Geophysical Research Abstracts
Vol. 12, EGU2010-10523, 2010
EGU General Assembly 2010

High-resolution seismic imaging of near-surface fault structures in the Upper Rhine Graben, Germany

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Faults systems are important targets in different fields of exploration geophysics. Recently, exploration is focussed on deep-seated faults systems for hydro-geothermal utilization, where fluid flow may be enhanced compared to the surrounding host rock (fracture dominated aquifers). In fault related exploration, special interest of geothermal research is given to size, shape and age of fault patterns as well as to the geological periods of fault activity, because fluid flow critically depends on those parameters.
A well-established way to explore structural architecture of fault systems is the use of 3D reflection seismics. This technique, if applied to targets at several kilometers depth, inevitably leaves a gap in the near-surface domain due economic line spacing. To bridge the gap between target exploration at several kilometers depth (here 2-4 km) and the need to trace structures from the reservoir to the near surface, a study in the Upper Rhine Graben, Germany, was performed to supplement large-scale 3D seismic imaging of fault systems with high-resolution 2D reflection seismics.
Here, we present results from three different high-resolution reflection seismic profiles, which were carried out across the projected outcrop of local fault structures. These structures appear in 3D seismic datasets recently acquired for hydro-geothermal exploration, but fade out towards surface. The new shallow seismic sections image Quaternary and Late Tertiary units between approximately 20 m and 1000 m depth. The sedimentary strata are resolved at high-resolution and different fault patterns can be identified therein. At one site, a 300 m wide normal fault zone was observed, while the other site shows a prominent horst structure with bounding faults branching into smaller ones at depth. From these fault images the last geological time of activity could be narrowed. Imaging limitations can be explained by an increasingly high-energy depositional system on one site, preventing unequivocal fault imaging into Quaternary times, or are methodology inherent to a depth of approximately 20 m at the other site, which reveals at least a sub-recent activity of this fault system.
In summary, structures are visible and can be deduced from these 2D measurements, which are not apparent in the lower frequency, large-scale 3D datasets. Thus high-resolution 2D measurements are well suited for complementing the missing near-surface information of 3D datasets; the imaging of structural details allows a deeper insight into the architecture and kinematics of fault systems.