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Microseismic monitoring in advance of geothermal projects in the northern Upper-Rhine Graben:
borehole noise studies and swarm events

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1. Introduction

The seismicity of the northern Upper-Rhine Graben (URG) and its seismic hazard have recently attracted new attention due to the potential of this region for geothermal power generation. The characterization of the natural seismicity in this region well in advance of a geothermal project is one of the main goals of the project SiMoN (Seismic Monitoring of the Northern Upper-Rhine Graben), which is funded by the German Federal Ministry for Economic Affairs and Energy (BMWi). The natural seismicity can be used to determine active fault zones and stress conditions within the crust. It also provides important background information for the estimation of seismic hazard and possible induced seismicity. The natural seismicity of this area is also interesting because of swarm earthquakes which occurred in the 19th century.

2. Local seismicity

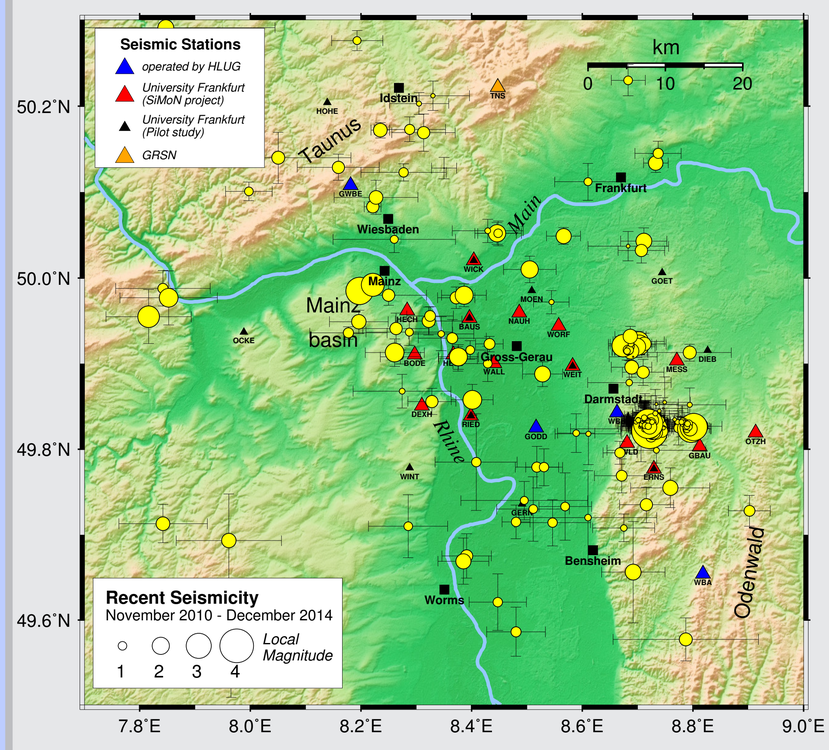

Fig. 1: Station distribution and recorded seismicity in the northern Upper Rhine-Graben.

Recordings from a network of 13 seismic stations serve as data base for the characterization of natural seismicity in an area of approximately 50 x 60 km^2 (Fig. 1). Starting in November 2010 we have recorded a number of 360 local earthquakes within the immediate vicinity of the network with magnitudes ranging between M_L = -0.5 and M_L = 4.2. The detection threshold of the whole (surface) network is a local magnitude of approximately 0.5; the magnitude of completeness is M_c = 1.2. The majority of the epicenters are located along the eastern shoulder of the URG, while the western graben shoulder shows a lesser activity. A further active region is located along the southern rim of the Taunus Mountains to the northwest of the study area. The seismicity extends to a depth of 24 km with a pronounced maximum in the depth distribution between 12-18 km.

3. Swarm activity

Since May 2014 swarm earthquakes occur southeast to the city of Darmstadt in the northern Upper-Rhine Graben. During the period from May to December 2014 we have recorded more than 256 earthquakes with a maximum magnitude of M_L = 4.2. (Fig. 2). The hypocenters are divided into two clusters that are spatially separated from each other.

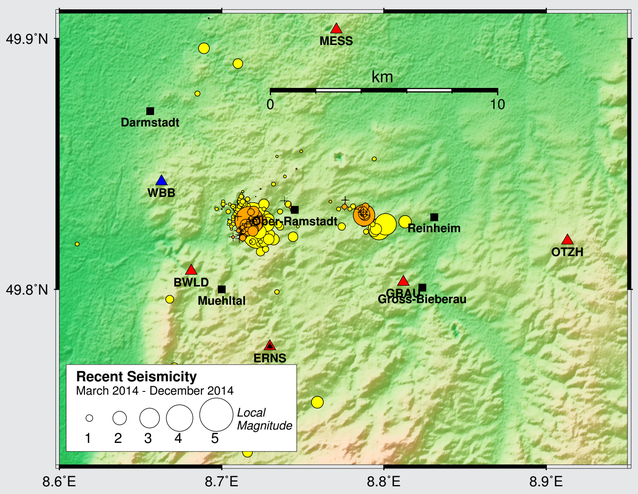

Fig. 2: Recorded seismicity between May 2014 and December 2014 (yellow = absolute; orange = relative locations).

