Shallow seismic anisotropy surveying in the area of the KTB-location Oberpfalz (Germany)

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Introduction

During the last two years the authors carried out vertical seismic profiling (VSP) studies in the area of the KTB-location Oberpfalz (Fig.1). The aim of the investigation was to investigate, whether the anisotropy, detected at the pilot-hole of the KTB-location during the DEKORP-campaign ISO 89, extends to shallower depths. Incorporated in this study was the attempt to elucidate, whether the origin of the anisotropy is foliation-dependent (rock-inherent) or crack-induced and therefore generated by the regional stress-regime.
Consequently the wells were preferentially chosen to be located in zones of non-oriented and mainly homogeneous rock formations (granite). Any exhibition of anisotropy could then be interpreted as caused by oriented microcracks and would offer the opportunity to estimate the influence of the above mentioned causes of anisotropy.

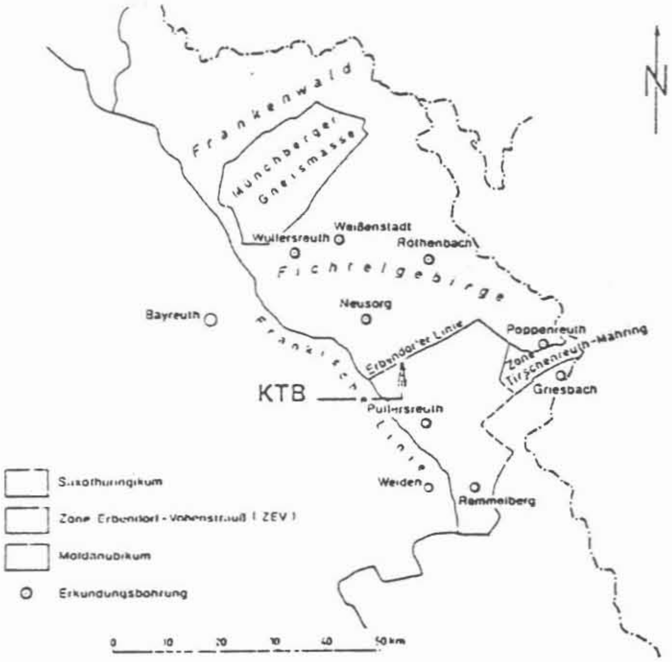

Figure 1: Map showing the location of the pilot-holes in the area of the KTB-location Oberpfalz

Layout of the experiment

The diagnosis of anisotropy is mainly based on two effects:

1) observation of seismic bodywave velocities as a function of the direction of propagation
2) identification of shear-wave splitting by means of polarization analysis

The identification of shear-wave splitting, which is the most reliable criterion to differentiate between anisotropy and inhomogenity, usually requires the acquisition of three-component data. To avoid any problems arising from the fact, that even inhomogenities could generate polarization effects similar to shear-wave splitting (Helbig and Mesdag, 1982), it is important to observe the invariance of the wavelet of the S-wave with regard to the horizontal source-orientation. This leads to the application of the so called nine-component-technique:

At each source-offset preferably P-waves were generated with a weight drop device. Then a horizontal hammer source was positioned twice to generate separately orthogonally polarized horizontal motion. This was accomplished by orienting the horizontal source transverse and inline each offset. Multioffset vertical seismic profiling (VSP) on different azimuths was used to investigate the spatial dependence of the vertical slowness-vector (Fig. 2). The depth of the mentioned wells ranged from 150 m to 300 m (Falkenberg: 500 m), but various problems excluded the access to the maximum depth. Therefore the average sampled depth interval was limited to approximately 150 m, except at Falkenberg, where a maximum depth of 240 m was reached.

The downhole-tool was a wall-lock geophone consisting of a 10 Hz Triphone (i.e. transducers arranged in a Gal'perin configuration), two vertical oriented transducer elements (10 Hz, 100 Hz) and two hydrophones. Triphones are especially useful in VSP-measurements, since they usually exhibit a better calibration and a higher consistency of amplitude, frequency and phase-behaviour among the three transducer-elements than data recorded in an orthogonal XYZ-geometry. For this reason, any amplitude scaling prior to the data-processing could be omitted. The orientation of the geophone in the well was measured by a fluxgate-gyroscope and an inclinometer. Data were recorded at 0.5 ms sampling interval with 300 ms record length on a 24-channel recording-system. The geophone spacing in the well was held stationary at 4 m and source-offsets ranged from 15 m to 150 m. At all locations, except Falkenberg, those measurements were followed by subsequent moving-source-profiling (MSP) at certain geophone-levels to estimate the spatial dependence of the horizontal slowness-vector (Fig. 2). For this survey the parameters - compared to the VSP-measurements - remained unchanged. At Falkenberg, the availability of adjacent parallel wells facilitated the measurement of the spatial dependence of the horizontal slowness-vector, which was carried out according to a technique developed by White et al. (1983). To carry out refraction statics split-spreads, covering up the MSP-profiles, were shot.

