Microseismic Imaging at KTB

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Summary

We have applied our approach for microseismic imaging to the data obtained from the German Continental Deep Drilling program (KTB project), 2004 experiment. This is a continuous data stream containing induced microseismicity data recorded at a single 3C geophone located at approximately 3.5 km depth. Using P- and S- time picks we have located 414 microseismic events using data from the borehole geophone and from near-surface stations. Since microearthquakes occur not at the same time, we have managed to separate continuous data stream recorded at the receiver to the number of 3C traces containing waveforms from different events. Using these traces we have produced seismic gather for the microseismicity cloud. We apply our imaging approach to the produced seismic gather and construct 3D images of the seismic data between P- and S- direct waves which we interpret as PP reflections. There is a complicated network of the reflectors revealed within the microseismicity cloud which belong to SE2 reflector. In order to check consistency of the obtained results, we compare our results with seismic attributes obtained from the surface seismic 3-D depth migrated image. Obtained result is mainly consistent with seismic attributes by the location and dip, furthermore it provides with more detailed image of the fault zone fine structure.

Microseismicity location

The long-term experiment in the KTB pilot hole at 4 km depth started at May 27, 2004. Injection rate was constant at 200 l/min, interrupted by several short-term pump failures (see Shapiro et al. (2006)). The cumulative volume of the injected water was 84600 m3. at the end of the activities in April 2005. 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 stations were installed within radius of 3 km from the KTB (Figure 1). 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 is 146, and more than 3000 for the borehole sensor. All events are small with magnitudes in the range of ~ -3.0 to +0.3.

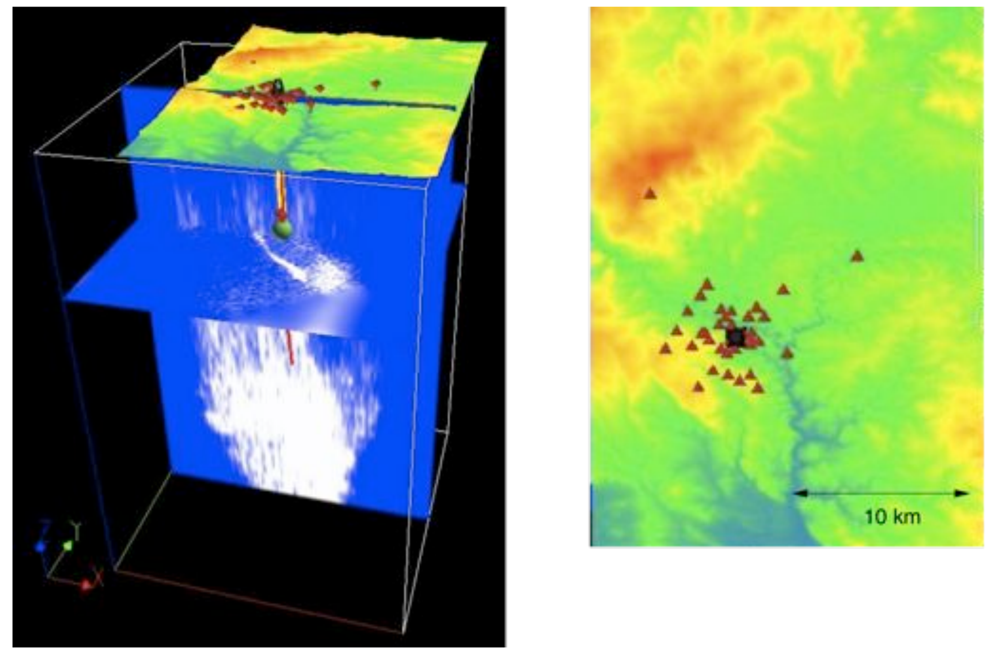

Figure 1. Left: Configuration of the KTB injection test in 4 km depth (green bullet) and the seismic sensors (red diamonds). Also shown is the seismic reflectivity after Buske (1999). Right: Map view of the station distribution; black square symbol is the KTB site.

