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

Abstract

Spectral analysis was performed on a group of microseismic events (1.9 < M< 1.7) that occurred during a stimulation experiment at the Geothermal Research 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 to (~500m) 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 spatio-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.

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<sub>n</sub> = 15Hz, sampling rate 1000Hz). The additional six instruments were located in the basement, in the north and in the volcanic section (Lower Rottleng). Regional seismic events and calibration shot fired at 4000 m depth in the injection well served to calibrate the network. The pinnae of the borehole seismic 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 signals. As a result, recording conditions were limited during periods of large injection rates.

Injection treatments

In August 2007 three fracturing treatments were performed in well GrSk 4/05: two in the sandstone section (Upper Rottleng, Delthingen Formation) and one in the volcanic section (Lower Rottleng). In the low permeable volcanic rocks a massive cyclic waterfrc was performed over a period of 6 days to achieve a long-term productivity. A total amount of 13,000 m<sup>3</sup> 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 Rottleng sandstone formations. 500 m<sup>3</sup> of crosslinked gel were injected in each of the treatments, with a load of about 100 tons high pressure propants.

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 group to the injection point. The P-S times using the recordings of the deep borehole sensor.

Results

The E<sub>p</sub>/E<sub>s</sub> 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 20-30 and may be attributed to possible non-double couple source mechanisms. In this case 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 perform. The non-double couple 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 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.