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Application of OVT Domain Processing Technology in 3D Seismic Exploration of Coalbed Methane in Heshun Hengling Block

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ABSTRACT

This study introduces the OVT (Offset Vector Tile) domain processing technology to improve the accuracy of small structure detection in 3D seismic exploration of coalbed methane in the Heshun-Hengling block in China. The OVT technology optimizes wide azimuth seismic data processing through steps such as facet division, five-dimensional regularization, pre-stack time migration, and azimuthal anisotropy correction. The results show that OVT processing retains azimuth information, enhancing the ability to reflect stratum changes with azimuth; azimuthal anisotropy correction improves the resolution of the profile. The profile after OVT processing has a natural waveform, good continuity of the phase axis, and a wide frequency band, meeting the requirements of the “Coalbed Methane Seismic Exploration Specification”. It demonstrates the advantages of OVT technology in imaging complex geological structures, providing a new perspective for seismic exploration.

KEYWORDS

Offset Vector Tile; Seismic Exploration; Data Processing; Azimuthal Anisotropy Correction.

1. INTRODUCTORY

In the field of seismic exploration, the progress of data processing technology plays a crucial role in improving the accuracy and quality of seismic imaging. This paper focuses on a new seismic data processing technology, OVT domain processing technology[1], and applies it to the 3D seismic exploration of coalbed methane in the Heshun Hengling block in China.

The OVT domain processing technique is a processing method based on the subdivision of cross aligned datasets, which has the advantages of good noise suppression, high data consistency, and more reliable processing, etc. The OVT domain processing technique not only solves the azimuthal anisotropy problem triggered by wide azimuthal observation, but also contains azimuthal angle information in the data it generates, which has an important value for tasks such as crack prediction and azimuthal anisotropy parameter extraction.

It is found that the OVT domain processing technique can effectively improve the data processing accuracy, enhance the imaging effect of complex geological formations, and provide important technical support for the exploration and development of coalbed methane resources. The goal of this paper is to provide a new perspective to understand and solve some common problems in seismic data processing through an in-depth study of OVT domain processing technology, with a view to promoting the progress and development of the technology in the field of seismic exploration. We hope that the research results in this paper will provide valuable references for seismic exploration workers and help them better understand and apply OVT domain processing techniques, thus improving the effectiveness and efficiency of seismic exploration. We also expect that more researchers and engineers will participate in this field in the future to jointly promote the development of seismic data processing technology.

2. PRINCIPLES OF OVT DOMAIN PROCESSING TECHNOLOGY

The OVT, or gun check distance vector slice as in Figure 1, is a method for fine-grained segmentation of the cross arrangement dataset. Each cross alignment contains all the gun check distance and azimuth information within it. Within this domain, we divide the small rectangles according to the equal distance between the gun line distance and the detector line distance, and then extract the information of the small rectangles at the same position from all the cross alignments, which is the grouping of the data in the domain of the cross alignments, forming the corresponding OVT planes, i.e., the co-gun detector distance and co azimuth vector slices. The main feature of this segmented dataset is that each dataset has approximately the same offset distance and azimuth angle. This method can effectively extract and utilise the information in the data and improve the accuracy and efficiency of data processing[2].

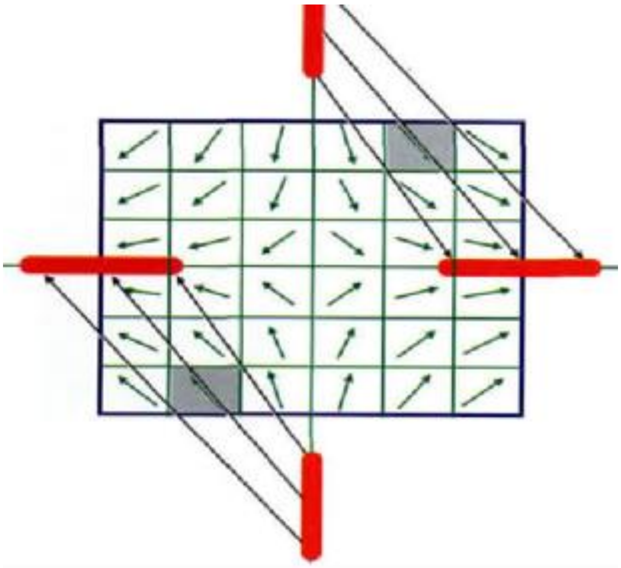


Figure 1 Schematic diagram of the cross arrangement and the gun check distance vector sheet

