Research on improving conventional marine seismic streamer data imaging quality using OBS data from Northern South China Sea

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Abstract

It is very important to convert the seismic data from the time domain to the depth domain. Here we discuss the approaches of inverse modeling of travel times for determination of the P-wave velocity (Vp) using OBS data, and also using the inverted velocity to improve the conventional marine seismic streamer data imaging quality. The migration section of the single channel seismic data is used to define the model horizons and help to control their geometry. Wide angle hydrophone data of OBS are used to determine P-wave travel times. The picked travel times from various shots are inverted for P-wave interval velocities using RayInvr, which calculated theoretical travel times via ray tracing. Damped least squares optimization is performed to fine tune the fits between observed and calculated travel times. In the end, two conventional marine seismic streamer data’s migration sections are compared and the result shows that the section using the inverted velocity of OBS data is much better than that using the velocity of conventional velocity analysis method to the streamer data.

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1. Introduction

In the South China Sea continental margins, the presence of gas hydrates has been reported (Chen et al., 2005; Han et al., 2008; Wang et al., 2012; Wu et al., 2005, 2007). Gas hydrate is a solid, ice-like crystalline substance 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.

RayInvr (comprehensively described in Zelt and Smith, 1992) software has been used widely to invert the P- and S-wave velocities in the South China Sea (Wang et al., 2010; Zhao et al., 2010). Here we firstly introduce the ray tracing principle and method, then use the RayInvr software to invert the P-wave velocity on five OBS hydrophone data, including relocating the positions of the OBSs, defining model’s horizons, picking the P-wave travel times, performing P-wave ray tracing inversion processes, and finally we got the inverted P-wave velocity/depth model. In the end, two conventional marine seismic streamer data’s migration sections are compared and the result shows that the section using the inverted velocity of OBS data is much better than that using the velocity of conventional velocity analysis method to the streamer data. This illustrates that the inverted velocity is much more accurate than that of the conventional velocity analysis method.

2. Data collection

The study area is located in the northern continental margin of the South China Sea (Fig. 1). Single-channel seismic (SCS) data were collected. In order to investigate the shallow sedimentary structures above the BSR, OBS data were also collected in this area in 2012 using the R/V HaiYang Liu Hao. By taking bandwidth output and bubble effect into consideration, a new type of GI gun point source was designed and then applied to investigate the gas hydrate. The OBS instrument, MicrObs, is from the company Sercel. There are 39 parallel seismic lines shot normal to the continental margin with a distance of about 25 m between two adjacent shots (inlet in Fig. 1). There are also 27 lines shot parallel to the margin as tie lines (inlet of Fig. 1). For the 39 NW–SE trending parallel lines, the spacing between two adjacent lines was about 50 m, and five OBSs were deployed in water depths of about 1500 m along the central line (inlet of Fig. 1).

3. Streamer data processing

The following workflow (Fig. 2) is used to process the streamer data. Firstly the Segy format data is loaded and the geometry is set up. Secondly spherical divergence compensation and predictive deconvolution processing are used to the data. Thirdly velocity analysis is done and the velocity is used to eliminate the multiple processing. In the end pre-stack time migration and Pre-stack depth migration processing are done to the data. After the above processing, the pre-stack time migration section (Fig. 3) and the Pre-stack depth migration section (Fig. 4) are achieved.
4. Relocation OBS

In OBS seismic experiment carried out at sea, the real locations of OBS on the seafloor may drift from designed points (deployed locations) since OBSs are of free-fall type and usually affected by sea currents during their descent. So determining the OBS positions is a basic step for later studies. Here the time-slice relocation method is presented and used to relocate the position of the ocean-bottom seismometer (OBS) on the sea bottom.

