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3-C vector fidelity for Shear-wave polarizations characterization in hot dry rock geothermal reservoir: observed anisotropic effects of fractures

Sebastien Soulas
Avalon Sciences Ltd

Introduction

A single near rig source VSP with vibrator was acquired in our test site at Rosemanowes ex. HDR (hot dry rock) geothermal research site in the deep deviated well RH15 in both open and cased hole as part our routine customer training courses. The main intent was to use our conventional P-wave vibrator source (12-96Hz sweep) and analyze the clear high amplitude direct S wave arrival recorded by our high fidelity 3-C geophone tool string which showed excellent data quality on horizontal components. One of the objectives was to evaluate the coherency of the shear-waves polarization in respect to the maximum stress direction and strike-slip faults that were detected during hydraulic stimulations experimental work at Rosemanowes quarry a Carnmenellis granite environment drilled in the 80s. On this site, hydro-fracturing proved to be almost irrelevant, and the granite rock was dominated by natural fracture system. Additionally, we qualitatively showed that stress fields in crystalline rock are invariably anisotropic using shear wave splitting analysis.

Method

The recorded 3C data was geographically oriented using our 3C solid state inclinometer system called a High Side Indicator accelerometers (HSI) as the measurement well RH15 is deviated from 15 to 29 degrees in the deep interval 1500-2500m MD (ref Wills, 2017) as depicted in figure 1.

Three rotations were applied at each downhole station to orientate the 3C signals as follows:

- First rotation in relative bearing plane (orthogonal to well trajectory).
- Second rotation in vertical plane of deviation
- Third rotation in horizontal plane to compute the North and East horizontal components

The geographically orientated 3C seismic signals are displayed on figure 2.

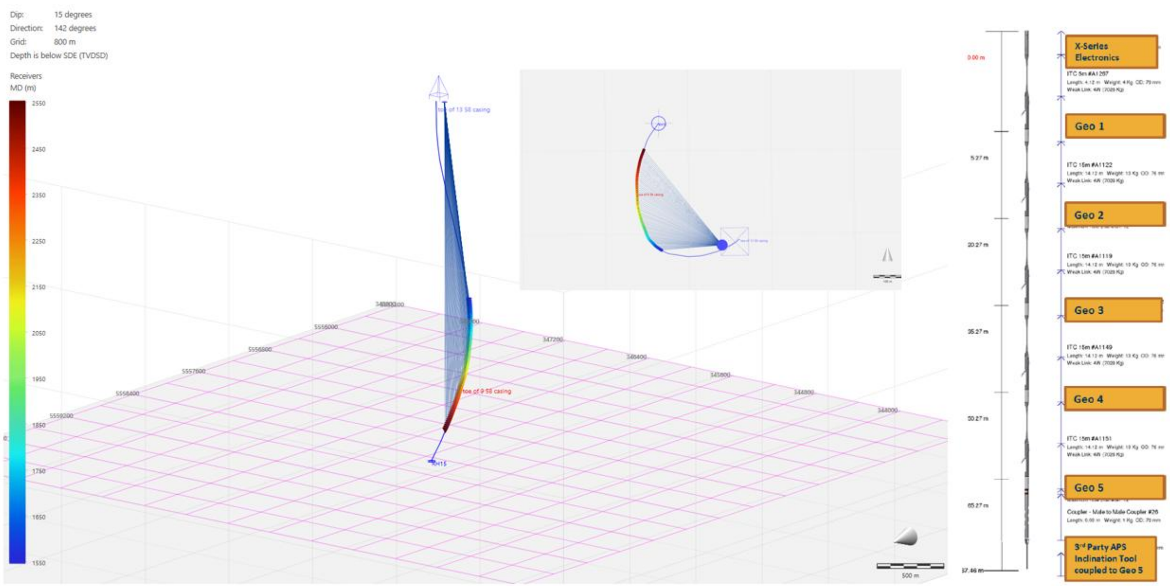

Figure 1 *RH15 well trajectory showing zero offset survey aperture (1500-2500m MD). Top middle is the 2D view of well geometry. Right hand side is showing the borehole receiver string schematic, a 5 level 3-C VSP tool string with 15m separation between each tool.*

