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Accurate Seismic Imaging Methods on Complex Fault Blocks of Subei Basin

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Abstract

Subei basin is well-known for its complex fault block reservoirs and has wide growth of shallow igneous rocks. These inherent geological characteristics seriously affect the accurate seismic imaging of target layers. Pre-stack depth migration is an effective imaging method for complex structure and velocity field zones. In order to verify nice imaging ability of Kirchhoff's pre-stack depth migration (KPSDM) and reverse-time migration (RTM), imaging tests were carried out based on the velocity model for complex fault block of igneous area in Subei basin. Experimental results showed that under the condition of reliable high-frequency velocity field, RTM had obvious advantage in imaging of fault blocks, otherwise, KPSDM was a viable option. In order to verify above experimental results, by selecting seismic data with higher signal to noise ratio (SNR), a reliable high-frequency velocity field was established, and the imaging processing was carried out. The results showed that RTM has obvious advantage over KPSDM in the aspect of improving imaging results of fault blocks and target layers under igneous rocks. Therefore, the choosing of imaging methods for complex fault blocks with igneous zone depends on SNR of seismic data. If seismic data has high SNR, a more accurate high frequency velocity field can be set up. Thus RTM can achieve precise imaging for target layers. If the seismic data has low SNR, KPSDM will become a good choice.

Key words: Subei basin; Complex fault block; Igneous rock; Velocity model; Reverse time migration

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INTRODUCTION

Small complex fault blocks are typical reservoirs in Subei basin, which is well known for its dense faults, small traps and widely developed igneous rocks. These shallow igneous rocks are of strong amplitude, low frequency and good continuity on profile. Due to the shield of igneous rock, the underlying major target layers are of weak energy and low S/N ratio[1-3]. Complex structures as well as irregular distribution of igneous rocks lead to velocity field variation, velocity inversion, and difficulties in target layers imaging. KPSDM method could not cope with the velocity field variation, while the RTM method could adapt to any velocity variation and has achieved good effect in Mexico Gulf of America, western Africa and North Sea oilfield. With the development of petroleum exploration, processing result is required to enhance the recognition precision of complex structural reservoirs and subtle reservoirs. In Subei basin with complex fault blocks and igneous rocks, the application of RTM is of great significance.

1. IMAGING METHODS OF COMPLEX FAULT BLOCK IN IGNEOUS ROCK AREA OF SUBEI BASIN

3D seismic acquisition has been carried out in major sags of Subei basin, and even high precision acquisition for 2 times or 3 times in some areas, thus the data quality has been greatly enhanced. With the application of pre-stack depth migration, imaging of complex fault block and area with igneous rock development has been improved. Common pre-stack depth migration technique includes Kirchhoff's pre-stack depth migration (KPSDM) and reverse-time migration (RTM), and the KPSDM is of high computing efficiency while the RTM could adapt to complex velocity field.

1.1 Kirchhoff's Pre-Stack Depth Migration

Kirchhoff's pre-stack depth migration is made up of two parts: Travel-time calculation and integration processing. Migration precision lies on the precision of travel time calculation，which is based on ray theory, namely Fermat principle: The optical length of the path followed by light between two fixed points, A and B, is an extremum. The direct method to compute travel time is to do ray tracing in defined velocity field. If the velocity do not changes great, limited difference method of adaxial ray could lead to a favorably good result. But aiming at wave field area and misfocusing in the lower part of high-velocity volume, KPSDM could not get a good imaging effect due to the lack of imaging ray[4]. Although the KPSDM has enhanced the computing precision and imaging quality, there are following disadvantages:

(a) High-frequency approximation and far-field approximation are adopted in wave equation solving, thus it is accurate for the instance that long time t × angle frequency ω. Therefore, diffraction points which are several wave lengths away from the source or receiver could not be imaged correctly. That is to say, this high-frequency approximation affected subsurface imaging.

(b) The pre-stack depth migration aperture is big owing to the quick lateral velocity variation. Ray path of travel time is multi-paths during the long-distance focusing, while the Kirchhoff's integration method, which is single path, cannot handle multi-paths condition.

(c) Imaging effect is not accurate enough.