3. REGIONAL GEOLOGICAL PROFILE AND OBSERVATION TECHNIQUES

3.1. Earthquake geological conditions

The geological structure of the Qingshui Basin has been profoundly influenced by tectonic movements such as the Hercynian and Himalayan periods. At present, the main tectonic lines of the sedimentary cover of the basin are mainly distributed in a north-north-east direction, but in the marginal part, influenced by the boundary tectonics, the direction of the tectonic lines will be deflected to a north-north-east-east or nearly east-west direction. The internal features of the basin are mainly manifested as broad short-axis folds with skip-like slopes at the north and south ends, and basically symmetrical on the east and west sides. Among them, the stratigraphic dip is larger on the west side, while it is relatively gentle on the east side. At the edge of the basin, the stratigraphy of the Lower Palaeozoic outcrop area shows a monocline with a large dip, which gradually flattens out towards the inner part of the basin and forms a reverse fault at the outer part of the basin. The geomorphology of the whole basin is characterised by a broad compound syncline, which together with the Datong-Jingle depression belt in the northwestern part of the mountain constitutes a giant compound syncline belt arranged in the rows of geese, located between the Luliang Mountains and the Taihang Mountains. The main oblique axis is located in the line of Yushe-Beizhai-Qinxian-Wangbi, and the strike is north-north-east. The faults in the interior of the basin are mainly small-scale faults, and larger-scale faults are developed only in the marginal parts. Fractures that have a greater impact on coalbed methane gathering: including the Jinshou Fracture Zone and the Sitou Fracture Zone, in addition, there is a group of nearly east-west oriented fracture zones in the south-central part of the basin, i.e., the Shuangtou-Xiangyuan Fracture Tectonic Zone. The use of OVT domain processing technology for 3D seismic exploration can effectively improve the data processing accuracy, enhance the imaging effect of complex geological structures, and provide important technical support for the exploration and development of CBM resources.The OVT domain processing technology helps to identify faults, folds, and other geological structures more accurately, optimize the deployment of CBM wells, and enhance the success rate of the exploration by means of refined velocity modelling and inversion.

3.2. Acquisition Observation System

In order to acquire more seismic trace information, this 3D seismic survey adopts an omni-directional (horizontal to vertical ratio of 0.83), long arrangement (maximum gun check distance of 2,471m), high coverage (64 times), reduced lateral rolling distance, and guaranteed azimuthal and gun check distance uniformity of the 16-wire, 5-gun orthogonal, omni-directional-type 3D observing system scheme[3]. When choosing the direction of the line beam arrangement, the line beam was chosen to be arranged in the direction of 18°40′ north-east. In this 3D seismic project, a total of 17 bundles of gun lines are arranged according to the observation system with line distance of 200m, channel distance of 40m, gun line distance of 240m, and gun point distance of 40m, and a total of 18 wave detectors are laid. The number of times covered by the observation system and the distribution of this data collection system are shown in Figures 2 and 3, respectively. From Fig. 2, it can be seen that high coverage times and omni-directional acquisition are adopted to suit the sub-orientation and OVT processing to further improve the signal-to-noise ratio.

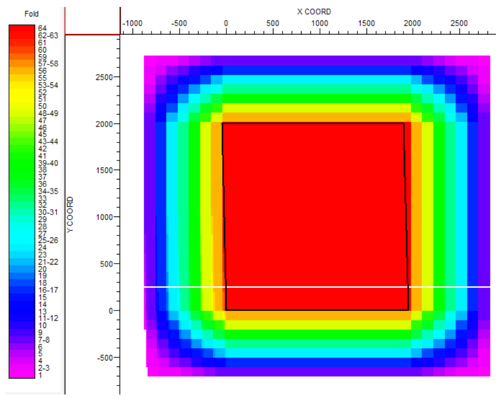


Figure 2 Chart of number of times covered

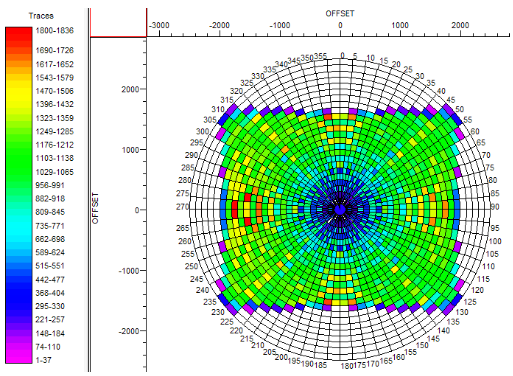


Figure 3 Rose diagram of the observing system

4. ANALYSIS OF RESULTS OF OVT DOMAIN PROCESSING TECHNIQUES

4.1. Data preprocessing

Before performing the pre-stack time shift in the OVT domain, the data must be pre-processed. Firstly, the data need to be divided into OVT cells, this is done by dividing the data into rectangles based on distances such as gunline spacing and detector line spacing. Ideally, an OVT data should be the smallest subset of data that satisfies a primary coverage of the subsurface. Figure 4 illustrates the one OVT grouping and the number of times of coverage in which the number of times of coverage is one in most cases. However, the location of some gunpoints in this work area can be irregularly distributed due to surface obstructions. In addition, in some areas with a high concentration of gunpoints, the number of coverage times will be more than 1. These are the factors that need to be considered before performing the pre-stack time offset in the OVT domain[4].

