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High-precision relocation of induced seismicity in the geothermal system below St. Gallen (Switzerland)

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From July to November 2013 a sequence of more than 850 events, of which more than 340 could be located, was triggered in a planned hydrothermal system below the city of St. Gallen in eastern Switzerland. Seismicity initiated on July 14 and the maximum Ml in the sequence was 3.5, comparable in size with the Ml 3.4 event induced by stimulation below Basel in 2006.

To improve absolute locations of the sequence, more than 1000 P and S wave arrivals were inverted for hypocenters and 1D velocity structure. Vp of 5.6-5.8 km/s and a Vp/Vs ratio of 1.82-1.9 in the source region indicate a limestone or shale-type composition and a comparison with a lithological model from a 3D seismic model suggests that the seismically active streak (height up to 400 m) is within the Mesozoic layer. To resolve the fine structure of the induced seismicity, we applied waveform cross-correlation and double-difference algorithms. The results image a NE-SW striking lineament, consistent with a left-lateral fault plane derived from first motion polarities and moment tensor inversions.

A spatio-temporal analysis of the relocated seismicity shows that, during first acid jobs on July 17, micro-seismicity propagated towards southwest over the entire future Ml 3.5 rupture plane. The almost vertical focal plane associated with the Ml 3.5 event of July 20 is well imaged by the seismicity. The area of the ruptured fault is approximately 675x400 m. Seismicity images a change in focal depths along strike, which correlates with a kink or bend in the mapped fault system northeast of the Ml 3.5 event. This change might indicate structural differences or a segmentation of the fault. Following the Ml 3.5 event, seismicity propagated along strike to the northeast, in a region without any mapped faults, indicating a continuation of the fault segment.

Seismicity on this segment occurred in September and October. A complete rupture of the NE segment would have the potential to produce a magnitude larger than 3.0. Similarity of waveforms suggests that an Ml 3.2 in 1987 and an Ml 2.2 event in 1993 occurred on a similar structure with a similar slip direction as the Ml 3.5 event. It appears that the fault zone targeted by the geothermal project is not only oriented favourably for rupture relative to the regional stress field, but is also close to failure.