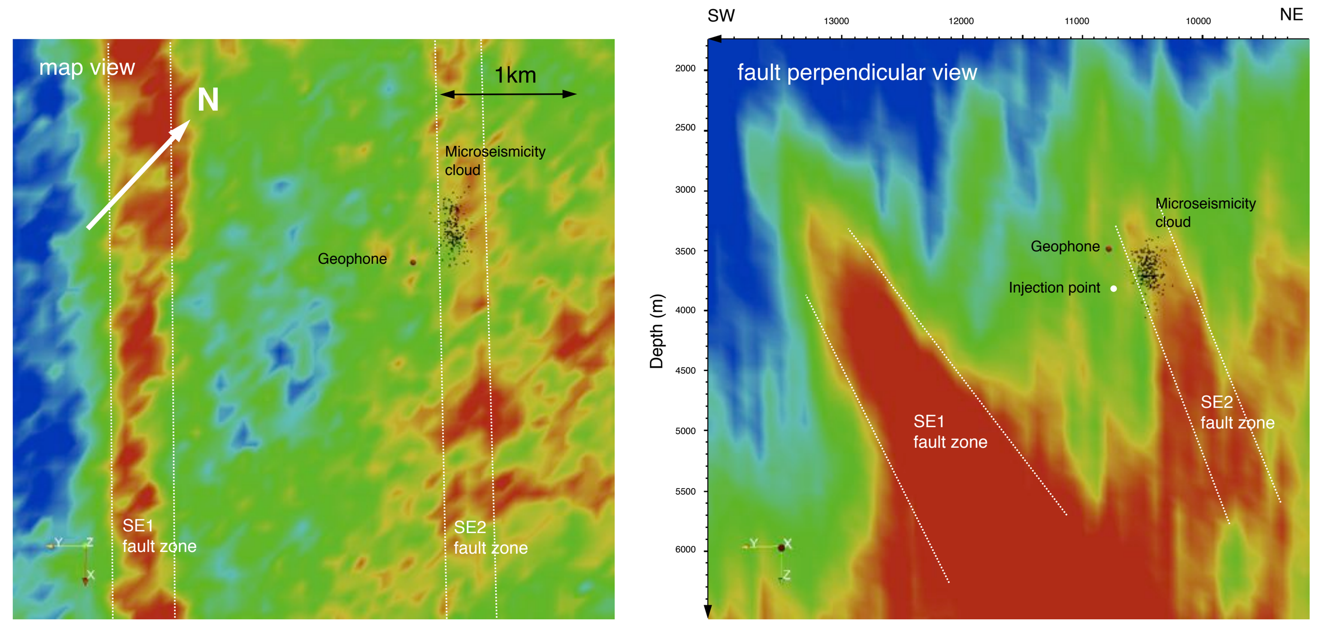

Figure 2. 414 located microseismic events (black dots), borehole sensor (red dot), injection point (white dot) and seismic attributes obtained from surface seismic imaging (background).

Seismic data

The seismic data recorded at geophone is a continuous three component data stream which is supplemented by preliminary picked P- and S- arrival times for different microseismic events. Using this data we extract the 3C traces for each event and shift it to its origin time. Then these traces are sorted out according to the distance from the geophone to the event. The 58 traces recorded from reference events are combined to seismic gather what is demonstrated in Figure 3. Obviously, it is not a complete analogue of VSP seismic gather, but since the microseismic cloud is distributed along some plane with roughly constant inter-event distance it should be similar to standard VSP data. From the obtained gather one can clearly see the P and S arrivals. This indicates the data consistency. Furthermore there is a possible presence of some reflections.