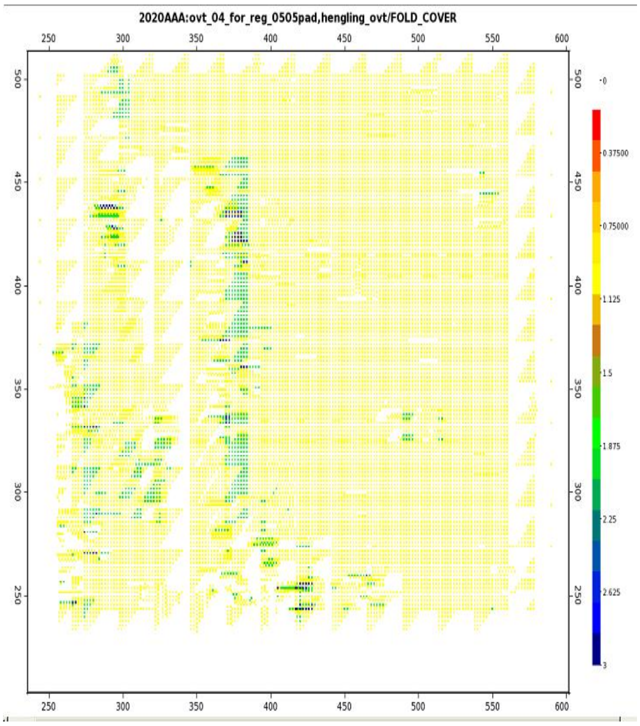


Figure 4 An OVT coverage count chart

Therefore, the OVT grouping and tract set extraction need to be optimised according to the characteristics of the raw data in the region, firstly moving the centre point of the grouping start is beneficial for near bias shifting distance, grouping is more uniform and improves shallow imaging; however, the grouping surface element remains unchanged. Then the grouping is exchanged and the far and near offsets are separated in the OVT.

Figure 5 shows the comparison of offset distance distribution before and after optimisation. The optimisation resulted in a more uniform distribution of offset distances within an OVT, which is very beneficial for subsequent work.

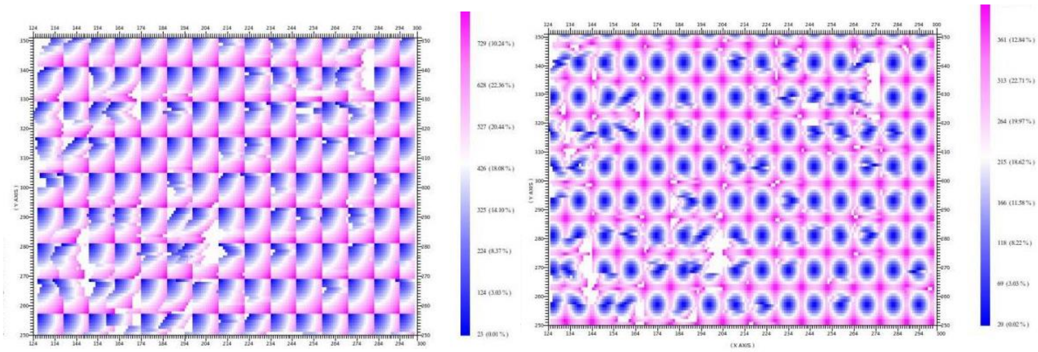


Figure 5 Distribution of offset distances before (figure left) and after (figure right) optimisation

4.2. Five-dimensional interpolation in the OVT domain

During the collection of 3D seismic data, the distribution of some of the gun check points in this work area is irregular due to factors such as surface obstacles, which leads to spatial sampling inhomogeneity, which in turn generates problems such as offset noise and reduces the quality of seismic imaging. It is necessary to interpolate the data to achieve a regular distribution such as the gun check distance and the number of coverage. Therefore, a five-dimensional interpolation method can be used, which selects the appropriate five dimensions for different purposes to perform the interpolation process and eliminate the problems caused by irregular sampling.

In the OVT domain, the data of each vector slice has similar gun check distance and azimuth angle, which makes the similarity of the data enhanced and the interpolation more reasonable. As a result, the amplitude preservation and data consistency of the OVT domain are enhanced, which is very favourable for performing five-dimensional interpolation processing. The five-dimensional interpolation method is performed by sorting the seismic data into the OVT domain in five directions: gun line, detector line, azimuth, gun detection distance, and time, and then using the five-dimensional Fourier transform to compute the Fourier spectra, and the leaf spectra are used as the constraints for interpolation and reconstruction[5][6]. This method defines and reconstructs missing seismic traces, removing abrupt changes in the data in terms of coverage counts, gun check distance and azimuth, resulting in a more homogeneous data distribution. This homogenised data satisfies the need for OVT pre-stack time offsets, significantly improves the effect of fluctuation equation offsets, and ultimately improves the resolution and accuracy of seismic imaging.

The slice diagrams before and after the vector slice data regularisation (e.g., Fig. 6) show the reduction of voids after the data regularisation, which can effectively reduce the scratch arcs for the subsequent pre-stack time offset processing. After five-dimensional interpolation, in the pre-stack channel set completed 20m * 20m surface element interpolation to 10m * 10m, in addition, due to irregular collection and other factors, caused by the number of coverage and attributes on the collection of footprint traces, need to be eliminated through the targeted OVT domain interpolation processing, zoomed in the display can be seen that the signal-to-noise ratio and spatial continuity has been enhanced, and the collection of footprints have been eliminated to some extent.

As shown in Fig. 7, the number of overlay times across the region becomes more uniform after five-dimensional interpolation processing. By observing the control line superposition, it can be found that the inhomogeneity of the coverage counts and the null channel problem have been solved, and the signal-to-noise ratio has also been significantly improved.

