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Fault identification and interpretation based on frequency-divided coherence technique

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Abstract

The fault identification and interpretation is one of the key issues of oil and gas exploitation. However, it is difficult to identify and combine faults using conventional interpretation methods, due to the complicated seismic and geological conditions in many areas with complex structures. Take the fault identification and interpretation based on frequency-divided coherence technique of Dengying Formation in PL gas field in the north-central Sichuan Basin as a example. The original data is processed for imaging enhancement under the control of the inclination angle, and the pre-processed seismic data is subjected to a spectral decomposition method to obtain amplitude data volumes of different frequency bands. The optimal calculation parameters are selected for coherent calculation and coherent slices along the layer are extracted. The result showed that the high-frequency coherent data reflects more clearly on faults and fracture development zones. The problem of fault combination in conventional interpretation is solved.

Keywords

Frequency-divided coherence technique; Identification; Interpretation; Fault; PL gas field.

1. Introduction

The fault combination system is a key factor affecting the distribution of oil and gas reservoirs [1]. Therefore, the identification and interpretation of faults is of great significance to oil and gas reservoir exploration. However, it is difficult to identify and combine faults using conventional interpretation methods, due to the complicated seismic and geological conditions in many areas with complex structures. At present, the coherence technique is relatively mature in the identification of faults, river channels, and special lithological boundaries [2-3]. Spectrum decomposition is often used in conjunction with coherence analysis to identify small faults by highlighting high-frequency coherence bodies, so as to complement the full-frequency coherence.

Thus, a study of the the fault identification and interpretation based on frequency-divided coherence technique of Dengying Formation in PL gas field can provide a significant case study for gas exploration in the Sichuan Basin.

2. Geological setting

PL gas field is located in north-central Sichuan Basin, which is trending roughly in northwest to southeast, and and covers an area of approximately 0.3×10^4 km^2 (Fig. 1). The Sinian Dengying Formation unconformably overlies the Pre-sinian layer and unconformably underlies the Cambrian Maidiping Formation [4-5]. The Dengying Formation contains marine deposits and can be divided

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into four members, the Deng-1 to Deng-4 members, which carbonate shoals were developed within the carbonate platform and were present in the Deng-2 and Deng-4 members. The Primary studies suggested that there are 5 large carbonate shoals in the Deng-2 Member of the Dengying Formation in PL gas field, which showing huge potential for gas exploration and development. The fault identification and interpretation is one of the key issues of the gas exploitation in PL gas field.

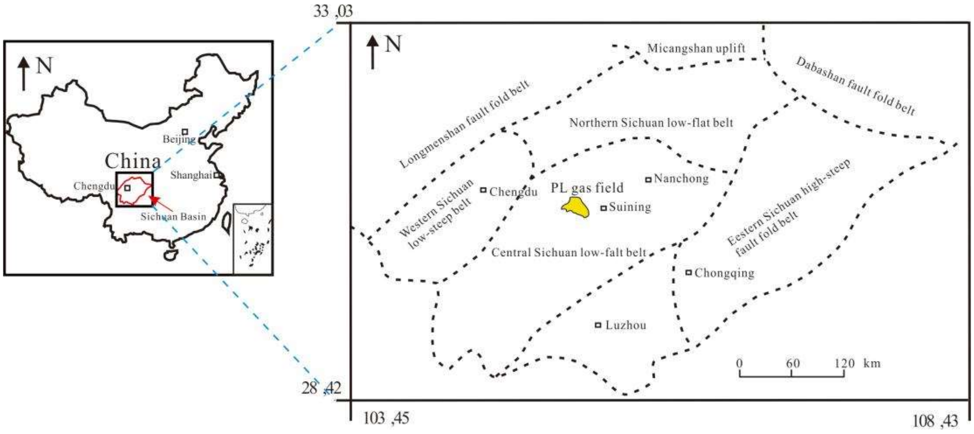

Figure 1. Tectonic units in the Sichuan Basin and the location of the PL gas field

3. Basic principle of frequency-divided coherence

3.1 Coherence method

Coherence method describes the lateral heterogeneity of formation and lithology by calculating the similarity of seismic waveforms between adjacent traces in a three-dimensional data volume [6]. Since the coherence method was proposed, its algorithm has undergone improvements in the first-generation C_1 based on cross-correlation, the second-generation C_2 based on multi-channel similarity, and the third-generation C_3 algorithm based on the intrinsic structure based on intrinsic structure [7]. In the coherent calculation, it composes the covariance matrix of multi-channel seismic data, adopts the idea of principal element analysis method, applies multi-channel eigen decomposition technology to obtain the coherence of the matrix, and decomposes the eigenvalues and eigenvectors [8].