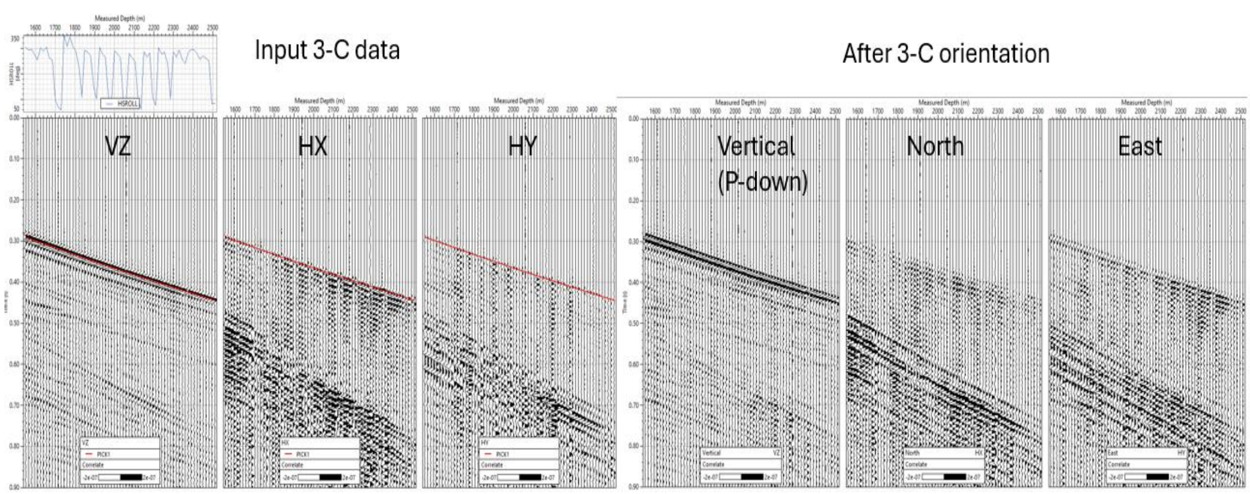

Figure 2 *Zero offset VSP 3C dataset in RH15 deviated well. Left 3 panels are the raw 3C dataset. Right 3 panels are after 3C orientation in geographical Vertical, North and East horizontal axes*

Direct S-wave analysis and S-wave splitting detection

The 2C H-North and H-East signals on the 5-35 Hz band passed input data are then maximized on a short time window taken along the S-wave first arrival peak time picked on the filtered modulus signal, applying the method described by Naville et al., [2012], resulting in figure 3.

This procedure is like the common maximization of the direct P-wave energy on offset VSP recorded in a vertical well to orientate the horizontal components, along the P-wave time pick.

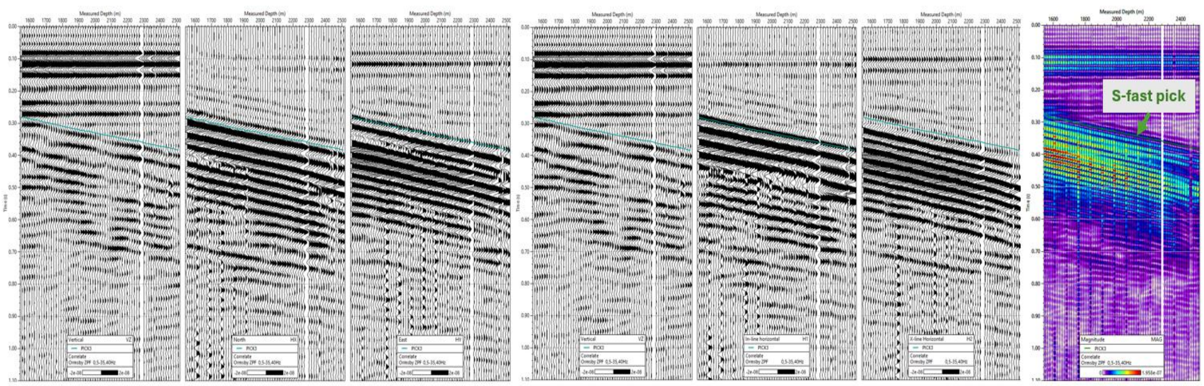

Figure 3 *Flattened data at 100ms on direct P-wave arrival time, left three panels are before S-wave polarization (3-C orientated data 5-35Hz) and middle three panels are after S-wave polarization to S-fast and S-slow components (panels 4 and 5). The right panel shows the filtered modulus signal with the S-fast time pick in green*

S-fast arrival (S1) green pick on figure 4 left panel is clearly ahead of S-slow arrival (S2) up to half a period. Those graphs clearly highlight the S-wave signal coherency after polarization separation, thus the mechanical coupling quality of the 3-C VSP tool string.

