were modelled and textured in Google SketchUp before importing the 3D model back into ArcScene.

By working with 3D features it is also possible to import other 3D visualizations of the GPR data such as isosurfaces into the ArcScene project, allowing one to perform a more comprehensive 3D interpretation of the data. Related to the present application, this kind of integration, requiring the use of the

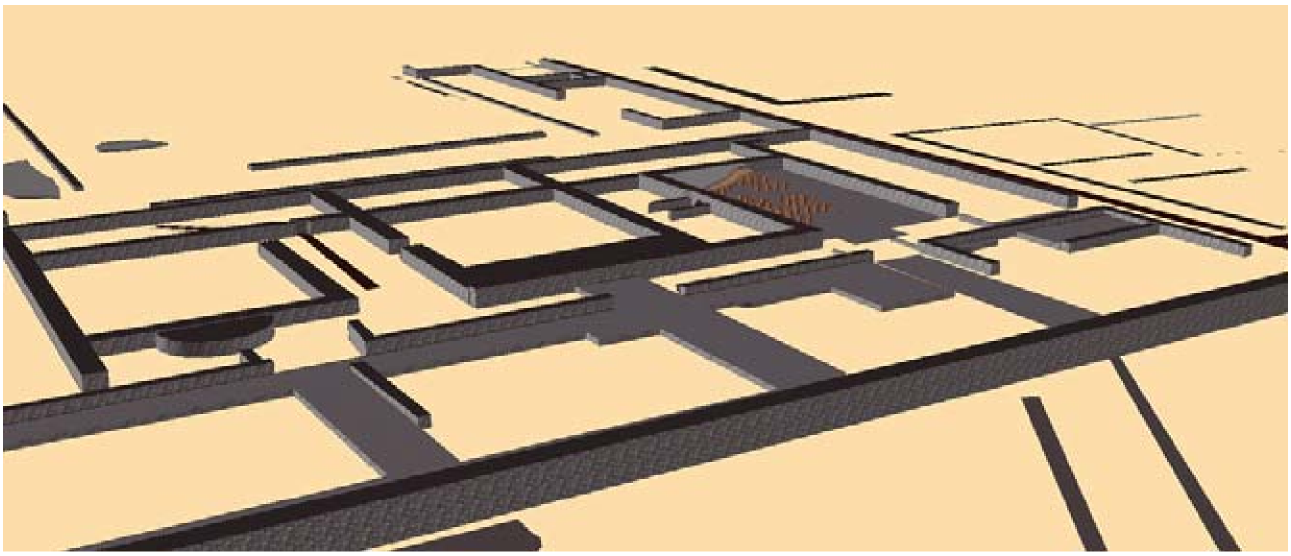

Figure 3: *The 3D interpretation model of the Forum of Carnuntum after modelling in Google SketchUp.*

