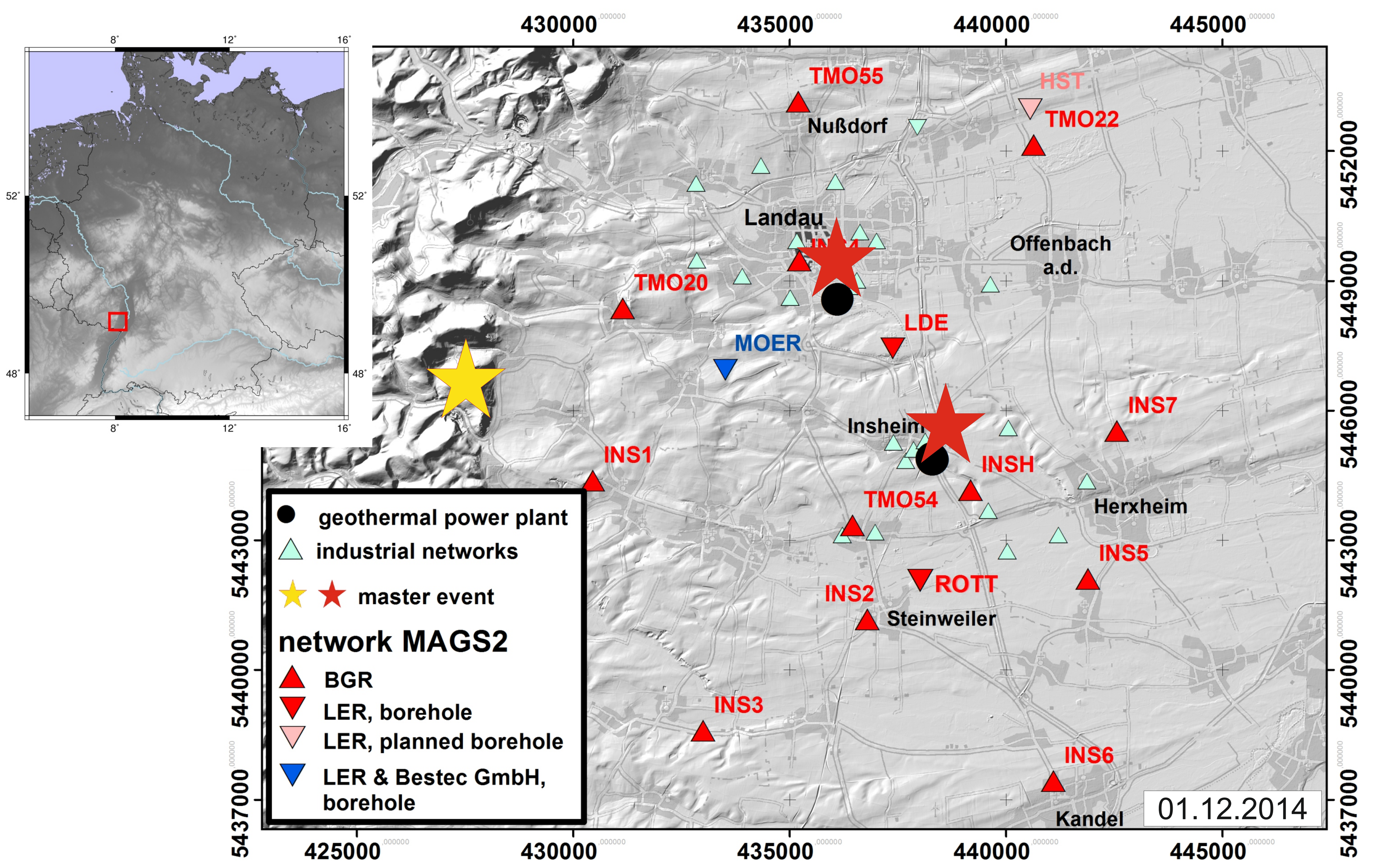
Detection and location of induced earthquakes at the Landau and Insheim geothermal reservoirs, SW Germany

Brüstle, A.[1], Vasterling, M.[2], Richter, T.[1], **Schmidt, B.**[1] & Wegler, U.[2]

[1]Geological Survey and Mining Authority of Rhineland-Palatinate, Mainz, Germany; [2]Federal Institute for Geosciences and Natural Resources, Hannover, Germany

