Geophysical Research Abstracts,
Vol. 10, EGU2008-A-09647, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-09647
EGU General Assembly 2008

Illustrations of VSP efficiency for the characterization of a deep crystalline reservoir (the Soultz-sous-Forêts EGS case study)

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At the Soultz-sous-Forêts EGS (Enhanced Geothermal Systems) and in general in other crystalline reservoirs, the fluid flow paths between the injection and the production boreholes are mainly controlled by a set of permeable and non-permeable structures. We found that the acquisition of 4C-VSP (Vertical Seismic Profiles) recorded with three oriented orthogonal components of geophones plus a hydrophone, with multiple surface source positions, followed by isotropic processing methods, allows to investigate the geometry of this kind of deep basement accidents in the well vicinity.

Isotropic processing:

A recent test of 3C VSP data processing from an old acquisition (in 1993) at the Soultz-sous-Forêts EGS in the GPK1 well showed spectacular P-S reflections occurring on fault planes intersected by the well and recognized as the most permeable fault zones (Place et al, 2006). Other seismic arrivals like diffractions are also identified. Thus, a structural investigation is proposed by identifying the structures responsible of these seismic responses. The major permeable fault zones intersected by the well can be investigated hundreds of meter away from the well. Their structural parameters (dip and azimuth) can be indeed inferred from these VSP results, and are in accordance with the results of logging data (UBI, ARI, FMI...). In addition, a fault located far from the acquisition borehole is well imaged and could be drilled in the future.

Acquisition:

Following these successful and convincing results, a large VSP survey was carried out at Soultz-sous-Forêts in April 2007 in GPK3 and GPK4, two of the three deepest boreholes of the reservoir (5000 m TVD). Two High temperature ASR 4C tools were deployed simultaneously in two wells at the same depth level for each record. Two vibrators generating simultaneous sweeps were positioned both in close and far offsets. A total of 60 profiles (70 km length) has been recorded and is still in preprocessing phase.

Preliminary results confronted with existing well logs: the preprocessed and oriented 4C VSP data exhibit a new and definite fault pattern associated with apparent refracted arrivals affecting the direct P wave arrivals, although no major velocity contrast occur between fault compartments. The amplitude of the refracted arrival becomes higher than the direct arrival amplitude as depth increases, then the refracted arrival totally obscures the initial direct arrival below the depth of intersection of the fault by the well. Commented results and confrontation with open hole and cased logs illustrate this singular seismic response from crystalline faults, observed for specific surface VSP source positions only. In addition, P tubes waves confronted to flow data shows a correlation allowing to discriminate some permeable structures, confirmed by casing and cement inspections.

In our case and in this kind of deep geothermal applications, a special attention has to be paid concerning the down hole instruments. They are indeed exposed to both high pressure and high temperature, corrosion by acid brines, and the high helium content of the fluids represents a risk for the rubber membrane of the hydrophone for example.