Analysis of microseismic events induced by stimulation treatments at Geothermal Research Well GrSk4/05 in Groß Schönebeck, Germany

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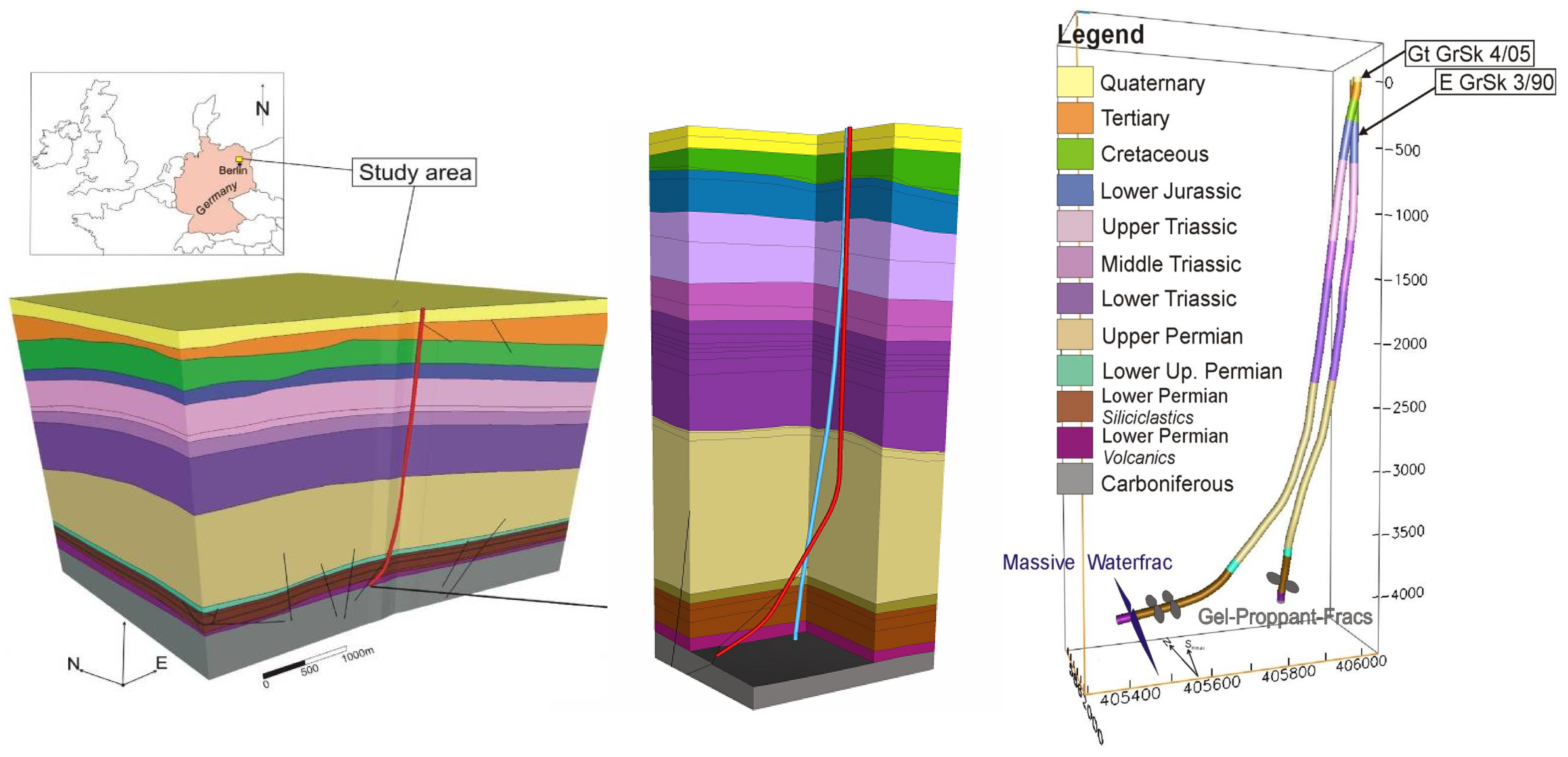
Abstract

