Correlation of P-P and P-S Data in Yinggehai Basin, South China Sea

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Summary

Making offset P-S synthetic seismograms and calibrating the P-S seismic sections are the key elements of multi-component seismic data interpretation. Compared to P-P synthetic seismograms, additional factors should be considered when making offset P-S synthetic seismograms: 1) estimation of S-wave velocities, 2) environmental corrections of dipole sonic logs, 3) averaging of the P- and S-wave velocities, and 4) wavelet extraction. Further, polarity of the P-S section, sample rates of P-P and P-S data, and frequency bandwidth of P-P and P-S reflectors should also be carefully considered when generating PS seismograms. Having analyzed the above factors, we created P-S synthetic seismograms and correlated them to a P-S section from a 2D/4C seismic line in Yinggehai Basin, South China Sea. The P-S synthetic seismogram helped us to identify the target sheet sand in P-S seismic section and explained the previous interpretation failure.

Introduction

Joint interpretation of P-P and P-S seismic data can reduce the non-uniqueness of P-wave seismic interpretation. As an example, with the use of multi-component seismic data, a fuzzy zone identified in P-wave data in Yinggehai Basin, South China Sea, was successfully imaged. However, a correlation of P-P and P-S seismic section still led to erroneous reservoir prediction. The reason was that certain problems still remained in calibrating the P-S section and in correlating the P-S and P-P events. The main problems were 1) to make a P-S offset synthetic seismogram, 2) to calibrate the P-S wave reflection amplitudes, and 3) to identify the polarity of the P-S seismic section. Although methods for generating P-P synthetic seismograms and calibrating P-P section are well known, these methods cannot be directly extrapolated to P-S cases.

In this paper, we describe a technique for generating P-S offset synthetic seismograms and discuss its application to a 2D/4C seismic line in Yinggehai Basin in South China Sea.

Method

The theory for making P-S offset synthetic seismograms using convolutional model was proposed by Stewart (1991). In the weak contrast of the boundary, P-S wave reflectivity can be written as follows, based on Aki and Richards' (1980) simplification of Zoeppritz equation:

$$R_{ps_j} = c_j \ln(\frac{\rho_{j+1}}{\rho_j}) + d_j \ln(\frac{\beta_{j+1}}{\beta_j}) \quad , \tag{1}$$

where c_j and d_j are:

$$c_j = -\frac{\sin\theta_j}{2\cos\varphi_j}(1-2\sin^2\varphi_j + 2\frac{\beta_j}{\alpha_j}\cos\theta_j\cos\varphi_j), \qquad d_j = \frac{\sin\theta_j}{2\cos\varphi_j}(4\sin^2\varphi_j - 4\frac{\beta_j}{\alpha_j}\cos\theta_j\cos\varphi_j).$$

Here, θ_j is incidence angle of P-wave in layer j, ϕ_j is the transmission/reflection angle of S-wave layer number j, ρ_j is the density in layer j, and α_j and β_j are its P- and S-wave velocities. Equation (1) can be further simplified by assuming constant density or replacing density by P-wave velocity by using Gardner's equation. Full Zoeppritz equation can be used to calculate the P-S wave reflectivity as well.

Based on equation (1), P-S offset synthetic seismograms that incorporate AVO effects will be generated by convolving the P-S reflectivity series with a wavelet in the time domain. Construction of the P-S reflectivity series relies on P- and S-wave velocity and density logs obtained from well logging. In addition to the conventional steps for making P-P synthetic seismograms, several processing steps and factors should be emphasized in making such P-S reflectivity series and offset synthetic seismograms:

1) S-wave log correction

A dipole sonic log was measured in this area. However, mud filtrate zones made the S-wave velocity slow so that we had to make carefully wellbore environmental corrections for S-wave sonic log by using a median filter. Widely spread mud chimney in this area also made very slow S-wave velocity in several depths. We carefully corrected this by comparing with other logs.

2) Polarity of P-S wave data

Although a polarity standard for multicomponent seismic data had been proposed (Brown, Stewart & Lawton, 2002), it is often difficult to determine the P-S reflection polarity in processed P-S stacks. This was the case of the Yinggehai Basin line, and therefore, both positive- and negative-polarity versions of P-S data was used when we made P-S offset synthetic seismograms and correlated P-S evens to P-P.

3) Resample and Depth to time conversion

Because the S waves travel slower than P waves, well log data in P-S time domain contain more thin-layer information than the P-P data given the same sample rate. This means that a thin bed imaged in the P-S time domain might be lost in the P-P time domain after depth to time conversion. As a result, thin beds in P-P and P-S synthetic seismograms would not match each other during calibration. To overcome this effect, we used log resampling method (Leaney and Ulrych, 1987; Ma et al., 1999) when converting the well log from depth to time domain in order to keep the same thin layers in both P-P and P-S synthetic seismograms.