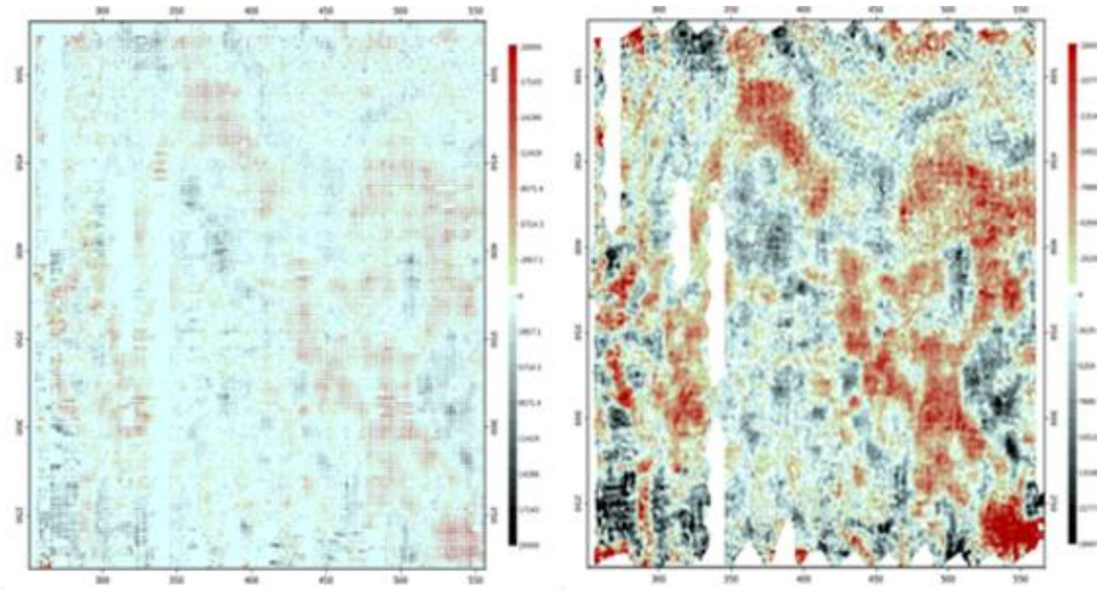
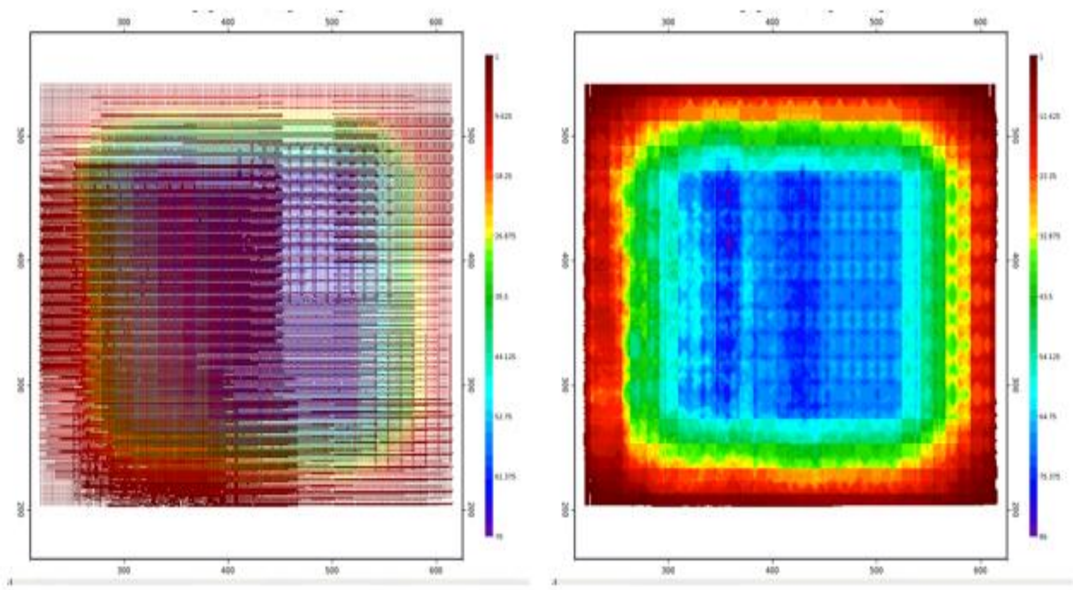


Figure 6 Comparison of slices before and after 5D interpolation



Before **After**

Figure 7 Comparison of the number of coverages before and after five-dimensional interpolation

4.3. OVT domain time offset

When dealing with high-density 3D seismic data, the distribution of azimuth angles is usually large. If the variation of azimuth angle is neglected, it may lead to the reduction of imaging accuracy. Therefore, the variation of azimuth should be fully considered during data processing.

The OVT domain pre-stack time offset is consistent with the conventional technique in the basic theory, and the data it processes is the OVT channel set[7]. During the OVT domain pre-stack time offset, the average gun check distance and azimuth of each OVT tract set is considered as the representative gun check distance and azimuth of the tract set, which is superior to the conventional method of separating the data within a fixed range of gun check distances. The azimuth information is retained after the OVT pre-stack time shift is completed; however, the azimuth information is not retained in the conventional common gun check distance pre-stack time shift data. Compared with the CRP channel set, the OVT-shifted OVG channel set has more channels and a more balanced overall energy; the signal-to-noise ratio of the former is significantly higher than that of the latter.

The current OVT domain pre-stack time offset is the Kirchhoff offset method, which is the basis of the conventional pre-stack time offset and the key to obtaining an accurate layer velocity model. As shown in Fig. 8, both OFFSET and Azimuth information are preserved after the OVT domain offset. For other pre-stack offset parameters, including aperture, anti-false-frequency parameter and inclination, there is no difference between the two. The pre-stack time offset imaging accuracy is related to the offset algorithm, but more closely related to the accuracy of the offset velocity field. Only when the offset velocity field is relatively accurate, the pre-stack time offset can be homed more accurately, thus obtaining better imaging.

