Walkaway VSP Multi-wave Imaging over a Gas Cloud Area

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Summary

It has been shown in many cases that gas cloud imaging could be improved by using the converted or shear wave. In the main structure of CS gas field in Western China, the reservoir crest was difficult to image with conventional P-wave data because the gas filled overburden attenuates P-wave energy and distorts P-wave velocity field. Previous multi-component surface exploration has indicated that the converted-wave or shear wave is better for imaging sub-gas-cloud sediments, but there were difficulties in the shear wave static correction due to …. To overcome this challenge, we have employed walk-away three-component (3C) VSP surveys. We illustrate in this paper how to image the structure with such 3C VSP data. The results show that the P-wave, converted wave, and S-wave images are all clearer than reflection seismic sections and reveal that VSP could play a more important role in gas development in this area.

Introduction

In recent years, tremendous progress has been made in VSP techniques. Walkaway VSP (WVSP) has become a very convenient survey method for oil field development and has been applied broadly. In CS gas field located in Western China, multi-component surface exploration using the converted-wave (C-wave) and shear wave (S-wave) images have been distinctively improved (Li et al., 2007). Figure 1 shows that P-wave data provide unreliable structural images and the interpretation is dubious in an area with a lateral extent of approximately 5,000 m. C-wave and S-wave sections give clearer pictures of the major target reflectors within the gas filled area. With the C-wave data, the horizontal extent of the uncertain area was narrowed to approximately 2,000 m. With S-wave data extracted from the horizontal component, the target horizons of the uncertain area were properly imaged. As we know, surface multi-component exploration is very expensive, and there are several technical issues such as difficulties in resolving the S-wave static correction. To develop a more cost-effective exploration method, we conducted a 3-C WVSP this year. Two kinds of sources were used in this project: dynamite for P-wave and a vibrator for S-wave. The final images indicate that VSP P-wave, C-wave and S-wave all yield clearer images than the surface P-wave data. As expected, the resolution of P-wave data is lower than that of C-wave and S-wave due to attenuation in the WVSP survey. The S-wave data achieved the highest resolution among them.

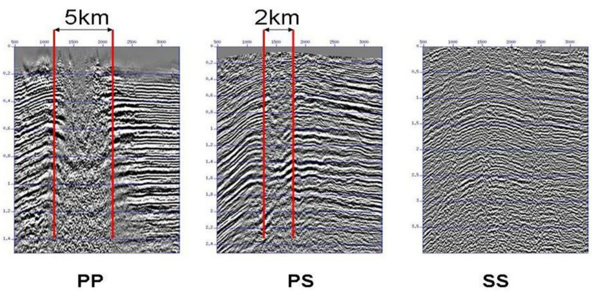

Figure 1. PP, PS and SS sections over a gas cloud area

WVSP acquisition

CS field is located to the east of the CDM Basin, Western China. The gas cloud area is about 10 km^2. Gas-saturated reservoirs are distributed in many layers from the near surface to subsurface up to a depth of 2,000 m. In order to image all of these targets, receivers were deployed in entire wellbore. Two kinds of sources were used in this project, dynamite for P-wave and a vibroseis for S-wave. The maximum offset was selected as 3,000 m according to the depth of the target. Two source lines were designed, a west –east line (Line W –E) with dynamite source and the other line (Line N) with both dynamite and S–wave vibroseis sources. The S–wave vibrator applied a shear motion in the cross–line direction, both left and right start motions were recorded. The Minus method was used to enhance S–wave energy and suppress P–wave energy. Figure 2 is a WVSP common receiver gather of the radial component obtained from the P–wave dynamite and the S–wave vibrator, respectively. We can see strong S–wave reflections in the vibrator–generated record.

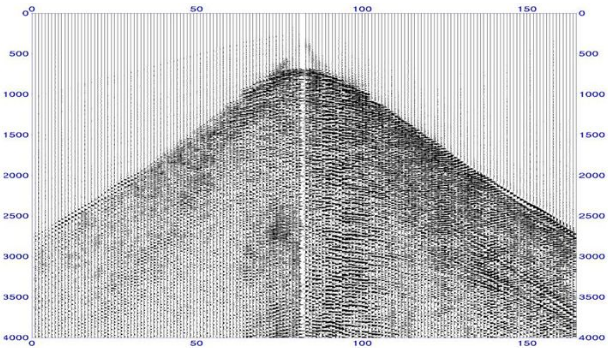

Figure 2. WVSP CRG records of the radial component obtained using dynamite (left) and a S–wave vibrator (right).

First break Picking

Picking first breaks is the first step in WVSP data processing. Conventional picking methods are time–consuming. In this project, WVSP 3C traces are first converted to modulus traces according to formula (1).

$$A_i = \sqrt{x_i^{\ 2} + y_i^{\ 2} + z_i^{\ 2}} \qquad (1)$$

where A_i is the amplitude of i–th 3C samples, x_i, y_i and z_i. In modulus traces, the amplitude of the first break becomes positive and steady, so picking becomes easier. In order to improve the precision and efficiency, the picking window can be restricted according to the ray tracing travel time calculated using the velocity obtained from zero offset. Once the picking window is defined, picking is very efficient. The adjacent first break time difference has been used in quality control of picking (Li et al., 2009). Slight smoothing of first break times across traces has been used to remove outliers. For a set of shot gathers, the combined display of the first break time and adjacent time difference keeps the picking procedure under control, and some poor picks can be easily identified. Thus procedure improves the picking quality significantly.

