Velocity Anisotropy from Core Measurements, VSP and Sonic Logs Analysis in a Single Well Study in NE Alberta

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Summary

The presence of fractures and textures of the subsurface rocks can cause imaging problems in the conventional seismic processing routine as a result of seismic anisotropy. Problems arise from the directional dependence of wave propagation that was unaccounted for in the original isotropic velocity model. To quantify the degree of seismic anisotropy in the subsurface, one method is by estimating the anisotropic parameters from laboratory measurements performed on a core sample. However, with the limited cores available from our borehole of interest in NE Alberta, additional field measurements of the walk-away vertical seismic profile (VSP) and sonic scanner were performed to obtain anisotropy measurements for the rest of the borehole. This case study examines the result of seismic anisotropy from three different types of data which indicates the presence of intrinsic anisotropy at various depth intervals.

Introduction

The study borehole is located west of Fort McMurray with a total depth of 2363 m. The purpose of this site in our recent study is to provide a subsurface characterization of the rocks using a combination of wireline logs, seismic reflection profiles, zero-offset VSP and walk-away VSP (Chan and Schmitt, 2013). Some of the reported observations include the presence of a potential dyke that is recognizable in the density, photoelectric factor and magnetic susceptibility wireline logs, fractured zones in resistivity and formation microimager (FMI^{TM}) logs, dipping reflectors in the seismic reflection profiles, and upgoing tubes wave in response to fractured zones and the *in-situ* condition of the borehole. To date (January 2014), we have evaluated the degree of seismic anisotropy from a core sample and down to a depth of 1797 m in the walk-away VSP data. The latest logging campaign occurred in November 2013 to obtain the sonic scanner log to support our existing interpretations and extend our seismic anisotropy analysis. This should extend our current understanding of seismic anisotropy in the open hole section of the borehole from 1005 m to 2325 m.

Methods

Core Measurements

Using the ultrasonic pulse transmission method, measurements of the compressional and shear wave phase velocities as a function of confining pressure were used to calculate the elastic stiffnesses of the core sample (Figure 1). Velocities were measured parallel, normal and oblique to an identified foliation plane in the sample with a presumed axis of symmetry. The compressional wave velocities were measured to be in the range of 5158 to 5776 m/s along the foliation plane and 4518 to 5096 m/s normal to the foliation plane in a confining pressure environment from 0 to 60 MPa. Thomsen's (1986) paramters of weakly anisotropic behavior were calculated from the measurements under the assumption of transversely isotropic medium with a tilted axis of symmetry (Figure 2).

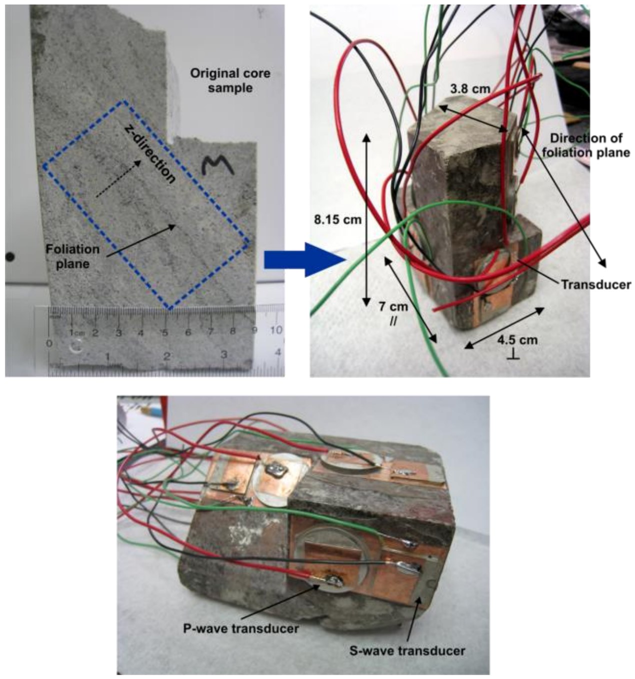

Figure 1. Photographs of the rock sample before (top left) and after (top right and bottom) sample preparation. Due to the limited cores available, the sample has to be carefully cut along the dotted blue lines with respect to the identifiable foliation plane in order to obtain a sample with the largest dimension possible from the core.

