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Characterisation of a geothermal reservoir using microseismic data

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In this paper we considered the geological structure at the German deep drill site (KTB) as a prototype of a geothermal system. We used microseismic data in combination with surface seismic imaging results for characterization of the geothermal reservoir.

The long-term fluid injection experiment in the KTB pilot hole at 4 km depth started at May 27, 2004. The seismicity was monitored by a seismic network, which consisted of a borehole seismometer in KTB main hole at 200 m horizontal distance from the injection source and variable number of near-surface stations (on average 10–15 stations). Most of the stations were installed within radius of 3 km from the KTB. All instruments were 3-component seismometers and data were recorded continuously at sample rates 200–1000 Hz. The cumulative number of events detected by near-surface stations was 146, and more than 3000 for the borehole sensor. All events were small with magnitudes in the range of -3.0 to +0.3.

Only the events which were also recorded by near-surface stations could be precisely located. We applied a two-step location procedure: absolute location was first determined by a grid-search algorithm in a local 3D velocity model. These locations were then refined by a double-difference relocation. Then using the only recordings from borehole instrument and similarity of the events we additionally located approximately 3000 small events.

In order to get a large scale model of the fault zones we used the image obtained from a 3-D prestack depth migration of the ISO89-3D data set. To enhance specific geological features which were we not able to obtain using only the original migrated seismic data we also conducted additional seismic attributes analysis. The seismic attributes were represented in the form of absolute energy values calculated using the Hilbert transform of migrated seismic data.

We applied Seismicity Based Reservoir Characterization (SBRC) approach to the three stages of the fluid injection experiment and estimated rock diffusivity using three clouds of microseismicity at 9 km depth which corresponded to SE1 fault zone, at 4 km depth (SE2 reflector) and 5.4 km depth (background rocks). In order to construct 3D permeability cube we made an assumption about the positive correlation between the seismic reflectivity and the hydraulic diffusivity. Our suggested permeability model consists of three bodies: isotropic body of background permeability, low permeable SE2 fault zone and high permeable SE1 zone. Using seismic attributes as a reference map of the reflectivity, we separated the whole volume into three parts by specifying two thresholds for the attribute values.

In order to get a high resolution image of SE2 fault zone we applied our microseismic imaging approach to the waveforms recorded at the borehole sensor. Using Fresnel-Volume-Migration technique we constructed 3D images of the data between P- and S- first arrivals which we interpreted as PP reflections. There is complicated network of reflectors revealed in the vicinity of microseismicity cloud which belongs to SE2 reflector. Obtained result is mainly consistent with seismic attributes by the location and dip. Furthermore, it provides a more detailed image of the fine structure of the fault zone due to the higher frequencies used in our study (60 – 350 Hz).