Microseismic Activity in Low-Hazard Geothermal Settings in Southern Germany

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Abstract

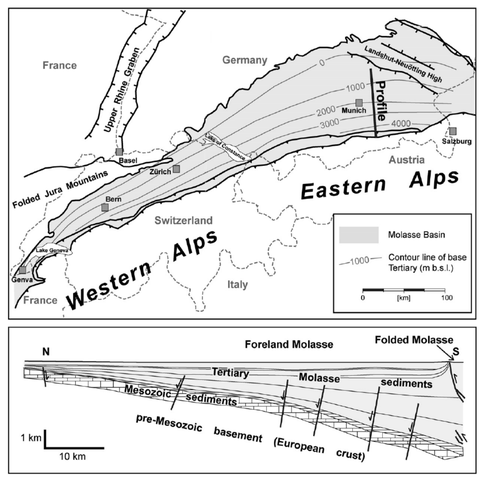
In 2008, an M_l 2.3 earthquake south of Munich attracted public attention. The event happened near a geothermal power plant that took up production about six months earlier. The Bavarian Molasse Basin is generally considered as aseismic. As several geothermal facilities are currently in planning and construction stages, it was decided to install a temporary network to monitor the observed seismicity and investigate possible reasons and implications.
Over the course of about 18 months more than 40 events mainly ranging from M_l 0 to 1.5 with 5 events of a local magnitude above 2.0 were detected. Absolute locations in a 3D velocity model show the hypocenters close to the bottom of the re-injection well.
Further work includes refinement of hypocenter locations using differential techniques on existing event clusters and estimation of source mechanisms to allow a clearer association with mapped fault structures. Questions remain about the exact forcing mechanism of the man-made influence on the observed seismicity and the unique features of the monitored reservoir. These aspects will be investigated in the framework of the upcoming MAGS project.

Setting and Station Network

The Bavarian Molasse Basin in southern Germany provides conditions well suited for geothermal exploitation. Many geothermal facilities are already in production and several larger geothermal power plants are under construction.

Bavarian Molasse Basin

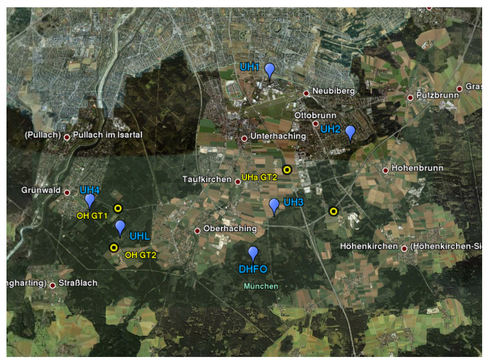
- Malm
  - karstified and fractured limestone formation
  - dipping south, at ≈ 4 km depth near Munich
  - natural aquifer
- suited for operation of geothermal power plants
  - high temperatures (> 120°C)
  - high production rates possible (> 150 l/s)
- exploitation commonly regarded as harmless
  - sparse natural seismicity, region mainly considered as aseismic
  - no need for hydraulic stimulation and hydrofracing
- but:
  - Malm fracture zones are prospected and deliberately targeted by production wells



Sketch of regional geological setting. (from Reinecker et al. [3])

Station Network

- temporary stations to monitor seismicity south of Munich partly funded through LIAG
- difficult noise conditions
  - area of Greater Munich with relatively dense population
  - many roads / speedways around epicentral region



Network map. Stations are indicated by blue pins, locations of well bottoms of geothermal plants are indicated by yellow circles.

(Map: Google Earth)

References

[1] Fertig, J., 1986. Scherwellen in der angewandten Geophysik. 6.Mintrop-Seminar, DVGI-Fachausschuß Geophysik.

[2] Lin, G., Shearer, P., 2007. Estimating Local Vp/Vs Ratios within Similar Earthquake Clusters. Bulletin of the Seismological Society of America.