Spectral analysis was performed on a group of microseismic events ($-1.9<M_W<-1.1$) that occurred during a stimulation experiment at the Geothermal Resesearch Well GrSk4/05 in Germany. These events were recorded by a downhole 3-component sensor (natural frequency 15Hz, sampling rate 1000Hz) located in the accompanying borehole GrSk 3/90 at 3800m depth, close (~500m) to the injection point. The seismicity level was very low and only 70 events were detected during an injection period of 6 days. They exhibited strong spatial and temporal clustering and mainly occurred towards the end of stimulation phases. Calculated source parameters provide the evidence for the dependence between the static stress drop and seismic moment as well as for scaling of apparent stress with seismic moment.



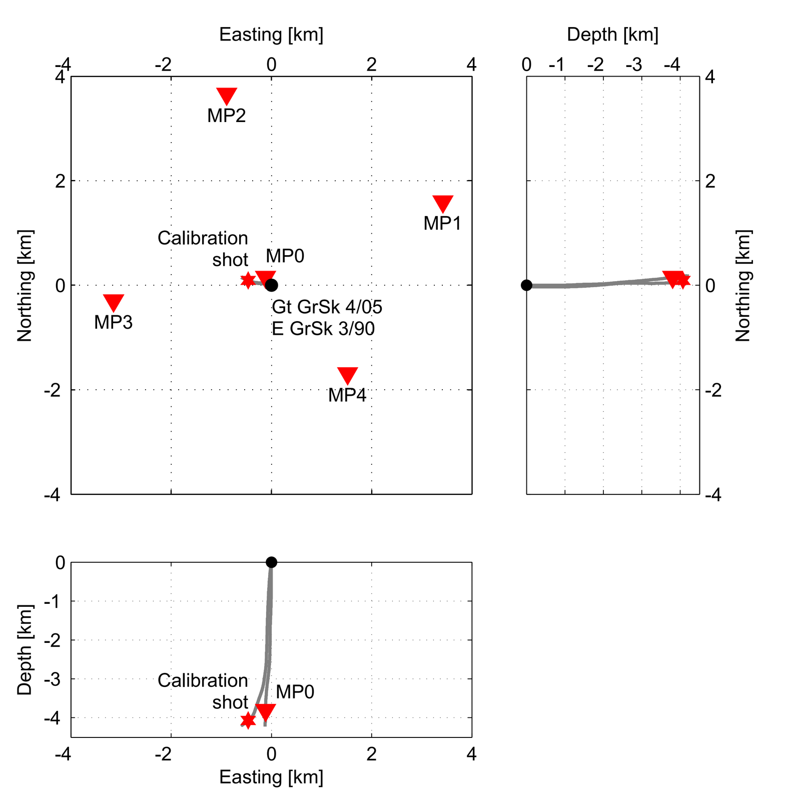
Geothermal laboratory

The Groß Schönebeck Research wells GrSk 3/90 and GrSk 4/05 are located north of Berlin, Germany, in the eastern part of the North German Basin, which is characterized by sedimentary deposits of several km thicknesses and no noteworthy recent tectonic activity. Low enthalpy geothermal reservoir rocks are to be found here as siliciclastic sediments and volcanics of the lower Permian at an average depth of about 4000 m and at formation temperatures of up to 150°C. For the development of a maximum effective pay zone, the injection well GrSk 4/05 is inclined in the reservoir section with 47° and was drilled in the direction of the minimum horizontal stress (288°) for optimum hydraulic fracture alignment in relation to the stimulated pre-existing well GrSk 3/90.

