THE NEW KINGDOM POPULATION ON SAI ISLAND: APPLICATION OF SR ISOTOPES TO INVESTIGATE CULTURAL ENTANGLEMENT IN ANCIENT NUBIA

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Abstract: *Sr isotopes were applied to identify possible allochthony of skeletal remains retrieved from Tomb 26 of the pharaonic cemetery SAC5 on Sai Island (Nubia). Tooth enamel of nine individuals, including the Overseer of Goldsmiths Khummose and his presumed 'wife', dating from the New Kingdom, were investigated to gain information whether these individuals were first generation immigrants from Egypt (= allochthonous) or members of the local population inhabiting the area of Sai Island (= autochthonous). The interpretation of supposed allochthony and autochthony was based on the comparison of the Sr of human enamel to an assumed autochthonous Sr isotopic composition. The autochthonous Sr signal on Sai Island during the New Kingdom was derived from archaeological animal samples (rodent, sheep/goat, dog and local mollusc shells dating from the New Kingdom) in combination with local environmental samples (paleo sediments dating from the New Kingdom and literature Sr isotope value of Nile River water for the New Kingdom era). As the Sr values in enamel of all individuals investigated lay within the determined autochthonous Sr range on Sai Island during the New Kingdom, all individuals were classified as supposed members of the local population on Sai Island.*

Elevated Sr, V, Mn and U mass fractions indicated a high degree of post-mortem alterations of human primary dentine. Hence, a mathematical approach was tested in order to correct the Sr isotope ratios in human primary dentine for diagenetic alteration considering a diagenetic Sr proportion and the Sr isotopic composition of the repository material.

The rich funerary equipment associated with the burials in Tomb 26 allowed a dating of the family members of Khnummose and illustrated that they belonged to the Egyptian elite on Sai Island as far as their cultural identity is concerned. In combination with the Sr isotopic analysis, Tomb 26 provided fresh information on the complex coexistence and biological and cultural entanglement of Egyptians and Nubians on Sai Island during the New Kingdom.

Keywords: *Sudan, Nubia, Egypt, New Kingdom, Sr isotope ratio analysis, cultural entanglement*

1. Introduction

The Egyptian 'colonisation' of Upper Nubia (Kush) started in the reign of Ahmose Nebpehtyra, introducing major changes for the local population as they were confronted with Egyptian culture and representatives of Pharaonic administration.[1] Recent evidence suggests that Ahmose founded the Egyptian site on Sai Island,[2] which used to be a strategic stronghold of the Kerma Kingdom. This makes it a key site for the Egyptian expansion towards the South.[3]

Major campaigns of the Egyptian kings of the 18th Dynasty are attested for Thutmose I, who also expanded the Egyptian site on Sai to enable his troops to go much further south.[4] Ongoing fieldwork at the major early New Kingdom sites in Upper Nubia (Sai Island, Sesebi, Tombos, Dokki Gel) has yielded structures and finds dating to the early 18th Dynasty, especially to Thutmose I,[5] complementing the textual evidence from royal stelae.[6] By the time of Thutmose I, there was an increased presence of Egyptians in the area which went hand in hand with a rapid 'Egyptianisation'.[7] The Egyptian influence remained unstable only in

* See affiliations at the end of this paper (p. 380).

1 Smith 2003, 56–96. See also Budka 2015a; Spencer et al. 2017.

2 See Budka 2017a, 19; Morris 2018, 119–120.

3 Morris 2018, 120.

4 Török 2009, 158–159; Morkot 2013, 913; Davies 2017.

5 See in particular Bonnet 2012, 67, Fig. 9; 2018, 72–77; Valbelle 2014, 107.

6 Davies 2008, 47; Valbelle 2014, 107; Davies 2017.

7 Morkot 2013, 947; Valbelle 2014, 107; Williams 2018, 101.

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the area of the Third Cataract, and a Nubian rebellion is attested following the arrival of Thutmose I, and the area being settled during the reign of Thutmose II.[8] The Egyptian conquest of Upper Nubia came to an end with the final victory of Thutmose III against the Kingdom of Kerma – the realm of Egyptian domination now reached as far as the area of the Fourth Cataract.[9] Sai Island turned into one of the centres of the Egyptian administration implemented for Nubia. This administration and also the location of the main New Kingdom sites in Upper Nubia are closely linked to the character of the area as a rich gold ore region.[10]

We have to assume that most of the Egyptian officials present in Nubia in the early 18th Dynasty were newcomers to the newly built sites in Upper Nubia, such as Sai Island, Sedeinga, Sesebi and Tombos. However, material evidence from Sai Island testifies to a cultural fusion between Egyptians and Nubians from the foundation of the town in the early 18th Dynasty throughout the New Kingdom.[11] During the heyday of Sai Island in the mid-18th Dynasty, the occupants represented the second generation of witnesses to the campaigns of the first kings of the 18th Dynasty.[12] It seems straightforward that the relationship of these individuals with the Egyptians was considerably different compared to their ancestors still living under Kerma rulers. Considering the general developments in Upper Nubia during the times of Ahmose to Thutmose III, it is not surprising that the persons traceable in the archaeological records were fully integrated into the Egyptian power structure and administrative system.[13]

1.1 Tomb 26

The 'Egyptianisation' of Upper Nubia becomes especially evident examining funerary remains in elite cemeteries such as SAC5 on Sai Island, where burials in Egyptian-style are attested from Thutmose III onwards.[14] In this respect, Tomb 26, discovered in 2015, is of special importance. This Egyptian-style rock-hewn shaft tomb with a pyramid as superstructure yielded several burials from the New Kingdom.[15] The original burial chamber (feature 6) was found sealed with flood deposits and had obviously been undisturbed since ancient times. This chamber held two painted wooden coffins, of which only traces survived in the flood sediments, and rich burial equipment of Egyptian style including scarabs, faience vessels, pottery vessels and one stone shabti. Traces of the funerary masks have also survived, especially inlayed eyes and gold foil. According to the inscribed finds and the human remains, the double burial in the original burial chamber of Tomb 26 can be identified as the Overseer of Goldsmiths Khnummose and an anonymous female, presumably his wife. Additional family members seem to have been buried in another chamber of the tomb (feature 5). All in all, these interments from the mid- to late 18th Dynasty enable a reconstruction of a family whose members were engaged in gold mining, one of the main functions of Sai Island as an Egyptian administrative centre during the New Kingdom. However, despite the Egyptian names and titles and the funerary objects in Egyptian-style, the individuals themselves might still be of Nubian origin.[16] It might have been more convenient to accept the various items offered from the new Egyptian workshops than to maintain an independent production of traditional Nubian objects and pottery in New Kingdom Nubia.[17] Sr isotope ratio analysis was applied to get additional information about whether Khnummose and his family are more likely to be interpreted as Egyptian colonialists or as Egyptianised Nubians.

1.2 Sr isotope ratio analysis in human migration studies

The analysis of Sr isotope ratios in human skeletal remains, such as teeth and bone, by thermal ionization mass spectrometry (TIMS) or multi-collector inductively coupled plasma mass spectrometry (MC ICP-MS) has been widely used as an analytical approach in anthropological and archaeological research to reconstruct provenance, migration and

8 See Bonnet 2012, 71; Zibelius-Chen 2013, 138; Valbelle 2014, 107; Bonnet 2018, 75–77; Morris 2018, 224.

9 Smith 1995, Fig. 6.1; Török 2009, 165; Zibelius-Chen 2013, 138.

10 Cf. Spence and Rose 2009, 38–39. See also Klemm and Klemm 2013; Vieth 2018.

11 Budka 2017b.

12 See Budka 2015b.

13 Cf. Morkot 1995, 181.

14 See Minault-Gout and Thill 2012; Budka 2017c; 2018.

15 See Budka 2017c, 2018.

16 Cf. Minault-Gout and Thill 2012, 415; Budka 2018, 193. See also Smith and Buzon 2017.

17 Morris 2018, 224.

mobility patterns of past humans and animals.[18] The main interest lies in the radiogenic $n(^{87}Sr)/n(^{86}Sr)$ isotope amount ratio (commonly also noted as the $^{87}Sr/^{86}Sr$ ratio),[19] which can vary geographically based on the natural-abundance variation of ^{87}Sr as a product of the radioactive decay of ^{87}Rb (half-life of 4.88×10^{10} years). The local Sr isotope ratio is, therefore, a function of the geological age and original Rb/Sr ratio of the bedrock material.[20] Sr is mobilized via physical and chemical weathering processes and transport through climatic and atmospheric events into the environment (soil, water and, subsequently, incorporated into plants). Because of its chemical similarity to Ca, the Sr ions released substitute for Ca ions in the biological uptake. The bioavailable, radiogenic Sr isotopic ratio is taken up by animals and humans in the course of the food chain without significant fractionation[21] and is stored in Ca-rich matrices (such as bones and teeth[22]). Because of *intra-* and *inter*-tissue variability in turnover rates and formation time of bone and teeth material, Sr is known to be distributed inconsistently throughout the whole skeleton and to have a different turnover regarding the tissue and actual position within the skeleton. Therefore, the different tissue types reflect different uptake periods of Sr isotopic signature as a function of a particular geographic location inhabited during a certain period of an individual's life:[23] human enamel incorporates Sr only during the tooth-formation period (varying between teeth[24]) and, therefore, preserves the isotopic information of Sr taken up prenatally or during early childhood[25] ('archive of the childhood'[26]). When compared to an autochthonous (= humanly available) Sr signal of the habitat under investigation, the enamel Sr signature can be used to identify individuals who were born/spent their childhood years in a locality other than the habitat under investigation (= allochthonous), and individuals who were supposedly born, lived and died locally at the same place (= autochthonous) or places with the same Sr signature. Human dentine, on the other hand, is a living tissue[27] and re-equilibrates to some extent with an individual's metabolism due to its intimate intergrowth with capillary veins.[28] The majority of human dentine builds primary dentine, which secretes before apical closure of the tooth root.[29] After root formation is completed, a thin layer of secondary dentine forms unevenly around the pulp cavity,[30] and when the tooth is damaged (e.g. caries), tertiary dentine forms newly as a response.[31] Once formed during adolescence and early adulthood, human primary dentine does not remodel or undergo significant metabolic or structural changes, but its odontoblasts lining the pulp chamber retain the ability to produce new dentine throughout life.[32] Hence, similar to enamel, it is expected that human primary dentine preserves Sr isotopic information about the place of residence of an individual during certain time spans of its adolescence ('archive of the adolescence'), which varies between teeth as a result of time-resolved teeth formation.[33] When compared to the Sr signature in enamel and an autochthonous Sr signal of the habitat under investigation, the primary dentine might give an additional indication of past living conditions.

Diagenetic modification by cumulative physical, chemical and biological alteration can lead to a post-depositional overprint of the Sr isotopic signatures incorporated in ancient skeletal remains.[34] During deposition, diagenetic Sr from soil moisture and groundwater of the burial environment accumulates post-mortem in bone and tooth material. Processes of recrystallization of the hydroxyapatite lattice, adsorption onto the apatite crystal surface and crystallization of secondary

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18 As comprehensively described in recent reviews: Bentley 2006; Slovak and Paytan 2012; Szostek et al. 2015; Sehrawat and Kaur 2017.