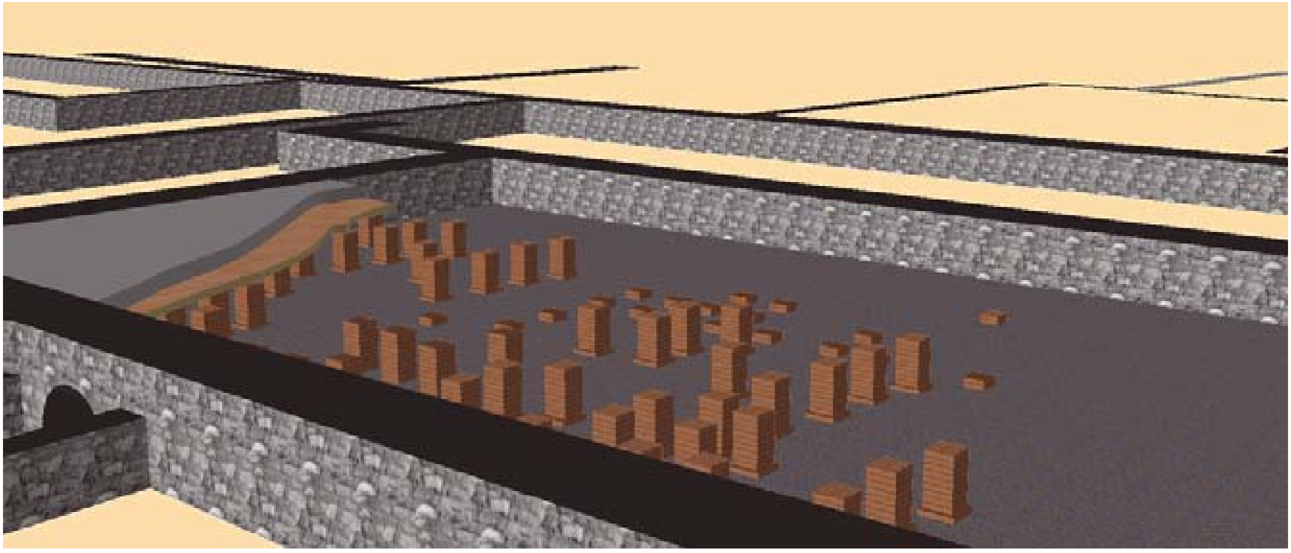

Figure 4: *Hypocaust of the building complex of the Forum (detail of the scene of Figure 3).*

ArcGIS software combined with the use of 3D visualization software (for example AVS/Express), is still in progress and will be improved in the near future.

An important aspect of the GPR data interpretation is represented by the possibility to analyse the data dynamically by means of animations of depth-slices (Linford, 2004; Neubauer et al., 2002): this allows for a better perception of the buried structures, especially in the case of sloping features (for example staircases, debris layers), and simplifies the detection of the main changes in the stratification (meaningful depth levels to be interpreted graphically). For this purpose the animated display of depth slices is nowadays increasingly applied to the GPR data interpretation (Piro and Campana, 2012). Nevertheless the animations are generally created outside the GIS environment, while the interpretation in GIS is often still conducted statically (turning on and turning off the layers corresponding to the depth slices).

In the present work, animation tools in the ArcGIS software are tested, with the goal of improving the interpretation of the data in GIS environment: by applying a layers animation, the animated visualization of series of depth slices is created directly in the GIS project (in ArcMap as well as in ArcScene), allowing a more efficient interpretation of the data. The use of animations in GIS also offers the possibility for a new approach in presenting the data, especially regarding the 3D approach. In the presented example, the 3D model of the remains of the Forum of Carnuntum is integrated into the animated sequence of depth-slices to give the effect of a "virtual excavation".

The archaeological interpretation of 3D GPR data can be efficiently conducted by using GIS software. The limitations of the 2.5D GIS environment are nowadays overcome (at least partially) by the 3D GIS technology permitting to work with 3D models. By using ArcGIS software the 2D graphical interpretation still remains an important step of the process, nevertheless by editing the features in the 3D environment (extrusion by attributes, creation of "multipatch" features, export, external editing and re-integration of 3D models) the archaeological interpretation can be further improved. The use of animations is very useful, allowing to perform the graphical interpretation directly on the animated display of depth slices. Further improvements of the method should be performed, regarding the use of temporal data (time animations) in order to display features diachronically (for example in connection with different phases). The possibility to automate workflows and a more efficient integration of 3D GPR data visualization in GIS environment also represent an important aspect of the future work.

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URBAN REFLECTIONS IN THE LANDSCAPE: EVALUATION OF URBAN SPATIAL ANALYSIS IN THE LIGHT OF ARCHAEOLOGICAL PROSPECTION

T. Tencer

Roads are the nervous system of the city. The investigation of spatial distributions and arrangements can reveal information about development of the urban environment as well as the landscape itself.