Despite all that, KPSDM is still the major processing method for current pre-stack depth migration owning to its effective ability on processing lateral velocity variation, high computation efficiency, adaptiveness for complex acquisition geometry, and higher imaging precision on medium dip structure.

1.2 Two-Way Wave Equation Reverse-Time Migration

Pre-stack reverse-time migration is to do wave field extrapolation based on the 2-way wave equation, which avoids dip angle limit in traditional wave migration. It could either realize the imaging of diving wave and multiple waves, or get more accurate amplitude information. In the complex structure imaging, RTM could adapt to quick lateral variation of velocity field, and achieve accurate imaging for the complex area (i.e., salt dome). RTM includes two steps: Reverse wave field extrapolation based on 2-way wave equation and imaging condition application[5].

The definite problem of 3D reverse depth migration could be described as:

$$\begin{cases} \dfrac{\partial^2 u}{\partial x^2}+\dfrac{\partial^2 u}{\partial y^2}+\dfrac{\partial^2 u}{\partial z^2}=\dfrac{1}{v(x,y,z)}\dfrac{\partial^2 u}{\partial t^2} \\ u(x,y,z,t)\,|_{t\geq T_{\max}}=0 \\ u(x,y,z,t)\,|_{z=0}=\Psi(x,y,t) \end{cases} \tag{1}$$

Where, u is the acoustic compression wave field. $\Psi(x,y,t)$ is the seismic data received on surface in time domain. $v(x,y,z)$ is the medium velocity. Difference resolution on definite problem could solve the problem of 3D reverse time migration imaging. The imaging condition is defined as

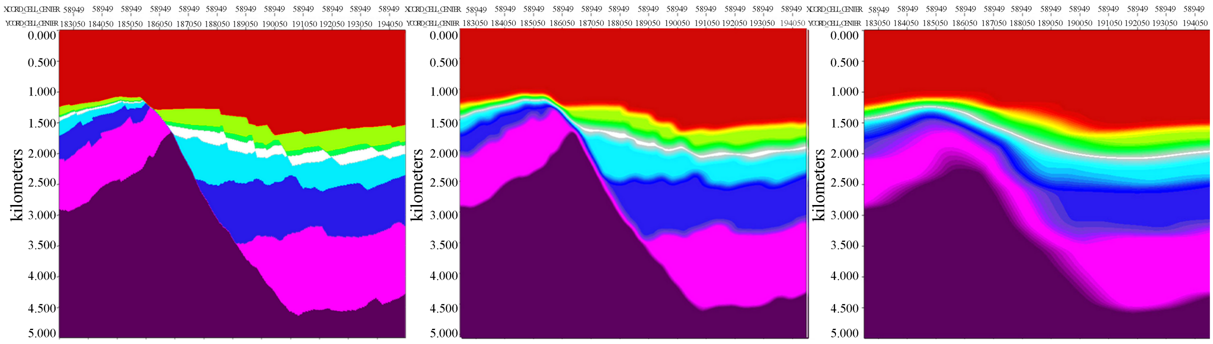
$$I(x,y,z)=\int_0^T u_S(x,y,z,t)*u_R(x,y,z,T-t)dt \tag{2}$$

In this equation, $u_s(x,y,z,t)$ is source extrapolation wave field, $u_R(x,y,z,t)$ is recorded extrapolation wave field. T is the max record time. Compared with other pre-stack depth migration method, RTM is more sensitive to the velocity model precision in area with great velocity variation. If there is error in velocity model, RTM would lead to fake reflection and mirror imaging, which greatly affect the structure interpretation. Therefore, RTM need high frequency velocity field[6-7].

