CREWES 2018 multi-azimuth walk-away VSP field experiment

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Summary

CREWES conducted a high-resolution multi-azimuth walk-away three-component vertical seismic profile (VSP) survey at the Containment and Monitoring Institutes Field Research Station (FRS) in 2018. This data is primarily intended for use in full-waveform inversion (FWI) and modelling studies. The FRS has three wells, referred to here as the geophysics, injection (CO_2) and geochemistry wells. Four of thirteen source lines (Figure 1) centred on the geophysics well were acquired with a 10 m VP spacing (0, 45, 90, and 135-degree bearings), and the remainder were acquired at 60 m VP spacing. The minimum source offset from the geophysics well was 6 m, and the maximum was 480 m. Vibe Points (VP) were acquired using an Inova Univib running a linear 1-150 Hz sweep with two sweeps per VP at 445 unique locations. Permanent vibratory sources from GPUSA were also tested. In addition to 24 existing permanent 3C geophones cemented into the geophysics well at a 5 m receiver spacing around the reservoir level (Geometrics Geode recorder) and a ~5 km horizontal and down-hole optical fibre loop at the FRS (Fotech interrogator), High Definition Seismic Corporation deployed a string of Inova 3C VectorSeis accelerometers in the geophysics well at a nominal 1 m spacing from the surface to 324 m depth (Inova Scorpion recorder). Surface receivers included a 100x100 m patch of permanent buried 3C geophones centred on the injection well (Inova Hawk nodes), 1C 10 Hz geophones at a 10 m spacing (Inova Aries recorder) along source line 13, and additional Inova Hawk and Quantum nodes along the same line for hardware testing purposes.

VSP Processing and Interpretation (VectorSeis)

The closest VP to the geophysics well has been processed using a standard zero-offset processing flow: 1) stack, 2) correlate, 3) first-break picks, 4) wavefield separation, and 5) deconvolution. Figure 2 shows the corridor mute and stack, and comparison to a P-P synthetic seismogram. The Basal Belly River sandstone is the zone of interest for CO_2 sequestration. Far offset VSP processing has thus far followed examples shown by Hinds et al. (1996) and, except for component rotations, follows the zero-offset processing flow. Component rotations from H1 and H2 to Hmin and Hmax (horizontal rotation angle theta), and from V and Hmax to V' and Hmax' (vertical rotation angle phi) were calculated using the Vista module VSPRPol. This module uses a method described by Grechka and Mateeva (2007) to calculate rotation angles using a least-squares minimization algorithm. Ray-tracing using a 1D model constructed from the zero-offset VSP interval velocity curve gives us time-variant rotation angles, which were used for our final component rotation to Z''up, mostly containing up-going P wavefield and Hmax''up which mostly contains the up-going Sv wavefield (right-hand panels; Figures 3 and 4).

A walk-around VSP conducted at the FRS in 2015 with a semi-circular source line at 400 m radius centred on the injection well resulted in observed travel time variations on the order of 3 ms for a single receiver at 383.5 m depth (Hall et al., 2015). The fast direction roughly coincided with source line 13 of the 2018 survey (SW-NE), and the fit to a 2PSI azimuthal travel-time variation model led to an interpretation of weak HTI anisotropy caused by fracturing due to the regional stress field. First breaks plotted against receiver depth and source-receiver azimuth show sinusoidal patterns with azimuth, as seen in the 2015 VSP data. We know from a previous 3C-3D surface survey acquired in 2014 that source statics at the FRS can vary by up to 15 ms across the survey area. Application of the 2014 source statics greatly reduces the amplitudes of the first-break sinusoids. HTI anisotropy, while likely present, may be even weaker than previously thought.

Discussion and Future Work

Downhole accelerometer data from the geophysics well at the CaMI.FRS have been processed to a zero-offset corridor stack that compares well to a P-P synthetic calculated from well logs recorded in the same well. In preparation for future full waveform inversion work, receiver components of far-offset VSP data have been rotated from 1) H1 and H2 (field orientation) to Hmin and Hmax (rotation angle theta), followed by V and Hmax to V' and Hmax' (rotation angle phi). Theta shows good consistency with increasing receiver depth, while phi shows a turn-over point that appears to track a phase change between up and down-going first motion observed on the vertical component. Time variant component rotations to Hmax''up and Z''up have been completed for all VP. These results will be input for future inversions. Analysis of the first-break picks shows that there may be very weak HTI anisotropy present on site, although this finding becomes less convincing after application of source statics from a 2014 vintage 3C-3D surface survey.

Future work includes (in no particular order), 1) additional processing flow parameter testing and quality control, 2) better constrained well ties and interpretation including comparison to prior surveys, 3) use of first-break picks to create a full 3D anisotropic (isotropic?) depth model, 4) completion of far-offset P-P and P-S VSP processing including pre-stack depth migration, 5) comparison to fibre and geophone data from this and other surveys at the FRS and, 6) inversion for physical properties of the Earth.