4.1. The principle of time-slice relocation method

When the velocity of seismic wave in the sea water is assumed to be constant and the sea surface is not undulate, then the traveling time of the direct wave will be the same for the different shots which have the same distances from the OBS. As seen in Fig. 5 (left), when the shots are on one circle, then the direct arriving wave’s traveling time for all shots is the same, and the distances from the shots to the projection of the OBS on the sea surface are the same. According to this concept, we first determine the shots which have the same traveling time of the direct wave, then the coordinates of all the shots are extracted, and it is shown that the shots are almost all on the same circle. Using the least squares method the center of the circle can be determined, and this can be seen as the horizontal position of the OBS.

One center of a circle can be achieved using one time slice, and when we use a number of time-slice data, a number of centers can be achieved. The final OBS horizontal position can be achieved by applying the statistics methods to the different circles’ centers, as shown in Fig. 5 (right).

4.2. Relocation results

Table 1 is the deployed and inverted OBS position. The first and second columns are the x and y coordinates of the deployed position. The third and fourth columns are the x and y coordinates of the inverted position.

In order to verify the accuracy of relocation, linear move out correction processing is used to the data. Fig. 6 (left) is the wave field of one shot line after linear move out correction processing using the deployed OBS position. Fig. 6 (right) is the wave field of one shot line after linear move out correction processing using the time slice relocation method; when we calculate, ten time slice data is used, and the maximum distance between each two inverted horizontal positions is 15 m. Because the gas hydrate lies in the layers near the ocean bottom, the accuracy of the OBS position is very important to the shallow layer’s velocity inversion. When using the time slice relocation method, we may see that the direct arriving wave is almost horizontal so we can say that the relocation result is reliable.
5. P wave velocity inversion

5.1. Ray tracing principle and method

A linearized travel time inversion procedure, primarily developed for modeling 2-D crustal refraction and wide angle data (applied in 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), was utilized in this study. The model is parameterized into a layered, irregular arrangement of trapezoids to represent the velocity structure. The model parameters are boundary nodes (which, connected through linear interpolation, define the structure of each layer boundary) 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. Because the travel times between a source and a receiver depend on the model velocity, the inversion problem is a non-linear one. This is solved by linearization using a Taylor series expansion about a starting model and ignoring higher terms, and then applying iterative analyses. Rays are traced through the model based on zero-order asymptotic ray theory by solving the ray tracing equations numerically (Cerveny et al., 1977) using the Runge–Kutta method. When a ray intersects a layer boundary, which constitutes a velocity change, Snell’s Law is applied.

Table 1
The deployed and inverted OBS positions.

<table>
<thead>
<tr>
<th>Station</th>
<th>X (m)</th>
<th>Y (m)</th>
<th>X (m)</th>
<th>Y (m)</th>
</tr>
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<tr>
<td>1</td>
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<td>696,850.90</td>
<td>2,436,188.85</td>
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<tr>
<td>2</td>
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<td>697,047.34</td>
<td>2,435,861.08</td>
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<tr>
<td>3</td>
<td>697,291.66</td>
<td>2,435,532.06</td>
<td>697,293.50</td>
<td>2,435,558.34</td>
</tr>
<tr>
<td>4</td>
<td>697,501.40</td>
<td>2,435,203.27</td>
<td>697,525.86</td>
<td>2,435,256.77</td>
</tr>
<tr>
<td>5</td>
<td>697,711.17</td>
<td>2,434,874.42</td>
<td>697,752.51</td>
<td>2,434,851.06</td>
</tr>
</tbody>
</table>

5.2. Defining model horizons and P-wave travel time picking

Definition of model horizons is a key consideration when building a realistic velocity/depth model. Thus, it is expedient to gather all possible information about the geology of the area and combine that with the available geophysical data to create a satisfactory model. Also, proper seismic phase identification is important in order to avoid potential gross errors in the final model (Zelt and Smith, 1992). Each significant part of the subsurface must be presented in a realistic fashion by its interval velocity.