2. METHOD OPTIMIZATION

2.1 Method Optimization of Complex Fault Block

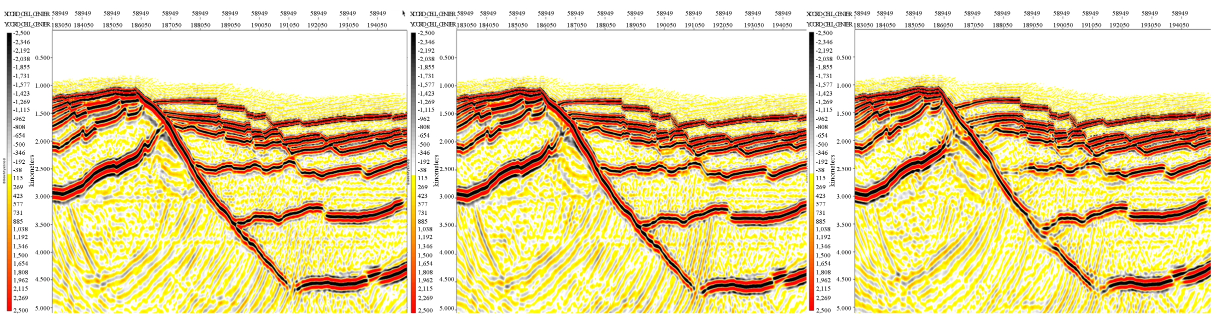
Model tests were carried out to verify the imaging effect of above methods in fault blocks in Subei basin. Firstly, the typical fault block geological model of Subei basin was set up (Figure 1(a)), with the model grid of 10 m × 10 m. The model consists of big steep fault, many small faults, and 7 reflectors from up to down- T^3_2, T^4_2, T^5_2, T^0_3, T^1_3, T^3_3 and T^0_4. Based on the geological model, high frequency approximated velocity model (Figure 1(b)) was made by grid approximation of 100 m × 100 m, and low-frequency velocity model was made by 1,000 m × 1,000 m grid approximation (Figure 1(c)).



(a) Accurate Model (b) 100 m × 100 m Grid Approximation (c) 1,000 m × 1,000 m Grid Approximation

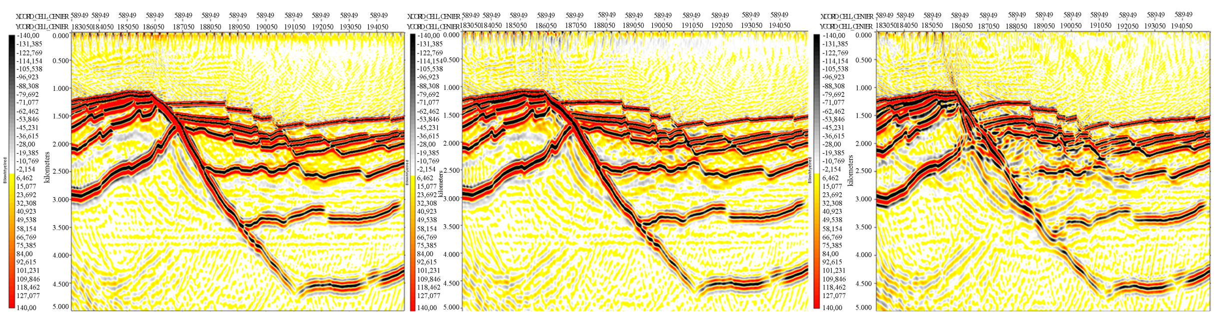
Figure1
Complex Fault Block Geologic Model and Approximate Model in Subei Basin

Wave equation forward modeling was made by using the velocity model in Figure1(a), and KPSDM (Figure 2) and RTM (Figure 3) were applied in these three velocity models with different precision.