19 In this manuscript, the isotopic composition is reported as isotope-amount ratios ($n(^{87}Sr)/n(^{86}Sr)$), which is the recommended notation according to IUPAC guidelines. Coplen 2011. In the following, the $n(^{87}Sr)/n(^{86}Sr)$ ratios are also called Sr isotope ratios.

20 Capo et al. 1998.

21 Capo et al. 1998; Blum et al. 2000.

22 Price et al. 1998; Bentley 2006.

23 Capo et al. 1998; Bentley 2006.

24 Hillson 1996; AlQahtani et al. 2010.

25 For example, the incremental growth of human first molar enamel (used in this study) starts formation at birth and continues until completion at 3.5 years of age. AlQahtani et al. 2010.

26 Prohaska et al. 2002.

27 Fortes et al. 2015.

28 Fergusson and Purchase 1987; Chiaradia et al. 2003.

29 Arana-Chavez and Massa 2004.

30 Shepherd et al. 2012; Beaumont et al. 2015.

31 Beaumont et al. 2015.

32 Nanci 2013.

33 Hillson 1996; AlQahtani et al. 2010.

34 Wilson and Pollard 2002.

minerals (e.g. brushite ($CaHPO_4 \cdot 2H_2O$) or carbonate ($CaCO_3$)) in micro-cracks, pores and vacancies[35] add diagenetic Sr and change the *in vivo* incorporated Sr fingerprint (often referred to as biogenic Sr). In wet climates, the diagenetic processes usually involve pronounced interaction with groundwater accompanied by strong dissolution/recrystallization effects and microbial bioerosion. Crystallization of secondary phases is more important than bacterial attacks in arid environments.[36]

The impact of diagenetic contamination has to be considered properly if Sr isotopic analysis of archaeological bone and/or tooth material is conducted. Potential diagenetic alteration in studies of large populations is assessed by the correlation of the Sr mass fraction $w(Sr)$ and the $n(^{87}Sr)/n(^{86}Sr)$ ratios in bone/tooth in combination with the chemical information of the repository material in the burial environment.[37] Elevated (> 250 µg g^{-1}) and depleted (< 100 µg g^{-1}) Sr mass fractions in human enamel have been considered as indications of diagenetic changes.[38] The degree of diagenesis depends on the repository conditions.[39] Studies on the diagenesis of human and animal skeletal remains have revealed that elevated $w(Ca)/w(P)$ mass fraction ratios above the theoretical value of biogenic hydroxyapatite (2.16),[40] the presence of elevated contents of transition elements, such as Al, Si and Ba (*in vivo* < 10 µg g^{-1} to 100 µg g^{-1}), the presence of elevated contents of V, Fe and Mn, and/or the presence of elevated contents of (ultra-) trace elements (mainly REE, Y, Hf, Th, U; *in vivo* < 1 µg g^{-1}) are indicators of post-mortem alterations.[41] The extent of diagenetic alterations is matrix-dependent and site-specific.[42]

It is generally widely accepted that diagenetic alterations do not affect tooth enamel significantly due to its compact structure with very little pore space and a minor amount of organic content (~ 2 %). Consequently, tooth enamel is expected to preserve biogenic Sr isotopic values and represents a reliable matrix for mobility and migration studies.[43] Nonetheless, enamel is not immune to diagenetic changes.[44] Dentine and bone material have a higher porosity, smaller crystallites and a higher organic content (~ 30 %). Consequently, these compartments show more pronounced diagenetic alterations.[45]

It is a known fact that human dentine is likely be affected by diagenetic alterations and, as a result, its use in terms of archaeological migration studies is controversially discussed. The majority of studies dealing with archaeological migration excluded skeletal remains from the interpretations if diagenetic alterations have been identified. Consequently, the potential that diagenetic primary dentine is worth exploring in more detail even though substantial challenges have to be faced. A limited number of publications have discussed diagenetic proportions and preservation of biogenic Sr isotopic signatures of human/animal bone and (primary) dentine tissue.[46] In some cases, biogenic human/animal (primary) dentine might be preserved, which then cannot be used to approximate the local biologically available Sr isotopic ratio.[47] Subsequently, mathematical concepts have been developed and applied to estimate the biogenic Sr isotopic signature of diagenetically altered (primary) dentine based on the diagenetic Sr proportion and the Sr isotopic signature of the burial environment.[48] Nevertheless, the resulting values have to be treated with care.

1.3. Migration studies from the Middle Nile

Sr isotope ratio analysis which has been applied to investigate human migration in the Middle Nile ranges in place from the Nile Rivers First (Egypt) to its Fourth Cataract (Nubia), and in time, from the Bronze Age to Medieval times.[49]

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35 Nelson et al. 1986; Kohn et al. 1999; Nielsen-Marsh and Hedges 2000; Prohaska et al. 2002; Hoppe et al. 2003.

36 Maurer et al. 2014; Dudás et al. 2016.

37 Hoppe et al. 2003; Copeland et al. 2010.

38 Dudás et al. 2016.

39 Sponheimer and Lee-Thorp 2006.

40 Sillen 1986.

41 Kohn et al. 1999; Trueman et al. 2008; Koenig et al. 2009; Benson et al. 2013; Kohn and Moses 2013; Willmes et al. 2016; Kamenov et al. 2018.

42 Dudás et al. 2016.

43 Kyle 1986; Lee-Thorp and Sponheimer 2003; Bentley 2006; Montgomery 2010; Slovak and Paytan 2012; Szostek et al. 2015.

44 Kohn et al. 1999; Lee-Thorp and Sponheimer 2003; Dauphin and Williams 2004; Sponheimer and Lee-Thorp 2006; Dudás et al. 2016; Willmes et al. 2016.

45 Driessens and Verbeeck 1990.

46 Budd et al. 2000; Lee-Thorp and Sponheimer 2003; Copeland et al. 2010.

47 Copeland et al. 2010.

48 Budd et al. 2000; Copeland et al. 2010; Kreutz 2011.

49 Buzon et al. 2007; Buzon and Simonetti 2013; Schrader et al. 2019, and references cited.

A preliminary study by Buzon et al. has established the first local Sr isotopic range in the Nile Valley focusing on the Third Cataract region ($n(^{87}Sr)/n(^{86}Sr)$ = 0.70732 – 0.70754), to investigate the possible Egyptian occupation of the Nubian town in Tombos during the New Kingdom. The Sr values in tooth enamel of the human population investigated have ranged from 0.70712 to 0.70911, which indicated that several individuals had $n(^{87}Sr)/n(^{86}Sr)$ isotope ratios above the upper limit of the local environmental range, identifying allochthonous individuals. Considering the geological diversity along the Nile River (limestone formation in Thebes), Buzon et al. have argued that these individuals may have been Egyptian colonizers sent to Nubia.[50]

Sandberg et al. have analysed human samples from Kulubnarti during their preliminary study on human mobility during the Medieval Period in Nubia. The area is located south of Wadi Halfa in the Batn el Hajar region in the Second Cataract. They have found $n(^{87}Sr)/n(^{86}Sr)$ values in human samples ranging from 0.70710 to 0.70850.[51] Masoner et al. have performed the first preliminary Sr isotope ratio analyses for the Fourth Cataract region in Nubia to investigate human migration at the Ginefab School site. They have determined an autochthonous Sr isotopic range of 0.70650 – 0.70740 based on faunal samples.[52]

On the basis of their preliminary work, Buzon and Simonetti have extended their original research by investigating the variability of Sr isotopic signatures in human enamel across two Egyptian (Qurneh and Memphis) and five Nubian sites (Shellal, C-Group and Pharaonic sites of the SJE concession from the modern Egyptian border to 60 km southwards, Amara West, Tombos and Kerma) in the Nile Valley, stretching from the First to the Third Cataract. Herein, human individuals dating from the Middle Kingdom, Second Intermediate Period, New Kingdom and Third Intermediate/Napatan Period have been analysed. The $n(^{87}Sr)/n(^{86}Sr)$ values of human enamel from all sites overlap. The statistical analysis has revealed that the population at the Egyptian sites has a higher Sr signature (mean of 0.70775 ± 0.00027 (*SD*)) than the population at the Nubian sites (mean 0.70762 ± 0.00036 (*SD*)). This indicates a decrease in the $n(^{87}Sr)/n(^{86}Sr)$ values from north to south along the Nile Valley for the sites studied, with the exception of Nubian places with strong Egyptian presence.[53] Archaeological faunal remains from six sites (SJE concession, Askut, Amara West, Northern Dongola Reach, Kawa and el-Kurru) have been used for a broader characterisation of the Nubian Sr isotopic signatures. A set of ten modern rodent samples from Tombos have been used to define an autochthonous Third Cataract Sr signature (0.70710 – 0.70783), which has led to the identification of additional immigrants, possibly of Egyptian origin, from New Kingdom Tombos. The Third Intermediate/Napatan Period population at Tombos has been mainly autochthonous: only two individuals with allochthonous signatures have been identified.[54]

Buzon et al. analysed an extended dataset of early and late New Kingdom human individuals from Tombos in 2016, to compare these to Third Intermediate/Napatan Period individuals also from Tombos. Based on their previously established autochthonous Third Cataract (Tombos) Sr signature, immigrants have been identified. They found that a higher degree of allochthonous individuals were present during the early New Kingdom, whereas mostly autochthonous individuals were present during the late New Kingdom and Third Intermediate/Napatan Period. This finding has provided a new perspective of the establishment of the Napatan State.[55]

Schrader et al. have recently explored the Third Cataract population by investigating human individuals from Abu Fatima, dating from the Kerma period, and Hannek and Tombos, dating from the New Kingdom. The Sr values in the human enamel of the population investigated ranged from 0.70715 to 0.71473 at Abu Fatima, from 0.70713 to 0.70966 at Hannek and from 0.70696 to 0.70825 at Tombos. Due to the limited availability of faunal samples at these sites and based on the fact that the Third Cataract regional geology is notably uni-

[50] Buzon et al. 2007; see also Buzon 2016.

[51] Sandberg et al. 2008, cited in Buzon and Simonetti 2013; Schrader et al. 2019.

[52] Masoner et al. 2011, cited in Buzon and Simonetti 2013; Schrader et al. 2019.

[53] The statistical difference between Egyptian and Nubian sites is indistinguishable within common uncertainties for Sr isotope ratio measurements (U = 0.00015–0.00030, k = 2) performed by MC ICP-MS, therefore, interpretations have to be made with care.

[54] Buzon and Simonetti 2013.

[55] Buzon et al. 2016.