Introduction

The tertiary Upper Rhine Graben (URG) is the region with the highest temperature gradient in Germany. Since 2007 at Landau and since 2012 at Insheim (5 km S of Landau) two combined heat and power plants are running in the western part of the central URG, where the graben is divided in noumerous small blocks with various subsidence rates. The reservoirs are situated in the lower sediment fill and the upper crystalline basement. Both deep geothermal reservoirs are Hot-Wet-Rock systems with a doublet configuration. Production rates are up to 70 l/s at Landau with a temperatur of 155°C and up to 85 l/s at Insheim with a temperature of 165°C. In 2009 two seismic events of M_L 2.4 and 2.7 and six minor seismic events were felt at the city of Landau and the surrounding area. The earthquakes were located in the region of the power plant at depths of the geothermal reservoir. The hydraulic stimulation of the Insheim reservoir in April 2010 also caused two seismic events of M_L 2.2 and 2.4, respectively, which were felt by the population. As a consequence the local seismic monitoring network of the company was densified by an additional scientific network (MAGS project, 2010-2013).

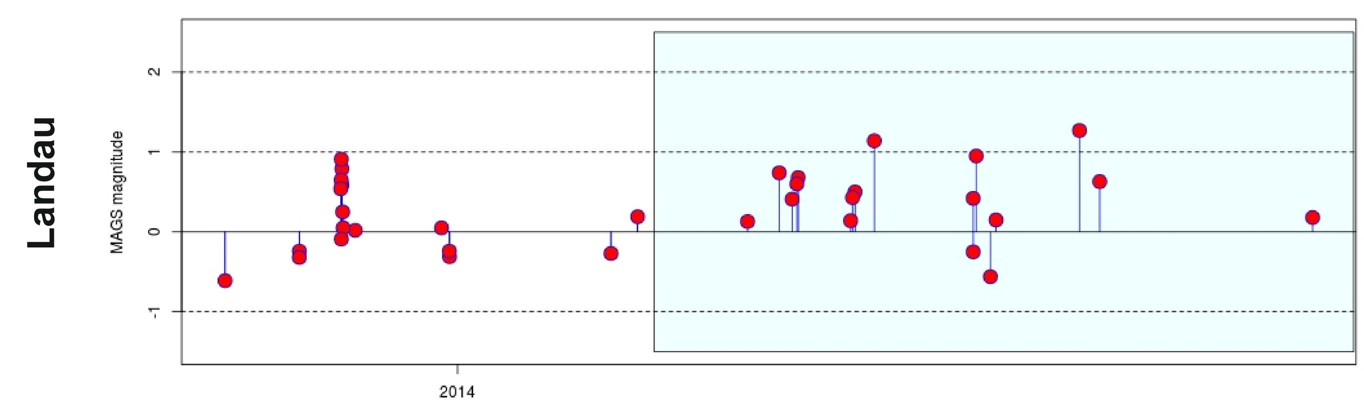


The MAGS2 network

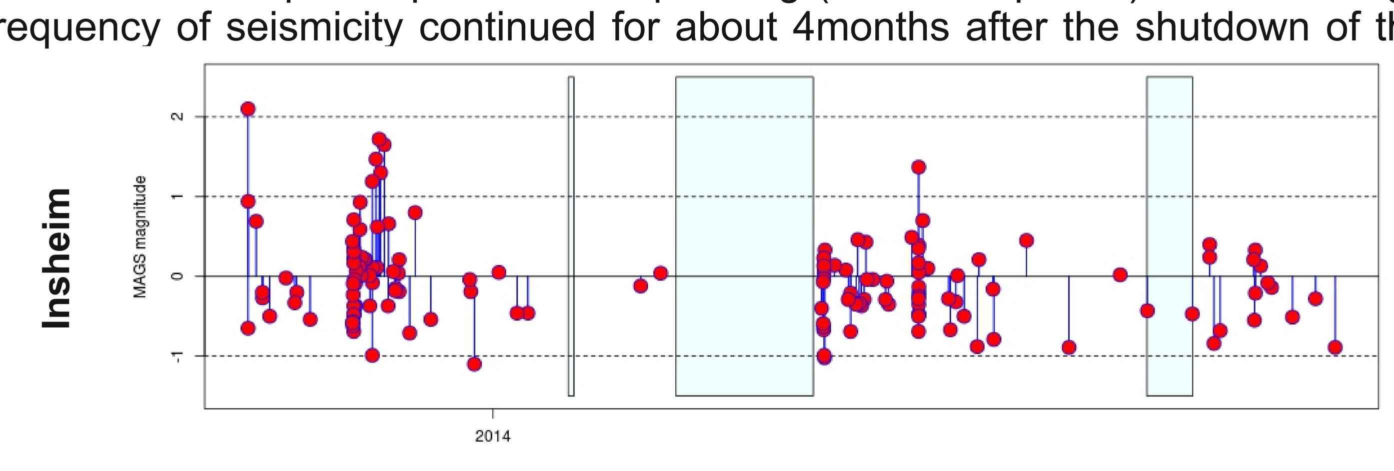
Since October 2013 the follow-up project MAGS2 is focusing on the study of a potential interaction of the observed microseismicity between the two geothermal systems. A temporary seismic network of 12 surface stations with station spacing of about 5 km is operated by the BGR. All stations are deployed within the graben structure on the sedimentary fill. The network is completed by 3 borehole stations, two of them (LDE, ROTT) operated by the local seismological survey of Rhineland-Palatine (LER) and the third (MOER) is jointly operated by LER and an industrial partner. The installation of an additional borehole station (HST) by LER is planned in 2015. The continuously recorded waveform data of the entire network is transmitted via seedlink in real-time to BGR and partners of the project.

