Seismic Anisotropy in Overburden

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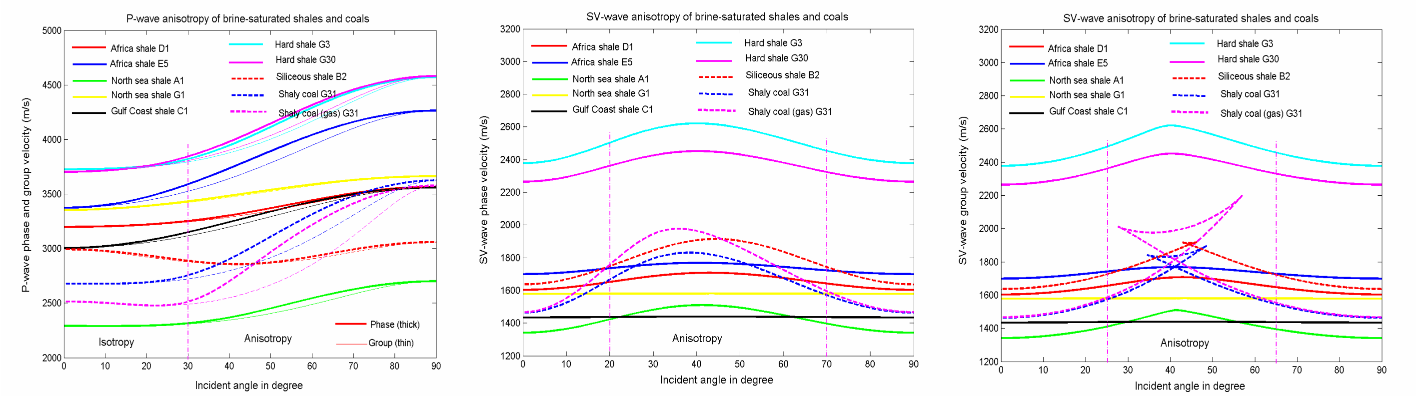
Introduction

Seismic survey may acquire large angle seismic reflections, for example, very long-offset seismic reflections in marine survey and shallow seismic reflections in the northern Alberta. However, conventional seismic data processing and interpretation technologies cannot handle far offset seismic reflections. Geophysicists have to do further seismic physics analysis for far-offset seismic reflections from both large-scale overburden anisotropy and small-scale heterogeneous reservoir by integrating rock physics and log data. This work discusses the propagation effects of seismic wave in anisotropic overburden.

Overburden Anisotropy

In sedimentary basin, shales (or clays) and fine layering are two main reasons to cause seismic anisotropy. Wang (2002) experimentally studied in detailed the anisotropy of rocks from different oil fields in the world and showed that intrinsic anisotropy ranges from 6% to 33% for qP-wave and 2% to 55% for qSV-wave in shales and usually less 5% for qP-wave and qSV-wave in sands and carbonates. Thin periodic layered structures can be seen as an overall anisotropy (Backus, 1962). Composite anisotropy produced by fine shale/sand or shale/carbonate sequence may have stronger anisotropy than shales. Most of rocks in sedimentary basin are shales and so overburden anisotropy may have significant influence on seismic reflections.

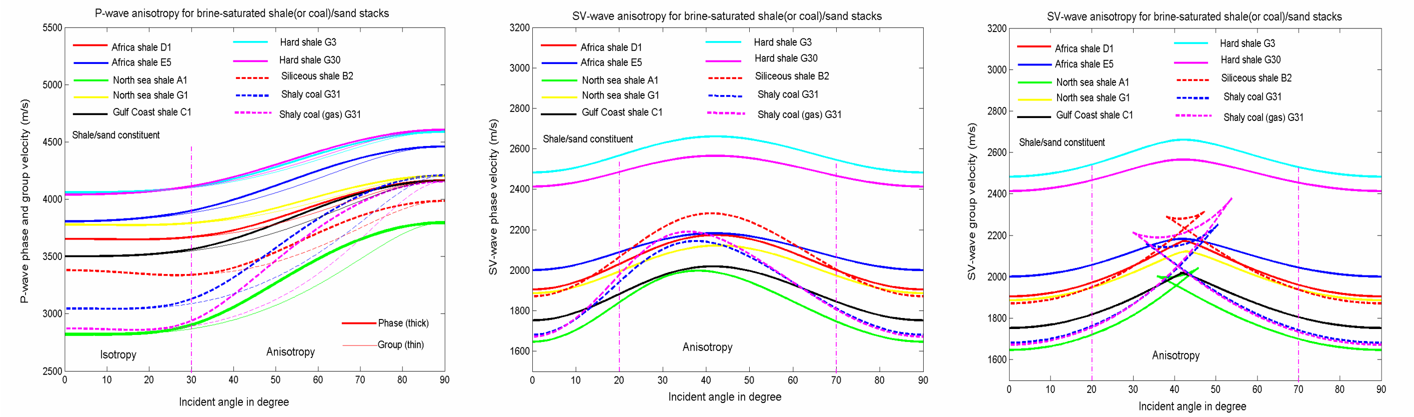


(a) (b) (c)