(a) Accurate Model K-PSDM (b) High Frequency K-PSDM (c) Low Frequency K-PSDM

Figure 2
KPSDM Contrasts of Three Velocity Models



(a) Accurate Model RTM (b) High Frequency RTM (c) Low Frequency RTM

Figure 3
RTM Contrasts of Three Velocity Models

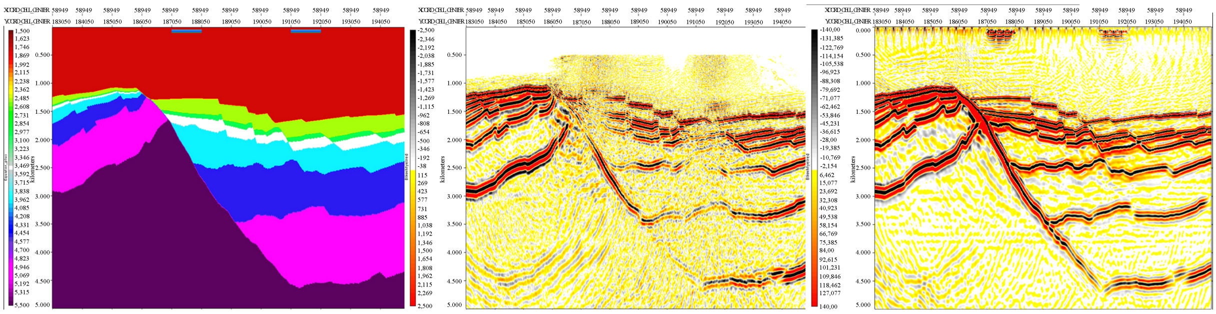
Figure 2(a) and Figure 3(a) show that, based on the accurate velocity field, RTM imaging results of faults and target layers are more accurate than K-PSDM's. However, it's impossible to get accurate velocity field as Figure 1(a), we could only try to approach it. In the 100 m × 100 m grid velocity model-high frequency approximation, break points were smoothed, but structural details are still clearly visible. In the 1,000 m × 1,000 m grid velocity model-low frequency approximation, the structure changing trends are visible only.

Figure 2(b) and Figure 3(b) show that, compared with the K-PSDM, the RTM imaging result based on high frequency velocity field is of higher S/N Ratio and precision, and horizon-fault contact relation on big fault' uplifted side has been greatly improved.

Figure 2(c) and Figure 3(c) show that, based on the low-frequency velocity model, K-PSDM is of inaccurate travel time (especially in the neighborhood of big fault), deviated integral summation surface, and misfocused energy, while the RTM is of serious deviation in forward modeling field of source wavelet and record wave field, and correlation imaging misfocusing of forward modeling and extrapolation wave field. Thus both methods did not lead to good imaging, especially the RTM method.

2.2 Method Optimization of Complex Fault Block With Igneous Rocks Development

Igneous rocks which are widely developed in Subei basin, cause the energy shield and structural imaging difficulties, which make it more difficult to recognize favorable traps. Model research has been made to study the RTM effect on Subei basin. Figure 4(a) is the geologic model of typical small fault block in Subei basin, and two sets of igneous rocks (50 m thickness, 500 m length) were developed on shallow layer. Figure 4(b) is the K-PSDM imaging result; Figure 4(c) is the RTM imaging result.

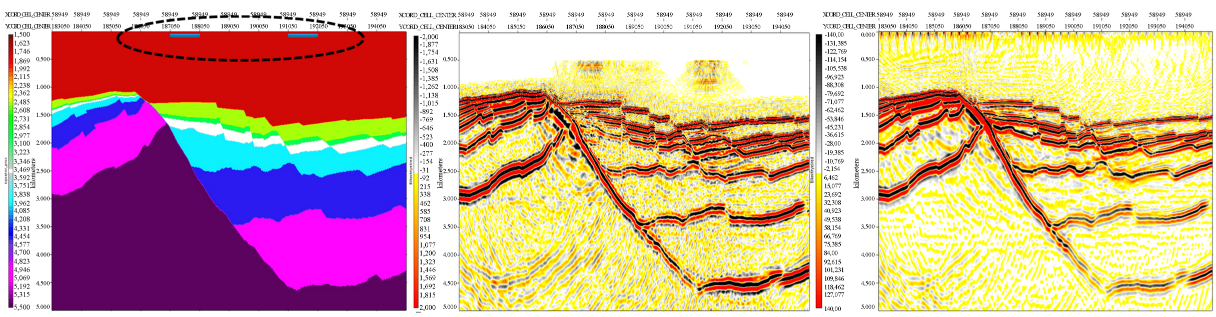


(a) Accurate Model With Shallow Igneous Rocks Development (b) K-PSDM Method (c) RTM Method

Figure 4
Complex Fault Block Geologic Model With Igneous Rocks and Imaging Effect

It is found that RTM can realize accurate imaging of target layers, horizon-fault contact relation, and shallow igneous rocks' distribution, while KPSDM made a poor imaging effect under the igneous rocks.