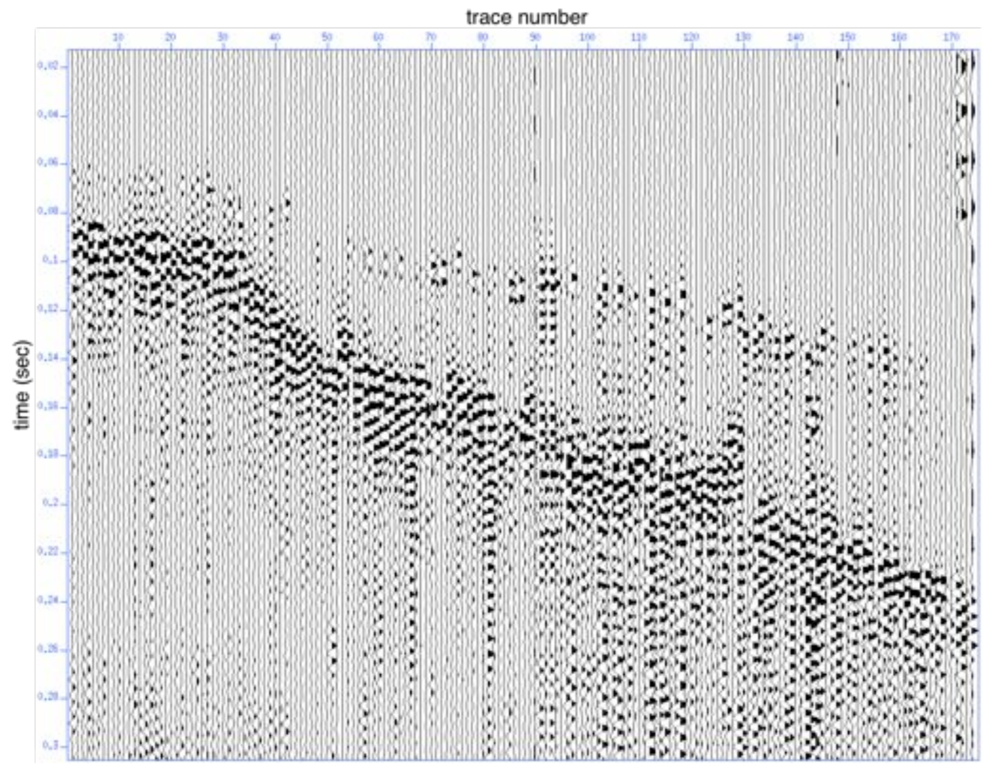

Figure 3. Seismic gather produced from the microseismicity cloud.

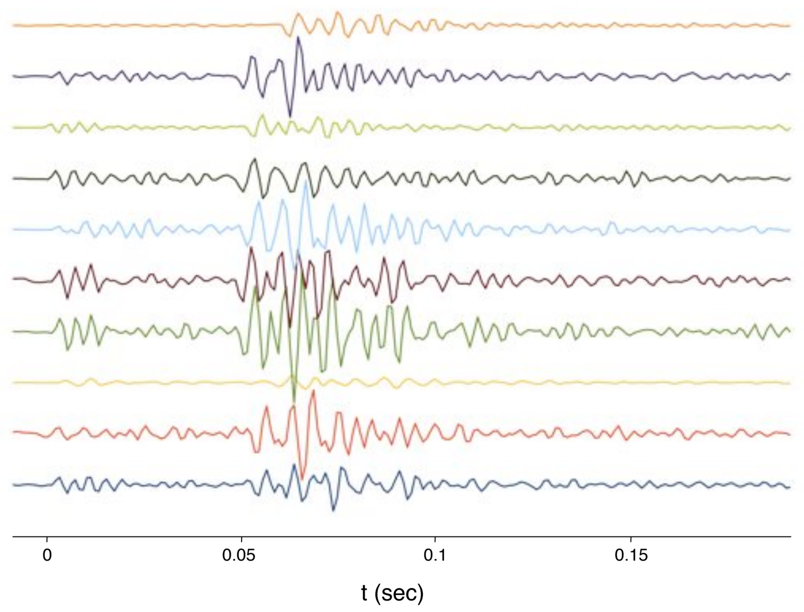

Figure 4. Vertical components of the 10 random traces.

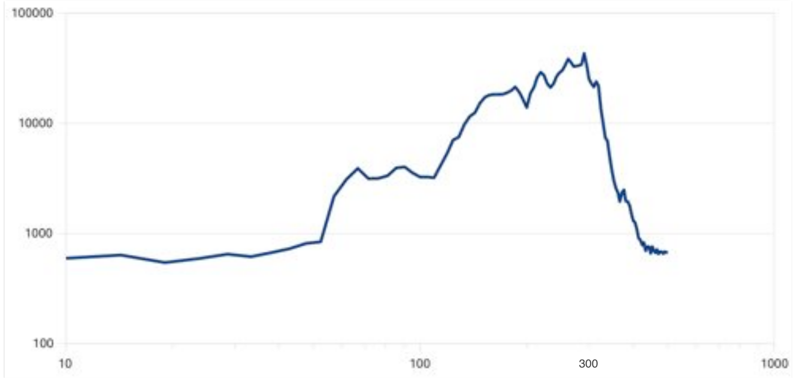

Figure 5. Amplitude spectrum of the traces shown at Fig. 4.