Nile Cataract	Locality	Period	$n(^{87}Sr)/n(^{86}Sr)$ range of human individuals (enamel)	Sample for local environmental/ autochthonous range	Local/Autochthonous $n(^{87}Sr)/n(^{86}Sr)$ range	Reference
First	Nile Delta	Recent		Modern marine taxa (e.g. molluscs, foraminifera, ostracods)	0.7090 – 0.7092	Reinhardt et al. 1998
First	Memphis	New Kingdom	0.70735 – 0.70872			Buzon and Simonetti 2013
First	Qurneh	New Kingdom	0.70731 – 0.70798			Buzon and Simonetti 2013
Second	Shellal	New Kingdom	0.70705 – 0.70811			Buzon and Simonetti 2013
Second	C-Group, SJE concession from modern Egyptian border to 60 km southwards	Middle Kingdom	0.70701 – 0.70807	Archaeological remains of sheep/goat	0.70667 – 0.71086	Buzon and Simonetti 2013; Schrader et al. 2019
Second	Pharaonic Sites, SJE concession from modern Egyptian boarder to 60 km southwards	Second Intermediate Period and New Kingdom	0.70658 – 0.70769			Buzon and Simonetti 2013
Second	Kulubnarti	Medieval	0.70710 – 0.70850			Sandberg et al. 2008
Second	Askut	Middle Kingdom		Archaeological remains of rodent and sheep/goat, excluded cattle	0.70679 – 0.70769	Buzon and Simonetti 2013; Schrader et al. 2019
Second	Amara West	New Kingdom	0.70733 – 0.70817	Archaeological remains of sheep/goat, pig and dog, excluded cattle	0.70699 – 0.70802	Buzon and Simonetti 2013; Schrader et al. 2019
Second	Sai Island	New Kingdom	0.70713 – 0.70778	Archaeological teeth of rodent, sheep/ goat, dog, and mollusc shells	0.70693 – 0.70828	This study
Third	Tombos	New Kingdom	0.70712 – 0.70911	Burial soil, archaeological sheep/goat bone, recent cow tooth	0.70732 – 0.70754	Buzon et al 2007
Third	Tombos	New Kingdom	0.70712 – 0.70912	Recent remains of rodent	0.70724 – 0.70773	Buzon and Simonetti 2013; Schrader et al. 2019
Third	Tombos	New Kingdom	0.70696 – 0.70825			Schrader et al. 2019
Third	Tombos	Napatan Second Intermediate	0.70661 – 0.70789			Buzon and Simonetti 2013
Third	Kerma	Period	0.70718 – 0.70812			Buzon and Simonetti 2013
Third	Abu Fatima	Middle Kingdom	0.70715 – 0.71473			Schrader et al. 2019
Third	Hannek	New Kingdom	0.70713 – 0.70966			Schrader et al. 2019
Fourth	Northern Dongola Reach	Middle Kingdom		Archaeological remains of sheep/goat	0.70678 – 0.70755	Buzon and Simonetti 2013; Schrader et al. 2019
Fourth	Ginefab School site	N.N.		Faunal samples	0.70650 – 0.70740	Masoner et al. 2011
	Downstream the confluence of Atbara and main Nile	Recent		Sediments	0.7057 – 0.7066	Krom et al. 2002
	Khartoum till Nile Delta	2050 BC – 400 BC, compassing the New Kingdom		Sediments, (water)	0.7080 – 0.7082	Krom et al. 2002
	Blue Nile	Recent		Water	0.7065	Talbot et al. 2000

Table 1 Literature overview of $n(^{87}Sr)/n(^{86}Sr)$ ratios of human individuals and local/autochthonous ranges from sites along the Nile River (First to Fourth Cataract).

form, human Sr signatures have been compared to the Third Cataract Sr signature determined at Tombos from modern rodent samples. The results suggest that both autochthonous and allochthonous individuals were part of these Third Cataract populations during the Kerma and New Kingdom age. Long-distance trading networks and/or pastoralism may have been active during the New Kingdom. According to this and considering the high degree of variability in the Sr isotope values for cattle published by Buzon and Simonetti, the autochthonous Sr ranges of the Second and Fourth Cataracts have been redefined based on faunal samples (excluding cattle): SJE concession 0.70667 – 0.71086, Askut 0.70679 – 0.70769, Amara West 0.70699 – 0.70802, Tombos (modern rodent) 0.70724 – 0.70773 and Northern Dongola Reach 0.70678 – 0.70755.[56]

Table 1 gives an overview of the Sr signatures of the local environmental/autochthonous ranges and human individuals investigated from sites along the Nile River (First to Fourth Cataract) conducted in the studies mentioned above.

2. Experimental

2.1. Materials and standards

Preparatory laboratory work was performed in an ISO class 8 clean room according to ISO 14644-1. Consumables were cleaned with acid prior to analysis. Purification of water and nitric acid was accomplished. Further details are described elsewhere.[57]

Certified reference materials NIST SRM 1486 (bone meal, NIST, Gaithersburg, USA) and NIST SRM 1400 (bone ash, NIST) were used as quality control for digestion, separation and isotopic analysis.[58]

Certified reference material NIST SRM 987 (highly purified $SrCO_3$, NIST), diluted in nitric acid (2 % *w*/*w*), was used as a Sr isotope ratio reference in standard-sample bracketing for the correction of the instrumental isotopic fractionation applying an internal inter-elemental approach.[59] Separated samples and standards for standard-sample bracketing were spiked with diluted Zr solution (Merck-Millipore, Darmstadt, Germany) to allow for additional internal inter-elemental instrumental isotopic fractionation correction according to standard protocols.[60] The measurement results are reported as absolute $n(^{87}Sr)/n(^{86}Sr)$ isotope amount ratios.

2.2 Samples

Samples were collected during interdisciplinary fieldwork conducted between 2015 and 2017, in the course of the 'Across borders and cultures' project (FWF START Y615-G19; project lead: Julia Budka). The archaeological samples were provided by the Institute for Oriental and European Archaeology (Austrian Academy of Science) and the Natural History Museum Vienna, having been exported from Sudan with the kind permission of the National Corporation for Antiquities and Museums of Sudan (NCAM).

Nine human individuals from the New Kingdom era deposited in Tomb 26 in the pyramid cemetery SAC5 on Sai Island were analysed for their Sr isotope ratio. These individuals included the Overseer of Goldsmiths Khummose (H159) and his presumed 'wife' (H160) from the double burial in feature 6.[61]

In the present study, the first molar[62] was preferably used for analysis, depending on availability. In three cases, the second molar[63] and in another three cases, the third molar[64] was analysed (Tab. 2).

A set of 19 sediment samples, including eight recent sediments, six paleo sediments and five repository materials, and four recent water samples were taken in the northern half of Sai Island to determine the local environmental range of $n(^{87}Sr)/n(^{86}Sr)$ ratios. The environmental samples were taken at a maximum distance of five kilometres from

[56] Schrader et al. 2019.

[57] Irrgeher et al. 2012.

[58] Galler et al. 2007.

[59] Yang et al. 2008; Kramchaninov et al. 2012; Irrgeher et al. 2013; Irrgeher et al. 2015; Horsky et al. 2016.

[60] Yang et al. 2008; Kramchaninov et al. 2012; Irrgeher et al. 2013; Irrgeher et al. 2015; Horsky et al. 2016; Retzmann et al. 2017.

[61] Budka 2017c.

[62] The incremental growth of human first molar enamel starts formation at birth and continues until completion at 3.5 years of age. AlQahtani et al. 2010.

[63] The incremental growth of human second molar enamel starts and continues until completion between 2.5 years and 7.5 years of age. AlQahtani et al. 2010.

[64] The incremental growth of human third molar enamel starts and continues until completion between 8.5 years and 13.5 years of age. AlQahtani et al. 2010.

Sample ID	Find number	Tomb	Sex and age	Tooth (FDI)	Enamel/ dentine	$n(^{87}Sr)/n(^{86}Sr)$ (U, k = 2)	Sr mass fraction (µg g^{-1}) (U, k = 2)	Diagenetic proportion (%) (U, k = 2)	Biogenic $n(^{87}Sr)/n(^{86}Sr)$ (u_c, k = 1)	Classification
H366	SAC5 366/2016	26, feature 2	Male?, adult	38	Enamel	0.70742 ± 0.00016	240 ± 26			Supposedly autochthonous
					Dentine	0.70772 ± 0.00016	380 ± 42	0 %		
H367	SAC5 367/2016	26, feature 2	Infant	37	Enamel	0.70745 ± 0.00016	196 ± 22			Supposedly autochthonous
					Dentine	0.70765 ± 0.00016	506 ± 56	52.7 % ± 5.8 %	0.70727 ± 0.00030	
H356	SAC5 356/2016	26, feature 2	Male?, late mature to senile	28?	Enamel	0.70729 ± 0.00016	249 ± 27			Supposedly autochthonous
					Dentine	0.70781 ± 0.00016	577 ± 63	47.3 % ± 5.2 %	0.70765 ± 0.00030	
H159	SAC5 159/2017	26, feature 6	Male, mature	47	Enamel	0.70759 ± 0.00020	270 ± 30			Supposedly autochthonous
					Dentine	0.70768 ± 0.00020	449 ± 49	26.6 % ± 2.9 %	0.70752 ± 0.00030	
H160	SAC5 160/2017	26, feature 6	Female, mature	16	Enamel	0.70755 ± 0.00020	330 ± 36			Supposedly autochthonous
					Dentine	0.70759 ± 0.00020	512 ± 56	21.3 % ± 2.3 %	0.70746 ± 0.00030	
H145	SAC5 145/2017	26, feature 5	Male, adult	47	Enamel	0.70744 ± 0.00020	297 ± 33			Supposedly autochthonous
					Dentine	0.70791 ± 0.00020	550 ± 61	34.1 % ± 3.8 %	0.70777 ± 0.00030	
H324	SAC5 324/2017	26, feature 5	Female, adult	28	Enamel	0.70755 ± 0.00020	268 ± 29			Supposedly autochthonous
					Dentine	0.70805 ± 0.00020	487 ± 54	33.0 % ± 3.6 %	0.70799 ± 0.00030	
H124	SAC5 124/2017	26, feature 4	Female?, adult	46	Enamel	0.70757 ± 0.00020	236 ± 26			Supposedly autochthonous
					Dentine	0.70781 ± 0.00020	413 ± 45	36.8 % ± 4.0 %	0.70799 ± 0.00030	
H259	SAC5 259/2017	26, feature 5	Female, adult	26	Enamel	0.70743 ± 0.00020	193 ± 21			Supposedly autochthonous
					Dentine	0.70796 ± 0.00020	456 ± 50	48.3 % ± 5.3 %	0.70786 ± 0.00030	

Table 2 The (biogenic) $n(^{87}Sr)/n(^{86}Sr)$ ratios, Sr mass fractions and diagenetic Sr proportion of enamel and primary dentine of all human individuals investigated, given with the expanded uncertainties U (k = 2) except for estimated biogenic Sr signatures of human dentine, which are given as combined uncertainties u_c (k = 1).