[3] Reinecker, J., Tingay, M., Müller, B., Heidbach, O., 2009. Present-day stress orientation in the Molasse Basin. Tectonophysics.

Seismicity and Event Locations

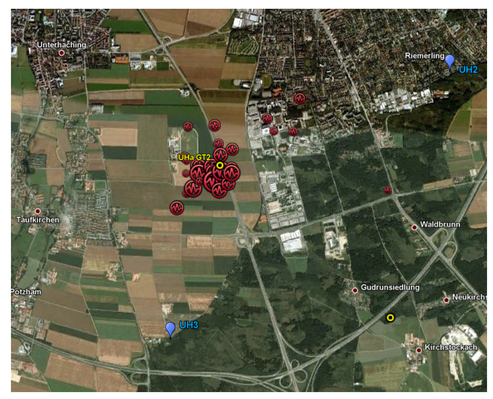
Since the first felt event in February 2008 more than 40 microseismic events were detected with temporary stations in the epicentral region. The distribution of epicenters and hypocenters clearly suggests a connection to the fluid injection at the re-injection well of the Unterhaching geothermal power plant.

February 2008

- magnitude 2.3, shallow (< 10km)
- just a few kilometers south of Munich
- ≈ 6 month after start of production at geothermal plant

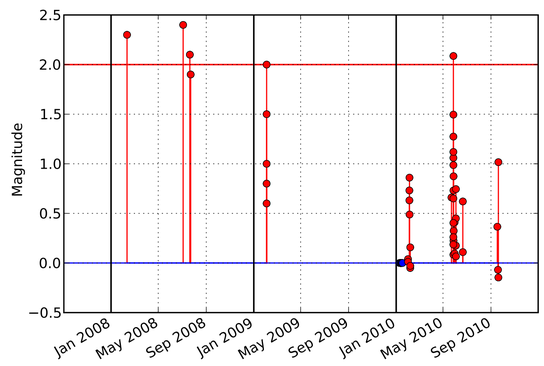
2008 – now

- 5 events with magnitude >2
- event clusters separated by quiet intervals of ≈ 6-12 months
  - correlated with operational parameters?
  - loading cycle of fault?
  - possible change in viscosity caused by cooling of surrounding?
- > 40 microseismic events with magnitudes 0-1.5
- epicenters near *UHA GT2* re-injection well
- hypocenters about 1 km below well bottom
- small seismic events (M_l <≈ 1.5) not detectable prior to 2009
- catalog probably not yet complete for smallest events (M_l <≈ 0.5)



Map view showing epicenters of located seismic event.

(Map: Google Earth)



Detected seismicity near re-injection well UHA GT2.

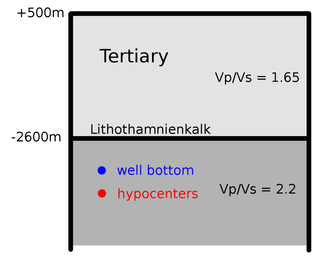
Velocity Model

Events are located in a local 3D velocity model using NonLinLoc (http://alomax.free.fr/nlloc/). The P-wave model is constructed from a high-resolution seismic 3D survey (personal communication, E. Lüschen). An S-wave velocity model is constructed from the P-wave model via a layered v_p/v_s model.

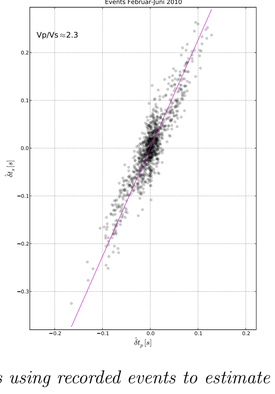
The following constraints were incorporated:

- seismic 3D survey
  - traveltime ratios of reflected P waves and converted/reflected S waves
  - $v_p/v_s \approx 1.62-1.67$, averaging tertiary layers
- seismic reflection profile with shear wave excitation (70 km east of study area, [1])
  - $v_p/v_s \approx 1.9$
  - average of tertiary and upper jurassic layers
- cluster analysis of recorded events [2]
  - differential P and S phase onsets of events recorded in local network
  - $v_p/v_s \approx 2.1-2.3$
  - local v_p/v_s estimate at hypocentral depth, no averaging

The resulting v_p/v_s model roughly is equal to a homogeneous model of $v_p/v_s \approx 1.8-1.9$ being consistent with the findings of Fertig [1].