The archaeological landscape of Roman Carnuntum lies about 45 km east of Vienna. The whole landscape lies within the Danube basin and the river's slightly wavy, gravel terraces. Being the capital of the Roman province, Carnuntum was an important town during the first four centuries of the first millennium AD (Jobst *et al.*, 1983). The Roman remains extend over an area of 5 km^2, of which most are covered by undeveloped agricultural landscape. Over the last 50 years, the area has been the focus of aerial archaeology, and hundreds of aerial photographs were recently used for systematic mapping of the whole area (Doneus, 2004). Additionally, a large part of the Roman civil town in the western part of the area has been surveyed using various geophysical prospection techniques. This project provides more than just a collection of new data. It offers a possibility to change the research focus, from traditionally based excavation of monuments and structures to the wider context of landscape and the spatial organization of urban environments. Regarding archaeological excavation and the large-scale archaeological prospection, Carnuntum is one of the few Roman sites where the study of urban environment in a large scale is possible.

The combination of geophysical prospection methods applying high-resolution sensors provides a unique chance to capture detailed information about urban structures of the Roman city of Carnuntum. Geophysical prospection (magnetics and ground penetrating radar (GPR)) produces clear visualizations, showing the street network and basic layout of the city and surrounding landscape (Figure 1). Data gathered by geophysical and airborne prospection, together with the excavation data (Doneus and Gugl, 1999; Kandler *et al.*, 1999), enables the study of city planning beyond its theoretical conception, and the recognition of the city's practical realization and evolution.

Space Syntax Analysis (SSA), as a tool for revealing social behaviour indicated by space structures (Hillier and Hanson, 1984), offers a new level of cognition of the city's space. The configuration of the space in the city is not only in mutual relationship with anthropological activities within its boundaries, but also reacts to the changes in the landscape that integrates the city as its part. Streets and open public spaces, building blocks, or individual dwellings represent the city in different scales. While these categories are a city's unique and explicit spatial entities, they are also components of the cities' whole spatial organization, just like the city itself is a part, or a component, of the landscape (Stöger, 2011, p. 61).

The behaviour of the urban landscape is influenced by natural, anthropogenic, and social-economic factors. These determine the formation of urban structures both directly and indirectly. Landscape, on the other hand, depends on numerous and different urban-economic and social complexes, which determine landscape properties (Kurbatova and Bashkin, 2006, p. 184). This research investigates the above-mentioned relationships through the results of fusion of archaeological prospection data and spatial and statistical analyses.

Space Syntax research makes it possible to analyze different kinds of spatial patterns. By observing these structures, we can reveal hidden social activities embedded within each space, study the internal layout of a city, spatial patterns, and relations between the groups of buildings or even compare these to other groups of buildings. Together with spatial analysis, SSA helps to investigate the relationship between the city and its surrounding landscape.

Exploration of both the urban street network (Figure 2) and the landscape road network brings new information about the flow of inhabitants and goods, as well as revealing structural features of the landscape.