Network

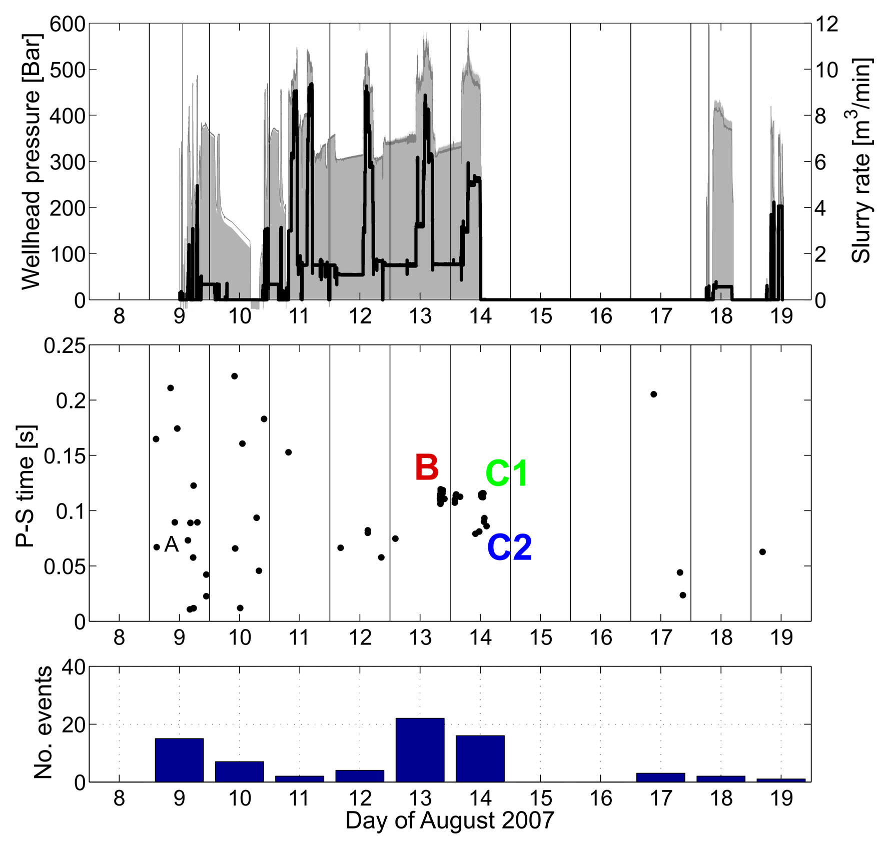
Seismic network consisted of seven three-component seismometers including a downhole seismometer operated at 3800 m depth in GrSk 3/90 at only ~500 m distance to the injection point (F_N=15Hz, sampling rate 1000Hz). The additional six instruments were located at the surface and in shallow (~60 m deep) boreholes framing the surface positions of the deep boreholes (F_N=1Hz, F_N=4.5Hz, sampling rate 200Hz). Regional seismic events and calibration shot fired at 4000 m depth in the injection well served to calibrate the network and determine the orientations of the downhole sensors at an accuracy of 15°.

During injection, the recordings from the deep downhole sensor were contaminated by noise that partially overlap with the frequency band of expected seismicity. As a result recording conditions were limited during periods of large injection rates.