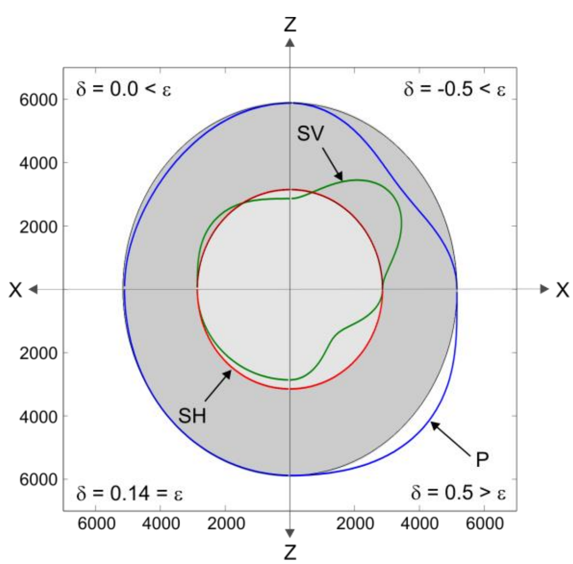

Figure 2. Illustration of the anisotropic behaviour of Thomsen's (1986) parameters (ε, γ, and δ) of a weak transversely isotropic medium. The ellipsoids of the longitudinal (dark grey) and horizontally-polarized shear waves (light grey) are included as references.

Walk-away VSP Study

A walk-away VSP was acquired at two different receiver depths to determine the degree of velocity anisotropy. By placing the geophones directly in the borehole and using a series of source points on the surface, the ray geometry for each receiver is equivalent to that of the downgoing ray in a common-depth point reflection profile (Kebaili and Schmitt, 1996). The wavefront geometry created by a seismic energy source and detected by the borehole geophones approximates an ellipse (Figure 3). Seismic velocity is then determined from the known recording depth, source offset distance, and arrival time. Seismic anisotropy can be quantitatively described by the coefficient of anisotropy (A) as denoted by (Birch, 1960, 1961):

$$A = (V_{max} - V_{min}) / V_{max}$$

where V_{max} and V_{min} are the maximum and minimum velocity values. Readers should note that this is just one definition of ‘anisotropy’, and one needs to take note of how a given author has defined it.

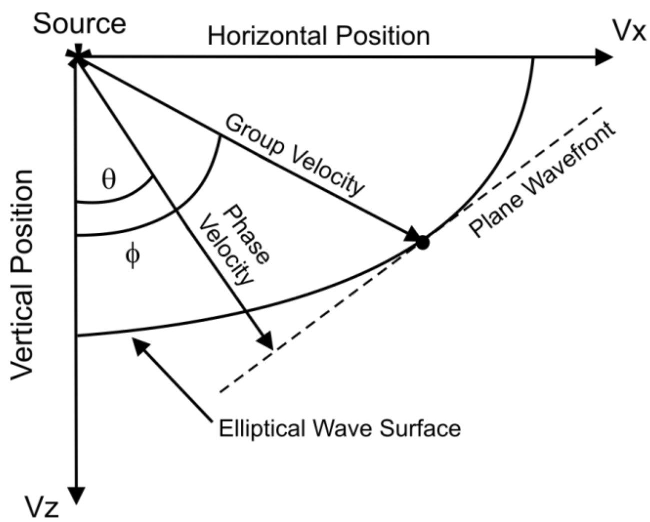

Figure 3. The relationship between ray (group) and phase velocities when energy propagates in the shape of an elliptical wave surface. The axis of symmetry is along the z-direction (modified from Kebaili and Schmitt, 1997).

Sonic Scanner Analysis

This is the most recent data set that was conducted in the study borehole and is expected to provide an extended interpretation of seismic anisotropy in addition to the previous two methods. The sonic scanner tool offers a comprehensive acquisition of waveforms using a wide frequency range to enable a deeper understanding of the acoustic behaviour in and around the borehole and also to assist in the existing interpretation of fractured intervals present in the subsurface (Schlumberger, 2005). Preliminary shear dispersion analysis reveals intrinsic anisotropy at varying depth intervals. We anticipate that the sonic data will be further processed and interpreted in the next few months for a more integrative interpretation of the data mentioned here.

Conclusions

Besides providing valuable in-situ velocity information for the velocity models, the results of the core measurements and walk-away VSP study also confirm the anisotropic behaviour of the rock sample in the study borehole from surface to about 1800 m depth. The estimated compressional and shear wave anisotropic values averaged at 14 % and 10 % respectively from the laboratory measurements. Significant anisotropy was also observed in the walk-away VSP study with reported values of 12 to 15 % between surface to 797 m depth and 16 to 18 % between 797 to 1777 m depth. The varying degree of anisotropy at various depths can be attributed to the presence of fractures and the mineral composition of a potential dyke in the subsurface. The anistropic values from the sonic scanner are unavailable at the time of this abstract submission, but preliminary shear dispersion analysis reveals the presence of intrinsic anistropy at various depth levels. Such degree of seismic anisotropy should be taken into consideration at the seismic scale when working with three-dimensional geophysical models of the subsurface to minimize any out-of-plane anomalies in the final seismic sections.

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