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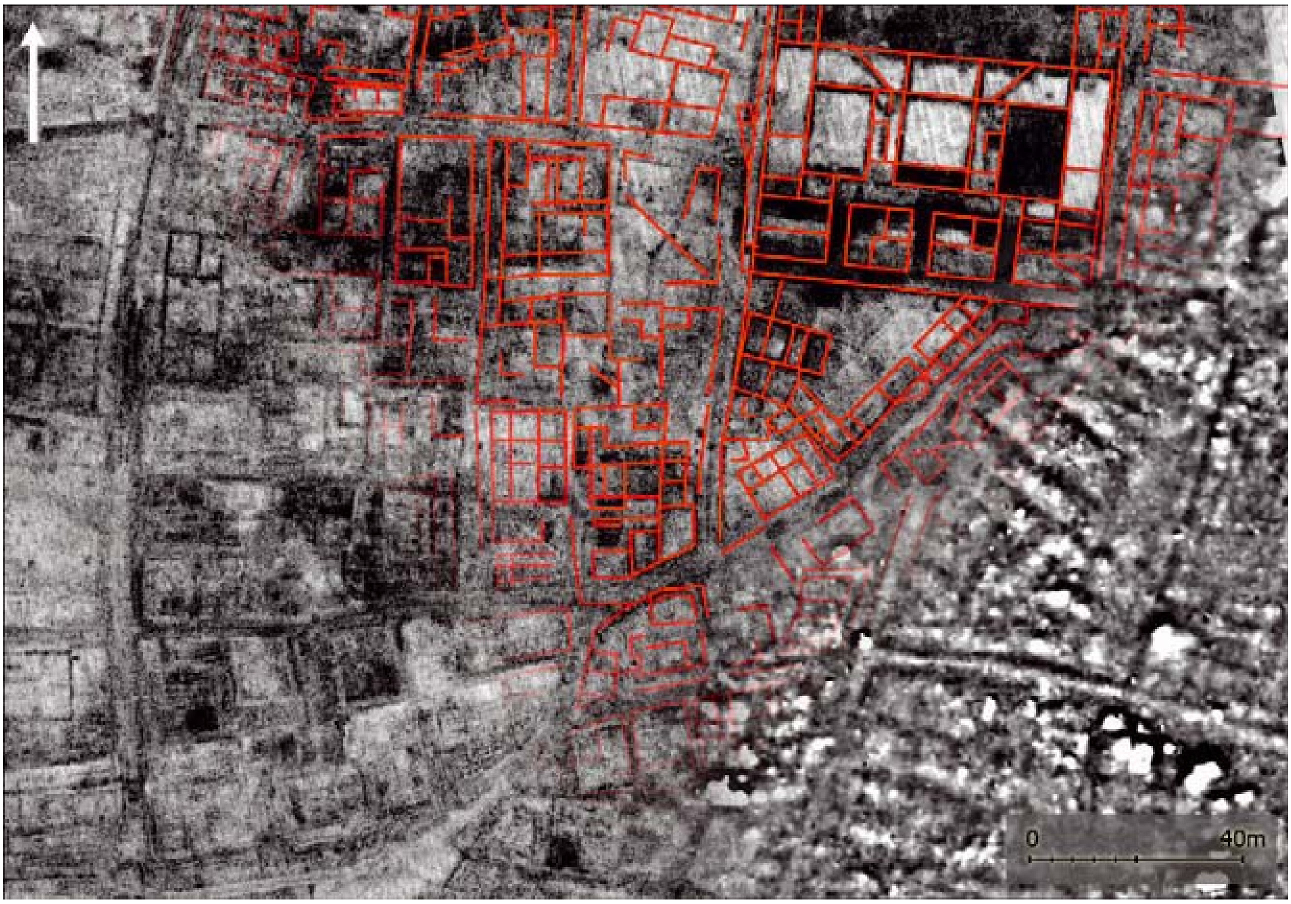

Figure 1: *Geophysical prospection produces clear visualizations, showing the street network and basic layout of the city.*

