PS-wave processing and S-wave velocity inversion of OBS data from Northern South China Sea

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1. Introduction

It has been reported that gas hydrates are present in the South China Sea continental margins (Chen et al., 2005; Han et al., 2008; Wu et al., 2005, 2007). Gas hydrates are solid, ice-like crystalline substances formed from water molecules containing methane. Methane hydrates are stable under low temperature and high pressure, and are detected on seismic data by identifying the characteristic bottom-simulating reflector (BSR), representing the base of the hydrate stability zone.

Raynvr (Zelt and Smith, 1992) software has been widely used to invert the P- and S-wave velocities (Vp and Vs, respectively) in the South China Sea (Wang et al., 2010; Zhao et al., 2010). We have previously used the Raynvr software to invert the P-wave velocity to OBS hydrophone data (Wang et al., 2013). For the work presented here, we will first introduce the ray tracing principle and method, then present the data acquisition and finally describe the PS-wave processing. The results of the Vp inversion performed in 2013 will be presented followed by the results of the PS-wave travel time and the inversion of the Vs from the Raynvr software. Lastly, the Vs and Vp curves are shown to be similar with the increase in velocity in the layer where gas hydrates are present.

2. Ray tracing principle and method

A linearized travel time inversion procedure is utilized in this study. Ray tracing is performed by numerically solving the ray tracing equations for 2-D media, a pair of first order ODEs, using the Runge Kutta method. This procedure was primarily developed for modeling 2-D crustal refraction and wide angle data and has been applied in past studies (Jose et al., 2008; Karastathis et al., 2001, 2002; Ogunsuyi et al., 2009; Parsiegla et al., 2009; Pim et al., 2008; Song and ten Brink, 2004). The model for the travel time procedure is parameterized into a layered, irregular arrangement of trapezoids to represent the velocity structure. Boundary nodes define the structure of each layer boundary and are connected through linear interpolation. The model parameters consist of these boundary nodes and upper and lower layer velocity points. The velocity field in each block varies linearly with depth between the upper and lower velocities in a layer, as well as laterally across the velocity points along the upper and lower layer boundaries.

Based on the work of Zelt and Smith (1992), rays are traced through velocity models in an iterative search mode using zero-order asymptotic ray theory. The travel times between a source and a receiver depend on the model velocity, the inversion problem is non-linear. It is solved by performing a linearization by using a Taylor series expansion about a starting model and ignoring higher degree terms, followed by applying iterative analyses. Rays are traced through the model based on zero-order asymptotic ray theory and are found by solving the ray tracing equations numerically.
cordings include PP- and PS-wave. When the PS wave component wavefield after filtering is shown in Fig. 2b. It can be seen that the PP-waves included in the upper part are basically eliminated and the residual later reflections are not only PS phases but also some residual PP phases. After decomposition, the PP-wave becomes weak and the PS-wave becomes strong, allowing for a much easier identification of the PS reflections.

5. Data processing — rotation of horizontal components

When carrying out the OBS data collection, the OBS was not moved along the sea bottom and the shot moved along the shot lines on the sea surface. This led to a different amplitude and polarization direction for the data of each trace, and when the OBS data was processed, the amplitude difference had to be corrected (Benhama et al., 1988; Xia et al., 2010).

Let us define $U_x$ and $U_y$ as the wavefields of the two horizontal components before rotation, $X$ and $Y$, respectively, and also define $U_r$ and $U_t$ as the wavefields of the radial and transverse components after rotation, respectively (Fig. 3). The direct wave method is used to calculate the rotation angle, $\alpha$, by scanning each angle and finding the angle that minimizes the transverse component of the direct wave energy.

After finding the rotation angle, $\alpha$, Eq. (1) was used to rotate the horizontal components and get the final polar direction of the wavefield (Benhama et al., 1988).

$$
\begin{pmatrix}
U_r \\
U_t
\end{pmatrix} =
\begin{pmatrix}
\cos \alpha & \sin \alpha \\
-\sin \alpha & \cos \alpha
\end{pmatrix} 
\begin{pmatrix}
U_x \\
U_y
\end{pmatrix}
$$

(1)

In Fig. 4a and b the horizontal components of the X and Y directions are shown and it can be seen in the panel that the energy is weak. Fig. 4c shows the wavefield of the radial direction and Fig. 4d shows the wavefield of the transverse direction. Consistent with the theory, the radial direction wavefield is enhanced effectively.