Imaging

To image the obtained seismic gather, we apply the Fresnel-Volume-Migration approach (Lüth et al. (2005), Buske et al. (2006)). The method takes into account the emergent angle of the recorded wavefield and limits the back-propagation to the region around the actual reflection/diffraction point. The calculation of polarization is necessary in terms of this approach. However, this additional computations are compensated by the fact that it is suited for situations of low spatial receiver coverage and for low fold and steeply dipping reflectors, which is the case for KTB.

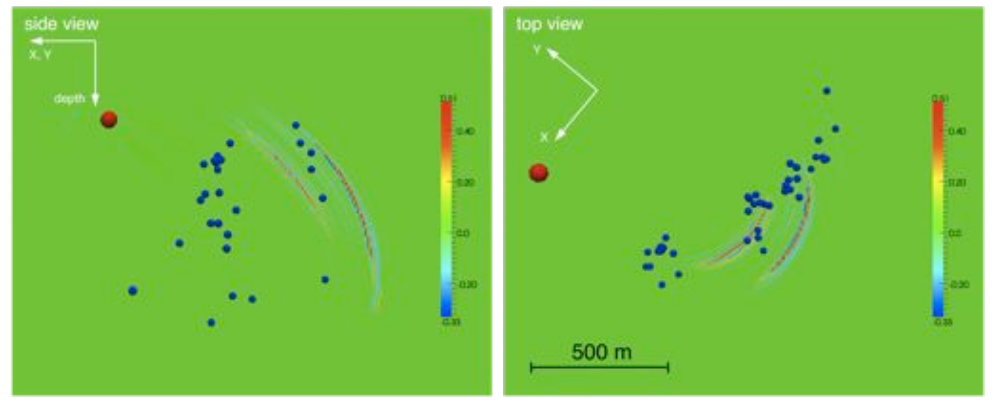

Figure 6. Microseismic images of the PP reflected waves from 58 reference events.