Event detection and verification

The event detection is done by defining master events of each reservoir (red stars, see network map) as well as other frequent sources of induced seismicity, e.g. quarry blasts (yellow star, see network map). The enveloppes of these master events are cross-correlated with the ones of the real time waveform data (for details see poster Wegler et al.). The verification of the automatically detected events is done by LER by the manual determination of phase onsets using the SeisComP3 software. The location of the events is performed with NonLinLoc using local 1D-velocity models of each reservoir. During the first 12 months since the beginning of the project in October 2013 in total 89 per cent of the 227 detections were triggered correctly as induced earthquake of the Landau or Insheim reservoir as well as for quarry blasts.



Since March 2014 the Landau power plant is not operating (blue time period) due to leakage problems. But frequency of seismicity continued for about 4months after the shutdown of the power plant.



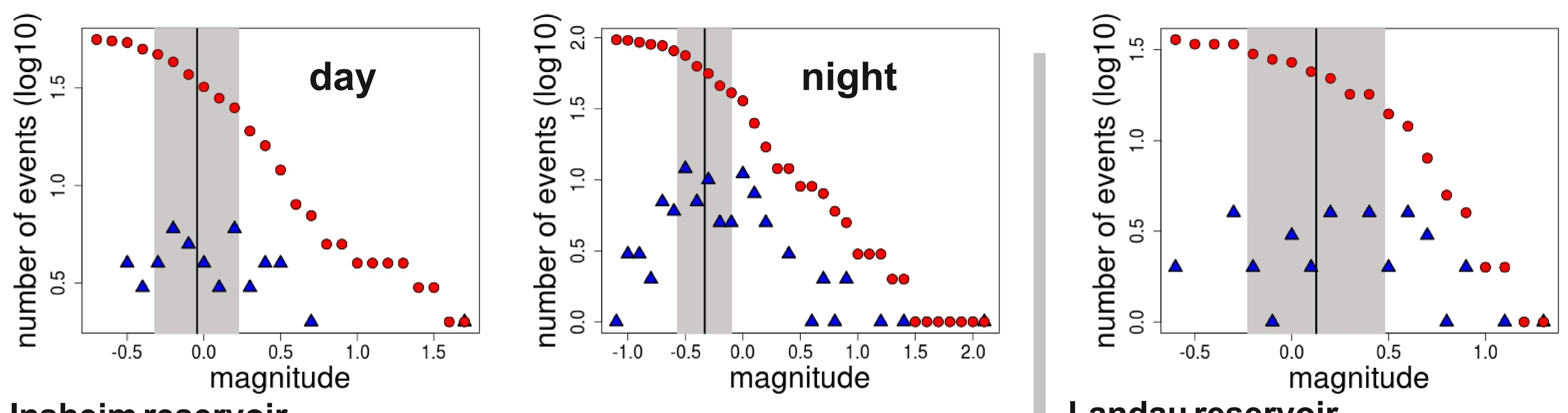
In 2014 the Insheim power plant was shutdown due to maintenances in January, March and August (blue time periods; source: www.geothermie-insheim.de), where no seismicity was observed.

