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PSSP waves – their presence and possible utilization

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Summary

While the interpretation of reflected P-waves on seismic data remains the main vehicle for seismic interpretation, there are other signals in seismic reflection recordings that are fully utilized in seismic inversion. There are reflection signals that are due to the conversion of P-wave energy to S-wave energy in transmission followed by conversion from S-wave to P-wave upon reflection. These waves, known as PSSP waves, have significant amplitude and normal moveout and are seen on reflection records at wide offset. We model PSSP waves by ray tracing and finite-difference wave equation computations. While PSSP amplitudes are essentially zero at normal incidence for flat reflectors, their energy is considerable at larger offsets. In addition to the identification of the PSSP modes, there is the challenge of utilizing this energy for estimation of seismic velocities. While the NMO for PSSP arrivals allows it to be suppressed through stacking in imaging P-wave reflections, it is feasible that full waveform inversion could be used for utilizing the PSSP energy as useful signal rather than treating it as undesirable "noise".

Introduction

Conventional seismic processing and interpretation has traditionally involved the analysis of P-waves that have undergone a single reflection. Converted mode seismic arrivals will generally not be handled appropriately with conventional seismic processing methods. However, seismic recordings may often contain converted mode signals as shown by the examples from Jones (2014) in Figure 1. Jones showed that reflections from chalk formations contain not only P-wave reflections but contain useful converted wave arrivals (PPSP+PSPP, PPSS and PSSP) arrivals as well. Events on seismic data from Gray (private communication) show reflection events with considerably more NMO than P-wave reflections. The vertical component of these seismic recordings have large NMO suggesting that these are waves that involve conversion from P to S energy. In this study we develop a layered model based on blocking dipole sonic logs from the Long Lake area (Lines et al., 2010), and use this model in the computation of elastic wave synthetic seismograms. The synthetic seismograms utilize elastic wave (2D) finite-difference codes as described by Levander (1988) and asymptotic ray theory codes as developed by Daley and Krebes (2015).

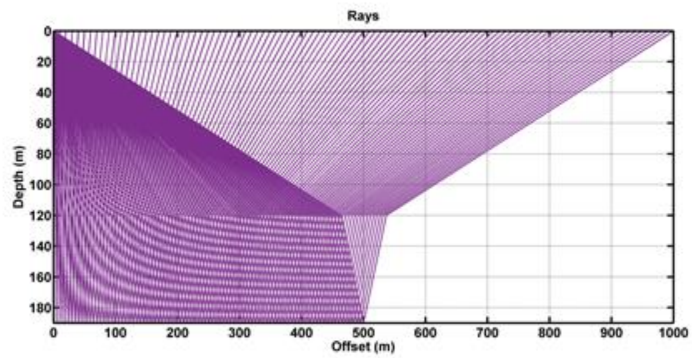
These seismic modeling codes are used jointly to identify converted seismic modes such as PSSP. We confirm and predict the location of converted modes on reflection seismograms. Traditionally, the converted wave energy has often been suppressed in conventionally processed through NMO-stacking to enhance the P-wave energy. We discuss how we might utilize the PSSP energy and other converted modes through the process of full waveform inversion.

Theory

In this paper, two main types of seismic modeling are used. To appreciate the nature of purely P-wave reflections (such as PPPP) and converted wave arrivals (such as PSSP), we model these waves by using asymptotic ray tracing and finite-difference wave equation modeling. It is instructive to perform both types of modeling since ray tracing allows us to isolate reflection events whereas finite-difference (FD) wave equation modeling gives all arrivals generated by numerical solutions to the wave equation. The ray tracing helps us to identify arrivals on the FD seismograms. The finite-difference method for computing P-SV seismograms as described by Levander (1988) is used to provide seismic full waveform solutions.

Examples

Figure 1 gives the ray paths and traveltimes for PSSP waves in a heavy oil field near Ft. McMurray. These are waves that pass through layer 1 as P-waves before being converted to S-waves in passing through layer 2 (McMurray) before being reflected from the top of the Devonian formation. These PSSP arrivals have considerably more NMO than the PPPP arrivals due to spending part of their journey as a lower velocity S-wave in layer 2.