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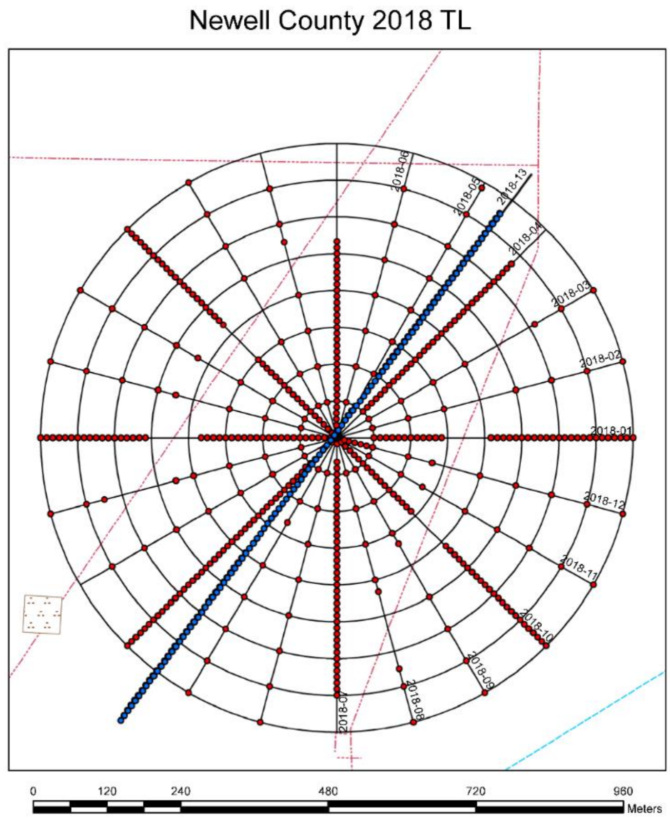

Figure. 1. Survey map. Black rings are 60 m interval circles centred on the geophysics well. Red dots are Vibe points, Blue dots are surface receiver locations, red lines are hydrocarbon pipelines.

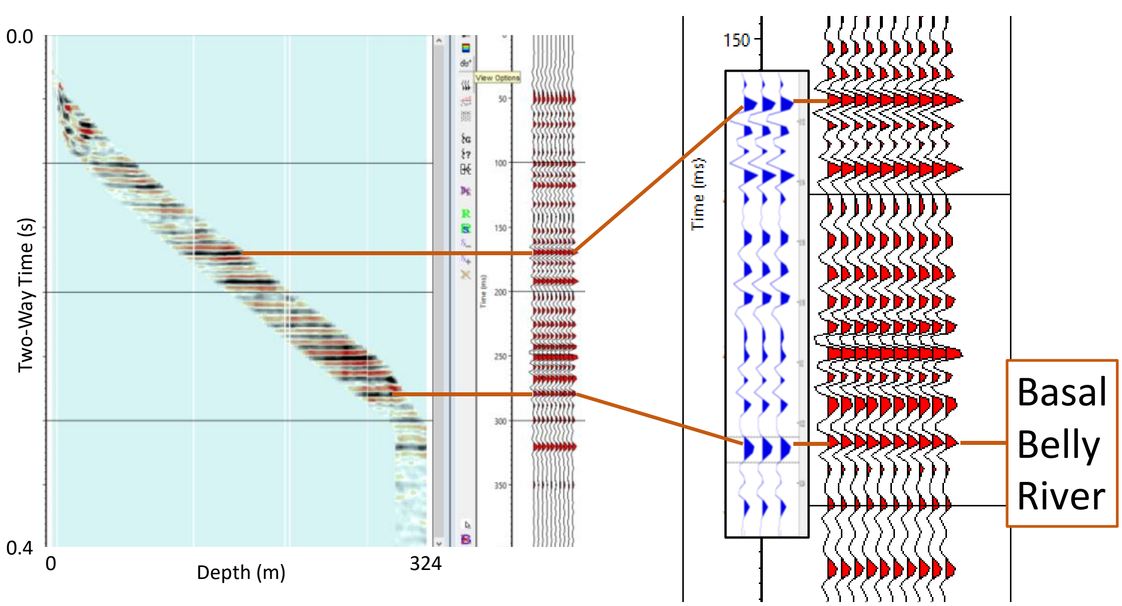

Figure 2. Zero offset VSP corridor stack after deconvolution with down-going P-wavefield compared to P-P synthetic.

