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Sonic anisotropy and monoclinic modelling at the CaMI site

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Summary

Sonic array waveform data are processed with slowness dispersion inversion to provide compressional and three shear slownesses in the Containment and Monitoring Institute (CaMI) research site injection well. These slownesses are used in a tensor completion algorithm to complete a simple orthorhombic medium. Significant VTI and HTI is observed. The fast shear azimuth from crossed dipole processing provides a depth-dependent symmetry axis rotation, making sonic scale logs of monoclinic stiffness moduli. After upscalng to a layered medium, ray theory simulations provide predictions of kinematic and dynamic seismic responses.

Workflow and results

Sonic data from the vertical and deviated wells were processed using dispersive slowness estimation and radial profiling inversion. For an overview of these techniques applied to a case study see Sinha et al., 2006. We focus here on results from the vertical well. In a vertical well sonic processing provides compressional slowness (modulus c33), fast and slow shear slownesses (moduli c44 and c55) and horizontal shear slowness from the Stoneley (modulus c66). From these four measurements, Bayesian sonic tensor completion (Leaney and Jocker, 2018) is used to complete an orthorhombic tensor corresponding to a vertically fractured VTI (FVTI) medium. The sonic fast shear azimuth provides a depth-dependent symmetry axis rotation angle, resulting in logs of monoclinic moduli. These logs are upscaled using generalized Backus averaging (Schoenberg and Muir, 1989) to a layered monoclinic medium.

In 2017 Schlumberger's Sonic Scanner tool was logged at the CAMI injection well. Figure 1 shows the results of Bayesian FVTI sonic tensor completion. Logs of Vp, Vs, background VTI parameters and HTI parameters are shown together with a lithology column (Isaac and Lawton, 2016) and a petrophysical volumetric analysis. VTI correlates strongly with the volume of clay and strong VTI is observed. The Basal Belly River formation, where CO_2 is being injected, is isotropic. The lower Lea Park Pakowki shale shows strong VTI together with significant HTI indicating orthotropy. While horizontal stress anisotropy is commonly observed in stress-sensitive formations which are usually sandstones, HTI in shales is more likely due to the presence of natural fractures. The fast shear azimuth from crossed dipole sonic processing (not shown) exhibits a depth-dependent orientation. Where the HTI anisotropy is significant the fast azimuth is a robust measurement of the symmetry axis orientation. At any depth the logs shown in Figure 1 are for the simplest type of orthorhombic medium – a VTI medium with a single set of compliant fractures added (Schoenberg and Helbig, 1997), but with a symmetry axis that varies with depth the medium must be treated as monoclinic. A monoclinic medium has a single plane of symmetry, in this case the horizontal plane, and can be constructed with multiple sets of vertical fractures, all with different orientations and compliances, but here the monoclinic medium is the simplest possible, with a single set of vertical fractures and depth-variable orientation. We determined average values of fast azimuth for formations and rotated the orthorhombic logs using a modified Bond transform (Chapman, 2004). The logs were blocked based on lithology and upscaled within layers using generalized Backus averaging (Schoenberg and Muir, 1989).