First define an analysis time window containing J channels of data, each channel of data contains n sampling points, D is the seismic data matrix (Eq. 1):

$$D = \begin{bmatrix} d_{11} & \dots & d_{ij} \\ \dots & \dots & \dots \\ d_{n1} & \dots & d_{nj} \end{bmatrix} \tag{1}$$

The covariance matrix of the entire seismic data volume is as follows (Eq. 2):

$$C = D^T \quad D = \sum_{n=1}^{n} d_n d_n^T \tag{2}$$

The formula for calculating the coherence value EC of the third-generation coherent is as follows (Eq. 3):

$$E_c = \frac{\lambda_1}{Tr(C)} = \frac{\lambda_1}{\sum_{i=1}^{j} \lambda_j} \tag{3}$$

The algorithm has high lateral resolution and enhanced noise resistance in the recognition of abnormal objects.

3.2 Parameters

The calculation parameters involved in the coherence method include the horizontal time window, the vertical time window and the maximum inclination scan range. Reasonable selection of these three parameters can effectively improve the accuracy of fault interpretation.

The horizontal time window is the number of seismic channels involved in the calculation. Generally speaking, the more channels involved in the calculation, the stronger the ability to suppress noise, the greater the average effect, and the clearer the imaging of the large tomographic; the less the number of channels, the weaker the average effect, and the clearer the imaging of the small tomographic. For data with high signal-to-noise ratio, you can open the hour window; for data with low signal-to-noise ratio, you can open a large time window. The lateral time window should be selected according to the research purpose and the quality of seismic data [9-10].

The vertical time window is determined by the apparent period T of the reflected wave. If the time window is too small (less than half a period), it is mostly a reflection of noise; if the time window is too large, it is difficult to highlight the reflected signals of small faults, which reduces the resolution of geological anomalies. Generally, the period range from 0.5 to 1.5 is selected. For steeply inclined or nearly vertical faults, the vertical time window can be selected larger.

The scan range of the maximum dip reflects the time difference of the event axis caused by the apparent dip of the formation. The larger the scanning range, the more the amount of calculation; the smaller the scanning range, it cannot reflect the change of steep inclination. It is generally obtained through statistics of the maximum time difference change value in the line direction or the track direction of the actual seismic data.

4. Case study

4.1 Data preprocessing

The original seismic data is linearly denoised by imaging enhancement technology under tilt control. If the calculated parameter is too small, the effect is not obvious, and if the parameter is too large, it will change the stratum occurrence and easily form stratum artifacts. After data preprocessing, the stratigraphic continuity at the fault zone has been improved compared with the original seismic data, and the breakpoints are simply crisp.

4.2 Spectrum decomposition

The effective frequency band of the target layer wave group after processing is 10 Hz to 50 Hz. The seismic data is frequency-divided by discrete Fourier transform with a short-time window to generate a three-dimensional data volume with 5 narrow frequency bands at equal intervals of 10 Hz.

4.3 Body attribute calculation

Experiments with multiple time windows and multiple methods on the coherent calculation parameters, and finally selected 5 orthogonal channels as the number of coherent channels, the vertical time window is 38 ms, and the maximum inclination scanning range is 1 ms/trace. The calculated coherence volume is ideal. Applying the above calculation parameters, the high-resolution intrinsic structure algorithm is used to perform coherent calculations on the five frequency-divided data volumes and the processed seismic data to form the corresponding coherent volume.

4.4 Attribute extraction along the layers

Perform plane interpolation and smoothing on the horizon data to eliminate the influence of outliers and reduce errors. Choose along the bottom of the Dengying Formation as the extraction time window to extract the coherent attributes along the layer.

4.5 Fault identification and interpretation

Use conventional methods and coherent slices to interpret the faults, and verify the faults with main survey line and contact survey line sections.