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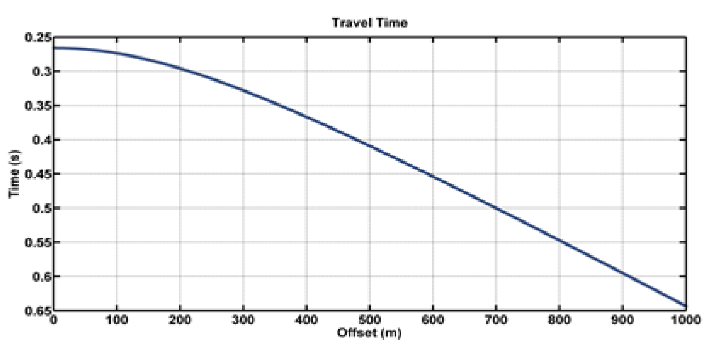

Figure 1. (Top) Reflected rays for the PSSP mode reflected from the interface between layers 2 and 3.
(Bottom). Traveltimes for the PSSP modes.

With ray reflectivity methods (Daley and Krebes, 2015), we can compute the amplitudes of converted modes. We do this for the recorded vertical component amplitudes. The converted wave amplitudes for PSSP and PSPP+PPSP are shown in Figure 9. As expected from the boundary conditions for 2-D elastic media, there is zero ampiitude associated with converted waves for a normally incident wave on a flat boundary. Therefore, for source-receivers with zero offset, the amplitudes are zero for these normally incident waves. As seen in Figure 2, the amplitudes for the converted modes all increase with offset. We will now examine the seismograms for waves computed using FD wave equation calculations.

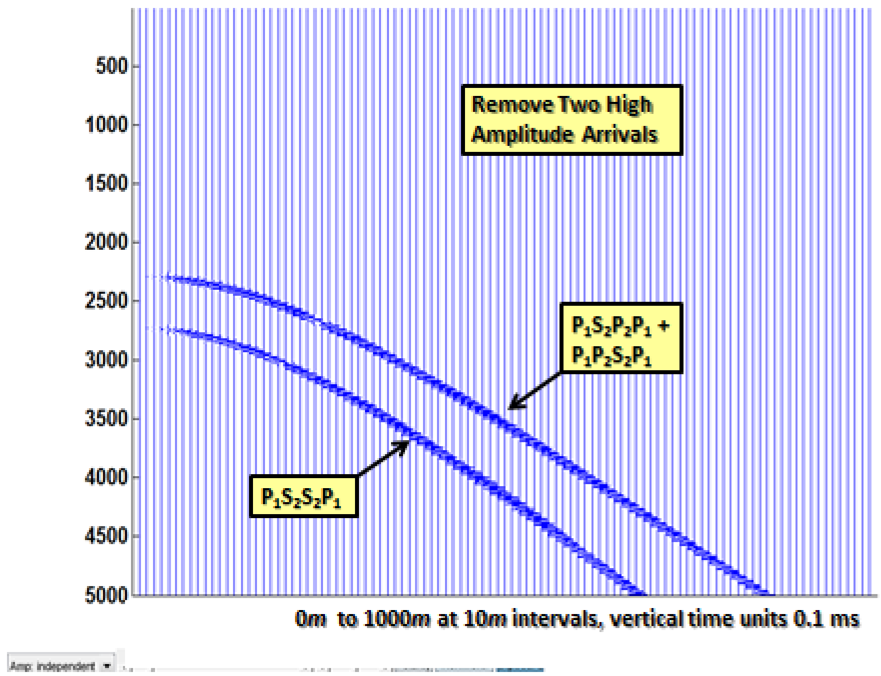

Figure2. Ray reflectivity amplitudes for the converted wave modes as a function of offset. Note the zero amplitudes at zero offset and the increase in amplitude with offset for both modes.

.Conclusions

There are seismic events of far offset recordings with significant NMO that are due to converted waves. These arrivals can be PSSP waves as predicted by ray tracing and wave equation modeling. While traditionally, these arrivals have been suppressed and treated as “noise” in conventional NMO stack, it may be worthwhile to treat these converted waves as signal and use them in full waveform inversion to improve our Earth models.

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