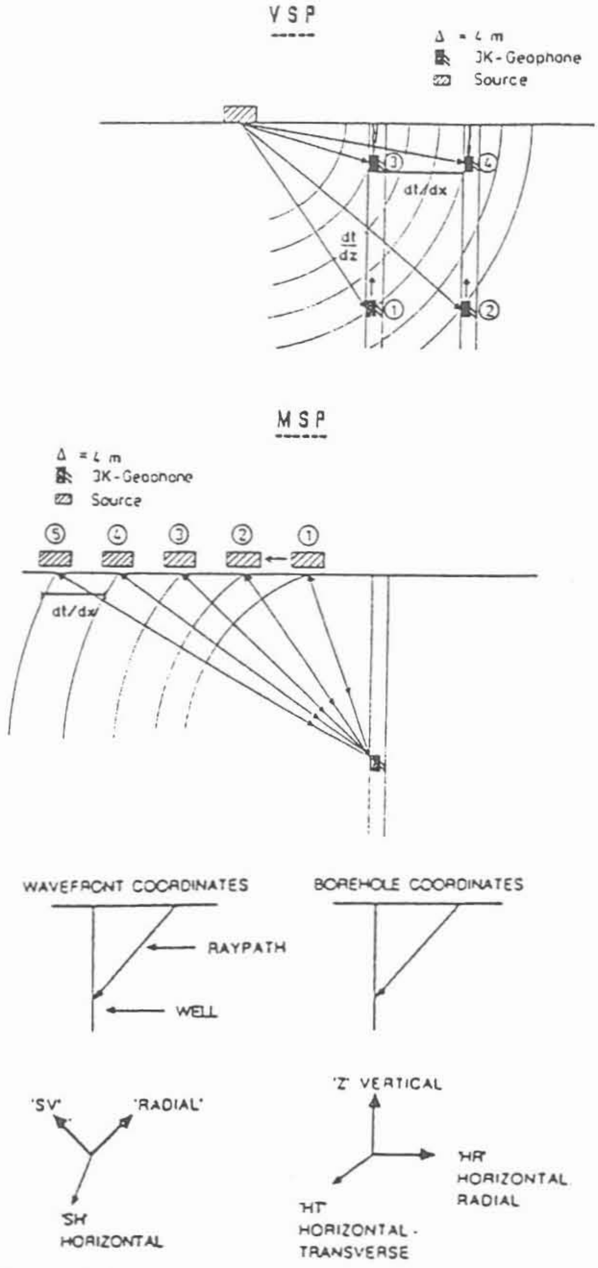

Figure 2: Schematic profiles, illustrating the acquisition geometry for studying the horizontal and vertical slowness-vector. The lower portion shows the coordinate systems used in the analysis.

Data processing

All recorded data were subjected to the subsequent processing-sequence:

Arranging the data to seismogram sections
Rotation of the three-component traces into a consistent coordinate system
Noise editing (notch- and band-pass-filtering)
Computation of particle-motion diagrams

The rotation of the VSP-data, recorded in Gal'perin configuration, was an important processing-step to facilitate the interpretation of the three-component traces. A first rotation yielded orthogonal three-component data with the 'Z'-component oriented along the vertical axis, whereas the 'HR'- and 'HT'-Component was oriented horizontally inline and transverse to the line connecting the source and well (Fig. 2).