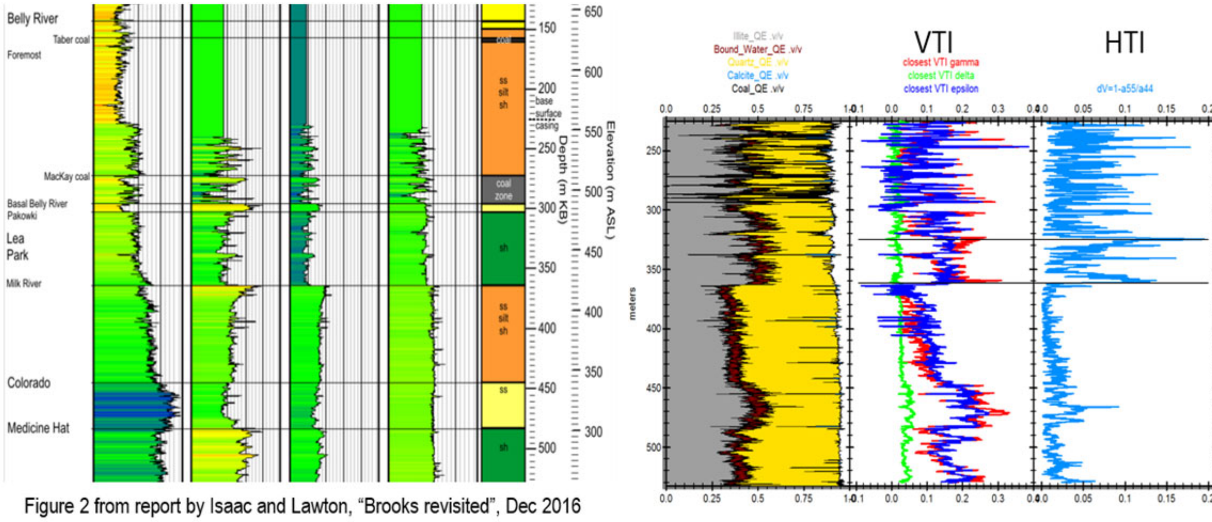

Figure 1. Lithology at the CAMI site (left) and petrophysical volumetric analysis with sonic anisotropy logs.

The upscaled monoclinic model is shown in Figure 2, along with rays and azimuth-dependent travel times for a simulated walk-around survey where the receiver is below the orthorhombic Pakowki shale formation. The azimuth-dependent signature that would be observed for a medium with a single fast azimuth for all depths is disrupted by the change of fast azimuth with depth, resulting in a second harmonic. Also shown in figure 2 are the P-p and P-sv AVAz reflection responses out to 60 degrees incident phase angle for top and base lower Lea Park formation. Multi -offset and -azimuth VSP data were acquired in September 2018 which should be able to confirm or refute these time and amplitude seismic response predictions.

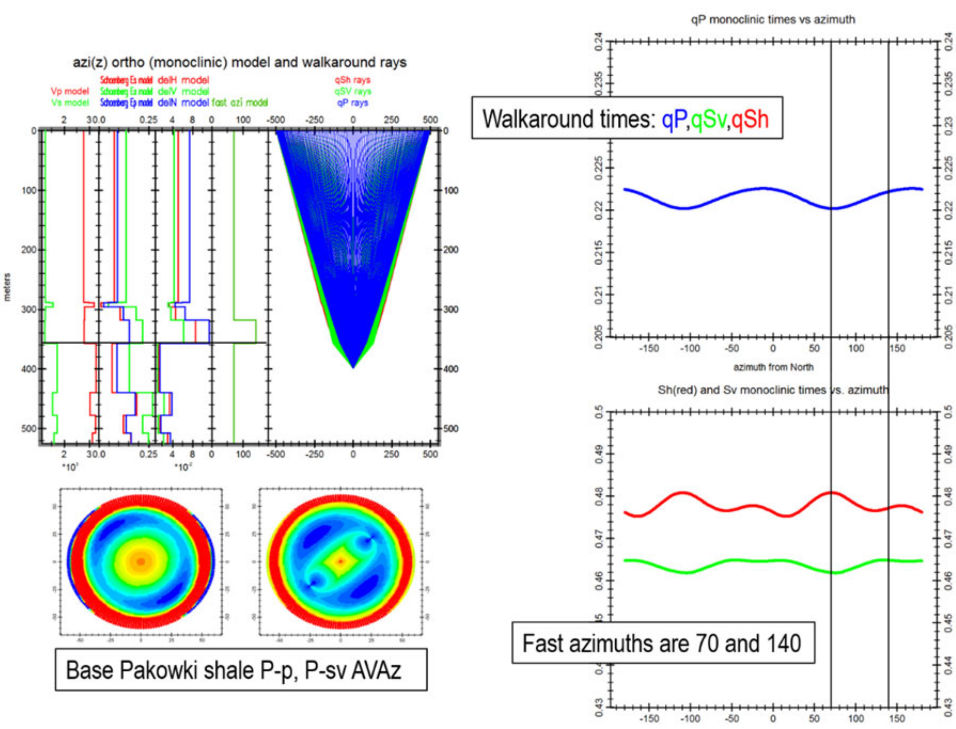

Figure 2. Upscaled monoclinic model with depth-dependent fast azimuth (upper left) and qP, qSv qSh rays from surface to a receiver at depth z=400m below the orthorhombic Lea Park formation. Lower left: Right: walkaround qP, qSh and qSv times for a circle at radius r=500m.

Acknowledgements

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