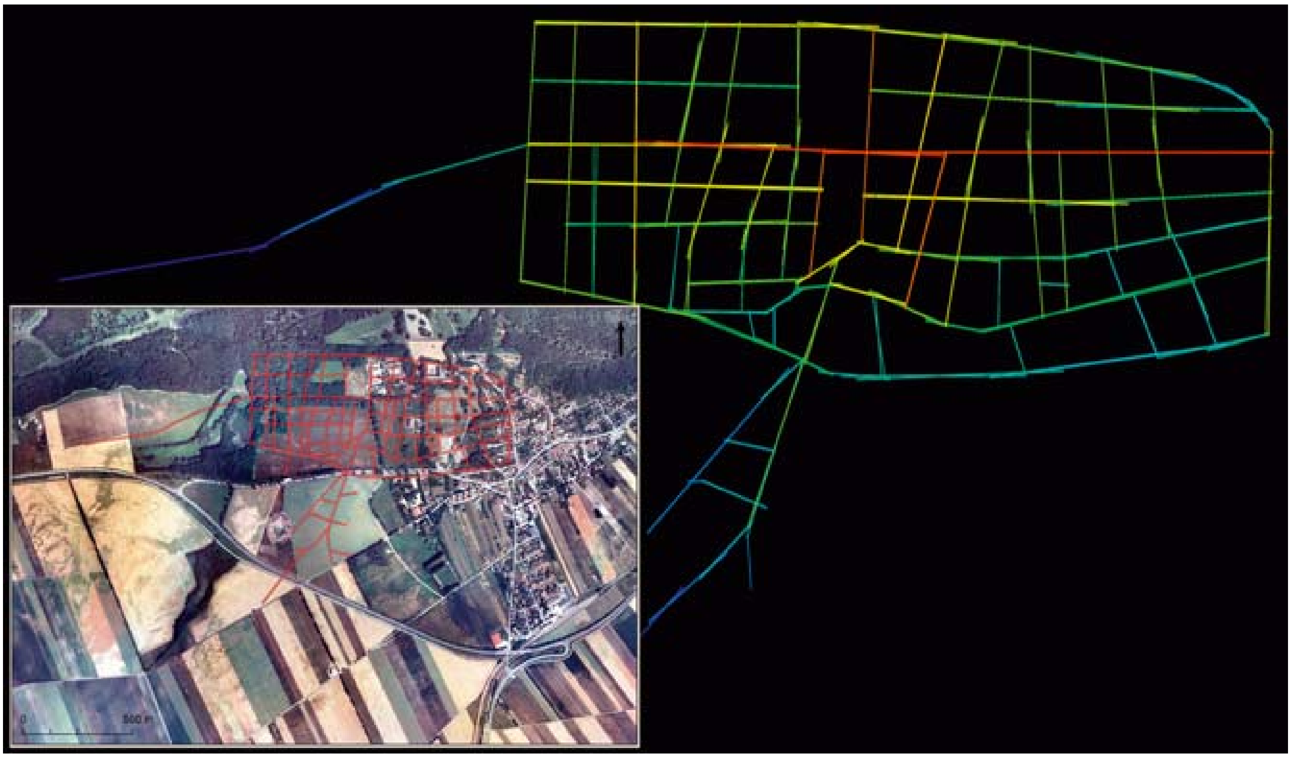

Figure 2: *Axial analysis on a reconstructed road network; Integration; red = max, blue = min.*

THE AMPHITHEATRE OF CARNUNTUM – TOWARDS A COMPLETE 3D MODEL USING AIRBORNE STRUCTURE FROM MOTION AND DENSE IMAGE MATCHING

G. Verhoeven, R. Docter

1. HARD- AND SOFTWARE IMPROVEMENTS IN LOW-ALTITUDE AERIAL PHOTOGRAPHY

Archaeological practice has always faced huge challenges in terms of fast and accurate three-dimensional data recording, whether during excavations, artefact analysis or the mapping of archaeological remains throughout the landscape. To enable the latter, aerial photography from a low-flying aircraft has been the archaeology workhorse, since it is one of the most effective methods for site discovery and documentation. However, since the beginning of aerial photography, researchers have also been using all kinds of unmanned devices (from pigeons, kites, poles, and balloons to rockets and satellites) to take still cameras aloft and remotely gather aerial imagery (Verhoeven, 2009). To date, many of these unmanned devices are still used, enabling so-called Low-Altitude Aerial Photography (LAAP). Besides these more traditional camera platforms, radio-controlled multiple-rotor platforms (multicopters) have recently opened a completely new approach to LAAP. The overwhelming variety of brands and types (tricopters, quadcopters, hexacopters, octocopters etc.), together with the wide variety of navigation options (e.g. altitude and position hold, waypoint flight) and camera mounts indicate that these platforms are here to stay for a while. Given the multitude of still camera types and the image quality they are currently capable of, an endless combination of low- and high-cost LAAP solutions is available, enabling the acquisition of aerial photographs with a spatial and temporal resolution impossible to achieve with the manned aircraft solutions.