Further improvement of the data could be achieved by the application of a subsequent rotation into the wavefront coordinate-system (Fig. 2). This rotation was controlled by a least-squares procedure maximizing the P-wave energy on the radial component of the particle motion (labeled 'Radial'). A second component was synthesized in the horizontal plane, orthogonal to the 'Radial'- particle motion (labeled 'SH') and the third component was constructed orthogonal to 'Radial'- and 'SH'-particle motion, in a vertical plane (labeled 'SV'). Since we had to distinguish between source polarization and the particle motion of the wave, the two horizontal force-directions and the orthogonal polarizations of the rotated data were defined arbitrarily and independently. For the source, 'SH' indicates the horizontal force oriented transverse to the line connecting the well and the source-point, whereas 'SV' presents the horizontal force oriented radially towards the well. Figure 3 presents near-offset VSP data, recorded at the Falkenberg location, after the rotation into the wavefront coordinate-system. Shown are the 'SV'- and 'SH'-component for the orthogonally polarized horizontal sources. In all seismograms, well pronounced S-wave arrivals on the 'SV'- and 'SH'-component are to be seen, i.e. both source-orientations produced motion of 'SV'- and 'SH'- polarization. The 'SH'-component from both sources however, clearly arrives earlier than the 'SV'-component. The travel-time-difference between the faster 'SH'-component (1760 m/s) and the slower 'SV'-component (1625 m/s) was determined to be 7 ms at 232 m depth. The polarization analysis was performed by the computation of hodograms and the derivation of instantaneous polarization parameters. In figure 4 hodograms, connected with the seismograms of figure 4, for the geophone levels of 224 m and 232 m, respectively, are drawn. They reveal a cruciform pattern of particle motion in the transverse (Z-Y) plane, which indicates a shear-wave splitting. The polarization of the faster shear-wave ('SH'-component) was estimated approximately N 110 E, parallel to the strike of the Fichtelberg fault-zone.

First Results

The enormous amount of data as well as the lengthy processing-procedure prevented an extensive interpretation up to the present. But as a first result the analysis of the Falkenberg data-set, which seemed to be the most significant of the whole survey, proved a velocity-anisotropy for subvertical travelling S-waves of approximately 8%. With regard to the homogenity of the non-oriented Falkenberg granite in the surveyed interval, the anisotropy is likely to be exclusively crack-induced and therefore dependent on the regional stress-regime.
Ongoing calculations of the authors, based on anisotropic ray-tracing and the computation of synthetic seismograms, should verify this assumption in the near future.

References

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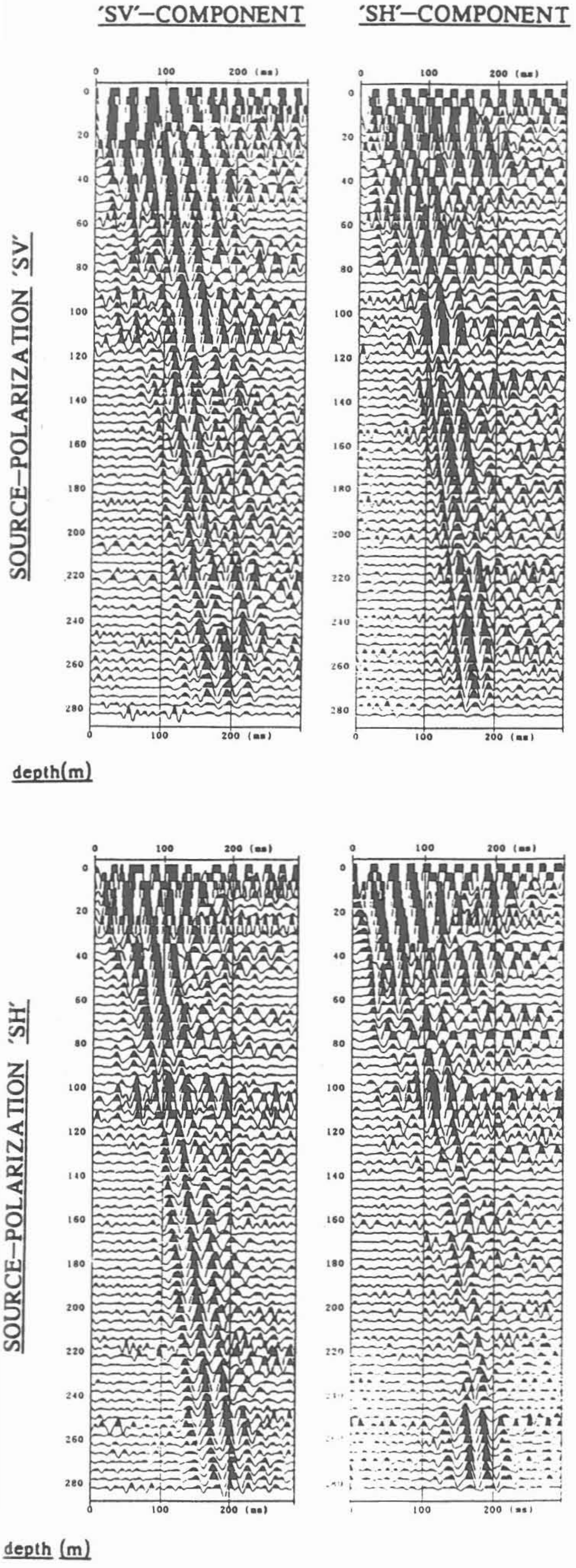