Due to the vague recognition on igneous rocks, shallow igneous rocks are usually ignored during velocity modeling. Figure 5(a) is velocity model, whose shallow igneous rocks were ignored during migration. Figure 5(b) is the imaging result by using KPSDM and Figure 5(c) is the result of RTM. It is found that KPSDM imaging had been improved owning to the sufficient ray reaching target layers under igneous rocks. However, some wrong rays lead to the imaging deviation (Figure 5(b)). The RTM result is of much migration noise because of the forward modeling deviation in time-space domain.



(a) Accurate Model With Shallow Igneous Rocks (b) KPSDM Ignoring Igneous Rocks (c) RTM Ignoring Igneous Rocks

Figure 5
Geological Model (Imaging Ignoring Igneous Rocks) and Imaging Effect

According to above model tests, the imaging countermeasures of complex fault block area with igneous rocks are concluded:

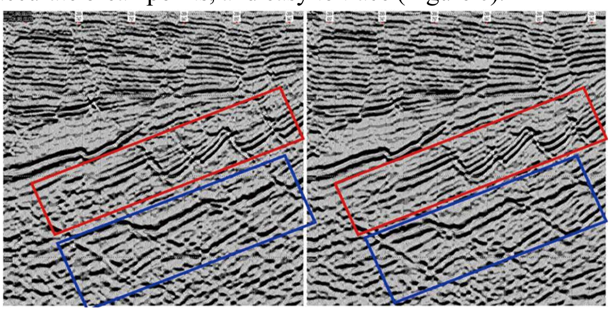
(a) Adopt high-density vertical RMS velocity analysis technology to set up reliable low frequency velocity field (velocity analysis points depend on structure complication, 200 m × 400 m in general);

(b) Choose 3D grid tomographic inversion to iterate the high frequency part of the velocity field (100 m × 100 m precision of velocity field).

(c) Based on the relatively accurate velocity field with high frequency, use RTM.

3. APPLICATION

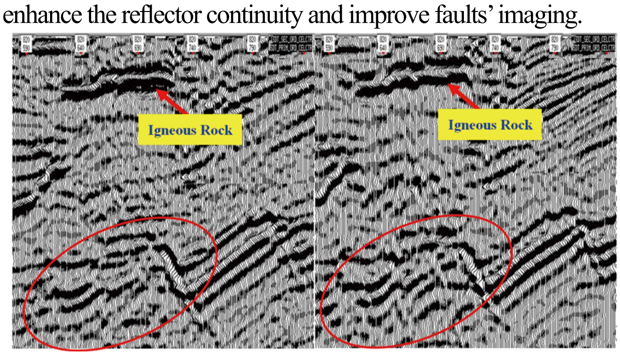
In order to verify the feasibility of above conclusions, practical and typical data was processed. The data is HW high-precision 3D in Gaoyou sag, Subei basin where Igneous rocks were widely developed and affect the imaging of underlying small fault blocks and target layers. Low frequency background velocity was set up through 200 m × 400 m velocity analysis , and high frequency detailed velocity field was made by using grid tomographic inversion. Based on the relatively accurate velocity field, RTM technique was adopted. Compared to traditional KPSDM method, the data using RTM method is of clearer faults, more accurate break points, and easy to trace (Figure 6).



(a) Result of KPSDM (b) Result of RTM

Figure 6
Imaging Results Contrast Map of KPSDM and RTM

Figure 7 is the imaging effect under igneous rocks. Compared with KPSDM, the target layers (red circle) of RTM method enhance the reflector continuity and improve faults' imaging.



(a) Result of K-PSDM (b) Result of RTM

Figure 7
Imaging Results Contrast Map of K-PSDM and RTM of Shallow Igneous Rock Zone

CONCLUSION

In summary, according to the test analysis and practical data processing, it is thought that RTM is more appropriate for imaging of small fault block in igneous rocks area of Subei basin. However, at present, migration velocity modeling technique is not mature, thus the RTM method cannot totally take the place of KPSDM. In practical data processing, choose the KPSDM method for poor data that could not set up reliable high frequency velocity field, and adopt RTM for data with good SNR.

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