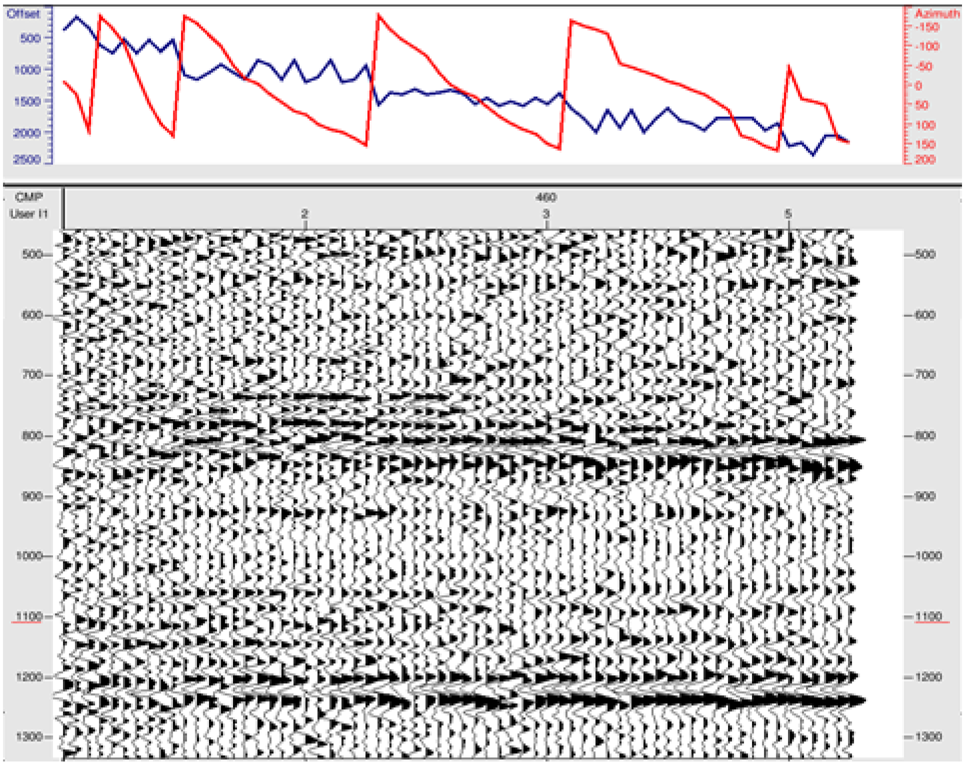


Figure 8 OVT domain offset channel set

The OVT domain pre-stack time offset can achieve a true co-reflective point stacking, which has some advantages in imaging geological details and homing of breakpoints and faults. By comparing the OVT domain pre-stack time offset profile with the horizontal stacked profile (see Figures 9 and 10), it can be found that the OVT domain pre-stack time offset profile does not have the phenomenon of offset arcing, the offset noise is relatively tiny, the homing imaging is clear, the signal-to-noise ratio after offset is high, and the reflected wave can be tracked by continuous comparison. All these features show the advantages of OVT domain pre-stack time offset technique in seismic data processing[8][9].