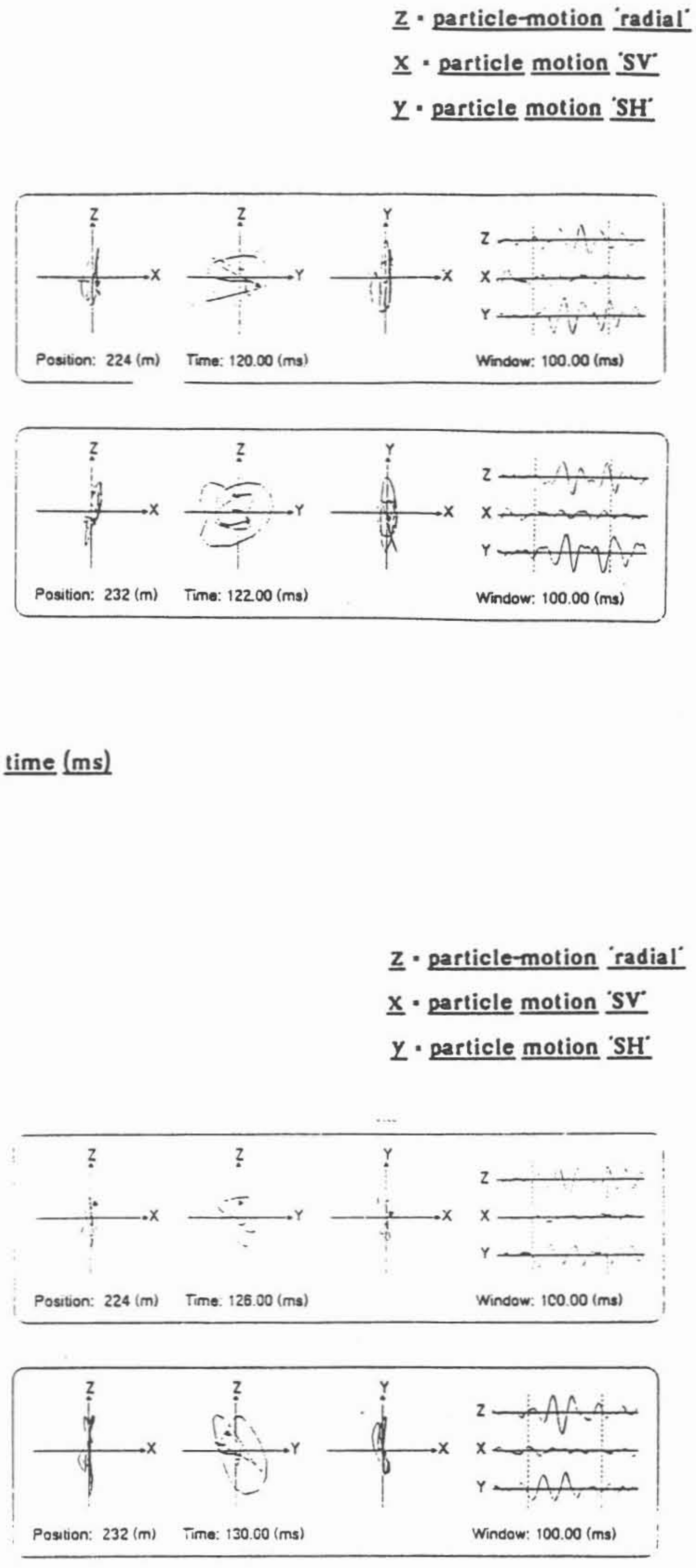

Figure 3: Near-offset VSP data of the Falkenberg location after rotation. The seismograms, labeled according to the convention mentioned in the text, show true amplitude data, band-pass filtered 10-100 Hz.

Figure 4: Hodograms of the data in fig. 3 for geophone-levels 224 m and 232 m. The upper portion of the figure presents the particle-motion generated by the 'SV'-source polarization, the lower portion traces the particle-motion generated by the 'SH'-source polarization.