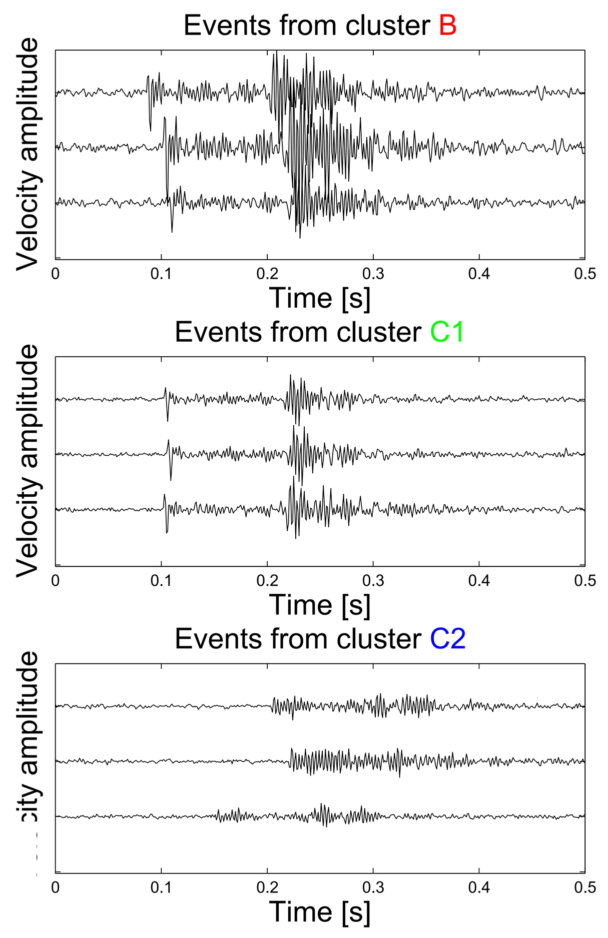
Injection treatments

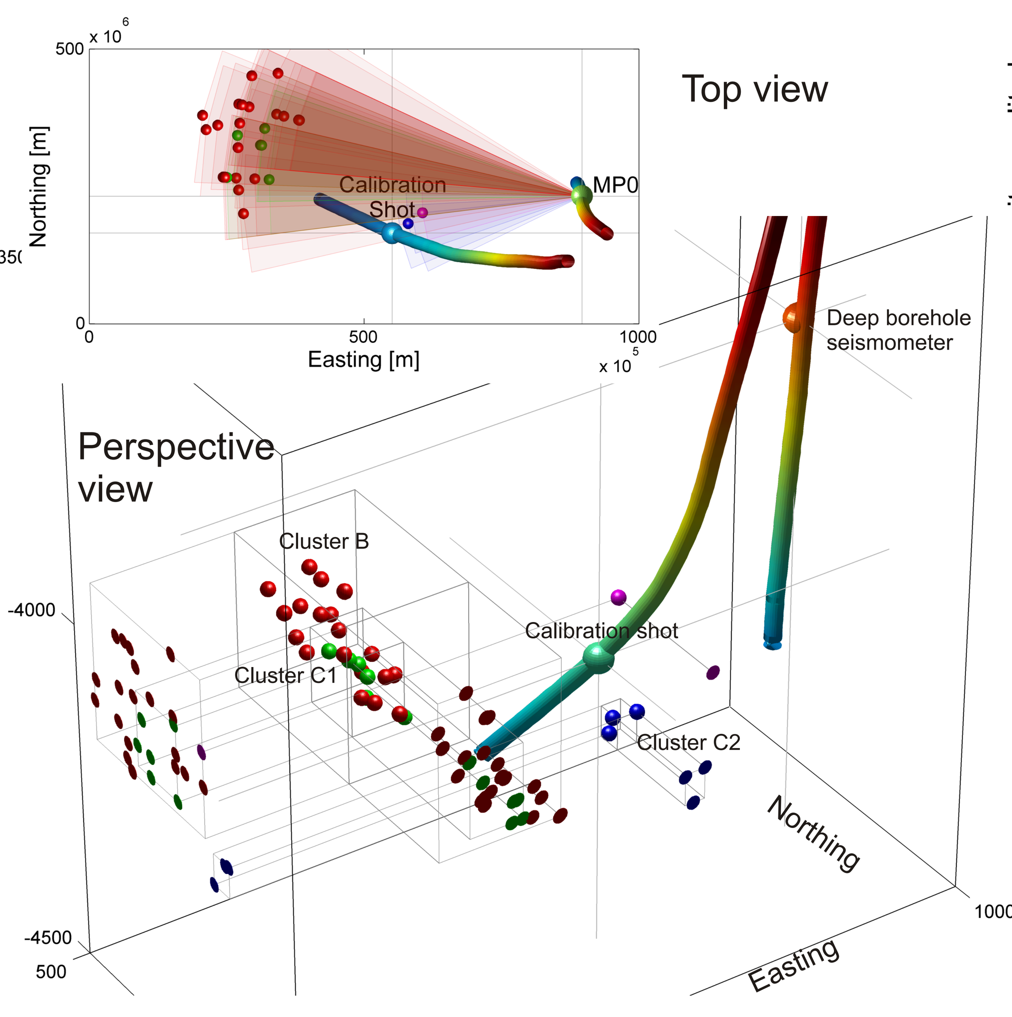
In August 2007 three fracture treatments were performed in well GrSk 4/05: two in the sandstone section (Upper Rotliegend, Dethlingen Formation) and one in the volcanic section (Lower Rotliegend). In the low permeable volcanic rocks a massive cyclic waterfrac treatment was performed over a period of 6 days to achieve a long-term productivity. A total amount of 13.000 m^3 of water was injected here with 24 tons of sand as proppant. In addition, two gel proppant treatments were carried out in the porous and permeable Upper Rotliegend sandstone formations. 500 m^3 of crosslinked gel were injected in each of the treatments, with a load of about 100 tons high strength proppants.