4) Partial-stack seismic data

P-S offset synthetic seismograms correspond to different offsets. Full stack P-S data is only related to one offset, which is the average offset of CCP gathers. In this 4C data, the largest offset was as far as 7 km, and therefore the offset varied greatly within the CCP and CDP gathers. A conventional full stack performed in order to increase the signal to noise ratio of P-S and P-P data, also decreases the AVO effect as well. Therefore, using partial or angle (offset) P-S stacks should retain the AVO information and lead to better understanding of the P-S section (Hilterman, 2000). Accordingly, the P-P offset synthetic seismograms should be computed in the same range of partial-stack parameters as well.

Yinggehai Basin example

2D/4C Multicomponent seismic data were acquired in 1998 by China National Offshore Oil Corporation (CNOOC) and Geco-Prakla (He et al., 2002) in Yinggehai Basin in order to image fuzzy zones in conventional streamer data and predict gas deposit. The P-S datasets includes both X, Y, Radial, and Transverse datasets. These data were processed by the Research Center of CNOOC and ARCO, and we processed a part of these 4C data as well.

In our study area, a large amount of sheet sand was predicted from both streamer and multicomponent data. Correlation of the P-P and P-S data was done by similarity analysis and by P-S synthetic seismograms. A constant β/α ratio was assumed, because no data on P-S wave average velocity and S-wave sonic logs were available. In the PZ (pressure component plus vertical component) seismic section, a strong reflection between horizons T30 - T31 was interpreted as sheet sand (Figure 1, left). The corresponding reflection in P-S section was interpreted as a relatively weak reflection (Figure 1, right). A gas reservoir was predicted from these data because Class 3 gas sand was previously found in this area. However, drilling showed the existence of sheet sand with no hydrocarbon content. At the same time, it was unclear which reflector was the sheet sand in the P-S seismic section, how did this lithological reservoir change laterally, and whether a comparison of P-P and P-S data could provide hydrocarbon information or good reservoir position.

Later, VSP and dipole sonic log were measured in this well, and therefore we could make a P-S synthetic seismogram and calibrate the P-S section. Before making the P-S synthetic seismogram, we made a P-P synthetic seismogram by using 25-Hz zero-phase Ricker wavelet, and calibrated the PZ section (Figure 2). VSP measurements only provided the average P-wave velocity in this well.

When making multiple P-S offset synthetic seismograms (Figure 3), we performed environmental corrections to the S-wave and P-wave sonic data by using median filtering (Leaney and Ulrych, 1987). Mud filtrate correction was also applied (Walls and Carr, 2001). Uneven depth sampling was used when converting the well logs data from depth to the P-P and P-S time domain in order to keep equivalent thin-bed information. The thickness of sheet sand was taken to be 10 m in our research area.

When using synthetic seismogram to calibrate the P-S seismic section, we estimated the initial P-S average velocity by using the β/α ratio obtained from the CCP velocity analysis. The accuracy of P-S average velocity was improved by time-shifting the P-S offset synthetic seismograms without stretching and squeezing, and by trying different polarities of the P-S section. 12-Hz Ricker wavelet with 80° phase was selected from an analysis of the P-S section spectrum. The final P-S offset synthetic seismograms and their match to the P-S section are satisfactory (Figure 3). The sheet sand corresponds to a strong reflector in P-P and a strong reflector in P-S.

Conclusions

When making P-S synthetic seismogram, we performed environment correction and mud filtrate correction of the dipole log. Uneven depth-to-time conversion method was used both in our P-P and P-S synthetic seismogram in order to keep thin layers consistent. When calibrating and correlating the P-S section to P-P, we tried both negative and positive polarities of P-S data. Offset ranges of the P-S synthetic seismogram we selected matched the partial-stack range of P-S data. Our identification to target reservoir resolved the controversy and gained understanding of the reservoir in this area.