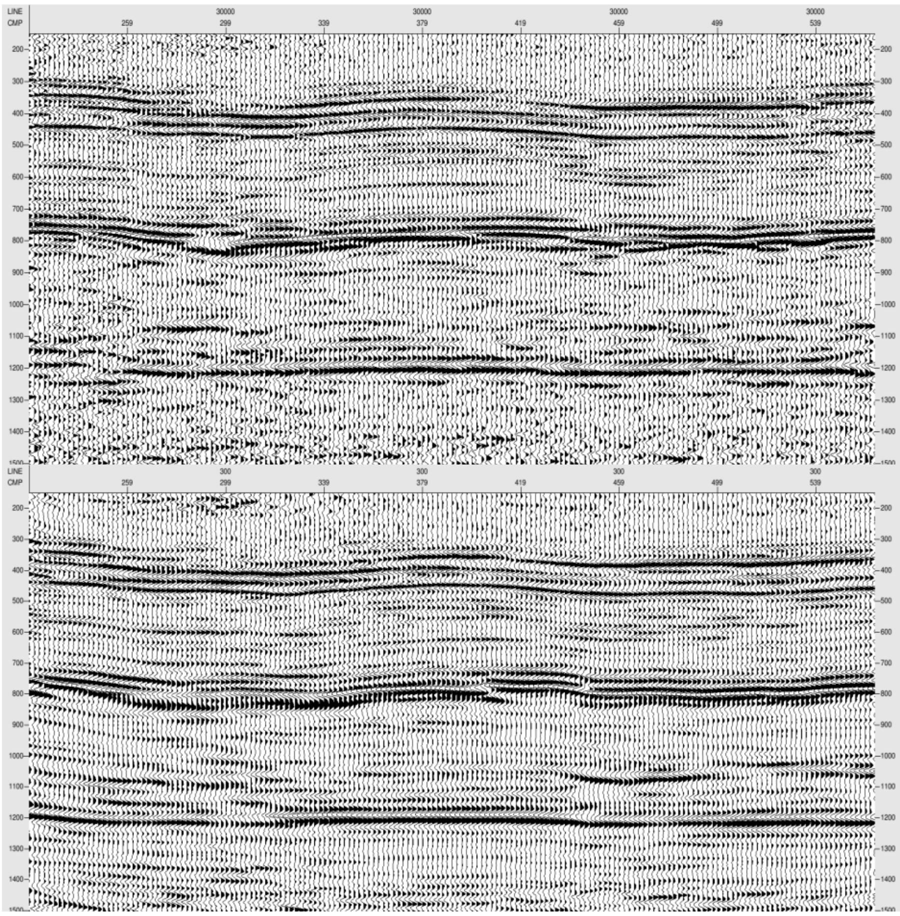


Figure 9 Stacked profiles (top) vs. OVT offset (bottom) time profiles

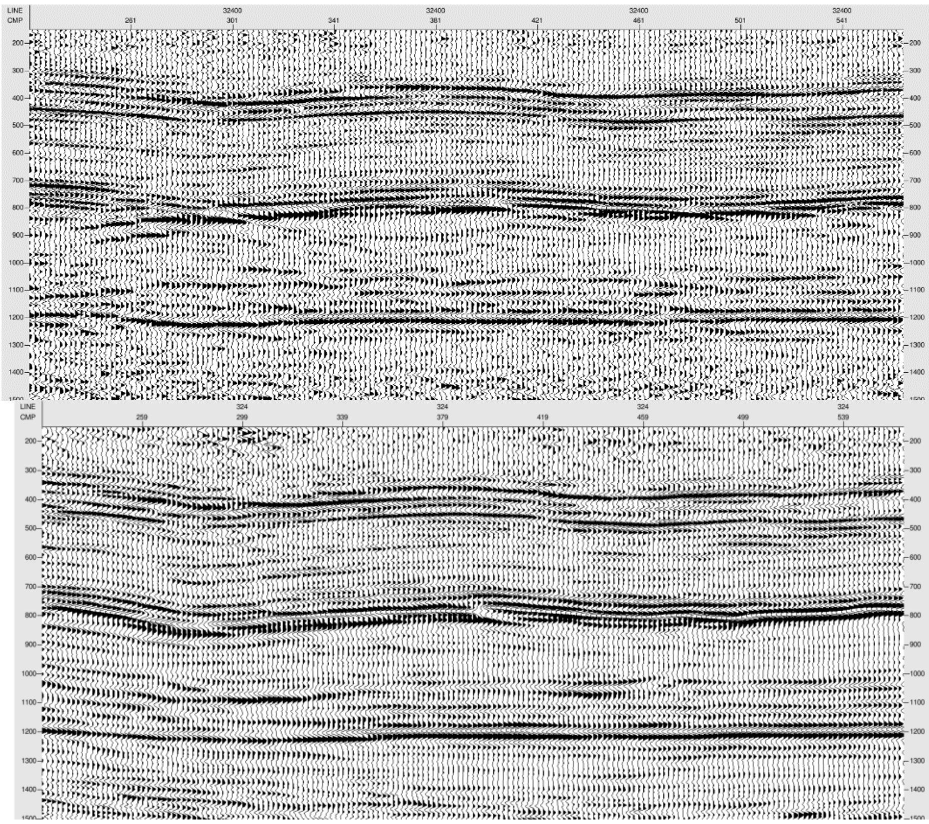


Figure 10 Stacked profiles (top) vs. OVT offset (bottom) time profiles

4.4. Azimuthal correction

After completing the OVT offset, the correction of azimuthal anisotropy is then carried out. The basic principle is to match the actual data of each course with the model course and calculate the time difference of each course to obtain the displacement field of the whole work area. Next, the displacement field is spatially smoothed and applied to the data to achieve spatially correlated local co-axial levelling. After the OVT offset, the presence of jitter in the isotropic axes can be observed on the obtained set of OVG tracts, indicating that the data are azimuthally anisotropic. For narrow azimuth data, although the azimuthal distribution of the obtained tract set is narrower and can also reflect the anisotropy phenomenon, this anisotropy phenomenon is not obvious.

When a seismic wave propagates in an azimuthally anisotropic (HTI) medium, the propagation velocity varies from one orientation to another.The velocity field of an HTI medium is defined by three parameters[11][12]: the fast velocity field, the slow velocity field, and the angle of the slow velocity with respect to the inline direction β. β is also known as the slow velocity field azimuth. Therefore, the velocity in a certain gun check direction Φ can be expressed as:

$$\frac{1}{V_{\phi}^{2}} = \frac{\cos^{2}(\alpha)}{V_{slow}^{2}} + \frac{\sin^{2}(\alpha)}{V_{fast}^{2}} \tag{1}$$

Figure 11 shows in detail the comparison between before and after azimuthal anisotropy correction. Before correction, there is an obvious jitter phenomenon in the in-phase axis in the channel set, which is a typical manifestation of azimuthal anisotropy. This jitter may adversely affect the interpretation and analysis of seismic data. However, after the azimuthal anisotropy correction, the situation has been significantly improved, and the 'jitter' of the coaxials in the OVG channel set has been significantly reduced. This change not only improves the continuity of the coaxials, but also enhances the interpretability of the seismic data. This correction effectively solves the problem of superposition of different phases caused by azimuthal anisotropy.

By comparing the stacked profiles before and after the anisotropy correction (Figure 12), the stacked imaging effect is improved after the anisotropy correction, which is more conducive to in-phase stacking, thus improving the quality of seismic imaging. At the same time, the resolution of the profiles is improved, and the signal-to-noise ratio and continuity are also improved. Compared with the conventional pre-stack offset channel sets, the channel sets obtained from the OVT domain processing contain rich pre-stack information, which is very favourable for anisotropy studies, fracture analysis and pre-stack inversion.