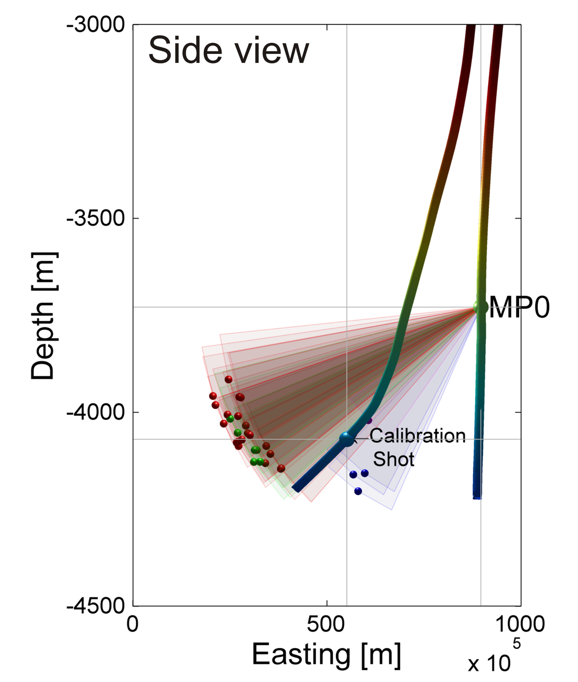


Seismicity

The downhole seismometer detected more than 70 high frequency microevents that were not recorded by shallow stations. The maximum daily event rates were observed on 13th and 14th of August, i.e. towards the end of waterfrac injection. Seismicity tend to cluster in space and time (sequences **B**, **C1** and **C2**). The events in each cluster display a common features: similar waveforms, P-S time and frequency content. During the gel frac in the more porous and permeable sandstone formations the number of observable induced seismic events was very small. The events were located by means of polarization analysis and P-S times using the recordings of the deep borehole sensor.