Sample ID	Type	lat. (°N)	lon. (°E)	Sampling spot	$n(^{87}Sr)/n(^{86}Sr)$
S1	Sediment	20.729367	30.32335	Old Nile deposit, north of Sai Island	0.70801 ± 0.00016
S2	Sediment	20.730017	30.336667	Eastern Bank (palaeo)	0.70752 ± 0.00018
S3	Sediment	20.730017	30.336683	Nile terrace over bank deposit, eastern bank (palaeo)	0.70799 ± 0.00018
S4	Sediment	20.7309761	30.3367997	Nile silt (palaeo) village Adou	0.70790 ± 0.00018
S5	Sediment	20.729333	30.323333	Nile silt north of Sai Island	0.70661 ± 0.00024
S6	Sediment	20.72075	30.31054	Nile deposit (alluvium) western bank spot sample	0.70701 ± 0.00018
S7	Sediment	20.7224	30.32	Nile silt (west of Sai Island)	0.70668 ± 0.00018
S8	Sediment	20.73821	30.33226	Eastern bank test trench	0.70706 ± 0.00018
S9	Sediment	20.73821	30.33226	Eastern bank test trench	0.70699 ± 0.00018
S10	Sediment	20.7309761	30.3367997	Nile palaeo-silt village Adou eastern bank	0.70779 ± 0.00018
S78	Sediment	20.751567	30.331883	Nile mud	0.70667 ± 0.00031
S79	Sediment	20.740983	30.337233	Nile mud	0.70671 ± 0.00031
S80	Sediment	20.751583	30.331867	Nile mud	0.70693 ± 0.00031
S81	Sediment	20.736217	30.325917	Nile mud	0.70763 ± 0.00031
S82	Sediment	20.729884	30.333291	Repository material from SAC5, T26, at H366	0.70799 ± 0.00031
S150	Sediment	20.729884	30.333291	Repository material from SAC5, T26, at H124	0.70791 ± 0.00029
S151	Sediment	20.729884	30.333291	Repository material from SAC5, T26, at H159	0.70809 ± 0.00029
S152	Sediment	20.729884	30.333291	Repository material from SAC5, T26, at H145	0.70819 ± 0.00029
S153	Sediment	20.729884	30.333291	Repository material from SAC5, T26, at H324	0.70819 ± 0.00029
W5	Water	20.747492	30.331889	Recent Nile, eastern stream	0.70681 ± 0.00024
W4_1	Water	20.751567	30.331883	Recent Nile eastern bank	0.70679 ± 0.00039
W4_2	Water	20.739317	30.337567	Recent Nile eastern bank	0.70682 ± 0.00039
W4_3	Water	20.736017	30.340817	Recent Nile eastern bank	0.70682 ± 0.00039

Table 3 The $n(^{87}Sr)/n(^{86}Sr)$ ratios of all environmental samples investigated (sediments and water), taken at a maximum distance of five kilometres from the New Kingdom town and Pharaonic Cemetery, given with the expanded uncertainties U (k = 2).

the New Kingdom town and Pharaonic cemetery, based on the assumed area for agricultural activities which could be reached by walking (Tab. 3).

In addition, 14 archaeological mollusc shell samples (covering four different species present in the Nile River) retrieved from cellars (SAV 1E, SAV 1W) of the New Kingdom town on Sai Island were analysed as proxies for the historic Nile River water during the New Kingdom (Tab. 4).

Archaeological animal samples were taken from residual remains of rodent and domesticated animals (goat, sheep and dog) (Tab. 4), which were assumed to have pastured close to town or were fed with leftovers from humans. These remains most probably represent an autochthonous Sr isotope ratio of the New Kingdom town on Sai Island.

2.3 Methods

Sample preparation, analysis and evaluation were accomplished at the VIRIS Laboratory (University of Natural Resources and Life Sciences, Vienna). Sample cleaning was performed according to standard protocols.[65] The surface of teeth and the mollusc shells were precleaned using an electric drill (Dremel Moto-Tool, Wisconsin, USA) combined with 100 µm diamond drilling heads. Approximately 5–30 mg of enamel and primary dentine of animal and human teeth and the mollusc shells were sampled using an electrical drill (Dremel). The sample powders from animal samples were mixed with 2 mL 65 % (*w*/*w*) concentrated double sub-boiled nitric acid (further purified from nitric acid p.a., Merck, Darmstadt, Germany) and 1 mL 30 % (*w*/*w*) hydrogen peroxide (Merck). The samples were digested on a hot plate at 150 ºC for 2.5 h. Afterwards, 8 mol L^{-1} nitric acid was added until a total weight of approximately 10 g was reached. The human tooth sampled and mollusc shell powders were mixed with 1.39 mL 65 % (*w*/*w*) concentrated double sub-boiled nitric acid (Merck) and 0.34 mL 30 % (*w*/*w*) hydrogen peroxide (Merck). The samples were digested on a hot plate at 150 ºC for 2 h. Subsequently, 8.27 mL sub-boiled water (purified from Type I reagent-grade water (18 MΩ cm), F+L GmbH, Vienna, Austria)

[65] Irrgeher et al. 2012.

Sample ID	Find number	Animal type	Sample type/ species	$n(^{87}Sr)/n(^{86}Sr)$	Classification
A840	SAV1W 840/2015	Rodent	Whole tooth	0.70723 ± 0.00017	
A844	SAV1W 844/2015	Rodent	Whole tooth	0.70711 ± 0.00017	
A414	SAC5 414/2017	Rodent	Enamel	0.70784 ± 0.00020	
A222	SAC5 222/2015	Rodent	Enamel	0.70726 ± 0.00020	
A955	SAV1E 955/2016	Goat/sheep	Enamel	0.70748 ± 0.00016	
			Dentine	0.70731 ± 0.00016	
A283	SAC5 283/2016	Dog	Dentine	0.70766 ± 0.00016	
M11	SAV1W 11/2015	Mollusc	Corbicula consobrina	0.70785 ± 0.00019	Autochthonous
M830	SAV1W 830/2015	Mollusc	Chambardia rubens	0.70787 ± 0.00022	Autochthonous
M837	SAV1W 837/2015	Mollusc	Nitia teretiuscula	0.70801 ± 0.00022	Autochthonous
M1239	SAV1W 1239/2014	Mollusc	Etheria elliptica	0.70803 ± 0.00019	Autochthonous
M325	SAV1W 325/2017	Mollusc	Etheria elliptica	0.70901 ± 0.00019	Allochthonous
M585	SAV1W 585/2015	Mollusc	Etheria elliptica	0.70874 ± 0.00019	Allochthonous
M82	SAV1W 82/2017	Mollusc	Nitia teretiuscula	0.70895 ± 0.00019	Allochthonous
M1496	SAV1E 1496/2015	Mollusc	Nitia teretiuscula	0.70912 ± 0.00022	Allochthonous
M1620	SAV1E 1620/2015	Mollusc	Etheria elliptica	0.70890 ± 0.00022	Allochthonous
M1626	SAV1E 1626/2015	Mollusc	Etheria elliptica	0.70912 ± 0.00022	Allochthonous
M2093	SAV1E 2093/2014	Mollusc	Etheria elliptica	0.70844 ± 0.00019	Allochthonous
M173	SAV1E 173/2016	Mollusc	Etheria elliptica	0.70874 ± 0.00019	Allochthonous
M484	SAV1E 484/2016	Mollusc	Etheria elliptica	0.70881 ± 0.00019	Allochthonous
M244	SAV1E 244/2016	Mollusc	Nitia teretiuscula	0.70865 ± 0.00019	Allochthonous

Table 4 The $n(^{87}Sr)/n(^{86}Sr)$ ratios of all animal individuals investigated (enamel and dentine) and mollusc samples, given with the expanded uncertainties U (k = 2).

was added to the digests, resulting in a concentration of 2 mol L^{-1} nitric acid.

The mobile Sr fraction of sediments was extracted using ammonium nitrate, following the protocol DIN ISO 19730 (1997).[66] Water samples were filtered and acidified to 2 % (*w*/*w*) with double sub-boiled concentrated nitric acid (65 % *w*/*w*). The sediment extracts and water samples were prepared in 8 mol L^{-1} nitric acid for further purification.

Prior to Sr isotopic analysis, the Sr was separated from interfering matrix elements (mainly Ca, Rb and P). The digested animal tooth, sediment extracts and water samples were manually separated following standard protocol.[67] The human tooth samples digested and the mollusc shell samples digested were automatically separated (Sr-matrix separation) following a standard protocol.[68]

Multi-elemental analysis and screening were performed using an ICP-MS (NexION 350D, PerkinElmer, Waltham, MA, US), according to a standard protocol.[69] The measurement of the $n(^{87}Sr)/n(^{86}Sr)$ ratios was performed using a multi collector ICP-MS (Nu Plasma HR, Nu Instruments Ltd., Wrexham, UK). Separated samples were diluted with nitric acid (2 % *w*/*w*) to attain a mass fraction of 50 ng g^{-1}. A solution of NIST SRM 987 (NIST) was used as an isotopic reference for standard-sample bracketing during Sr isotopic analysis. Mass fractions of samples and standard-sample bracketing standards were matched within 10 %. All diluted samples and NIST SRM 987 solutions were spiked with Zr (Merck-Millipore) to allow for internal inter-elemental instrumental isotopic fractionation correction.[70] A detailed description of the instrument configuration, data collection, blank correction and measurement strategy can be found in Retzmann et al.[71] Combined measurement uncertainties were calculated using a Microsoft Excel spread sheet.[72]

66 Swoboda et al. 2008.

67 Swoboda et al. 2008; Irrgeher et al. 2013.

68 Zimmermann et al. 2019.

69 Retzmann et al. 2017.

70 Yang et al. 2008; Kramchaninov et al. 2012; Irrgeher et al. 2013; Irrgeher et al. 2015; Horsky et al. 2016; Retzmann et al. 2017.

71 Retzmann et al. 2017.

72 Horsky et al. 2016.

2.4 Data reduction

The local environmental $n(^{87}Sr)/n(^{86}Sr)$ ratio range on Sai Island during the New Kingdom was determined by the addition and subtraction of the double standard deviation to and from the mean $n(^{87}Sr)/n(^{86}Sr)$ ratio of a subset of sediment samples (paleo sediments and repository material), including the literature Sr isotope value of Krom et al.[73] for the Nile River water for the New Kingdom era.

An autochthonous $n(^{87}Sr)/n(^{86}Sr)$ ratio range was estimated by the addition and subtraction of the double standard deviation to and from the mean $n(^{87}Sr)/n(^{86}Sr)$ ratio of archaeological animal teeth as a proxy for Sr diet and a subset of mollusc shell samples as a proxy for Sr in Nile River water.

Supposed allochthony and autochthony to the New Kingdom town on Sai Island was classified by comparing the human enamel $n(^{87}Sr)/n(^{86}Sr)$ values to the local environmental and autochthonous Sr ranges.

The biogenic Sr isotopic composition of the primary dentine for the nine individuals was estimated taking possible diagenetic alterations into account. The correction assumed that the source of diagenetic Sr is the repository material. Consequently, the overall Sr isotopic ratio of the primary dentine shifts towards the diagenetic Sr value proportional to the amount of digenetic Sr.[74] The biogenic Sr isotopic signatures in human primary dentine was, therefore, estimated as summarized in equation 1:[75]

$$n(^{87}Sr)/n(^{86}Sr)_{bio} = \frac{n(^{87}Sr)/n(^{86}Sr)_{dentine} - n(^{87}Sr)/n(^{86}Sr)_{rep} \cdot p\%_{dia}}{1 - p\%_{dia}}$$

where $n(^{87}Sr)/n(^{86}Sr)_{bio}$ and $n(^{87}Sr)/n(^{86}Sr)_{dentine}$ are the estimated biogenic and measured (diagenetic) Sr ratios in human primary dentine, $n(^{87}Sr)/n(^{86}Sr)_{rep}$ is the measured Sr ratio of the repository material and $p\%_{dia}$ is the diagenetic proportion. The latter is estimated from the Sr mass fractions β measured in enamel and primary dentine considering the normal modern enrichment factor f_{enrich} for Sr in human (primary) dentine, according to equation 2:

$$p\%_{dia} = \frac{\beta(Sr)_{dentine} - \beta(Sr)_{enamel} \cdot f_{enrich}}{\beta(Sr)_{dentine}}$$

An estimated enrichment factor was calculated from the average Sr mass fractions for modern human enamel and dentine, given in Castro et al.[76] Individual enrichment factors of the study ranged from 1.06 up to 1.72. Similar factors can be calculated for modern herbivores, omnivores and carnivores with data given in Kohn and Moses,[77] and correspond to our own measurements of modern teeth (unpublished results). An average enrichment factor of $f_{enrich} = 1.2$ was applied in subsequent calculations considering an estimated relative uncertainty of 20 % (u_c). The uncertainty contribution has a minor effect on the estimated biogenic Sr signature in human primary dentine. The major contributors for the uncertainty budget of the estimated biogenic Sr signature in human primary dentine are the uncertainties of the $n(^{87}Sr)/n(^{86}Sr)$ ratio measured in diagenetic altered dentine (76 %) and the $n(^{87}Sr)/n(^{86}Sr)$ ratio measured of the repository material (16 %).