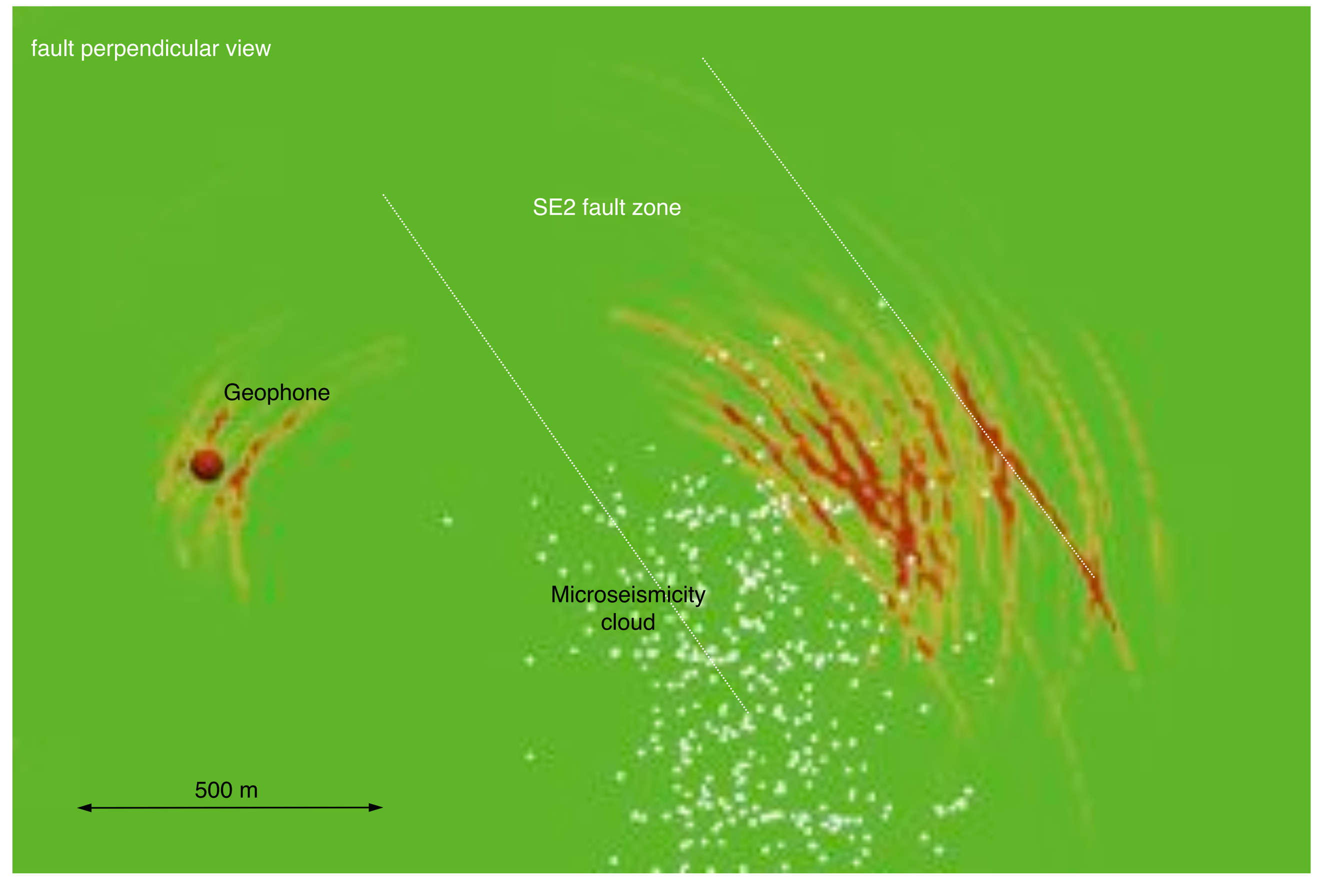

Figure 7. Microseismic images of the PP reflected waves from 414 events.

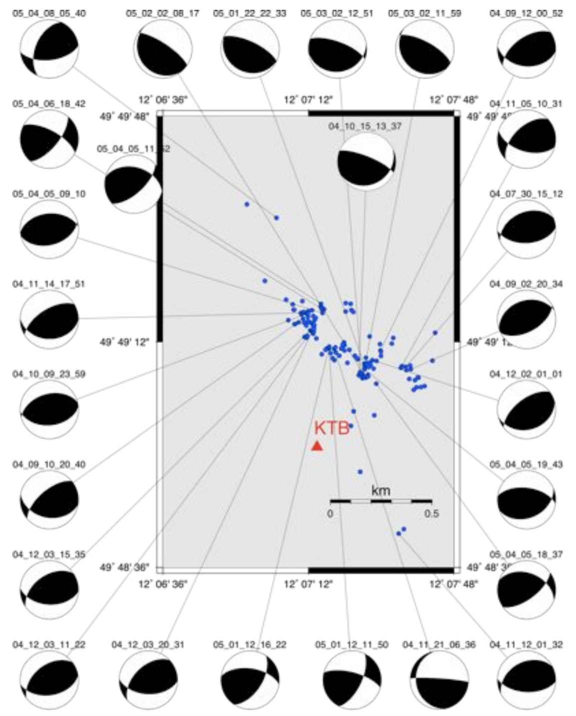

Figure 8. Single event focal mechanisms and hypocenters projections for 26 microseismic events (Kummerow et al. (2006))

Comparison with active seismic imaging results

To analyze our findings, we compare the resulting images to seismic attributes by Jaya et al. (2009) constructed from surface seismic imaging results by Buske (1999) . Figure 9 shows the seismic attributes on the background and the obtained reflectors. The inclined SE1 and SE2 fault zones (green, yellow and red colored areas) can be seen. The images cover only a small part of the SE2 fault, nevertheless the obtained reflector positions fit the emphasized seismic reflectivity related to SE2 fault quite well by both position and inclination.