Next to these significant hardware developments, research in computer vision and photogrammetry lead to advanced automated procedures in image orientation and image matching. When combined with the improvements in the power of computer processors and graphical cards, these software approaches now make it possible to generate 3D geometry from image data in a rather fast and straightforward way. To show the potential of integrating all aforementioned hard- and software developments, a 3D model and orthophotograph were created from the 2nd century AD amphitheatre of Carnuntum.

2. IMAGING CARNUNTUM'S CIVIL AMPHITHEATRE

The Roman town of Carnuntum (currently Petronell-Carnuntum in Austria, located 40 km southeast of Vienna on the southern bank of the Danube river – Figure 1), was home to some 50,000 inhabitants and consisted of both a Roman legionary camp with associated civilian settlement (canabae) and a civil town.

The photographed amphitheatre is located outside the gates of the civil town. The aerial imagery used in this reconstruction was acquired with a radio-controlled Microdrone md4-1000 quadrocopter (Figure 2). During the flight, photographs were taken at specific spots in such a way that they had a sufficient amount of overlap with the neighbouring photographs.

3. TOWARDS A 3D MODEL

After sorting out the sharpest images, a 3D model and orthophoto were calculated using this new approach. In a first phase, the process uses a technique called Structure from Motion (SfM; Ullman, 1979). In essence, SfM allows the reconstruction of three-dimensional scene geometry and the exact position of the cameras during image acquisition from a sequence of two-dimensional imagery captured by a camera moving around the scene (Szeliski, 2011; Figure 3A1). To do so, SfM relies on algorithms that detect feature points for each image (Figure 3A2) and subsequently tries to match those 2D points throughout the image series (Figure 3A3). Using these obtained point correspondences SfM computes the locations of those feature points

Figure 1: *The location of Roman Carnuntum.*

Figure 2: *The Microdrone md4-1000 quadrocopter.*

and renders them as a sparse 3D point cloud that represents the structure of the scene in a local coordinate frame (Figure 3B). As SfM greatly depends on the accurate knowledge of camera positions, estimating the latter is one of the core components in the whole process (Hartley and Zisserman, 2003). More specifically, the complete projection geometry of all images is computed: the interior camera calibration parameters (focal length, the principal point location plus lens distortion coefficients), the position of the camera projection centre and six exterior orientation parameters defining the camera orientation at the moment of image acquisition (Robertson and Cipolla, 2009; Figure 3B). At this stage, the reconstruction is still expressed in a local coordinate framework and equivalent of the original scene up to a global scale and rotation factor. To transform the camera positions and point cloud into an absolute coordinate system, a Helmert similarity transformation, using at least three ground control points with known altitude values, is applied.

SfM has recently received a great deal of attention due to Bundler, Microsoft's Photosynth and Autodesk's Project Photofly (now called 123D Catch): three SfM implementations that are freely available on the Web. Commercial SfM solutions are also available, including as AgiSoft's PhotoScan or Pix4D's cloud processing software. Most of these software solutions also come with additional functionality to yield a dense representation of the scene's surface geometry using one or more multi-view stereo (MVS) algorithms. Because such dense MVS solutions operate on the pixel values instead of on the feature points (Seitz *et al.*, 2006), this additional step enables the generation of detailed three-dimensional point clouds or triangular meshes (Figure 3C). When working with aerial images, the resulting model can be considered a digital surface model (DSM): a numerical representation of the topography and all its imposed structures such as trees and houses. As is known from conventional orthophoto generation, such a dense DSM is elementary when one wants to generate true orthophotos in which all objects with a certain height (such as houses, towers and trees) are also accurately positioned. Since all necessary information is available, a detailed and accurate orthophoto can now be produced (Figure 3D).