3. Results

The $n(^{87}Sr)/n(^{86}Sr)$ ratios of all samples analysed are given in Tables 2, 3 and 4. The Sr isotope ratios of the repository material from Tomb 26 and sediment and water samples taken at a maximum distance of five kilometres from the New Kingdom town and Pharaonic cemetery on Sai Island ranged from 0.70637 to 0.70848 (Tab. 3).

The mean $n(^{87}Sr)/n(^{86}Sr)$ isotope ratio of the four recent Nile River water samples was determined as 0.70681 ± 0.00039, and overlapped with the Sr isotopic signature of the recent Blue Nile River water (0.7065[78]) (Tab. 1), the main source of water (95 %) that flows into the Nile River downstream from Khartoum.[79] Today's Sr isotopic signatures of Nile River water and sediments do not change significantly between the confluence of the White Nile and the Blue Nile River downstream to Cairo.[80] Hence, a similar scenario is believed to be applicable to ancient times. Based on the Sr isotopic signature of the Nile River sediments reported by Krom et al.[81] for the period between 4000 B.P. and 2350 B.P. (= 2050 BC and 400 BC), the $n(^{87}Sr)/n(^{86}Sr)$ isotope ratio of Nile River water is assumed to be 0.7080 – 0.7082 during the New

73 Krom et al. 2002.

74 Montgomery et al. 2007; Copeland et al. 2010

75 Copeland et al. 2010; Kreutz 2011.

76 Castro et al. 2010.

77 Kohn and Moses 2013.

78 Talbot et al. 2000.

79 Buzon et al. 2007.

80 Buzon et al. 2007.

81 Krom et al. 2002.

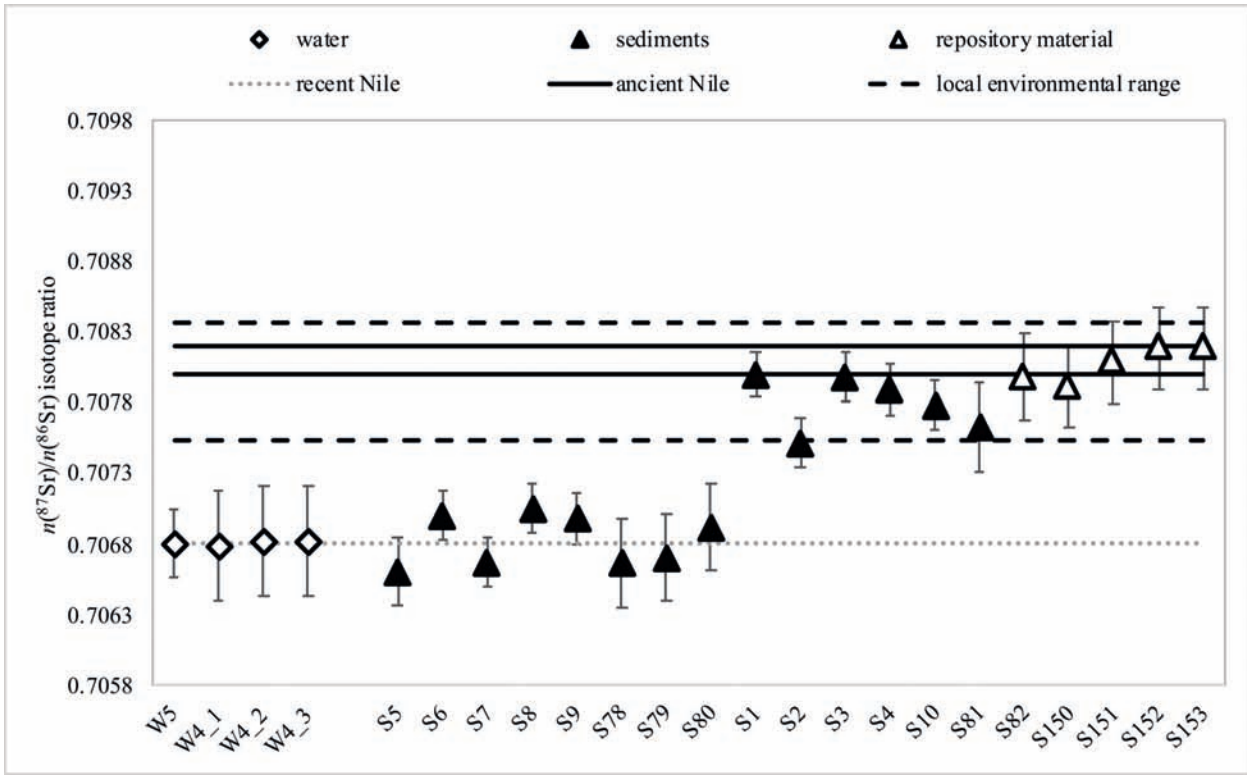

Fig. 1 The $n(^{87}Sr)/n(^{86}Sr)$ ratios of the environmental samples (sediments, repository material and recent Nile River water) and determined local environmental Sr range, including literature Sr isotope value for Nile River water during New Kingdom (Krom et al. 2002). *Error bars* correspond to expanded uncertainties U (k = 2).

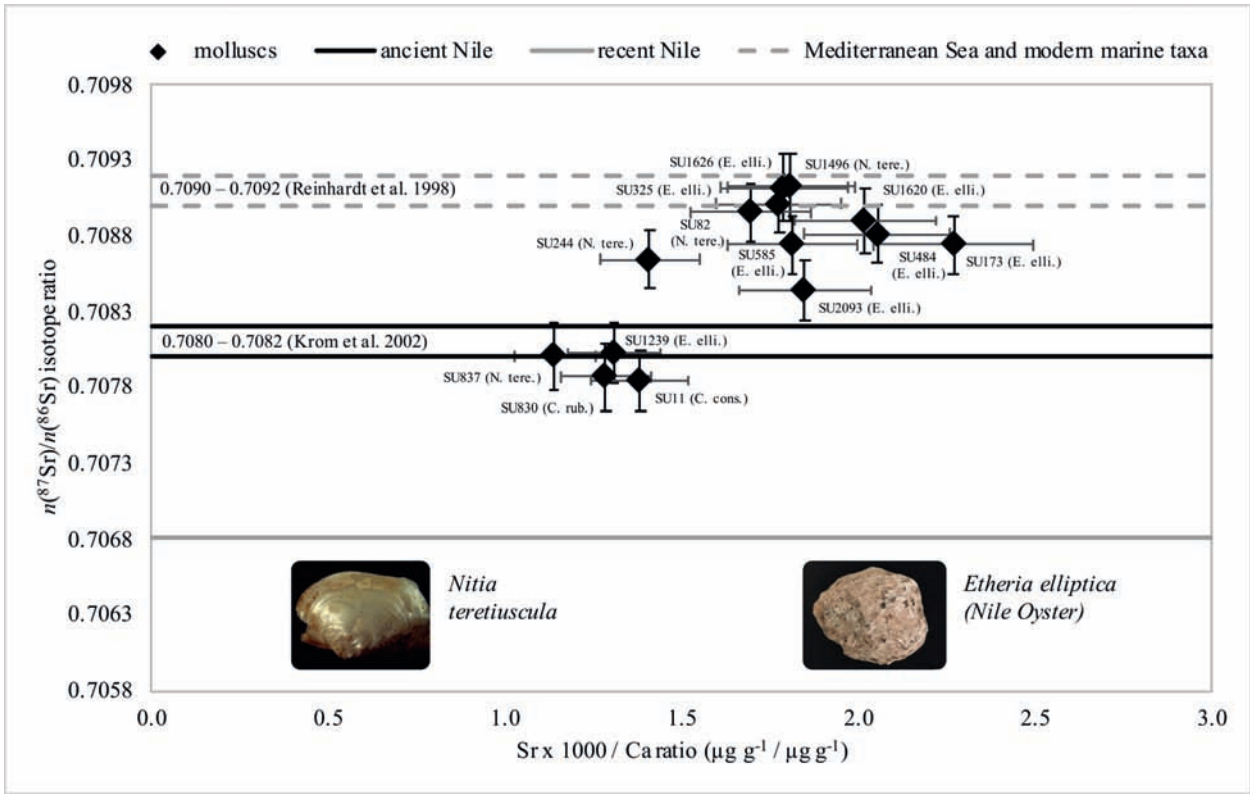

Fig. 2 The $n(^{87}Sr)/n(^{86}Sr)$ ratios plotted against the Sr x 1000 / Ca mass fraction ratios of all investigated mollusc samples, including literature Sr isotope value for Nile River water during New Kingdom (Krom et al. 2002), for Mediterranean Sea and for modern marine taxa (Reinhardt et al. 1998). *Error bars* correspond to expanded uncertainties U (k = 2).

Kingdom. The Sr signatures of the recent and the ancient Nile River water did not overlap within uncertainty.

The $n(^{87}Sr)/n(^{86}Sr)$ isotope ratios of the 19 sediments and repository materials sampled formed two clusters, which did not overlap within uncertainty (Fig. 1). The sediment cluster with the lower Sr isotopic ratios (0.70637 – 0.70724) overlapped with the recent Nile River water value of the present study. Krom et al.[82] report that similar Sr isotopic signatures are also obtained for recent sediment collected downstream of the confluence of the Atbara and main Nile River in northern Sudan (0.7057 and 0.7066), which is consistent with a dominant contribution (> 97 % for sediments[83]) from the volcanic rocks of the Ethiopian Highlands.[84] The sediment cluster with the higher Sr isotopic ratios (0.70734 – 0.70848) overlapped with the Sr isotope ratio of Nile River sediment and the Nile River water, reported by Krom et al.,[85] for the New Kingdom (Fig. 1). Hence, the literature Sr isotope values for the ancient Nile River water and the sediment cluster with higher Sr ratios (from paleo sediments and repository material) were considered to represent the local environmental Sr isotope signature on Sai Island during the New Kingdom. The local environmental Sr isotope ratios determined ranged from 0.70754 to 0.70837, which is comparable to the previously published preliminary local environmental range of Tombos (0.70732 – 0.70789),[86] ca. 100 km upstream on the Nile River (Tab. 1).