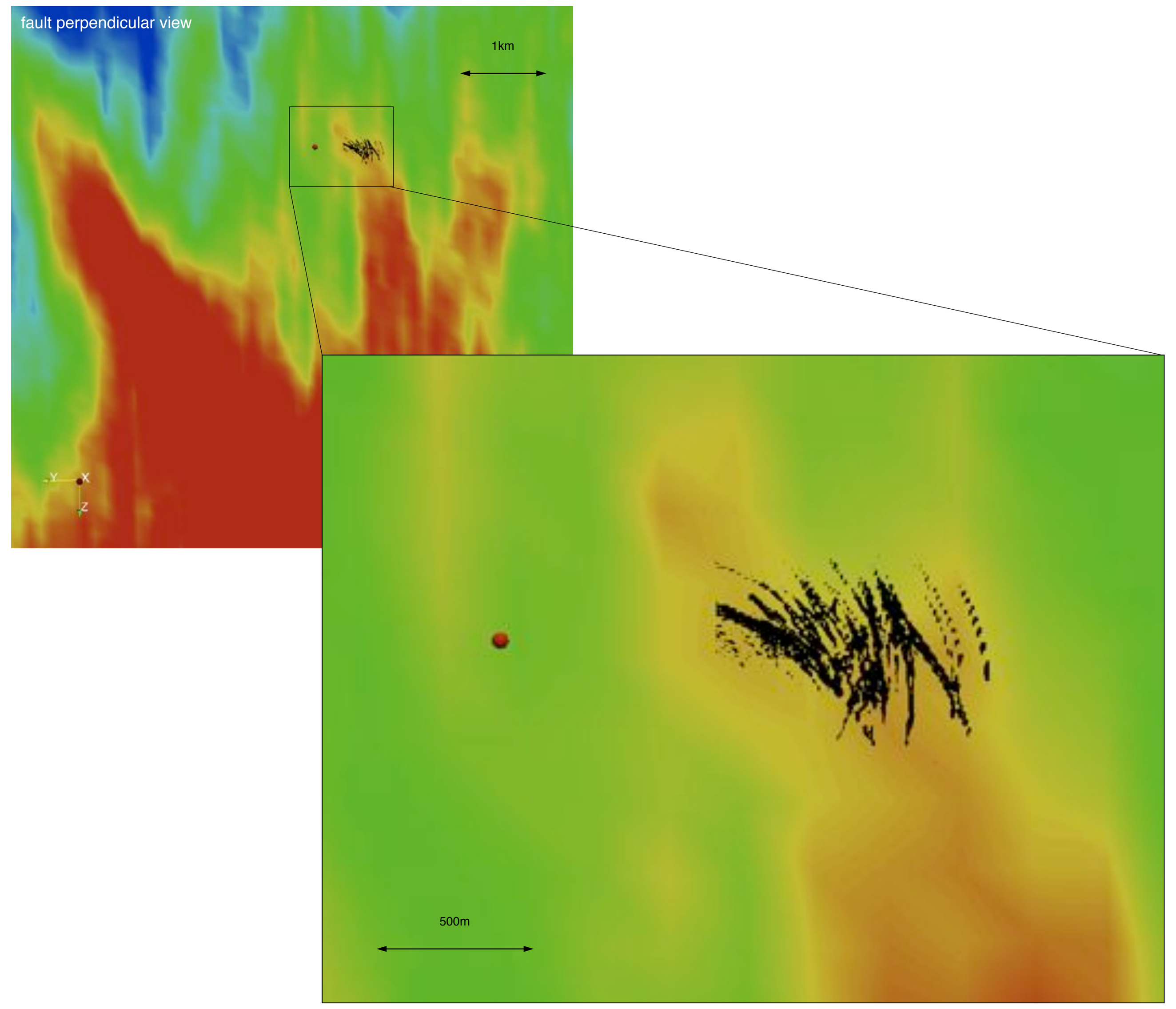

Figure 9. Comparison of seismic attributes obtained from surface imaging results (on the background) and images from microseismic events (black slices). Red point – HBU geophone position.

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