The joint project **MAGS2** - Microseismic Activity of Geothermal Systems - **From single reservoirs to geothermal fields** (FKZ: 0325662A-G) is founded by the Federal Ministry for Economic Affairs and Energy and supervised by the Project Management Jülich.

Project Management for Federal Ministry for Economic Affairs and Energy

Magnitude analysis

Due to the small network extension and the unsolidated sediment fill of the URG relative local magnitudes are determined by comparing amplitudes of master and detected events. The magnitude of completeness (M_c, black line) was determined using the maximum value of the first derivative of the cumulative (red points) magnitude-frequency-distribution (FMD), which corresponds in general with the highest magnitude frequency of the non-cumulative FMD (blue triangles; Wiemer & Wyss, 2000). The b-value is estimated using the maximum-likelihood-technique after Aki (1965). The uncertainty (grey band) of M_c and b-values is evaluated by using the Monte-Carlo approximation of the bootstrap method (Efron, 1977)



Insheim reservoir

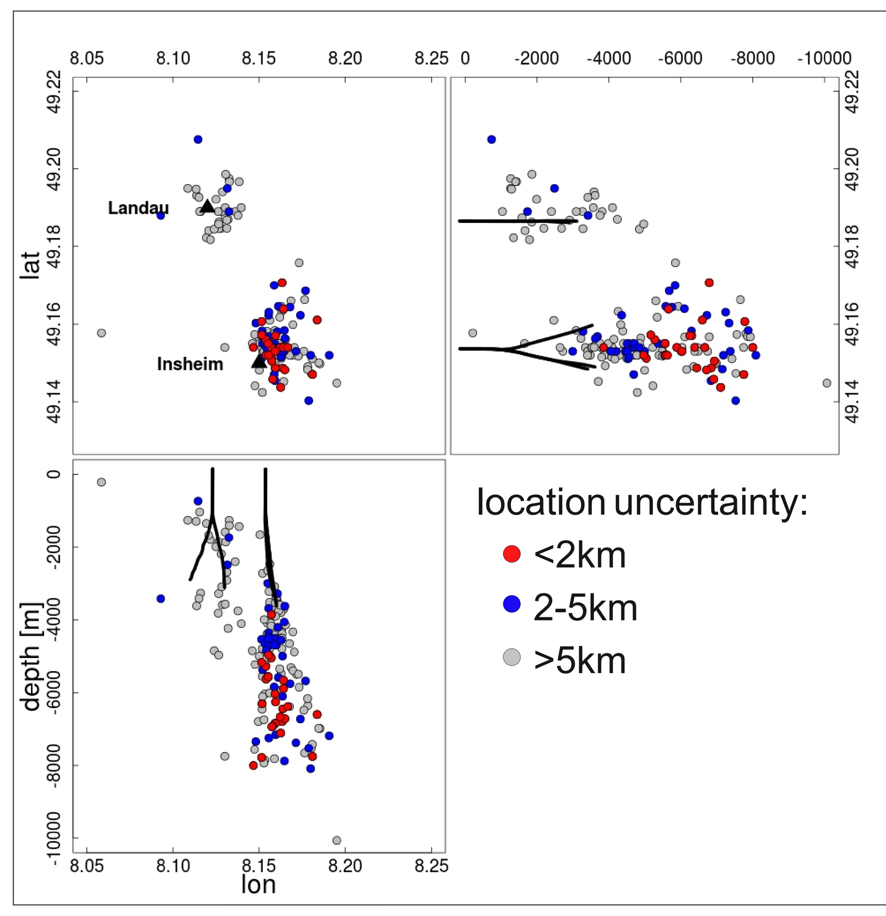
During day hours (6:00-20:00, 56 events) the catalogue of MAGS-detections is complete down to magnitudes of -0.04(+/-0.28). Due to the lower noise level the catalogue of MAGS-detections has a lower M_c of -0.33(+/-0.24) for night hours (20:00-6:00, 97 events). The mean b-value is 0.96(+/-0.26) for the entire catalogue of the MAGS-detections.