For the S–wave, picking becomes much more difficult because of the interference of the P –wave and birefringence of S –wave. Therefore, keeping the phase consistent is very important in picking S–wave first break.

Estimation of velocity and anisotropy parameters

The VSP interval velocity estimation depends on the precision of first break picking. Small offset shots were used to decrease the influence of picking error. Many small offset first break times are used to calculate the 1D velocity and then a least–squares method is used to optimize the velocity. The estimation of S–wave velocity is influenced by its first break picking so its precision is less than that of the P–wave.

When all first breaks have been picked, anisotropy coefficients can be estimated by the following formula (Thomsen, 1986):

$$V = V_0\left(1 + \delta \sin^2\theta \cos^2\theta + \varepsilon \sin^4\theta\right) \qquad (2)$$

where θ is incident angle, V_0 the vertical interval velocity, which is estimated from near offset shot gather, δ the anisotropy coefficient, which is estimated from middle offset, and ε, which is estimated from the far offset. When the time difference between the forward modelled and actual first breaks is minimized, the corresponding δ and ε can be output as an optimized estimation.

Rotation and wavefield separation

In a WVSP field survey, the horizontal geophones point to certain azimuths once the geophones are clamped to the casing. The rotation angle of the horizontal component can be estimated through maximization of the first arrival amplitude. The precision of the estimated rotation angle can be greatly improved by integrated statistical analyses in the common receiver gather. Subsequently, the rotation of horizontal components can be easily performed.

For the purpose of preserving some diffractions and fault reflections, only the strongest downgoing P-wave and S-wave are removed through a trimmed mean filtering. In the X-Z plane, we can obtain the exact emergence angle in the receiver position through ray tracing, so that we can maximize the desired wavefield energy through time-variant wavefield rotation. Combined with the trimmed mean filtering, more effective results are obtained. These procedures are applied many times for different wave modes. Final imaging indicates that this strategy is effective.

Other essential processing steps

Before proceeding to WVSP imaging, there are several other processing steps that shall be carried out. These include primarily wavelet shaping, statics, and deconvolution. These procedures are similar to surface seismic data processing. Thus many surface data processing modules can be used directly.

WVSP imaging

WVSP can be imaged through VSPCDP mapping or prestack depth migration. VSPCDP mapping is very efficient and flexible, but when the structure is complex, the reflection is not properly focused. Due to irregular surveying, very narrow survey aperture, asymmetry fold number, and halfway wavefield separation, the performances of VSP prestack depth migration are not always satisfying. Here we just use ray tracing-based VSPCDP mapping as the structure is relatively simple.

Analysis of results

The work area here is a gas-bearing reservoir. The targets can not be characterized in details using conventional seismic data. For conventional surface multi-component processing, there are several difficulties, one of which is obtaining S-wave statics at the receiver. With the WVSP survey, however, more detailed sediment reflections could be focused. With WVSP multi-wave VSPCDP mapping, structural features become clearer in the PP, PS and SS images (Figures 3 and 4). The final results could be used for geological interpretation.

Conclusions

Through PP, PS and SS processing of WVSP data, we have demonstrated that multi-wave WVSP processing greatly improves the images in gas cloud areas. Although PP is attenuated by the gas cloud and resolution is lowered, its image is still superior to surface seismic. The C-wave is stronger than PP and its resolution is higher, but its imaging range is smaller than P-wave. The SS wave image is the best both in resolution and in imaging range. However, separating fast and slow waves could further improve the image quality of the S-wave.

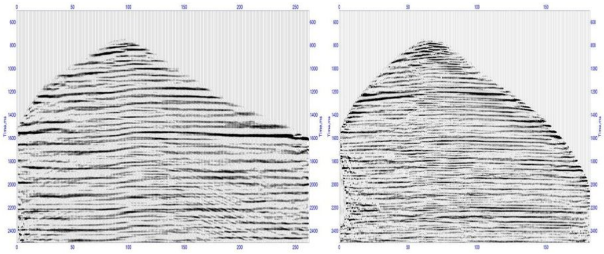

Figure 3. PP (left) and PS (right) images of WVSP Line W-E

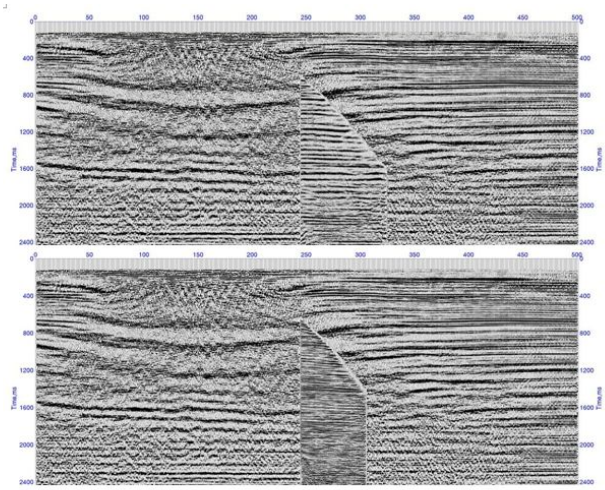

Figure 4. PP (upper) and SS (lower) images of WVSP Line N compared with P-wave section

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