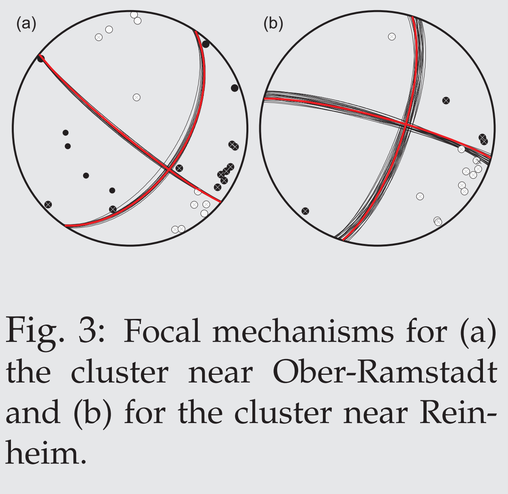

Fig. 3: Focal mechanisms for (a) the cluster near Ober-Ramstadt and (b) for the cluster near Reinheim.

The two clusters have different activity levels and show differences in the characteristic fault plane solutions (Fig. 3). The hypocenters within these clusters are aligned vertically extending over a depth range from 1 to 8 km with a lateral extent of about 2 to 3 km. To some extent, a migration of the seismic activity of these swarm events to shallower depths can be seen (Fig. 4). The events show a high waveform similarity, typical for swarm earthquakes (Fig. 5).

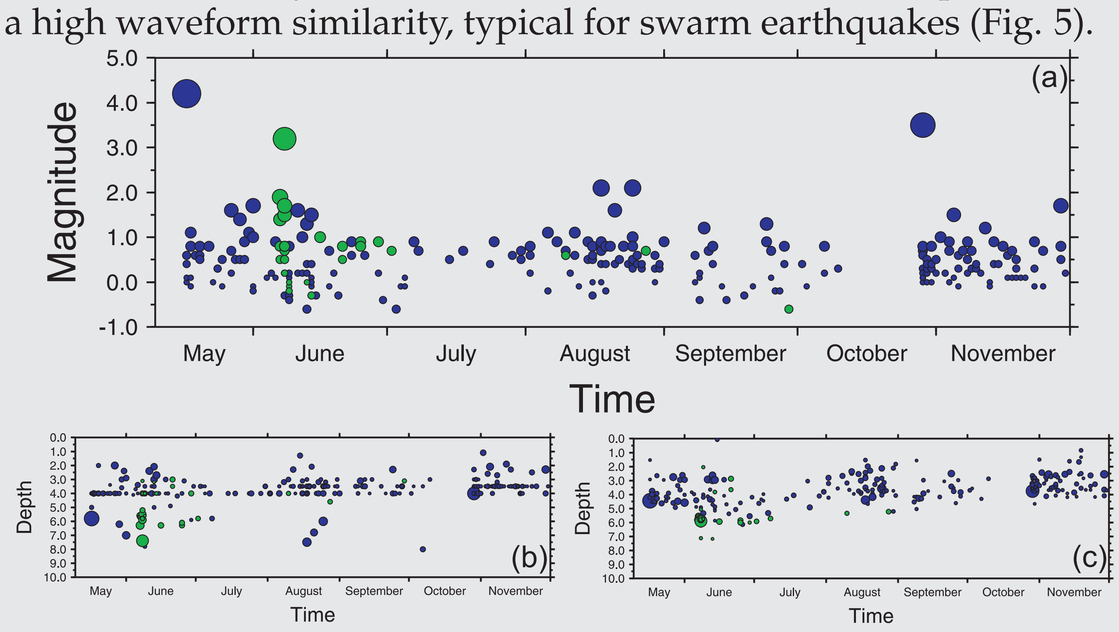

Fig. 4: (a) Magnitude distribution, (b) depth distribution (absolute localisation), (c) depth distribution (relative localisation) for the time period May 2014 to December 2014.