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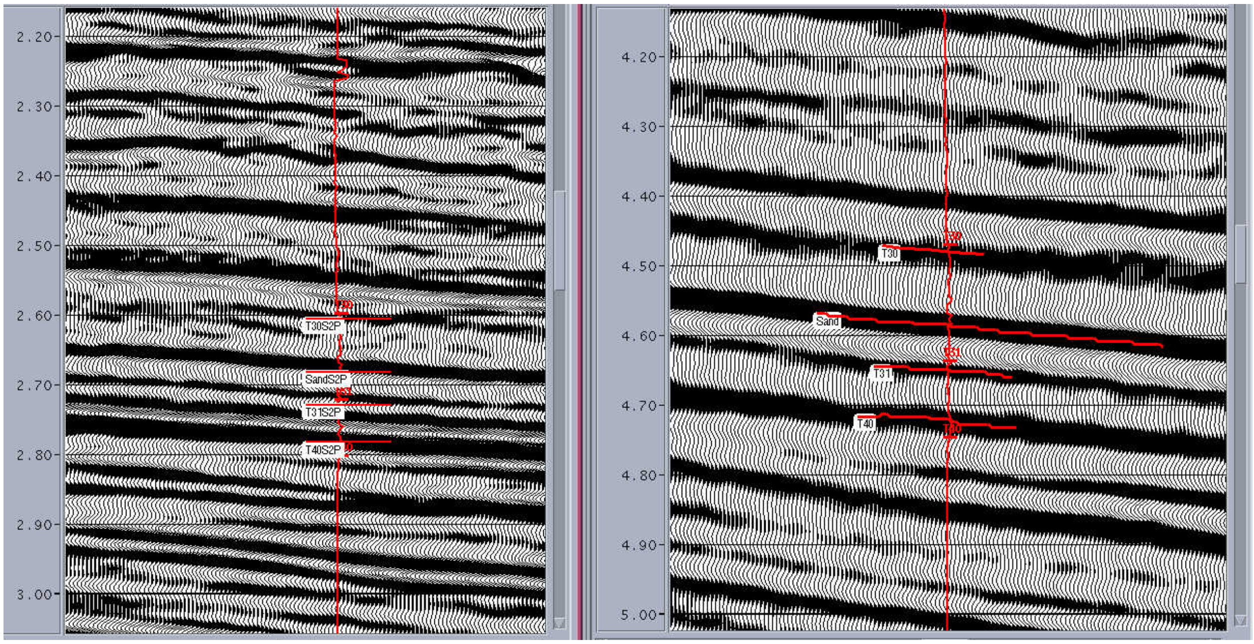

Figure 1. Correlation of PZ (left) and P-S seismic section in Yinggehai Basin.

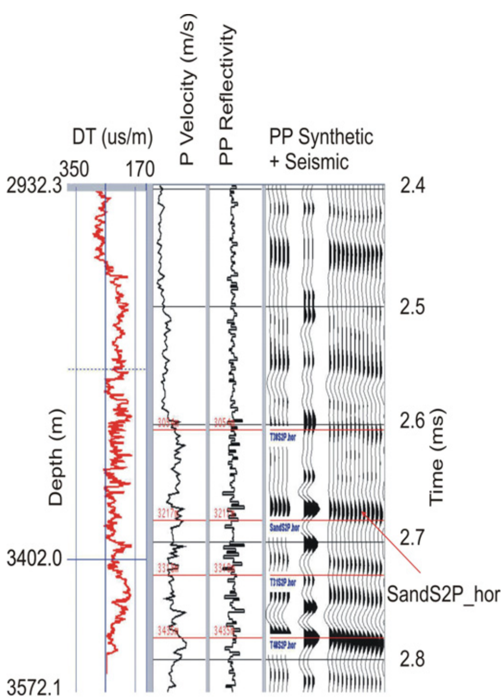

Figure 2. P-wave synthetic seismogram is used to calibrate PZ seismic section.

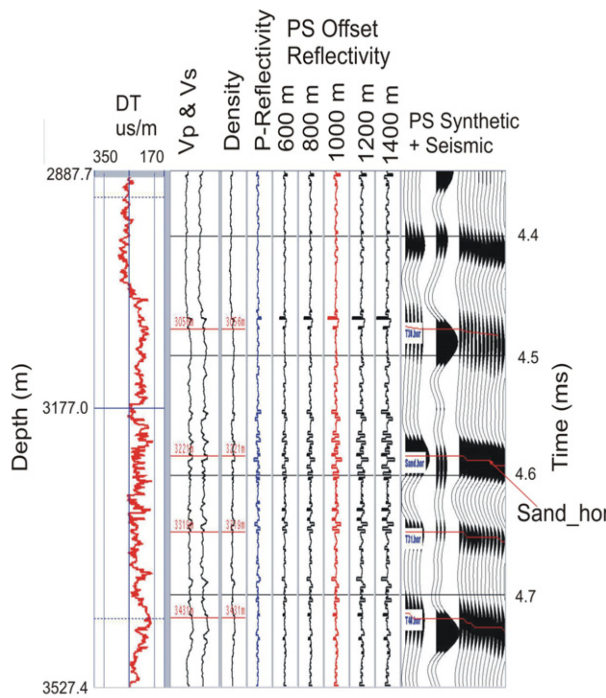

Figure 3. P-S offset synthetic seismograms. Label Sand.hor indicates target sheet sand.