4. SOME CONSIDERATIONS

Although the presented algorithms function best when run on computers with multicore processors, a decent amount of RAM (minimum 8 GB), a 64-bit operating system and a high-end graphical card, they offer an enormous advantage in that they can be used with archaeologists' usual oblique photographs. Apart from a sufficient number of sharp images covering the scene to be reconstructed and at least three GCPs to pin down the reconstruction, no other information is needed. Furthermore, only minimal technical knowledge and user interaction are required. However, it has to be stressed that it is not all roses here: the method is not applicable for an individual image, and the determination of the correct camera projection geometry can fail when dealing with blurred, noisy and badly exposed images or photographs that have a very dissimilar appearance (e.g. due to major underexposure or changing topographic terrain parameters). For a more elaborate overview and multiple examples of this 3D and orthophoto procedure applied on aerial archaeological imagery, consider Verhoeven *et al.* (2012a). Additionally, research by Doneus *et al.* (2011) proved how well this method holds up when compared with terrestrial laser scanning in an excavation context, while Verhoeven *et al.* (2012b) thoroughly evaluated the positional accuracy of the generated orthophotographs. This type of quality control and documentation is essential in order to ensure the proper quality of the final products.

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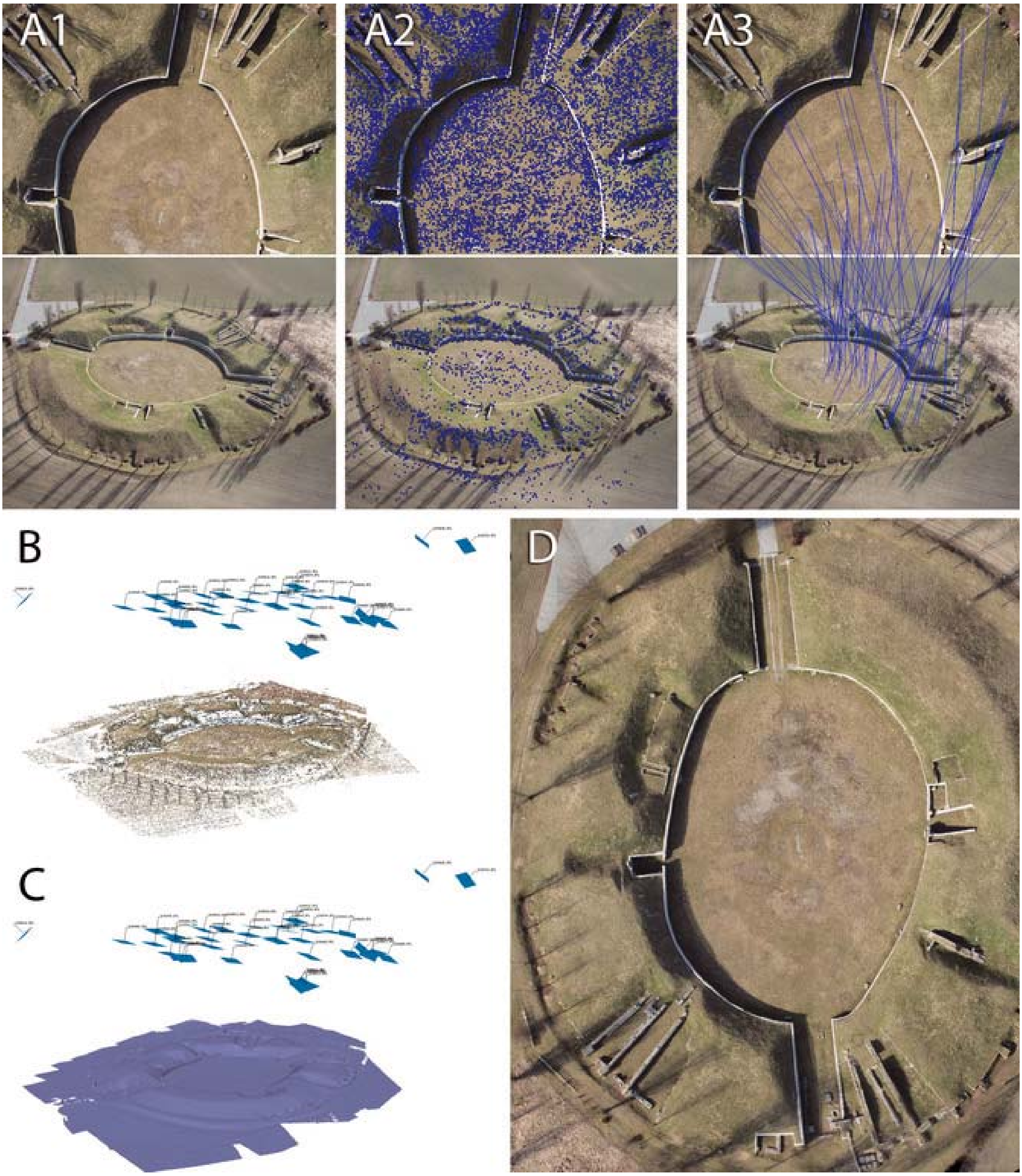