6. Setting up the Vp-depth model

First, the hydrophone data of OBS were used to do the prestack migration and the migration section (Fig. 5) was achieved. The initial Vp model was set up according to the migration section. The travel time of the P-wave for each reflection boundary is chosen (Fig. 6) and the Ramon software is used to invert the velocity of the P-wave. After several inversion iterations, the final Vp-depth model is achieved (Fig. 7).
7. Vs inversion

S-wave velocity was obtained by inverting the Poisson’s ratio within RayInv once a satisfactory P-wave model had been established (Exley et al., 2010). The geometry and P-wave velocity of the model were held constant while optimizing the fit to travel times for Poisson’s ratio in each layer. The chosen observed travel times of PS events from the radial horizontal component were then required to be correlated with their equivalent PP reflections. In order to resolve the ambiguity in this correlation, travel times were chosen from all the PS reflection

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Fig. 2. a. Horizontal component wavefield before PP- and PS-wave separation. b. Horizontal component wavefield after PP- and PS-wave separation.
events with sufficiently good signal-to-noise ratio in the seismic records. Working downward layer by layer the fit between modeled and observed travel times from these OBS for each possible PS reflection event was measured via chi-square values calculated for a range of Poisson’s ratios. With this approach, chi-square was mapped as a function of Poisson’s ratio and possible PS event for each model layer. This enabled the best fitting event and its corresponding value of Poisson’s ratio was obtained from the position of the chi-square minimum. The low conversion angles for the S-waves meant that the steep inclination of the ray paths for the OBS did not overlap and so the S-wave velocities obtained represented a narrow cone beneath each OBS. The travel time for the PS-wave of each reflection boundary was chosen using Fig. 8. For the fifth layer it is hard to choose the travel time accurately. Using the Raylnr software the final Vs-depth model is achieved (Fig. 9) after several iterations. From the second to the fifth reflections, the chi-squared values are 4.221, 24.870, 41.932, and 160.34, respectively, and the Trms values are 0.008, 0.020, 0.026, and 0.160, respectively. Because the travel time of the fifth reflection is not accurate, the velocity of the inverted S-wave is not accurate either. The Poisson’s ratio of the second layer to the fourth layer is 0.491, 0.488, 0.484, and 0.486, respectively. Finally, the OBS positions of the Vp and Vs-depth curves are shown in Fig. 10. The trends of the two curves are similar and both the P- and S-wave velocity is higher than the surrounding lithology.

8. Conclusion

Seismic travel time inversion was performed to analyze the OBS PS-wave data collected in the northern continental margin of the South China Sea where gas hydrate has been found in the sub-strata beneath the seafloor. The Vp model derived through the travel time inversion is consistent with the migration section of the SCS data. From the Vp and Vs-depth curves at the OBS location analyzed, it can be seen that a high velocity layer corresponds to the refection blank zone on the migration section. When a sub-strata contains gas hydrates, the Vp and Vs will increase. The results presented here suggest that the high-velocity layer contains gas hydrates.

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References


Fig. 4. a. X-horizontal component geophone recording. b. Y-horizontal component geophone recording. c. Radial component wavefield. d. Transverse component wavefield.
Fig. 4. (continued).

Fig. 5. The migration section of hydrophone data of OBS.

Fig. 6. The picked travel time of P-wave to each reflection boundaries.
Fig. 7. The final P-wave velocity-depth model (the vertical time axes are the reduced travel time, i.e. the real travel time divided by the horizontal distance), the color line is the picked travel time and the black line is the modeled time in the lower figure.

Fig. 8. The picked travel time of PS-wave to each reflection boundaries.

Fig. 9. The final S-wave's velocity-depth model (the vertical time axes are the reduced travel time, i.e. the real travel time divided by the horizontal distance), the color line is the picked travel time and the black line is the modeled time in the lower figure.
Fig. 10. a. The Vp-depth curve. b. The Vs-depth curve.