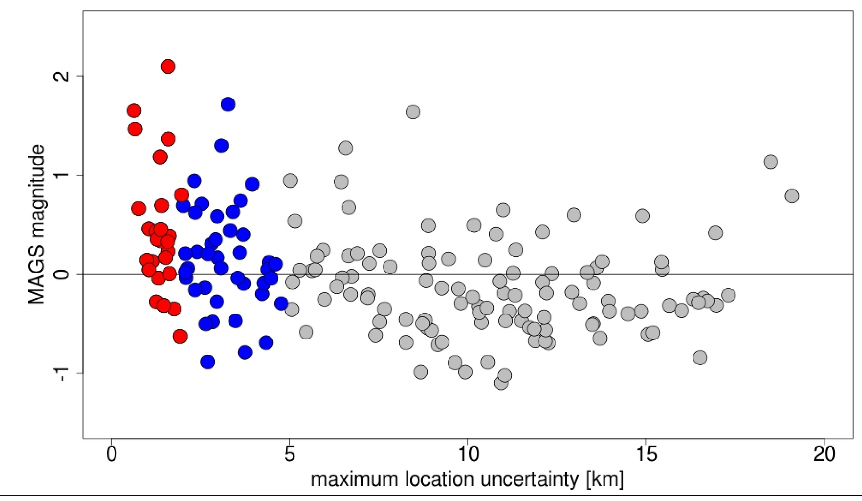
Landau reservoir

The catalogue of MAGS-detections (36 events) is complete for magnitudes larger than -0.13(+/-0.36) and the mean b-value is 1.26 (+/-0.66).

Seismicity

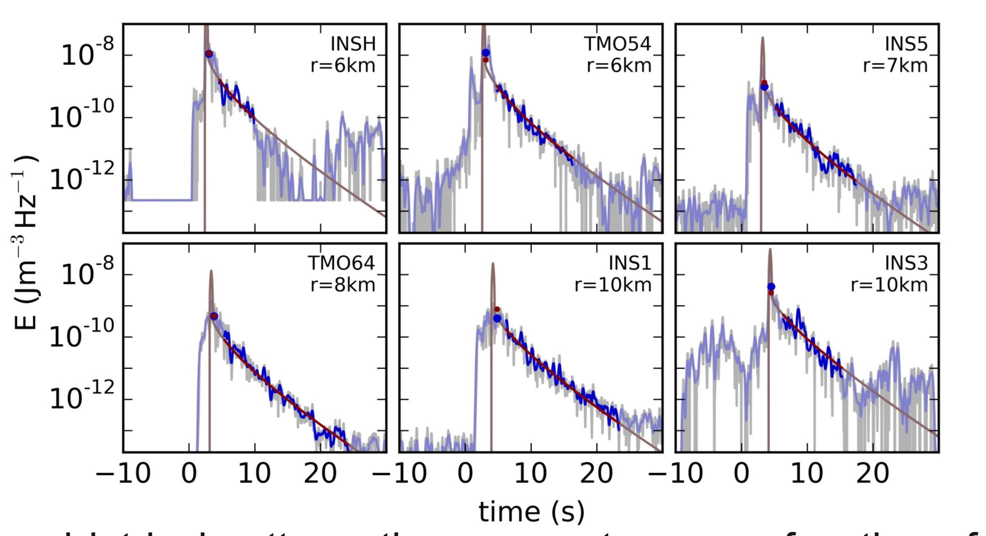
The 3D-plot shows the location of the detected and manually located events. The two clusters beneath the reservoirs are clearly separated from each other. The location uncertainty strongly corresponds with the size of the magnitude.