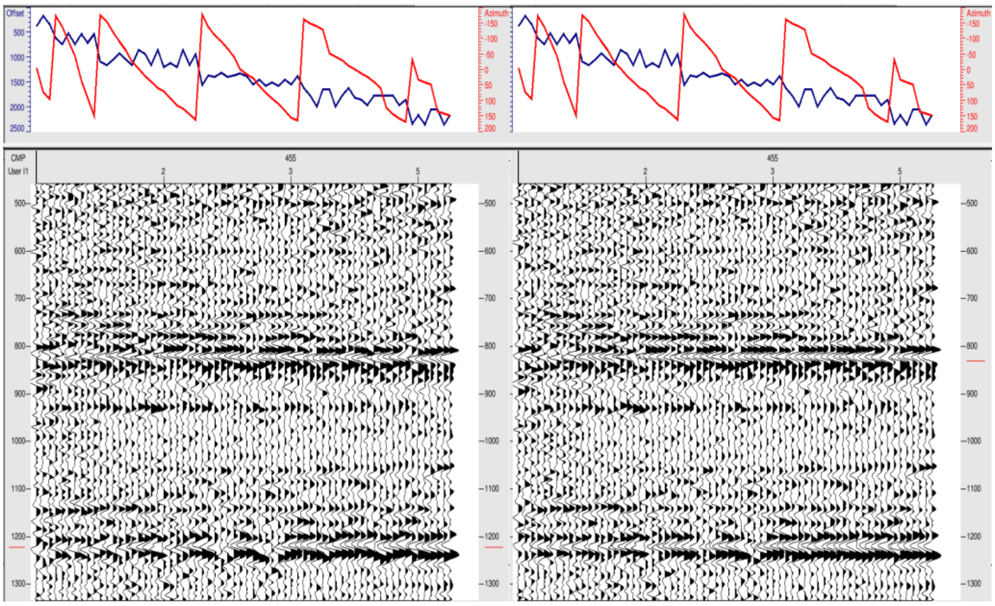


Figure 11 Comparison of azimuthal anisotropy before (left) and after (right) correction

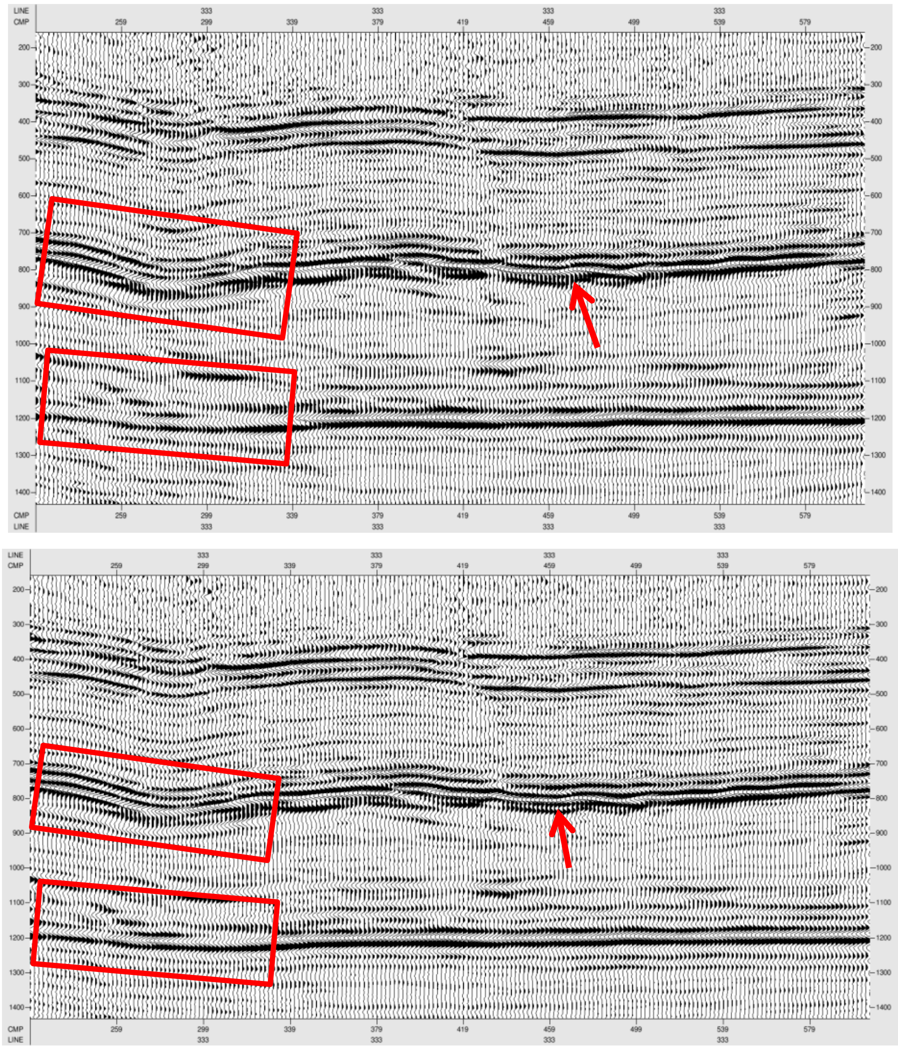


Figure 12 Comparison of azimuthal anisotropy corrected pre- (top) and post (bottom) time profiles

4.5. Superimpose in several directions

The division of azimuth is mainly determined based on the characteristics of fracture development in this area, and the tectonics in this area are mostly north-north-east oriented. The principle of azimuth division is: 0 degree direction is parallel to the cdp increase direction of the inline, the counterclockwise direction is the angle increase, and after 360° counterclockwise, the azimuth is coincident with the cdp increase direction of the inline. In accordance with this principle, the azimuths were grouped at 30° azimuthal intervals, dividing the azimuths into six angles[13][14].