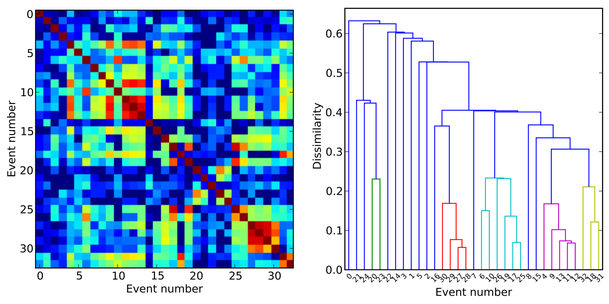
Layered v_p/v_s model to construct S wave velocity model from P wave velocity model.



Cluster analysis using recorded events to estimate v_p/v_s ratio at hypocentral depth.

Further Work

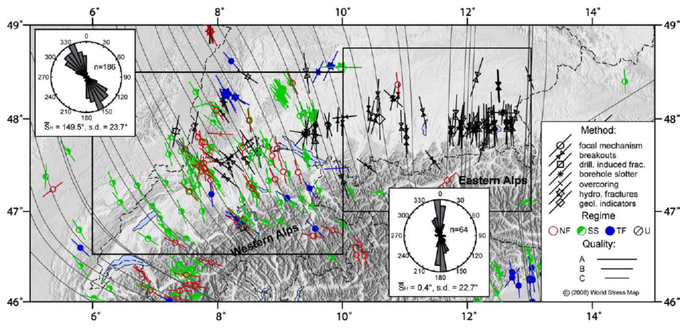
- improvement of locations with relative relocations, cluster analysis
- improvement of the magnitude of completeness of event catalog
- estimation of source mechanisms / moment tensors
  - association with mapped fault structures
- investigation of possible correlations with operational parameters



Results of waveform similarity analysis and hierarchical clustering

Open Questions

- Why seismicity only near the Unterhaching well?
  - only running facility with power production
  - higher production rates / lower injection temperatures?
  - fault orientation in local stress field
  - problem: no data on natural activity prior to production

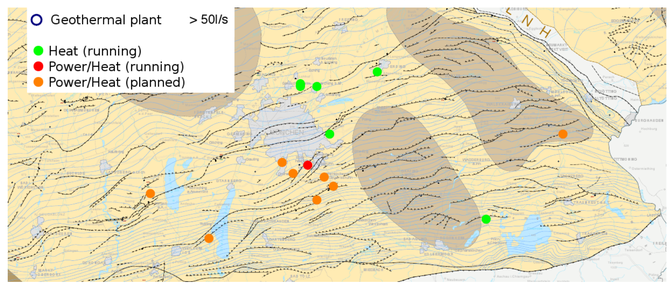


Present-day principal stress orientations (from Reinecker et al. [3])

MAGS

(Konzepte zur Begrenzung der mikroseismischen Aktivität bei der energetischen Nutzung geothermischer Systeme im tiefen Untergrund)

- seismometer network at planned geothermal facility near Bernried
- at least one year of pre-production data
- data set on possible natural activity in unperturbed state
- good cooperation with company operating the facility
- access to velocity model from seismic 3D survey and operational parameters (pressure, temperature, ...) in case of events



Fracture zones in Malm limestone and geothermal plants in the Bavarian Molasse Basin (map of faults by Thomas Fritzer, LfU)