Multicomponent Seismic and Borehole Experiment to Establish and Identify the Cause of Anisotropy in the 2nd White Specks at Garrington, Alberta

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An experimental orthogonal 2D (N-S,E-W) multicomponent seismic grid, using compressional P, polarized Sh (transverse/cross-line) and Sv (radial/in-line) shear sources, were acquired in combination with two 45° P-Sv converted wave offset VSP's, aiming to specifically establish fracture orientation. However, the results and analyses indicate and quantify unambiguously, the presence of Periodic Thin Layering Anisotropy or Transverse Isotropy (TI), as opposed to vertical fracture induced Azimuthal Anisotropy, in the vicinity of 2nd White Specks oil production at Garrington. Seismic velocities and hence impedance contrast, of P, Sh and Sv waves propagating through open fractures are affected by the reduction in bulk rock moduli given sufficient fracture density (>10 fractures/wavelength, Tatham et al. 1992 Geophysics 57/647-652). Polariisation of Sh/Sv particle motion, that align or cross the strike of a simple open fracture system, show travel time differences in reflection arrivals as 'fast' S1 and 'slow' S2 ray paths, respectively. This simple relationship for shear wave splitting or birefringence, that is seen as an interference effect between S1/S2 (akin to a polarizing Geological microscope), is only strictly true for near vertical, principal direction propagation, see fig.1 (also;Crampin et al. 1985 First Break 3/16-20 & Geophysics 50/142-152, Alford SEG.conv.1986 expanded abstracts 476-479, Thomsen 1988 Geophysics 53/304-313). An actual field example, is shown in fig.3, of splitting on a raw shot matrix (XX,XY,YY,YX) in the Austin Chalk of S Texas, from Li et al SEG.conv. 1992 expanded abstracts 299-302, for lines shot in and at 45° to the principal fracture strike.

Other causes of anisotropy leading to similar observations of S1/S2 split arrivals arise from ray propagation off principal directions (ie.30°-40°) through fine layering such as a clastic sand/shale sequence, where the layer thicknesses are significantly smaller than the wavelength of the propagating seismic wave (Backus 1962 J.of Geophys.Res.67/4427-4440). This phenomenon, due to an anomalus increase in the Sv ray (quasi Sv) velocity above the Sh ray, has been extensively documented, both observationally in seismic exploration and crustal studies, as well as in numerical/physical modeling that will be considered in the context of this study see fig.2 (also; Douma et al SEG.conv.1986 expanded abstracts 394-396, Helbig 1981 Geophys. Pros.29/550-577, Thomsen 1986 Geophysics 51/1954-1966, Ass'ad et al 1993 Geophys. Pros.41/ 323-339, Cheadle et al 1991 Geophysics 56/1603-1613).

Guided by these theoretical possibilities, conclusions on the type of anisotropy in the study area are drawn from observations of the initial shear shot matrix, through processing, to interpretation of the Omnipulse Air Gun surface data in conjunction with borehole measurements. Quality of both P and S-wave recordings are good with maximum frequencies of 50-60 and 25-30 Hz respectively. Some key processing issues to be considered include; a) excellent P and Sv mode separation achieved by summation/subtraction of inclined impulsive air gun shots, as well as orthogonal three component receivers, b) use of strong Sh first breaks for accurate calculation of large shear wave statics as opposed to an incorrect, more complex, shear vibroseis approach of double the P-wave static summed with the P-Sv converted wave residual, c) key observations of differences in NMO stacking velocities between in-line Sv and cross-line Sh, with incongruously consistent zero offset, T0 arrival times.

Comparing the raw shot shear matrix fig.4 with that from the Austin Chalk example fig.3, indicates only two of the three possibilities with regard to fracture induced Azimuthal Anisotropy, namely that the shear polarizations are in and perpendicular to the fracture plane strike or there is no measurable effect, but definitely not splitting, hence no rotation. The 2D grid, line ties are used to establish the anisotropic (Azimuthal or TI.) cause for velocity differences between in-line Sv and cross-line Sh, (Lynn et al 1990 Geophysics 55/147-156). Applying the Sh cross-line NMO correction to the Sv in-line data, results in event timing miss-ties between Sh and Sv stacks. This observed velocity difference (see figs.5&6 of coff.stacks & NMO velocity semblance scans) occurs with the in-line Sv being consistently faster (~10-20%) than cross-line Sh, irrespective of line orientation. Note however on fig.5, that the Sv and Sh corrected common offset stacks have the same T0 arrival times despite the obvious velocity difference, meaning the principal axis (vertical) ray propagations have the same velocity and only the higher angle rays show the anisotropy. The only conclusion for this anisotropic line consistent and offset dependant velocity behaviour, is as indicated by the theory (see fig.2), for faster Sv arrivals arising from propagation in off-principal directions (ie.30°-40°) through fine layering. This TI. effect is strongest in sand/shale sequences, giving rise to a quasi-Sv ray (Justice et al SEG. monograph Shear-Wave Exploration p154-164). Consequently two 45° azimuth offset VSP's were acquired with the specific objective to confirm or negate the shear wave conclusions. This can be seen by comparing the rotated transverse or 'Hmin' and radial or 'Hmax' horizontal axes between the VSP's for evidence of converted shear wave energy being 'split' between radial and transverse components. The distinct observable lack of splitting between the horizontal components confirms the surface data conclusions of TI. anisotropy as opposed to Azimuthal Anisotropy. Other recent confirmation of the lack of vertical fractures is shown, by a zero offset shear vibroseis VSP, Formation Micro Scanner and horizontal drilling.

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