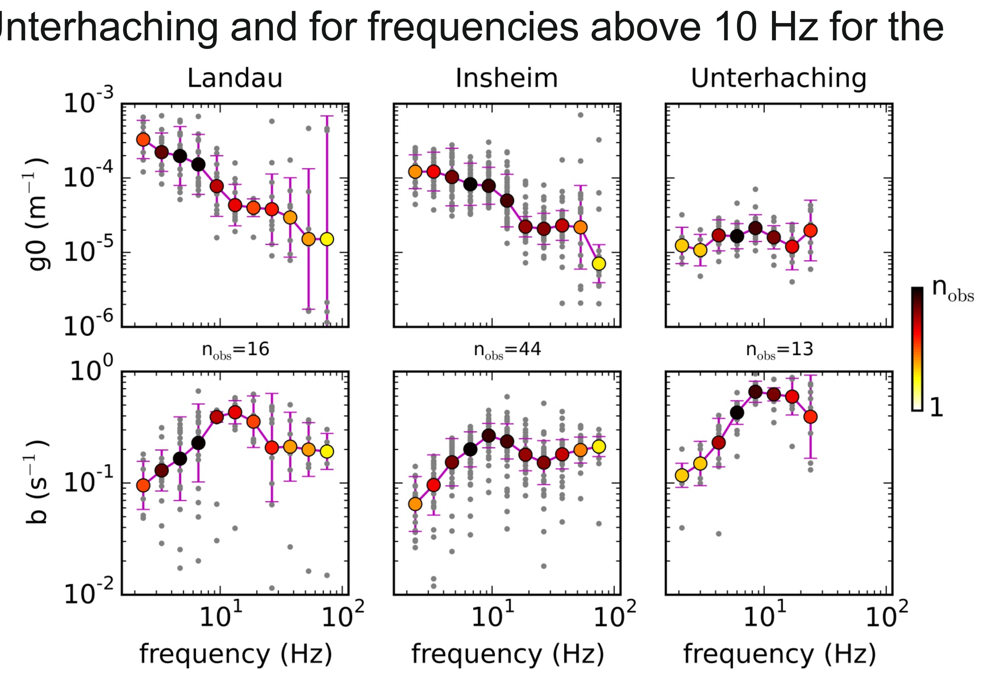


Measurement of scattering and intrinsic attenuation

It is planned to extend the applied detector by automatically generated shake maps. As the modeling of ground shaking at the surface is based on detailed velocity and attenuation models, intrinsic and scattering attenuation of observed shear waves are determined in the frequency range from 2 to 50 Hz. The inversion is performed by fitting Green's functions of the acoustic radiative transfer theory to the observed energy densities at the station sites (Sens-Schönfelder & Wegler, 2006). Results of the inversion are the scattering (g_0) and intrinsic attenuation (b) parameters. The corresponding Q values can be calculated with: $Q_{sc}^{-1} = g_0 v_0 / 2\pi f$, $Q_i^{-1} = b/2\pi f$ (v_0 - mean S-wave velocity, f - frequency). The figure (right) shows fits between observed (blue) and modeled (red) energy density for a microearthquake located at Insheim (frequency band 25 Hz to 50 Hz). The dots mark the mean of the envelope in a time window around the direct S-wave.



The figure below shows the scattering and intrinsic attenuation parameters as a function of frequency for the three geothermal sites in Landau, Insheim and Unterhaching. In Unterhaching g_0 is slightly increasing at a level of around 10^{-5} m^{-1} leading to a frequency dependency of $Q_{sc}^{-1} \sim f^{0.9}$. In contrary, g_0 is starting at a high level (10^{-4} m^{-1}) and decreasing with frequency for the two sites in the upper Rhine graben, yielding to a frequency dependency of $Q_{sc}^{-1} \sim f^{-1.8}$. Intrinsic attenuation is dominant over scattering attenuation for Unterhaching and for frequencies above 10 Hz for the other two sites. b has a peak at 10 Hz which could be the result of a transition in the subsurface. Scattering and intrinsic attenuation (top and bottom). The grey dots mark individual measurements, circles the robust geometric mean, errorbars the median absolute deviation. Color indicates the number of observations relative to the number of analyzed events (n_{obs}).



References

Aki, K. (1965). Maximum likelihood estimate of b in the formula log N=a-bM and its confidence limits, Bull. Earthquake Res. Inst. 43, 237–239.

Efron, B. (1979). 1977 rietz lecture, bootstrap methods - another look a the jackknife, Ann. Statist., 7, 1-26.

Lomax, A., Virieux, J., Volant, P., and Berge, C. (2000). Probabilistic earthquake location in 3D and layered models: Introduction of a Metropolis-Gibbs method and comparison with linear locations, in Advances in Seismic Event Location, Thurber, C.H., and N. Rabinowitz (eds.), Kluwer, Amsterdam, 101-134.

Sens-Schönfelder, C. & Wegler, U. (2006). Radiative transfer theory for estimation of the seismic moment, GJI, 167(3), 1363–1372.

Wiemer, S. & Wyss, M. (2000). Minimum magnitude of complete reporting in earthquake catalogs: examples from Alaska, the western United States, and Japan, Bull. Seismol. Soc. Am., 90, 859-869.

contact: andrea.bruestle@lgb-rlp.de

MAGS2

Landesamt für Geologie und Bergbau Rheinland-Pfalz

Bundesanstalt für Geowissenschaften und Rohstoffe

GEOZENTRUM HANNOVER