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Comment on "A numerical investigation of the acoustic mode waves in a deviated borehole penetrating a transversely isotropic formation"

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In the paper "A numerical investigation of the acoustic mode waves in a deviated borehole penetrating a transversely isotropic formation" by Liu et al. [1] numerical experiments are reported for a dipole sonic logging scenario with a deviated borehole penetrating a VTI anisotropic medium. In such a situation it is important to clearly define the meaning of group and phase velocities as this has led to much confusion in the literature as discussed by Miller, Horne and Walsh [2].

In the context of sonic logging it is essential to distinguish "phase" and "group" velocities in terms of 1) temporal dispersion, as described in the paper, and more importantly when considering anisotropic wave propagation the 2) spatial dispersion and to pay attention to what vector is aligned to the borehole axis.

In ref. [2] it is shown using field and synthetic data that the correct correspondence rule for sonic logging is that for a dipole sonic logging scenario with a deviated borehole penetrating a VTI anisotropic medium, to good approximation, the slowness measured with STC processing from sonic waveforms is equal to the reciprocal of the (spatial) group velocity for a signal with a group vector aligned to the borehole axis. To understand this statement requires a clear understanding of the following:

(1) the distinction between spatial and temporal dispersion,

(2) the distinction between spatial phase and group velocity and,

(3) the distinction between group and phase directions.

As shown in ref. [2], the small amount of temporal dispersion associated with the leaky P and S modes can be observed either by a frequency-by-frequency STC processing (which yields temporal phase slowness along the array, that is, along the borehole axis) or by a Prony-type method.

It is instructive to consider experiments where the borehole fill is matched exactly to the formation. This will reveal that even without a borehole, STC processing yields apparent slowness along the array. Because body waves in anisotropic media have wavefront normals that are not always aligned to the raypath direction connecting the source to the receivers, the apparent velocity normal to the wavefront is slower than the apparent velocity along the raypath. The former is the spatial phase speed, the latter is the group speed. When a borehole is added with a source and receiver array, the signal from the source, couples most strongly to body waves which would propagate between the source and receiver locations if the borehole was absent or filled with solid formation material. That is, to a signal with a group vector aligned to the borehole axis. The errors in the published literature are largely the result of authors, editors and reviewers failing to properly distinguish "group direction aligned to borehole axis" from "phase direction aligned to borehole axis" when

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(mis) interpreting numerical experiments.

This confusion is evident in Figure 7 of ref. [1] where a comparison of slow and fast flexural wave velocities obtained from the authors' frequency-wave number domain modelling results for the Cotton Valley shale model are plotted as a function of the modelled well deviation angle. In this plot they compare the numerical modelling results with the phase (plane-wave) velocities computed for phase angles equal to the well deviation angle. That is, the "deviation angle" is equal to the phase angle used in the solution for the Kelvin-Christoffel equation and it is assumed that the well deviation angle is equal to the phase angle. A considerably better fit to the numerical modelling results is obtained when the modeled fast and slow flexural waves are instead compared to the group velocity plotted as a function of the group velocity at the angle equal to the well deviation angle. We show this in the plot below (Figure 1) where we have taken Figure 7 from ref. [1] and overlain it with two new curves showing the SH wave (blue) and for the qSV wave (green) group velocity where we now set the group velocity angle to be equal to the well deviation angle.

Clearly the group velocity plotted as a function of the group velocity angle equal to the well deviation (blue and green lines) are a better match to the numerical modelling results (square and cross symbols) than the phase velocities computed with a phase angle equal to the well deviation (solid and dashed black lines).

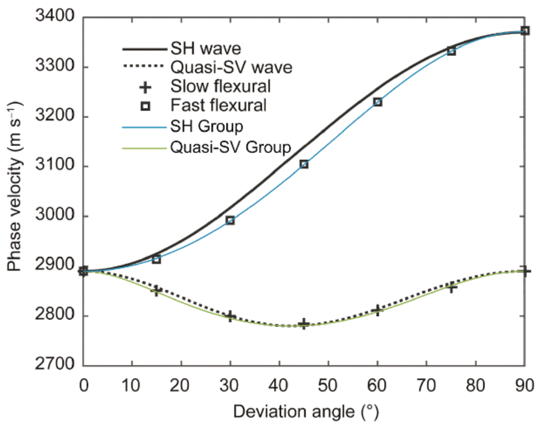

Figure 1 (Color online) Comparison of flexural mode wave velocity at a low frequency and shear wave velocity based on Figure 7 from Liu et al. [1]. Overlain on this figure in color are the computed group velocities plotted as a function of the group velocity angle for the SH mode (thin blue line) and qSV (thin green line).

A clarification of these results will benefit the community to resolve continuing confusion of the meaning of group and phase velocities in the context of acoustic logging measurements through anisotropic formations.

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