The $n(^{87}Sr)/n(^{86}Sr)$ isotope ratios of the mollusc shell samples resulted in two clusters, which did not overlap within uncertainty (Fig. 2). The cluster of the lower Sr signatures (0.70765 – 0.70822) included one sample per species (*Nitia teretiuscula*, *Etheria elliptica*, *Chambardia rubens*, *Corbicula consobrina*), and overlapped within uncertainty with the Nile River water range reported during the New Kingdom. Therefore, these four mollusc samples were classified as autochthonous to Sai Island and support the assumed Sr isotopic signature of the ancient Nile River water. The four mollusc shell samples were further included in the interpretation of an autochthonous signal as a proxy for Nile River water and, thus, as a signal for possible drinking water sources.[87]

The mollusc shell cluster of higher Sr values (0.70825 – 0.70934, including three *Nitia teretiuscula* and seven *Etheria elliptica*) did not overlap with the ancient Nile River water. The values were even higher than the local environmental range determined on Sai Island during the New Kingdom. Therefore, these molluscs were classified as allochthonous to Sai Island and, consequently, not included in the calculation of an autochthonous Sr isotope range.

The $n(^{87}Sr)/n(^{86}Sr)$ ratios of three (from a total of six) archaeological animal tooth samples (including the goat/sheep and the dog) overlapped with the lower limit of the local environmental range, while the other three archaeological animal tooth samples (rodent) showed $n(^{87}Sr)/n(^{86}Sr)$ ratios lower than the local environmental range calculated (Fig. 3). Since rodents are known for their limited habitat size area and assumed to be fed partly from human food sources, similar to the domestic dog, all archaeological animal tooth samples were included in the interpretation of an autochthonous Sr signal.

The resulting autochthonous $n(^{87}Sr)/n(^{86}Sr)$ ratio signature (including animal tooth and mollusc shells) of the New Kingdom town on Sai Island ranged from 0.70693 to 0.70828, encompassing the local environmental Sr isotopic range (Fig. 3), and represented the $n(^{87}Sr)/n(^{86}Sr)$ signal, which can be interpreted as most probably bioavailable for human individuals.

The $n(^{87}Sr)/n(^{86}Sr)$ ratios of the repository materials from burial environments are listed in Table 3. The Sr isotopic composition of repository material was further used to estimate the biogenic Sr isotopic composition of human primary dentine. The repository material S82 was used as reference to estimate biogenic Sr isotopic signatures of human individuals H367 and H356. The repository material S151 was used as reference to estimate

82 Krom et al. 2002.

83 Padoan et al. 2011; Woodward et al. 2015.

84 Krom et al. 2002.

85 Krom et al. 2002.

86 Established based on Sr isotope ratios of four samples of burial soil from the Tombos chamber tombs, of one archaeological bone (sheep or goat) from a New Kingdom trash pit nearby the Tombos cemetery site, and only one modern cow tooth local to Tombos. Buzon et al. 2007.

87 The edible mollusc bodies were not approximated by the Sr signature of the shell.

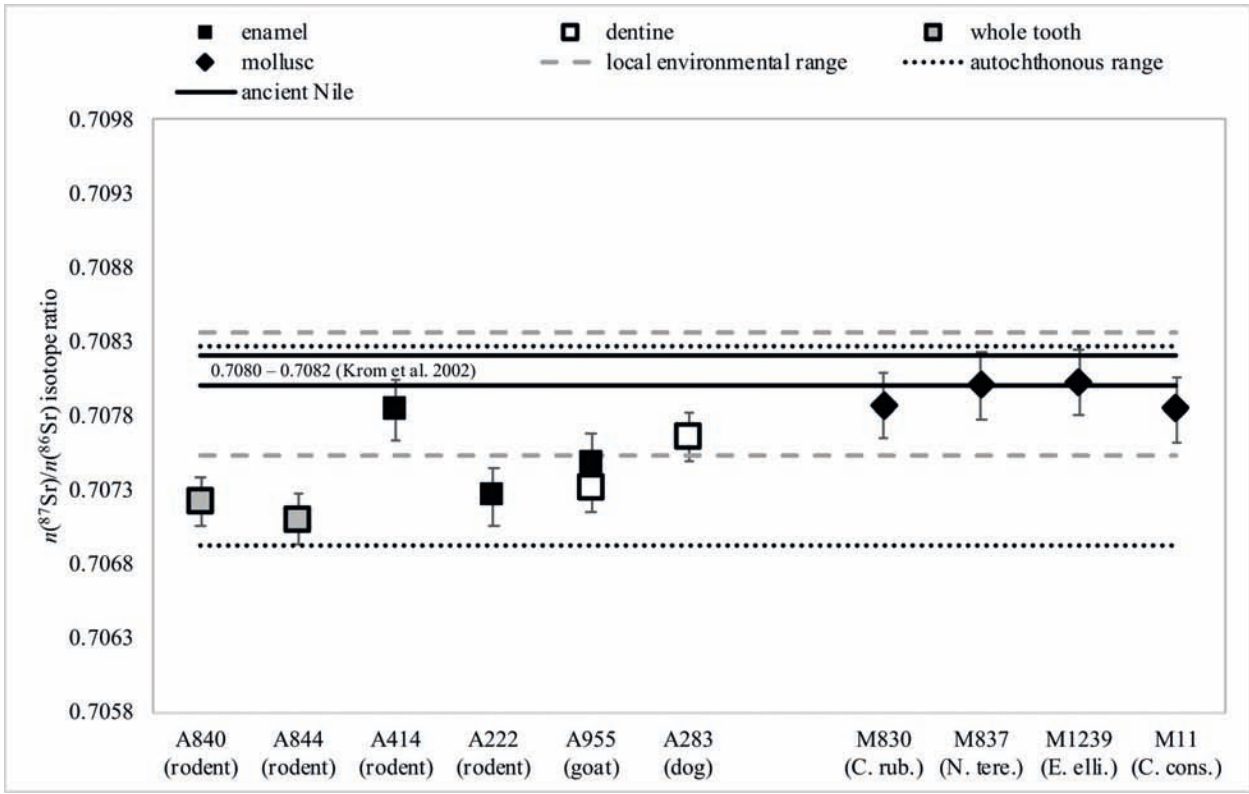

Fig. 3 The $n(^{87}Sr)/n(^{86}Sr)$ ratios from the archaeological animal tooth and allochthonous mollusc samples, and the determined autochthonous Sr range, compared to the determined local environmental Sr range, including literature Sr isotope value for Nile River water during New Kingdom (Krom et al. 2002). *Error bars* correspond to expanded uncertainties U (k = 2).

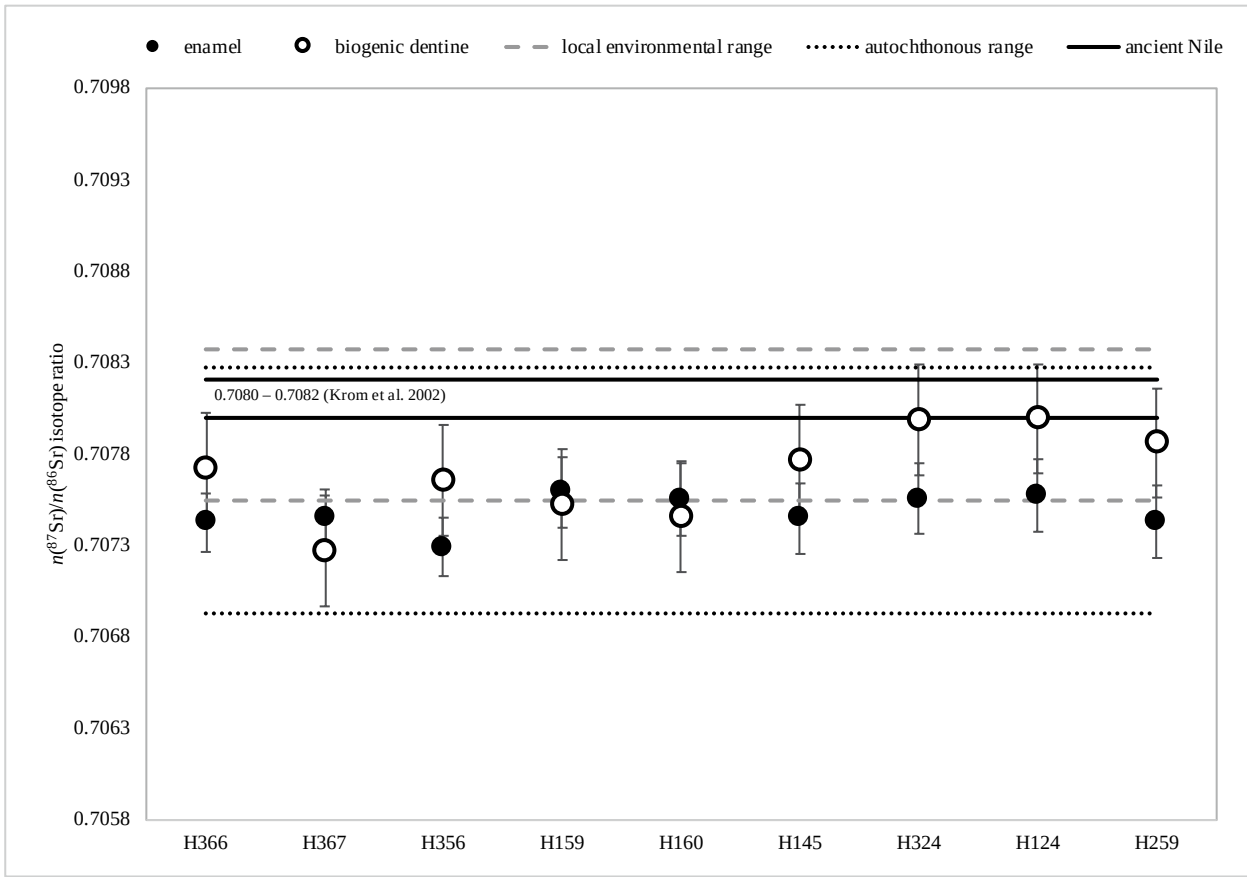

Fig. 4 The $n(^{87}Sr)/n(^{86}Sr)$ ratios of enamel and biogenic primary dentine from all human individuals investigated, compared to the autochthonous Sr range, including literature Sr isotope value for Nile River water during New Kingdom (Krom et al. 2002). *Error bars* correspond to expanded uncertainty for enamel U (k = 2) and combined uncertainty for biogenic primary dentine u_c (k = 1).

biogenic the Sr isotopic signature of human individual H160. In case of human individual H259, where no repository materials was directly associated, the mean $n(^{87}Sr)/n(^{86}Sr)$ isotope ratio of the repository materials (0.70807 ± 0.00031) was used.

3.1 Classification of human individuals from Tomb 26 using enamel data

The Sr mass fractions in human enamel ranged from 173 µg g^{-1} to 366 µg g^{-1}. Normal modern Sr mass fractions of human enamel are known to be geographically variable, but the enamel values overlapped with the typically reported modern values of 50 µg g^{-1} to 300 µg g^{-1}.[88] Moreover, human enamel revealed no or only slightly elevated mass fractions for V, Mn and U (Tab. 1). This suggested a negligible degree of diagenetic alterations of human enamel samples and supported the conclusion that the Sr mass fractions of enamel of the nine human individuals investigated from Tomb 26 were considered as biogenic.