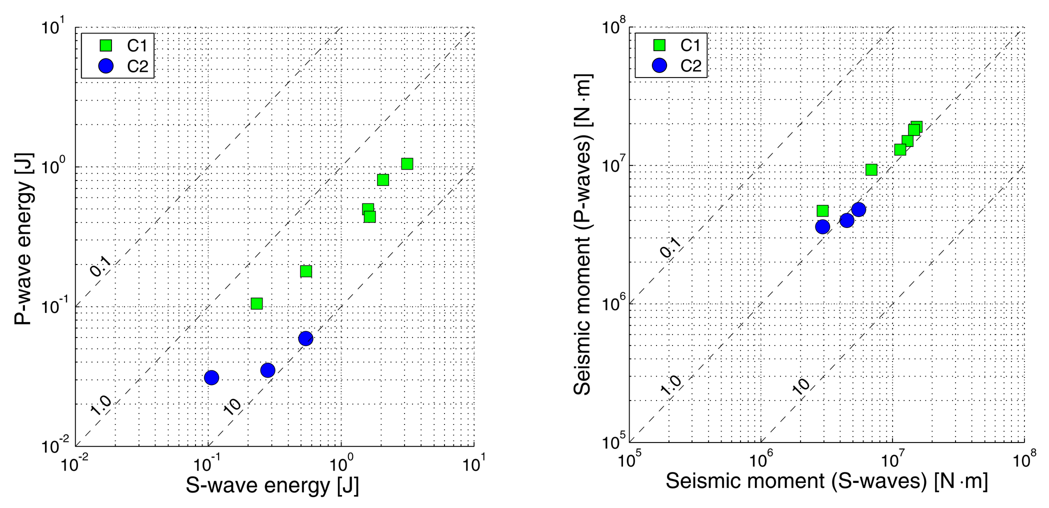


Spectral analysis

Using the results of polarization analysis the selected parts of 3C seismograms were rotated into the local ray coordinate system (Radial, SV and SH) and tapered. Calculated FFT spectra were only corrected for frequency-independent attenuation. Spectral parameters were estimated from SH and SV components of selected events from clusters B and C, assuming $^{-2}$ Brune's model and the methodology developed by Andrews (1986), based on J and K integrals. The bandwidth used in this study ranged from 50 to 220Hz. We also computed spectral parameters from radial component for clusters C1 and C2, where noise was sufficiently small allowing P-wave waveforms to be used for spectral analysis. In this study, the RMS average radiation coefficients were used to correct the values of seismic moment for unknown fault plane solutions. To calculated source radius, quasidynamic circular fault model of Madariaga was used with averaged correction coefficients. Calculated values of apparent stress and static stress drop are not independent.

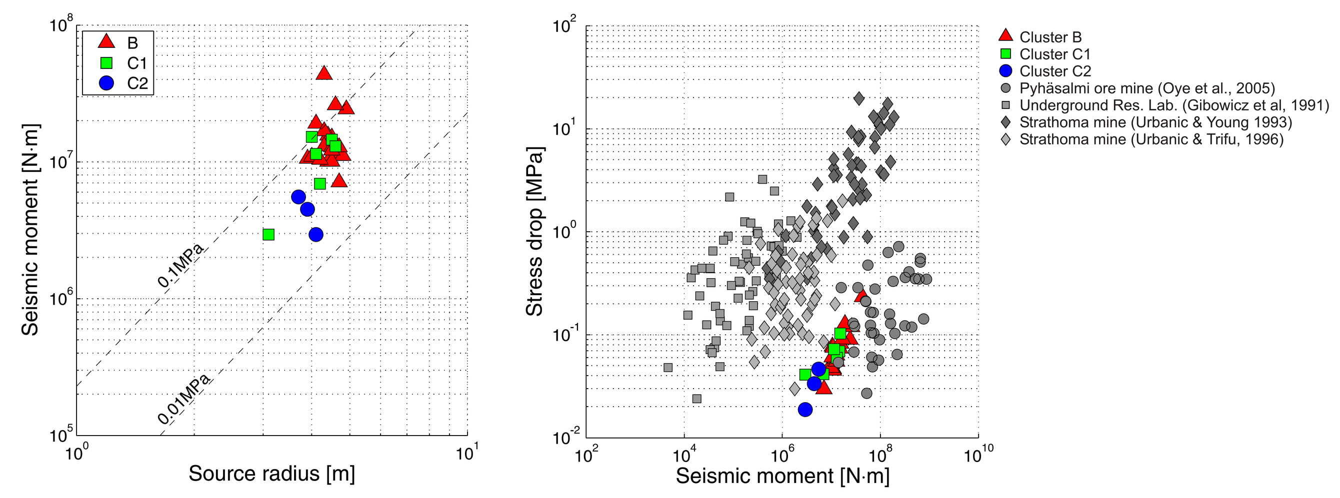
Results

The E_S/E_P ratio ranges from 2.2 to 3.8 for cluster C1 and from 3.4 to 8.0 for cluster C2. This is in disagreement with the typical values of this ratio (20-30) and may be attributed to possible non-double couple source mechanisms (Gibowicz et al., 1990) in case where the induced seismic events represent tensile faulting due to crack opening during the injection experiment. However, neither the radiation pattern, nor possible directivity effects due to the observations performed with a single three-component sensor have been taken into account which may significantly affect the energy calculations.



The source radii ranged from 3.1 to 4.9 m. We observed a clear dependence between the static stress drop and the seismic moment and slowly increasing source radii with seismic moment, what was also reported in Jost et al. (1998) for fluid-injection induced seismicity

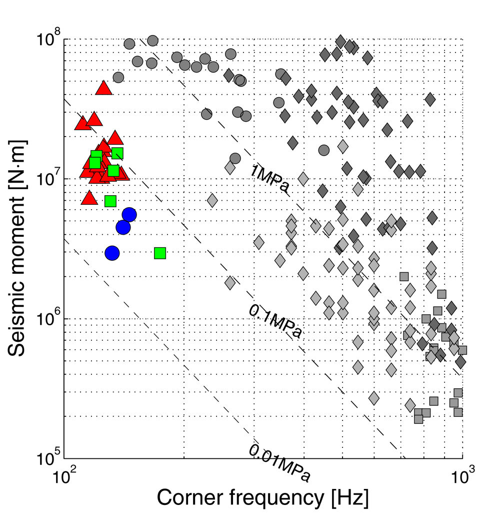
The values of static stress drop ranging from 0.01 to 0.1 MPa are rather low in comparison to other studies.