Figures 13 to 14 show the comparison of omni-directional and different azimuthal offsets, from which it can be seen that the omni-directional and different azimuthal offsets have some differences in imaging features, reflecting azimuthal anisotropy.

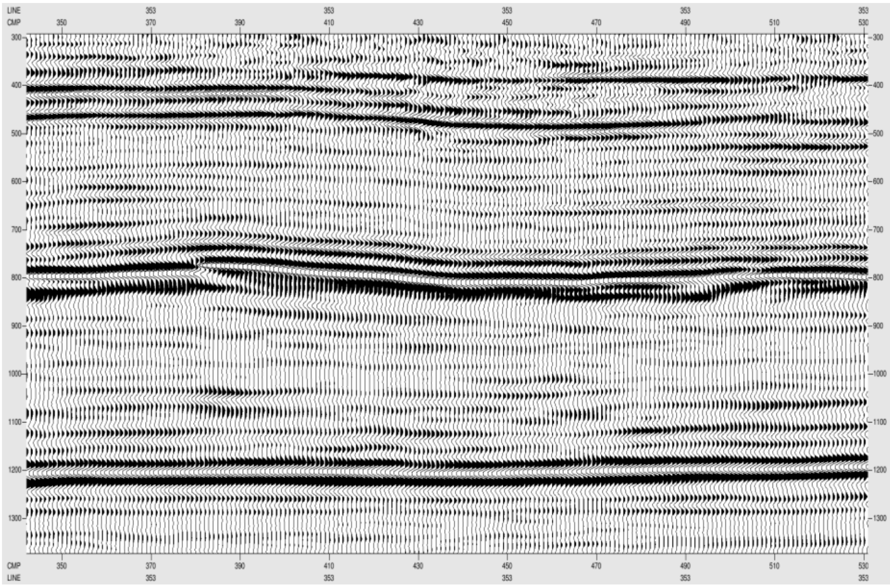


Figure 13 Omni-directional pre-stack offset time profiles

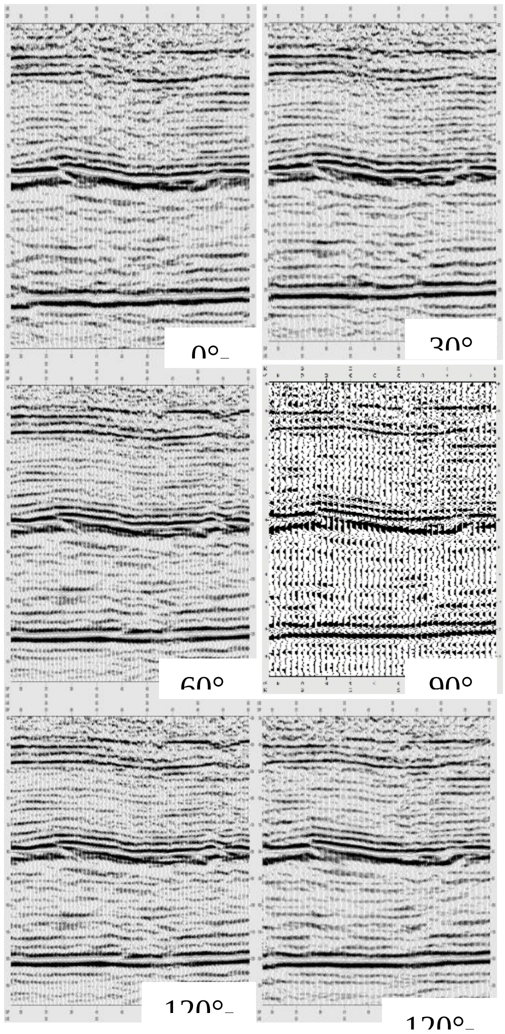


Figure 14 Pre-stack offset time profiles in different sub-azimuths

5. CONCLUDING REMARKS

This OVT domain pre-stack time offset has a significant effect, which can initially see the applicability and potential of this technique for this area and similar data.

1) The OVT processing technique is ideal for processing wide-azimuth data, which can make full use of the azimuthal information, and can even be useful in processing narrow-azimuth coal seam data. Compared with sectorised processing, OVT processing is able to obtain more accurate azimuthal velocities, resulting in better quality imaging.

2) The OVT channel set is very suitable for regularisation and offset processing. the OVT channel set can be extended to the whole work area, the magnitude of its spatial discontinuity is small, and the offset distance and azimuth angle are relatively constant within the OVT channel set. In many parts of the processing of wide-azimuth pre-stack data, truly new methods such as five-dimensional interpolation are required.

3) The OVT domain processed tract sets are more suitable for tasks such as AVO analysis and crack prediction. These properties give OVT domain processing techniques a significant advantage in seismic data processing[10].

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