Figure 3: *Structure from Motion and dense Multi-View Stereo steps for model generation. (details in section 3)*

DIGITAL CONSERVATION OF THE MILITARY AMPHITHEATRE IN BAD DEUTSCH ALTENBURG IN THE PROVINCE OF LOWER AUSTRIA

M. Pregesbauer, B. Stummer, F. Humer

1. INTRODUCTION

The Amphitheatre I in Bad Deutsch Altenburg is the only visible part of the former military city of Carnuntum. There were two entrances to the arena – one from the west and one from the east, and enough space for an audience of approximately 8,000 people.

The amphitheatre I, as named in research, was built in the first century by the military, and rediscovered at the end of the 19^{th} century. Located on the east of the military camp, it is currently the only visible excavation site of the canabae legionis. Due to its location, it can be assumed that the amphitheatre was primarily reserved for the use of the military. Hence, not only were the popular gladiator fights (munera) and show hunts (venationes) held here, but probably also military performances.

To document the visible and the buried structures and recently excavated parts of the amphitheatre, several 3D Laser-scanning campaigns have been carried out. Due to the fact that the excavation of parts of the amphitheatre is an ongoing process, the documentation is also a steady continuing progress. The data acquisition so far has been carried out with a terrestrial Laser-scanner from Riegl (type: LMS-z420i) . By now, approximately 250 scan positions have been acquired in order to obtain a gapless pointcloud of the archaeological site.

2. PROJECT DESCRIPTION

The military amphitheatre in Bad Deutsch Altenburg has dimensions of 97×76.60 m and deviates slightly from a shape of an ellipse. It is surrounded by a wider unequal *cavea* (auditorium) which is formed at the ends of the longitudinal axis. The main entrances for the actors were on the two short sides of the building, so the east and west tripartite, lockable gates were erected, which is tapered, like a funnel, from outside to inside. These gates were designed in time-consuming foundation stone architecture; a block could weigh up to 750 kg.

Erected on the southern side there is the Nemeseum sanctuary in the *cella* (central or core area). The cult statue of Diana and Nemesis, who served the worshipers here, is on a pedestal. This cella was connected over the use of a smaller story, erected in front of the enclosed *sacellum* through a hall and joined together to form an impressive architectural ensemble. This ensemble was excavated during the summer of 2008 and subsequently scanned in autumn 2008.

After scanning the ensemble, the excavated structures have been buried again. For future research, the archaeological wall structures are preserved in digital form as three dimensional representation.

A big challenge of the several data acquisition campaigns, spread over several years, was to ensure a proper georectifica-

Figure 1: *Virtual model of the Nemeseum, excavated in 2008.*

Figure 2: *Meshed and textured model of the military amphitheatre in Bad Deutsch Altenburg.*

tion of the different point clouds to enable a contiguous virtual model. The single scan positions were transformed into the national reference frame by using pass points. To increase the object precision, a multi-station adjustment, comparable to a photogrammetric bundle block adjustment, has been applied.

The final 3D virtual representation of the amphitheatre is a meshed and textured model (Figure 2), which contains the permanently visible parts as well as the temporarily excavated and subsequently reburied parts of the complete monument.

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