The single channel seismic profile data provide the basis for determining model horizons. Firstly, according to the conventional streamer data’s depth migration section (Fig. 7) and the migration velocity field (Fig. 8 top), the initial velocity depth can be set up.

For this study, the aimed layer is the shallow layers that the gas hydrate lies in, so we mainly inverted the shallow layers’ velocity-depth model. The traveling time is two-way traveling time in the streamer data’s time migration section, and to the zero offset OBS data the

![Fig. 5](image_url) The principle of time slice method, first determine the shots which have the same traveling time of the direct wave; second the coordinates of all the shots are extracted, then using the least squares method the center of the circle can be determined. When a series of time slice is used, a series of centers can be achieved, and last the centers are averaged as the final horizontal position of the OBS.

![Fig. 6](image_url) In the relocation results, linear move out correction processing is used to the data: (left) is the result using the deployed OBS position and (right) is the result using the inverted OBS position. The direct arriving wave is almost horizontal so we can say that the relocation result is reliable.
traveling time is one way traveling time. So when we compare the two
data, the traveling time of the OBS should be added a one way traveling
time.

By combining the conventional streamer data’s time migration sec-
tion and the OBS data, we can pick up the responding reflection events
of the OBS data (Fig. 9).

5.3. P-wave ray tracing

After setting up the initial velocity–depth model and picking the
travel times, ray tracing through the model was performed in a pro-
gressive layer by layer fashion, as the velocities and depths of the
layers above directly influence the velocities and depths in question.
Ray tracing is done by tracing through the model’s trapezoids using
the observed OBS travel time picks and the velocity/horizon depth
controls specified in the input v. in file. The model was fine tuned
using RayInvr’s damped least squares routine (dmplstsqr). The rou-
tine uses travel time residuals and partial derivatives output by
RayInvr. These outputs are used by the routine to apply the damped
least squares methodology of Aki and Richards (1980) and Lutter and
Nowack (1990) to solve a linearized inverse problem, and produce a
new optimized model. This technique is employed in determining
the changes in the model parameters, and the initial model is up-
dated with the new values. Rays are then traced through the new
model thereafter, and this procedure is repeated until a satisfactory
fit to the observed data is realized.

When we perform the inversion, the picked travel time error is an
important inversion parameter, here we give this error the same value
to all the horizons as 0.002 s for the minimum picked travel time error
we can control is one time sample interval. Ray coverage through the
model is illustrated in Fig. 10. Ray coverage near the OBS is shown to
be very dense, constraining the velocity depth trade off. However, re-
gions of the model outside the OBS array where few rays were traced
are not well constrained. It is worth noting that having the velocity
nodes only at the beginning and end of the model produces an un-
realistic velocity at the far lateral extremities of the model when the

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![Fig. 7](image1.png) Set up the initial depth model using the pre-stack depth migration section. The depth model is set up using the pre-stack depth migration section and also the 5 OBS are projected onto the section.

![Fig. 8](image2.png) (Top) set up the initial velocity model pre-stack migration velocity field; the velocity is achieved by the velocity analysis to the streamer data and then convert it from time domain to the depth domain. (Bottom) the inverted velocity model of OBS data; this is the final of the velocity–depth model inverted form the OBS hydrone data.
layer is represented by a single trapezoid. Finally the inverted velocity–depth model is shown as Fig. 8 (bottom).

6. Improve streamer data imaging quality

The inverted velocity model is used to do the pre-stack depth migration again and the migration section is shown as Fig. 4 (bottom). The other data processing is not changed. Compared to the migration section in Fig. 4 (top), the S/N ratio and the resolution are both improved. This shows that the inverted velocity model is more accurate than the velocity model derived from the streamer data.

7. Conclusion

The conventional marine seismic streamer data’s migration section using the inverted velocity of the OBS data is much better than that using the velocity of the conventional velocity analysis method to the streamer data. This illustrates that the inverted velocity is
much more accurate than that of the conventional velocity analysis method.

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