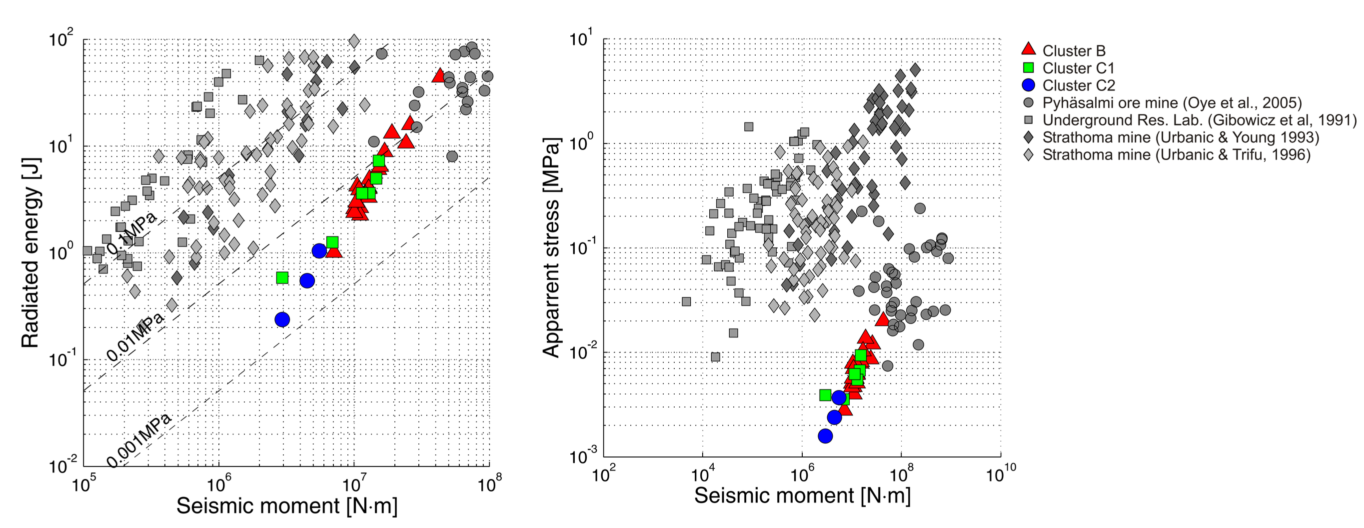


The calculated energy is generally smaller than that estimated in other studies for the same magnitude range, even after applying a correction for the significant amount of energy radiated as P-waves. The underestimation of attenuation does not seem to be the reason and the question remains open whether the influence of rupture directivity and radiation pattern can account for this. The apparent stress ranged from 0.001 to 0.01 MPa and is strongly dependent on seismic moment.

The values of seismic moment ranged from 2.89*10^6 to 4.21*10^7 Nm, corresponding to a range in moment magnitudes from M_W=-1.9 to -1.1

The corner frequency from SH component is constantly larger than that of SV by on average ~25 Hz. The values of S-wave corner frequency (averaged over SV and SH phases) range from 110 to 170 Hz.





Conclusions

It was shown for the first time that hydraulic stimulation in the Vulcanite formation in the NE German Basin causes induced seismicity. A total of 70 events were detected by a downhole sensor at ~500 m distance to the injection point. High attenuation and an anhydrite layer at 2.6 km depth consume most of the seismic energy. The induced seismic events are clustered in space and time and can be grouped into three sequences that all occur during shut-in phases. The overall seismic activity is small compared to that observed during stimulations in cristalline environments (e.g. Soultz, KTB, Basel).

The results might be explained by the absence of large-scale critically stressed faults at depth. Should they exist they are presumable misoriented with respect to the present stress field and not re-activated by fluid injection.

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