ORIENTED THREE COMPONENT VSP* METHOD APPLIED TO IMAGING HIGHLY DIPPING FAULTS IN THE DEEP GRANITE BASEMENT AT SOULTZ-SOUS-FORETS

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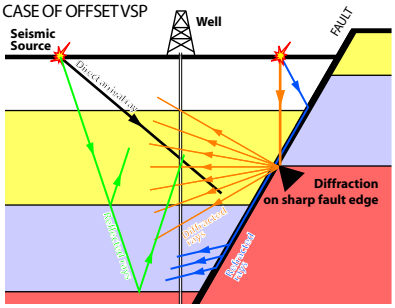
INTRODUCTION

One of the most important problems encountered in a geothermal site development is the understanding of the fluid flow path within the reservoir surrounding the wells and between wells. When applicable, the prospective geophysical methods constitute an attractive way to map the major and potentially permeable structures. The aim of this study is to assess the efficiency of the well seismic profiling method in the investigation of the geometry of the sub vertical and hydrothermalized structures affecting the deep granite of the Rhine Graben. Existing data sets recorded in 1993 (Le Bégat *et al.*, 1994) in the GPK1 well of Soultz-sous-Forêts with vertical vibrator (P-wave source) were fully processed for the first time, using the three components: the unexpected converted P-S seismic reflection results provide an invaluable structural information in the well vicinity.

*THE VERTICAL SEISMIC PROFILING (VSP) METHOD

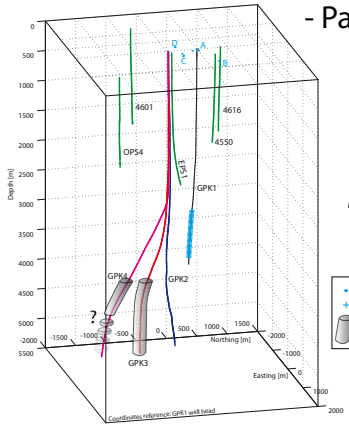


A Vertical Seismic Profiling is a field measurement procedure in which the seismic source is activated at a fix surface position and the seismic signal is recorded by sensors located in a well at successive depth levels.

If the source is located near the well, the survey is called a **Zero Offset VSP**; if the source is significantly far from the well, it is called an **Offset VSP**.

Aims of a VSP study:
VELOCITY SURVEY from waves travel time measurements,
STRUCTURAL INVESTIGATION using the seismic reflection, diffraction and refraction events generated by structures located in the borehole vicinity, within a radius of hundreds of meters from the well, and below the well bottom (Place *et al.*, in press).

THE WELLS AT THE SOULTZ GEOTHERMAL SITE

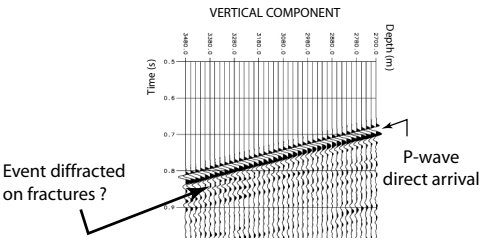


- Past and future VSP surveys -

Existing VSP data sets in GPK1:
1988 VSP's: from the surface to 2000 m deep
1993 VSP's: logged from 2700 m to 3480 m

Future acquisition in GPK3 and GPK4:
planned early 2007: from 4000 m to 5000 m

EXAMPLE OF RAW VSP DATA



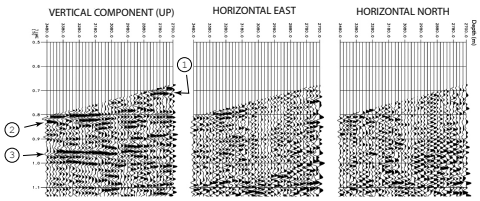
ISOTROPIC 3C DATA PROCESSING

- applied by VSfusion -

Isotropic upgoing/downgoing separation

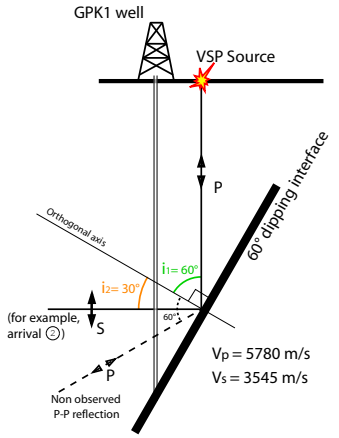
Single operator deconvolution of the three components

3C ISOTROPIC RESULT DISPLAY in raw VSP time



Most of the reflected energy appears on the VERTICAL component only, from dipping reflectors: it implies that the seismic reflections are recorded in SHEAR-wavemode by the VSP tool, after P-S conversion on the reflectors.

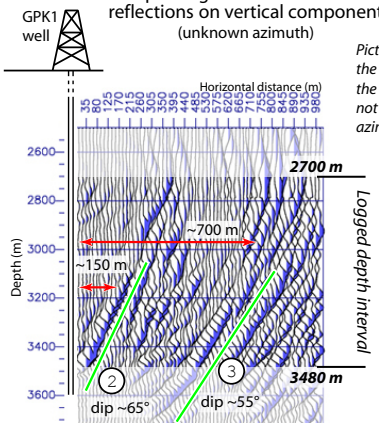
WAVES IDENTIFICATION



Events 1, 2 and 3 (previous figure) are converted P-S reflections from highly dipping fractured corridors, confirmed by the well logs.

FAULT IMAGING

2D depth migration of converted P-S reflections on vertical component (unknown azimuth)



Picture of the dip of the faults, not their azimuth !

The dip of the structures can be read directly on the depth migrated seimic image at a scale 1:1.

CONCLUSIONS

A geometrical characterisation of the major structures affecting the vicinity of a geothermal well in Soultz can be derived with confidence from the exploitation of P-wave source VSP data. Remarkably, several strong heterogeneities affecting the massive granite basement can be observed up to 700 m laterally away from the GPK1 well.

In the next VSP acquisition, numerous offset VSPs will be recorded in order to accurately constrain the position of the reflecting faults and map them as far away from the well as possible. A downhole VSP tool mounted with three HT gimballed orthogonal geophones and a HT hydrophone will be used in order to further discriminate the P and S wavemode arrivals at the receiver.

As the seismic response of a fault depends on its inner structure (kind of alteration, porosity distribution…), the hydraulic conductivity of a fault will be tentatively assessed by the amplitude of converted P-Tube arrivals observed on the hydrophone sensor, in addition with the seismic signature on geophone sensors alone.

For future geothermal sites development, this study shows that an intermediate VSP survey shot while drilling, or a post drilling VSP survey, is potentially efficient to assess the remaining depth that has to be drilled to intersect a fault or to plan a deviation of the borehole trajectory. The trajectory of a second deviated well from the same cluster may also be planned using the VSP survey images from the first well.

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