The $n(^{87}Sr)/n(^{86}Sr)$ ratios of enamel from all human individuals investigated overlapped within uncertainty and showed a narrow range of 0.70713 – 0.70778. This range lay within autochthonous Sr range, and overlapped within uncertainty with the local environmental Sr range (Fig. 4). Thus, the individuals investigated were classified as supposedly autochthonous individuals. No other study from the Middle Nile shows such a narrow range within the human population investigated. The $n(^{87}Sr)/n(^{86}Sr)$ ratios of the (local) population reported during the New Kingdom at Amara West (0.70733 – 0.70817[89]), located in the Second Cataract area a 20 km downstream, encompasses the Sr signature of the local population during the New Kingdom on Sai Island (Tab. 1).

3.2 Diagenetic status of human primary dentine and potential biogenic information

The Sr mass fractions in human primary dentine ranged from 338 µg g^{-1} to 640 µg g^{-1}. Even though normal modern Sr mass fractions of human primary dentine are known to be geographically variable, the primary dentine values did not overlap with the typically reported modern values of 50 µg g^{-1} to 300 µg g^{-1}.[90] Based on the average Sr mass fraction of enamel and the enrichment of the Sr mass fraction of primary dentine relative to enamel (1.2[91]), the biogenic Sr fraction assumed for primary dentine of human individuals on Sai Island during the New Kingdom was calculated and ranged from 165 µg g^{-1} to 398 µg g^{-1}. Except for individual H366, the Sr mass fraction of human primary dentine lay above this range (Tab. 2). Expecting an *in vivo* assimilation,[92] the elevated Sr mass fractions of human primary dentine were observed to be increased by diagenetic processes.[93] Multi-elemental analysis of human primary dentine determined mass fractions for V (20 µg g^{-1} – 52 µg g^{-1}), for Mn (8 µg g^{-1} – 1546 µg g^{-1}) and for U (0.1 µg g^{-1} – 5.1 µg g^{-1}), which were higher than the estimated maximum *in vivo* contents published by Kamenova et al.[94] Since more than one mass fraction of the diagenesis indicator elements was elevated in the human primary dentine, a diagenetic alteration was assumed.[95]

The biogenic Sr mass fraction for human primary dentine was estimated based on the Sr mass fraction of the according enamel sample multiplied by 1.2[96] (to account for enrichment of the Sr mass fraction of human primary dentine in relation to enamel). The determined diagenetic proportions of Sr in human primary dentine ranged from 0 % to 58.5 % (Tab. 2). Accordingly, the estimated biogenic $n(^{87}Sr)/n(^{86}Sr)$ ratios of human primary dentine overlapped within uncertainty with the local environmental and autochthonous Sr ranges (Fig. 4). However, one can see a slight difference between the $n(^{87}Sr)/n(^{86}Sr)$ ratios of enamel and the estimated biogenic primary dentine for six of the investigated individuals (H366, H356, 145, H324, H124, H259), with primary dentine Sr values approaching towards the Nile River signature during the New Kingdom era.

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88 Montgomery et al. 2007; Castro et al. 2010; Dudás et al. 2016.

89 Buzon and Simonetti 2013.

90 Montgomery et al. 2007; Castro et al. 2010; Dudás et al. 2016.

91 Calculated from the average Sr mass fraction for modern human enamel and dentine, based on data presented by Castro et al. 2010.

92 Budd et al. 2000; Dudás et al. 2016.

93 Castro et al. 2010; Chiaradia et al. 2003.

94 Kamenov et al. 2018.

95 Kohn and Moses 2013; Kamenov et al. 2018.

96 Calculated from the average Sr mass fraction for modern human enamel and dentine, based on data presented by Castro et al. 2010.

4. Discussion

4.1 Local environmental and autochthonous Sr signatures for the New Kingdom era

The classification of allochthonous and supposedly autochthonous individuals was generally conducted based on the determination of an autochthonous (commonly also called bioavailable) $n(^{87}Sr)/n(^{86}Sr)$ isotope range of the habitat under investigation. The autochthonous Sr signature in the food chain cannot be derived directly from the known Sr isotopic composition of the underlying bedrock geology,[97] and significant heterogeneity in Sr signatures of the different compartments in a given habitat can occur.[98]

Hence, in the present study, a local environmental Sr range was established under the following considerations: even though the modern flow regime of the Nile River settled at the beginning of the Holocene wet phase (ca. 10 000 BC),[99] fluctuation in the water and sediment discharge occurred, leading to fluctuating Sr isotope ratios of the Nile River sediment in the delta ranging between 0.7088 and 0.7075 over the past 7000 years.[100] During higher river flow, a significantly decreased input of Blue Nile–derived water and sediment occurred, which alternated the $n(^{87}Sr)/n(^{86}Sr)$ isotope ratios of Nile River water and sediments.[101] The climate became drier during the late New Kingdom. Consequently, greater proportions of windborne dust were deposited into floodplain soils.[102] Subsequently, this means that recent local environmental samples (sediment/plants/water) cannot be seen as representative of the local environmental Sr signature of Sai Island during the New Kingdom. Nevertheless, Sr signatures of plant material are seen to be more probably representative for the local biosphere Sr values compared to the extractable Sr fraction of soils/sediments.[103] However, in the absence of archaeological vegetation remains in the present study, the extractable Sr from paleo sediments dating from the New Kingdom and the literature Sr isotope value for the ancient Nile River signature at 2050 BC to 400 BC[104] are used to determine the local environmental Sr range and seen as an indicator for an autochthonous Sr signal of the New Kingdom town on Sai Island, and a reasonable proxy to capture the variability of Sr isotopic signals in the local environment of Sai Island during the New Kingdom.

Furthermore, in the present study, an autochthonous Sr range was established to estimate the Sr fraction, which is taken up via the food chain. Herein, a simplified approach from the concept of mixing models[105] was applied combining different sources representing bioavailable Sr (Sr that can potentially be taken up by living organisms) in nutrition supplies (food/water) of the given habitat, under the following circumstances: in general, the preservation of archaeological food (e.g. archaeological vegetation remains) and beverage supplies are crucial and in most archaeological contexts, have only limited availability. In the case of the New Kingdom town on Sai Island, no archaeological nutrition supplies have been available for Sr isotopic analysis so far. However, previous studies of the recent river water in the Blue Nile River[106] and in the Nile River's delta[107] successfully used modern mollusc shell samples as a proxy for the $n(^{87}Sr)/n(^{86}Sr)$ isotope ratios. Especially in the case of the Nile River, where the similarity of $n(^{87}Sr)/n(^{86}Sr)$ ratios of modern and historic waters is not given,[108] archaeological mollusc shell samples are identified as a powerful proxy to validate the Sr isotopic signature of the ancient Nile River water during the New Kingdom and are taken as a representative source of Sr for possible drinking water. In the absence of archaeological nutrition supplies, the local bioavailable $n(^{87}Sr)/n(^{86}Sr)$ signature can be estimated making use of presumably local (archaeological) animal remains,[109] assuming that they have mainly incorporated the locally bioavailable Sr.[110] In the light of fluctuations in Nile River water and sediment sources,[111] and variations in floodplain soils,[112]and the consequence

97 Price et al. 2002.
98 Price et al. 2002.
99 Talbot et al. 2000.
100 Krom et al. 2002.
101 Krom et al. 2002.
102 Woodward et al. 2015.
103 Maurer et al. 2012; Ryan et al. 2018.
104 Krom et al. 2002.
105 Lengfelder et al. 2019.
106 Talbot et al. 2000.
107 Reinhardt et al. 1998
108 In contrast to observations by Maurer et al. 2012.
109 e.g. Grupe et al. 1997; Price et al. 2002; Bentley and Knipper 2005; Maurer et al. 2012.
110 Lengfelder et al. 2019.
111 Krom et al. 2002.
112 Woodward et al. 2015.

that modern animals (especially domesticated animals) might have Sr sources other than those during the New Kingdom, only residual and domesticated archaeological animals,[113] which fed most presumably locally in the same habitat as the humans,[114] are considered for a representative autochthonous Sr signal of the New Kingdom town on Sai Island.

The resulting autochthonous Sr range of Sai Island is comparable to those determined from archaeological animals of the Second Millennium BC in Askut, at a C-Group site in the SJE concession and Amara West located in the Second Cataract area, and the extended range based on modern rodent samples of Tombos[115] (Tab. 1). Autochthonous ranges determined from faunal samples from the Northern Dongola Reach[116] and Ginefab School site,[117] both located in the Fourth Cataract region, are lower compared to Sai Island (Tab. 1).

4.2. Allochthonous molluscs

Considering that the Nile River water and sediments had been similar in Sr isotopic ratios from the confluence of the White Nile and the Blue Nile River downstream till Cairo also during the New Kingdom, the origin of the allochthonous molluscs (with a Sr isotope composition ranging from 0.70825 to 0.70934) might be found either in waters from limestone formations (e.g. Theban limestone assumed to be 0.70907 ± 0.00026[118]) with $n(^{87}Sr)/n(^{86}Sr)$ ratios higher than the Nile River water, or in the Nile River delta, which is influenced by the Mediterranean Sea water (0.709172) in the estuary.[119] For the latter, isotopic homogeneity of Sr is accepted at any instant of geological time.[120] Reinhardt et al. have reported a Sr isotopic composition ranging from 0.7090 to 0.7092 for modern marine taxa (including molluscs) in the high saline Nile River delta.[121] Six of the allochthonous mollusc samples investigated overlap within uncertainty with this Sr isotopic range (Fig. 2). In addition, the cluster of mollusc shells with higher Sr isotopic signatures is also characterized by a higher Sr x 1000 / Ca ratio of 1.27 µg g^{-1}/µg g^{-1} to 2.50 µg g^{-1}/µg g^{-1}, which correlated with higher Sr mass fractions in comparison to the autochthonous Nile River molluscs of the Sai Island region. This is seen as an additional indicator pointing towards a possible provenance from the high saline Nile River delta (Sr mass fraction of the Mediterranean Sea water of 9 µg g^{-1}).

(Zoo-)Archaeological interpretation

Etheria elliptica (= freshwater oyster) had been widespread in Africa, but is today considered as rare in the Nile and extinct in the Lower Nile in Egypt.[122] In Sudan, shells have recently been found at the Second Cataract.[123] However, the Pleistocene to Holocene distribution of *Etheria elliptica* was less fragmentary in Egypt and Sudan.[124] Within the archaeological findings of the New Kingdom town on Sai Island, the species is the most common mollusc. However, seven out of eight *Etheria elliptica* shells were classified as allochthonous by Sr isotopic analysis. The second species attesting allochthonous molluscs in the New Kingdom town on Sai Island is *Nitia teretiuscula*, which occurs in the Lower Nile and White Nile, including some African Lakes. Late Pleistocene – Holocene records include archaeological findings in Upper Egypt[125] and Sudan.[126] Three out of four *Nitia teretiuscula* shells were classified as allochthonous.

At present, it remains unclear why allochthonous mollusc shells were found at Sai Island in archaeological contexts. Autochthonous and allochthonous mollusc samples (including *Nitia teretiuscula*, *Etheria elliptica*, *Chambardia rubens* and *Corbicula consobrina*) were found in the cellar of SAV1W, whereas only allochthonous mollusc samples (*Nitia teretiuscula* and *Etheria elliptica)* were retrieved from the cellar of SAV1E (Tab. 4). The cellar at SAV1E (feature 15) seems to be related to the Egyptian temple of the town and was interpreted as a storage room connected with the tributes to Egypt which were collected in Nubia.[127] The allochthonous mollusc samples

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113 Trade, exchange of animals or animal products and unknown nutrition habits and preferences might hamper the determination of an autochthonous signal.