The direct S-fast polarization azimuth is about 65° West which is coherent with the maximum stress direction (σ_h max 52° West) and the nearest major joint set strike direction ~50° West (determined from micro seismic events analysis during the major stimulation of well RH15 carried out in 1985, and Pearson,et al., 1989) as per depicted in figure 5.

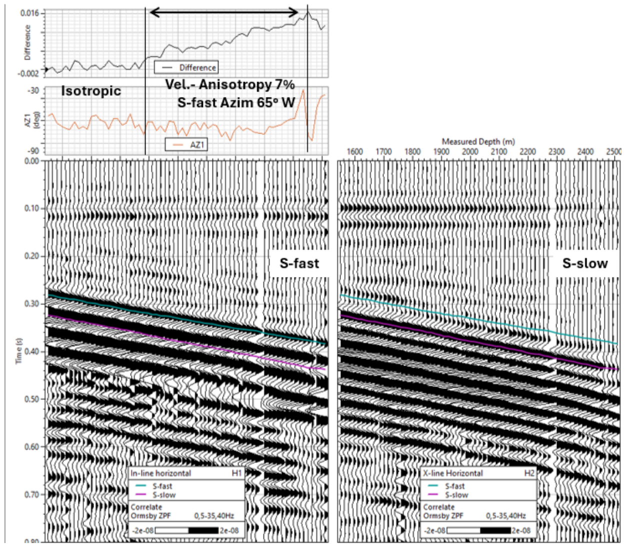

Figure 4 *Flattened data at 100ms on direct P-wave arrival time for S-fast and S-slow (right) components after split S-wave polarization separation. Direct fast shear pick arrival is the green pick on the (left side display. Direct slow shear pick arrival is the purple pick on the right-side display. Top black curve is the relative travel time difference between fast and slow shear arrival, and the bottom orange curve is the polarization azimuth of the S-fast wave from receiver back to source.*

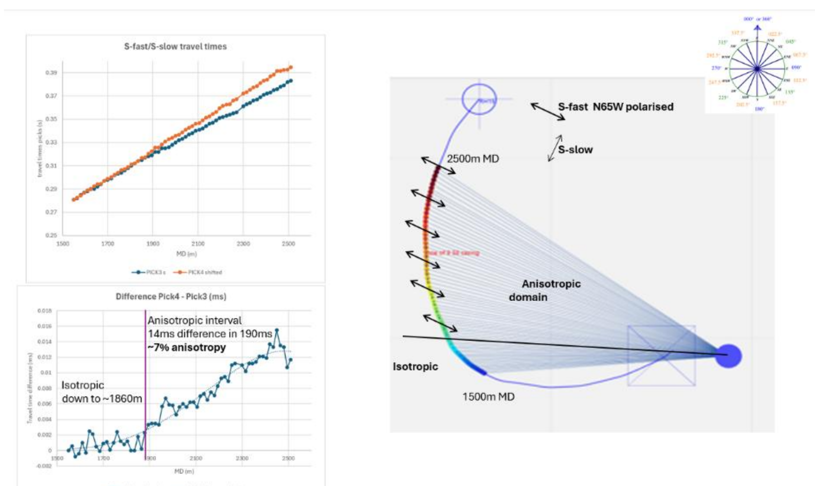

Figure 5 *Top graph shows fast and slow Shear wave picks (orange = S-fast pick, Blue = S-slow pick). Bottom curve shows the travel time difference between fast and slow S-wave. The bottom left graph shows that the interval from surface down to 1860m MD is isotropic as S-wave time difference is null, and anisotropic below as it shows up to 14ms difference with corresponds to about 7% anisotropy below 1860m MD. The right display is depicting a top view of the well trajectory and sketch of S-waves polarization in respect to MD.*

Conclusions

The analysis showed a clear shear-wave anisotropy of about 7 percent in the granite formation below 2000m.

The ability to record discrete electromechanical 3-C sensors with excellent vector fidelity and high SNR are critical for vector wavefield processing of downhole seismic measurements.

The successful integration of orientation device (HSI) and usage of measured relative bearing in deviated well for 3-C orientation procedure turned out to be a very robust solution as conventional method could not work due to low direct P-wave energy on horizontal components. Clear direct S-wave train allowed to determine the azimuth and velocities of fast and slow principal Shear waves and confront them with the known local stress directions, The ability to measure S-wave polarization variations is important to monitor subsurface pressured fluid movement and stress changes in either storage or recovery operations, and to illuminate 3-Dimension structures around the wellbore.

Acknowledgements

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