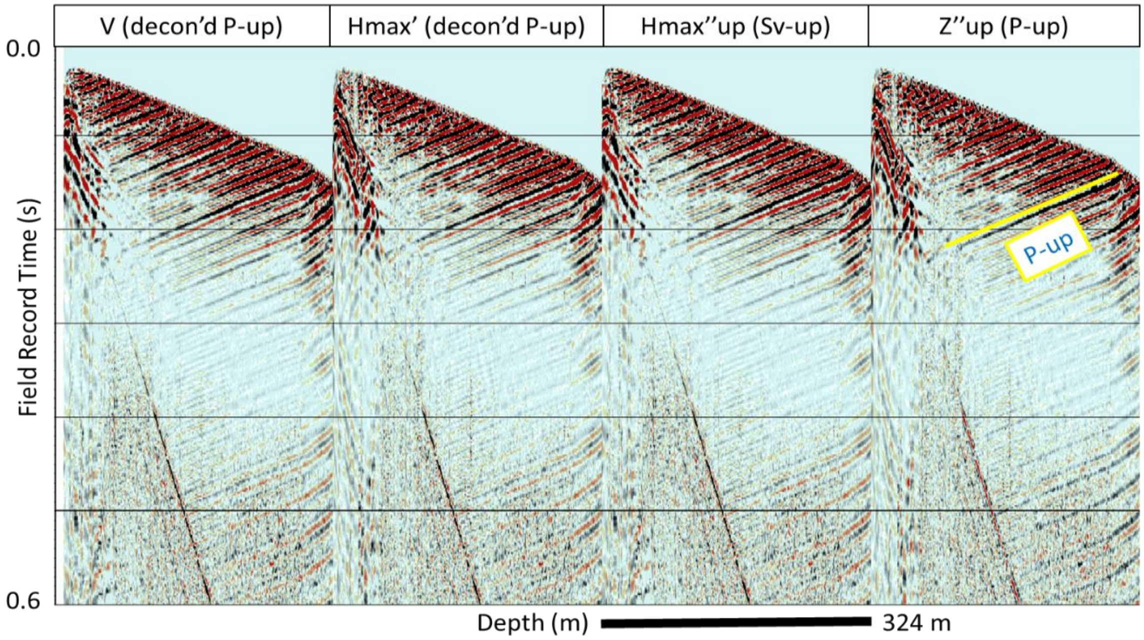

Figure 3. Time variant rotations to separate upgoing P and upgoing Sv. V and Hmax' were rotated to Hmax''up and Z'' up.

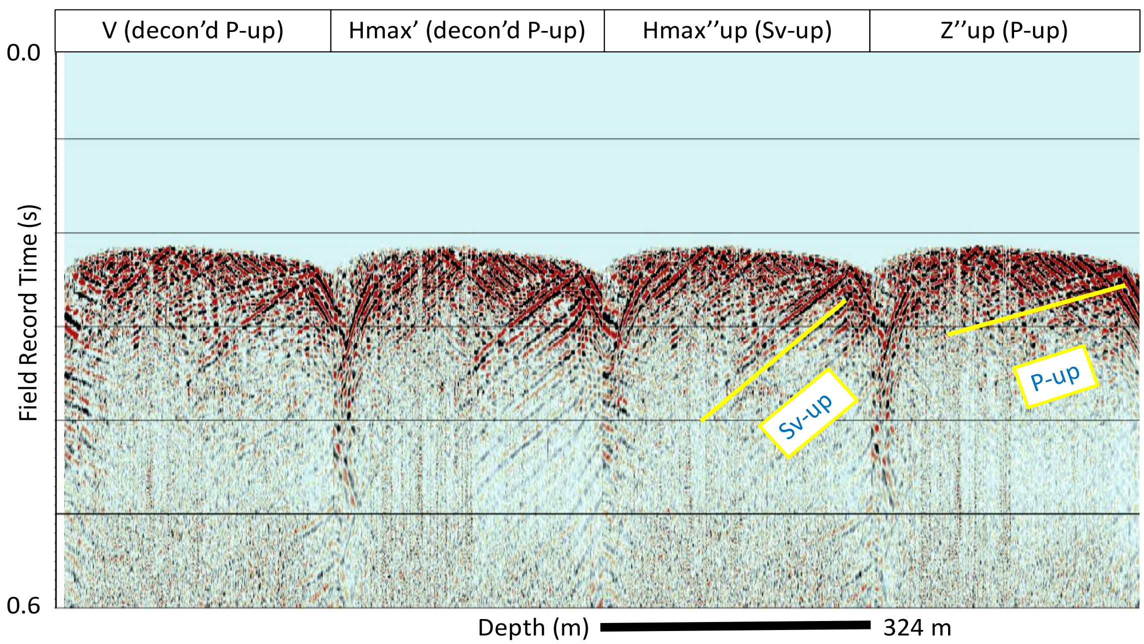

Figure 4. Time variant rotations to separate upgoing P and upgoing Sv. V and Hmax' were rotated to Hmax''up and Z'' up.