114 Maurer et al. 2012.

115 Schrader et al. 2019.

116 Buzon and Simonetti 2013.

117 Masoner et al. 2011, cited in Buzon and Simonetti 2013; Schrader et al. 2019.

118 Buzon et al. 2007.

119 Reinhardt et al. 1998.

120 Veizer 1989.

121 Reinhardt et al. 1998.

122 Van Damme and Van Bocxlaer 2009.

123 Marin 1968.

124 Van Damme 1984; Rodrigues et al. 2000.

125 Germain 1909.

126 Arkell 1953.

127 Budka 2015a, 44–45; 2017d, 18.

might, therefore, be explained as part of a collection of exotic products with widespread provenances. However, the question about the function of the molluscs within the New Kingdom town of Sai remains unanswered. Various human uses of *Etheria elliptica* in Africa are documented generally, from archaeological findings to modern records.[128] Furthermore, they were used as burial gifts in graves at Karnak and Ballas.[129] On Sai Island, the consumption of the mollusc bodies is possible,[130] but a high number of allochthonous findings could attest to another use. Perhaps the *Etheria elliptica* were used as a raw material/ingredient for producing plaster or mortar, as this is known from recent African tribes.[131] It is possible that *Nitia teretiuscula* shells were intentionally collected by people as food, tools and and/or ornamentation and, in this case, presumably outside Sai Island.

However, one needs to stress that the number of mollusc sample analyses for Sr isotope ratios from Sai is still very small and more material and comparable data from neighbouring sites and areas within the Middle Nile would be necessary to allow for a more detailed interpretation.

4.3 Supposedly autochthonous individuals from Tomb 26

The population investigated dating from the New Kingdom on Sai Island showed a quite narrow range of the measured $n(^{87}Sr)/n(^{86}Sr)$ ratios of tooth enamel (0.70713 – 0.70778) (Fig. 4, Tab. 2). This indicates an autochthonous population given that a substantial degree of diagenetic alteration can be excluded (which would also lead to a narrow spread[132]).

Comparison to other human migration studies from the Middle Nile

Previous studies have identified a substantial proportion of allochthonous individuals within the populations dating from the Middle and New Kingdom at the sites of Tombos (13 % – 35 %[133]), Abu Fatima (24 %[134]), Hannek (25 %[135]) and Kerma (13 %[136]). These observations indicate that these sites in the area of the Second and Third Cataracts have been home to both locals and immigrants, and suggest that complex migration networks existed during the New Kingdom.[137] Individuals with higher Sr signatures than the autochthonous Sr range were probably of Egyptian origin, whereas individuals with lower Sr signatures in their skeleton (the more rare scenario) than the autochthonous Sr range probably originated from the southern Nubian region.[138] Buzon and Simonetti suggest that late New Kingdom populations[139] and populations at Nubian sites without strong Egyptian presence[140] tend to show lower, most probably Nubian, $n(^{87}Sr)/n(^{86}Sr)$ values.

Sr isotope ratio analysis of the present study revealed that all individuals from Tomb 26 investigated are supposedly autochthonous. Eventually, no allochthonous individuals are identified in the population dating from the New Kingdom on Sai Island, so far. However, since Sr signatures determined of human individuals investigated from Sai Island overlap with the autochthonous Sr ranges at Askut, the SJE concession, Amara West, Tombos and the Northern Dongola Reach (Tab. 1), migration on a small-scale between the Egyptian and Nubian centres in the Second and Third Cataract areas cannot be excluded.

Archaeological interpretation

The archaeological interpretation of the findings in Tomb 26 has to keep the phenomenon of the 'Egyptianisation' of Upper Nubia in mind, which becomes particularly evident through the funerary remains in elite cemeteries such as SAC5. Major motivators for becoming overwhelming Egyptian in New Kingdom Nubia were probably the access to power, increased opportunity within the new system and simply convenience.[141] This implied speaking Egyptian, adopting an Egyptian name and cultivating an Egyptian appearance as a per-

128 Pilsbry and Bequaert 1927; Arkell 1953; compiled in Van Damme 1984.

129 Germain 1909.

130 For Nile oyster collecting at other sites in Nubia, see Kobusiewicz 1989.

131 Cf. Pilsbry and Bequaert 1927.

132 Copeland et al. 2010.

133 Buzon et al. 2016; Schrader et al. 2019.

134 Schrader et al. 2019.

135 Schrader et al. 2019.

136 Buzon and Simonetti 2013.

137 Schrader et al. 2019.

138 Buzon and Simonetti 2013; Schrader et al. 2019.

139 Buzon et al. 2016.

140 Buzon and Simonetti 2013.

141 Morris 2018, 224.

son of Nubian origin. It is quite likely that successful players in the higher social strata were then in turn becoming role models[142] for fellow Nubians who followed their example. One of these successfully converted citizens of the New Kingdom town on Sai Island might very well have been the Overseer of Goldsmiths Khnummose, whose Egyptian-style burial was discovered in Tomb 26 with a Sr isotope signature suggesting locality to the region of Sai Island. It still remains possible that Khnummose was an offspring of an Egyptian colonist who came to Sai Island during the early 18th Dynasty. It is, however, equally possible that a person appearing completely Egyptian based on his burial style and burial gifts, and carrying an Egyptian title, had roots in the indigenous population of Upper Nubia, which had been confronted with Egyptian culture ever since the campaigns of Ahmose.[143]

4.4 Sr in primary dentine – diagenetic challenge and potential

Previous human migration studies from the Middle Nile by Buzon et al. and Schrader et al. have observed that the measured $n(^{87}Sr)/n(^{86}Sr)$ ratios of human enamel of the population at Tombos of the New Kingdom have not correlated with the Sr mass fractions for each sample. In addition, the U content in their enamel samples has been close or below the detection level, assuming natural occurrence of U in ground water. Hence, the authors have concluded that the enamel samples have not been altered by diagenetic processes.[144] In the present study, the U content of the recent Nile River water samples investigated was < 0.4 ng g^{-1} and ranged from 1 ng g^{-1} to 6 ng g^{-1} in the sediments analysed. Hence, the absence of elevated U contents in tooth samples might be an insufficient indicator of diagenetic alterations caused by the environment on Sai Island (possibly even the Nile Valley). Therefore, further diagenetic parameters, such as V and Mn,[145] were considered, which indicated a high degree of post-mortem alterations of human primary dentine samples (section 3.2).

Hence, a mathematical approach was tested in order to correct the Sr isotope ratios in human primary dentine for diagenetic alteration considering a diagenetic Sr proportion and the Sr isotopic composition of the repository material (see section 2.4). When using Sr mass fractions of human enamel to calculate the diagenetic proportion of primary dentine, it has to be considered that the individual enrichment factor between modern human enamel and primary dentine shows large variations (1.06 – 1.72[146]), and with residual changes, the Sr mass fraction can also change. The calculated enrichment factor (1.2[147]) of modern human primary dentine in comparison to its enamel, as used in the present study, is in good agreement with enrichment factors of Sr calculated for modern herbivores (1.37), omnivores (1.10) and carnivores (1.27), based on the data presented by Kohn and Moses.[148] Furthermore, the major contributors for the uncertainty budget of the estimated biogenic Sr signature in human primary dentine are the uncertainties of the measured $n(^{87}Sr)/n(^{86}Sr)$ ratio in diagenetic altered dentine (76 %) and the measured $n(^{87}Sr)/n(^{86}Sr)$ ratio of the repository material (16 %). The variability of the enrichment factor neither affects the estimated biogenic Sr signature in the human primary dentine nor the uncertainty budget of it. Similar is true for changes of up to 20 % (*w*/*w*) in the Sr mass fraction of the enamel.

The biogenic $n(^{87}Sr)/n(^{86}Sr)$ ratios for the human primary dentine of the individuals H366, H356, H145, H324, H124 and H259, which were estimated using the mathematical approach, indicated a difference to the $n(^{87}Sr)/n(^{86}Sr)$ ratios of their enamel, which overlap slightly within uncertainty. Herein, a group of three human individuals (H324, H124, H259) revealing higher estimated biogenic Sr isotope ratios in the primary dentine (0.70756 – 0.70829) compared to the rest of the investigated population is noticeable (Fig. 4).

The period of an individual's life potentially preserved in their dentine, for example, as an elemental fingerprint or (biogenic) Sr isotopic signature is controversially discussed. The formation period of human dentine differs significantly from that of human enamel, for example, the incremental growth of human first molar enamel starts formation at birth and continues until completion at 3.5 years of age, whereas human first molar prima-

142 Cf. Morris 2018, 224.

143 See Budka 2018.

144 Buzon et al. 2007; Buzon and Simonetti 2013; Schrader et al. 2019.

145 Kamenov et al. 2018.

146 Castro et al. 2010.

147 Calculated from the average Sr mass fraction for modern human enamel and dentine, based on data presented by Castro et al. 2010.

148 Kohn and Moses 2013.

ry dentine continues formation minimally until apical closure of the tooth root[149] at 9.5 years of age.[150] Nanci has stated in his textbook on oral histology that once secreted during adolescence and early adulthood, human primary dentine does not remodel or undergo significant metabolic or structural changes. Then again, the odontoblasts lining the pulp chamber of human primary dentine retain the ability to produce new dentine for life,[151] and human secondary and tertiary dentine form throughout life.[152] This leaves unsolved and challenging questions about structural changes of dentine during the lifespan of an individual. Moreover, a limited number of studies indicate potential regeneration and remodelling of dentine layers, providing information about the elemental and isotopic composition related to more recent exposure/uptake.[153]

5. Conclusion

Sr isotope ratio analysis again proved to be a valuable tool to investigate potential mobility in archaeological contexts. In this study, because of fluctuations in Nile River water and sediment sources over geological time, paleo sediments from Sai Island and literature Sr isotope value for the ancient Nile River were considered a reasonable proxy for the Sr isotopic signal of the local environment during the New Kingdom. Furthermore, an autochthonous Sr isotopic range was determined based on residual and domesticated archaeological animals and local mollusc shell samples representing the most likely bioavailable Sr signature from food and drinking water sources available to human individuals at the time.

The careful consideration of representative local environmental and autochthonous Sr ranges enabled the classification of the humans investigated from Tomb 26 as supposedly autochthonous individuals. They belonged to the local New Kingdom elite population on Sai Island, well attested by their Egyptian-style burials. Considering the 'Egyptianisation' of Upper Nubia, the Overseer of Goldsmiths Khnummose and his family might represent successfully converted citizens.

The mathematical approach tested indicated the potential to determine biogenic Sr signatures in diagenetic altered primary dentine tissue. The estimated biogenic Sr isotopic signature of human primary dentine might reveal additional information about the past living conditions of a historic individual compared to the information gained from the enamel. This consideration is based on different formation times of enamel compared to dentine. Nonetheless, the estimated dentine data have to be considered with care.

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149 Arana-Chavez and Massa 2004.

150 AlQahtani et al. 2010.

151 Nanci 2013.

152 Shepherd et al. 2012; Beaumont et al. 2015.

153 Castro et al. 2010; Fortes et al. 2015.

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