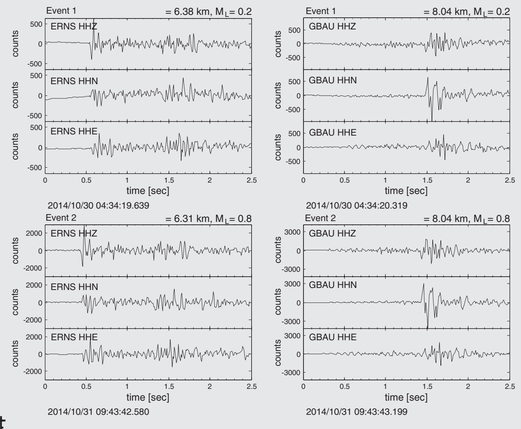

Fig. 5: Waveform similarity of cluster events. The plot shows the P- and S-waves of two events (upper and lower rows) recorded at stations ERNS (left column) and GBAU (right column).

4. Borehole noise measurements

The network was recently expanded by several borehole stations to accommodate for the relatively high noise levels in the densely populated Rhine-Main region. Systematic measurements in over 40 shallow boreholes (up to 30 m depth) in the study area were used to determine the local seismic noise and its lateral and vertical variations (Fig. 7) by comparing noise measurements in the boreholes with measurements at the surface (Fig. 6). In general, a reduction of noise amplitudes in depths up to 20 m by a factor of 1.5 to 2.5, in depths up to 40 m by a factor of 3 to 4 and in depths up to 70 m by a factor of 4.5 to 5.5 can be observed. Ongoing measurements in three up to 70 m deep boreholes are used to lower the detection threshold in the graben.

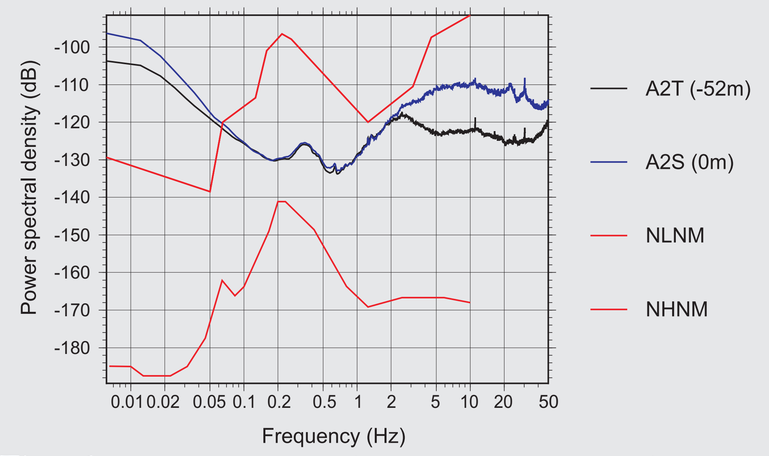

Fig. 6: Comparison of noise spectra (surface and borehole) for a borehole location in the northern URG (depth = 52 m).

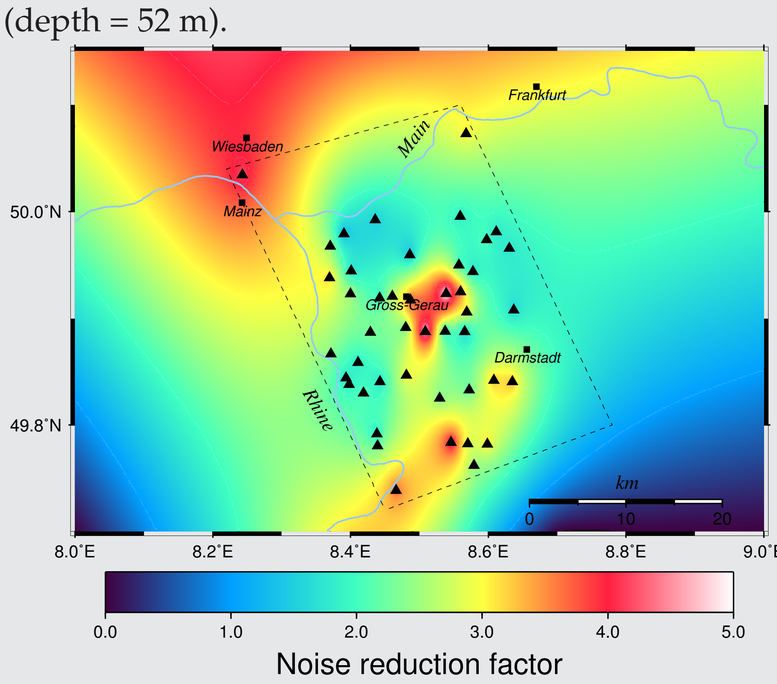

Fig. 7: Map of the northern URG showing the reduction factor derived from the relative difference of measurements at the surface compared to measurements in the boreholes.

5. Conclusions

- First detection of swarm events in the northern URG in more than 150 years.
- Spatial distribution of seismicity as well as differences in the focal mechanisms point to two active fault zones.
- Noise measurements in shallow boreholes show reductions of seismic noise amplitudes by a factor of 5 in depths up to 70 m.

Acknowledgements

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