Figure 1. Phase and group velocities for 10 kinds of shales. The thick and thin lines in Figure 1a stand for phase and group velocities, respectively. (a) qP-wave phase and group velocities; (b) qSV-wave phase velocity; (c) qSV-wave group velocity.

Seismic propagation velocity in anisotropy varies with direction. Direction-dependent propagation velocity results in phase and group velocities are not equal (Winterstein, 1990). Figure 1 shows that calculated phase (Figure 1a for qP-wave and 1b for qSV-wave) and group (Figure 1a for qP-wave and Figure 1c for qSV-wave) velocities for 10 kinds of different shales (Wang, 2002). It can be seen from Figure 1a that for qP-wave the propagation velocity is slow along vertical direction ($\theta = 0^{0}$) and fast along horizontal direction ($\theta = 90^{0}$), the changes of qP-wave phase and group velocities are small for small incident angles ($\theta < \text{about } 30^{0}$) and large for large incident angles ($\theta > \text{about } 30^{0}$).

Figure 1b and 1c show the calculated phase and group velocities for qSV-wave. It can be seen that properties of qSV-wave are much more complex than those of qP-wave. There is a convex portion (high propagation velocity) in the middle of propagation angles for qSV-wave phase velocity. The rapid variation of phase velocity in the convex portion results in the existence of the cuspidal triangle (or cusp) in the curves of group velocity in Figure 1c. No cusp appears for weak qSV-wave anisotropy like as Gulf Coast shale C1. The cusp means that there are three SV-waves which travel at different velocities and arrive at the observation point at different times, the later arriving SV-waves may be separated arrivals, or superimpose on the first arrival SV-wave and cause constructive and destructive interferences and results in qSV-wave waveform distortion. Note that qSV-wave cups is different from shear wave splitting or birefringence phenomenon, the later is the superimposition of horizontally (SH) and vertically (SV) polarized shear waves.



(a) (b) (c)

Figure 2. Phase and group velocities for 10 kinds of shale/sandstone sequences. The thick and thin lines in Figure 1a stand for phase and group velocities, respectively. (a) qP-wave phase and group velocities; (b) qSV-wave phase velocity; (c) qSV-wave group velocity.

Figure 2 shows the calculated phase (Figure 2a for qP-wave and Figure 2b for qSV-wave) and group (Figure 2a for qP-wave and Figure 2c for qSV-wave) velocities for shale/sandstone sequences by taking Backus's averaging. The thick and thin lines in Figure 1a stand for phase and group velocities, respectively. It can be seen the anisotropy in Figure 2 is stronger than that in Figure 1. This is because the heterogeneity between shale and sand is incorporated in anisotropy. The larger the contrast of elastic property between two kinds of constituent materials is, the stronger the composite anisotropy is. It can be seen that the changes of qP-wave phase and group velocities are similar to Figure 1a except with a little stronger anisotropy. The changes of velocities by layering are small for small incident angles ($\theta < \text{about } 30^0$) and large for large incident angles ($\theta > \text{about } 30^0$).These indicate that anisotropy produced by shale/sand sequences can be ignored for small incident angles or near offsets. However, the influence of anisotropy for large incident angle is strong as seen in far-offset P-wave NMO correction.

Figure 2b and 2c show the calculated phase and group velocities for qSV-wave. It can be seen that the changes of qSV-wave phase and group velocities are similar to Figure 1b and 1c except with stronger anisotropy because the combination effect of two kinds of constituent materials for shale/sandstone sequences. The interference of 3 SV-waves with different arrived times may have significant influence on shear wave waveform distortion because of thick overburden.

The converted wave seismic survey from long offset seismic reflections shows that reflection shear wave is much more complex than reflection P-wave. Case study by integrating rock physics and log data would help us to better understand seismic reflection characterization within sedimentary sequences.

References

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