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There are 32 groups of faults developed in the PL gas field (Fig. 2). The faults are mainly strike-slip faults and normal faults. They can be divided into three types according to their functions, namely control platform trough faults, control trap faults and general faults. Type I faults are mainly tension-type normal faults, with local strike-slip faults, console trough phase boundaries, serrated features on the plane, fault distance greater than 50 m, and lateral extension greater than 50 km. Type II faults are dominated by strike-slip faults, with normal faults locally present, and the distribution of lithological traps, with a fault distance of 0 to 50 m, and a long horizontal extension. Type III faults are dominated by strike-slip faults, with normal faults and non-phase-controlling faults in some areas, with a fault distance of 0 to 100 m, and a short lateral extension of much less than 50 km.

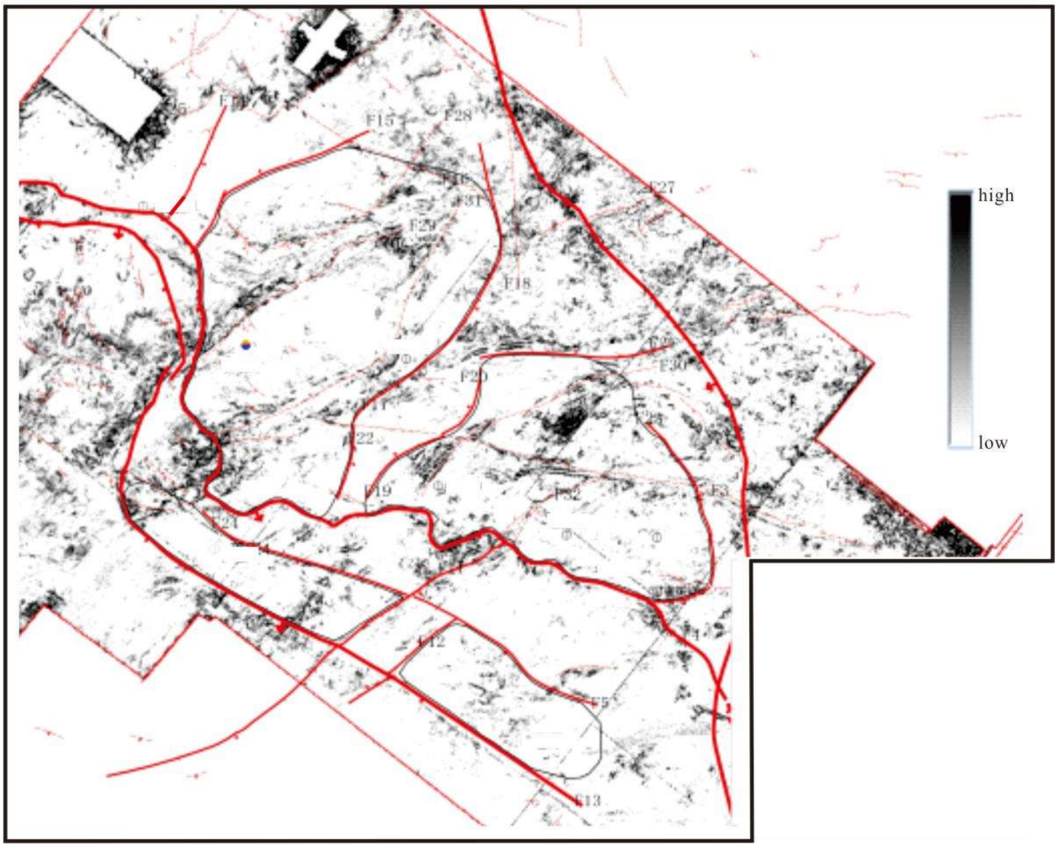

Figure 2. Fault identification and interpretation in the PL gas field

5. Conclusion

The frequency-divided coherence technology can identify some small faults and fracture development zones that are difficult to find with full-frequency data. The fracture development zones are located on both sides of the main fault. The coherence technology is greatly affected by the quality of seismic data. There are ambiguities and some artifacts on the coherent slices. The quality of seismic data needs to be evaluated and combined with section verification. In complex structures, fault identification should be comprehensively applied to a variety of means to make reasonable choices and complement each other.

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