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• Comment •

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

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We appreciate the comment from Horne, Miller and Wang on the paper 'A numerical investigation of the acoustic mode waves in a deviated borehole penetrating a transversely isotropic formation' by Liu et al. (2015) [1], for the opportunity to consider and clarify the group and phase velocity issue in sonic logging with a deviated borehole penetrating a VTI formation.

We re-read the paper by Liu et al. [1] and did some numerical tests and analyses. After discussions we agree that at low frequencies, dipole logs measure group velocity for propagation with the group angle equal to the borehole inclination angle.

In Liu's paper [1], he did numerical experiments for a dipole sonic logging with a deviated borehole penetrating a VTI formation, and extracted the phase velocity curves of fast and slow flexural mode waves at different deviated angles with different frequencies. He observed that at low frequency, the dispersion is weak. Then the processed velocities at low frequency were plotted in the same figure with the phase velocity curves of qSV and SH waves computed for phase angles equal to the well deviation (Figure 7 in ref. [1]). Although he did not specify that the processed velocities consistent with the phase velocity dispersions in the space, the figure induced confusions in the community. With the formation properties used in Liu's paper [1], the difference between phase and group velocity of the TI medium is small, while the mode wave dispersion with different frequency is more obvious. So in the paper the phase velocity variation with frequency was emphasized, leaving the velocity variation with angles unclarified.

In Horne's comment [2], the small amount of mode wave dispersion can be observed by STC processing or by a Prony-type method. When the frequency islow, STC processing yields group slowness along the array. We can explain this from another aspect. When waves propagate in a VTI medium, the group direction is not necessarily the same with the phase direction. Figure 1 shows a snapshot of a

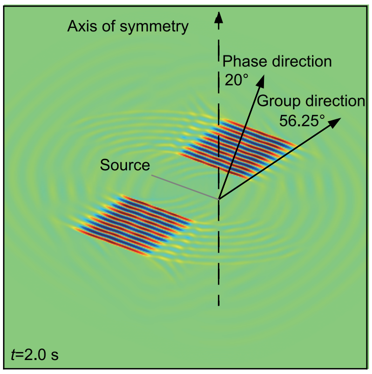

Figure 1 (Color online) A snapshot at t=2 s of a plane Q-SV wave propagating in a homogenous VTI medium with phase direction 20° from the axis of symmetry.

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plane Q-SV wave propagating in a homogenous VTI medium, in which we can see the difference between phase and group directions. The phase direction is 20° from the axis of symmetry of the VTI medium, while the group direction appears to be approximately 56.25° from the axis of symmetry. If we set an array of receivers along the group direction, the phase velocity yielded from the received waveforms is equal to the group velocity in this direction. When a borehole is added with a source and receiver array, the wave propagating along the borehole has a group direction aligned to borehole axis. So the velocity extracted from the received waveforms has a value equal to the group velocity in this direction.

To conclude, we agree that dipole logs measure group velocity in a deviated well penetrating VTI media when the frequency is low. We thank Horne et al. [2] for the comment and opportunity to make the issue more clear, and hope this discussion will help the community to resolve the confusion of group and phase velocity problems in sonic logging with anisotropic formations.

1 L. Liu, W. J. Lin, H. L. Zhang, and X. M. Wang, Sci. China-Phys. Mech. Astron. **58**, 084301 (2015).

2 S. A. Horne, D. Miller, and C. Wang, Sci. China-Phys. Mech. Astron. **59**, 684341 (2016).