Research on joint identification of basement faults by Gravity, Magnetic, Electricity and Seismic technologies in Sichuan Basin

Introduction

In view of the multiple attributes of underground geological bodies, joint exploration is an important trend in the development of future geophysical exploration. Non-seismic exploration has been widely used in China's oil and gas exploration industry. In recent years, BGP has successfully carried out joint seismic and non-seismic exploration in several CNPC’s oil fields, and formed a gravity, magnetic and electrical data processing and interpretation software (GME) with independent intellectual property rights. The application of joint exploration technology has shifted from regional exploration to target exploration which focus on high and steep structural areas, volcanic rock coverage areas and deep buried hill zones; and extended from structural morphology research to oil and gas prediction and evaluation. The study of Pre-Sinian basement faults is of great significance for basin oil and gas exploration in Sichuan basin because basement faults not only control the deep to ultra-deep palaeo structural evolution, tectonic features, and distribution of sedimentary facies, but also are main factors of development of middle-deep Permian volcanic rocks reservoirs and favorable facies. Due to the limitation of many factors such as the less contrasts of rock physical properties, complex seismic wave fields, and low signal-to-noise ratios of seismic data, it was severely restricted that the accuracy of seismic imaging and interpretation of basement faults. In this study, ultra-deep low frequency-widband preserved technology and interbeded multiple wave suppression technology were used to improve the imaging of deep to ultra-deep low-frequency signals and the accuracy of in the migration imaging especially. Deep faults in the Lower Paleozoic-Sinocene Proterozoic strata can be effectively identified by using joint exploration interpretation technology, and the role of basement faults in controlling volcanic lithofacies is also discussed and explored, which provide the basis for the exploration and deployment of volcanic natural gas in Sichuan Basin.

Method and/or Theory

The exploration target layer in the Sichuan Basin is mainly below 6000 meters, and previous seismic processing technologies used in the area were not dedicated specifically to the deep layers, so some special methodologies has been firstly used in the study for data processing below 6,000 meters. In the study, we found that the seismic frequency of the deep layers is only 10-30Hz, We used the combination of irregular coherent noise suppression technology and deep high-frequency abnormal amplitude attenuation technology to perform low-frequency and broadband processing on the target layer, which well suppressed high-frequency strong energy interference and high-frequency random noise, protected the low-frequency signal of basement faults and improved the data S/N(signal-to-noise ratio) and imaging accuracy.

Due to the multiple interference in the deep seismic data, the extended interlayer multiple wave suppression technology (XIMP) can well suppress the deep layer multiple waves. This technology effectively improved the imaging accuracy of deep seismic data. The seismic reflection characteristics of pre-Sinian basement faults are obvious, which provides a good data basis for subsequent interpretation of basement faults.

The joint inversion of gravity, magnetic, electrical, and seismic data has been used, which is the comprehensive inversion based on the rock’s density, magnetic susceptibility, electro-magnetic property, and elasticity combined with the drilling and geological information for geological-geophysical modeling. The general idea is: firstly, determining the geological significance of geological anomalies on the premise of physical properties; secondly, getting the structural characteristics through regional data analysis, then getting the basement information by gravity and magnetic analysis; and finally, characterizing the basement faults and volcanic rock morphology by joint inversion.

Specific workflow are as follows:

• Establishing an initial model with known seismic data. Calibrating target horizons based on geological, drilling and formation depth data;
Inputting the density and susceptibility values for each horizon, and the geophysical model (depth profile) will automatically complete. Comparing the output model with known drilling and seismic shallow structural maps;

Determining the gravity and magnetic anomaly data when the initial model consistent with the known data. The data in this step is generally Bouguer anomaly and magnetization anomaly;

Fitting the theoretical curve with the measured curve, analyze and modifying the model continuously until the two curves are best fitted by joint inversion.

**Examples**

The southwestern of Sichuan Basin experienced a long period of multiple tectonic activities. The extensional movement during the Emei taphrogenic period changed the inherited activity of the northwestward fault from compressional north-south to extensional east-west. In this study, we adopt three non-seismic methods research on basement faults: gravity, magnetic, and electrical. Both the gravity anomaly and magnetic anomaly characterize the distribution of underground geological anomalies on the basemap. It can be seen from the map of the total gravity gradient anomaly (Figure 2), the trend of gravity anomaly in the study area is NE-shaped with a pattern of high and low gravity. The gravity gradient anomaly area is the basement fault development area, which shows that the controlling boundary faults are mainly F1-F4. The F1 and F2 faults have a large scale and long extension. In addition, high-precision data in the north indicates that a series of NW-directional faults developed in this area.

Magnetic anomalies can roughly reflect the distribution of volcanic rocks. Unlike the gravity anomaly, which has a northeast trend, the aeromagnetic anomaly is generally multidirectional. From the residual magnetic anomaly map in southwestern Sichuan (Figure 2), a series of irregular bead-shaped magnetic bodies can be seen, which can be used as the basis for the study of the distribution of volcanic rocks. However, due to the large line spacing, these beads may still be seen as a whole. Overlap of basement faults identified from gravity anomaly maps and magnetic anomalies shows that, the magnetic anomalies in the northern region are located at the intersection of NE and NW faults, while anomalies in the south are mainly beaded along the NE direction, and the long axis of the magnetic anomaly is consistent with the fault direction. Therefore, it is believed that the development and distribution of volcanic rocks are related to the distribution of deep and large faults. The basement faults are dominated by NE and the north is developed by NW.

Electrical exploration is a geophysical exploration method that aim to find different types of useful deposits, identify geological structures and solve geological problems. From the time-frequency electromagnetic inversion resistivity profile, it can be seen that there are many groups of basement faults with mostly normal faults in the pre-Sinian, which control the distribution of Pre-Sinian strata, and are the main channels for the Permian volcanic rocks.
Due to the uneven stress during the fault tensioning process, the fracture surface formed by rock deformation is partially twisted, so the basement fault is basically a nearly vertical high-angle normal fault. From the seismic section (Figure 3), it can be clearly seen that the disappearance of the fault and the structural form of the overlying strata. The uplifts and depressions features above the basement fault indicated that the Pre-Sinian deep faults had a controlling effect on the overlying strata and stratigraphic morphology during the late tectonic stage, and the upper strata developed overall folds and fault systems. Furthermore, the geological model of the Sinian and overlying layers were established by using seismic data, and then the stratigraphic characteristics and the location of the basement faults are obtained by the joint inversion. It can be seen that the basement faults has a NE trend, and the basic structural pattern can be considered as "three-depression and two-uplift".

Eruption facies of volcanic rocks shows a medium to strong amplitude and intermittent lenticular characteristic on the seismic profile, with thicker thickness on the middle facies than that of two wings, and the top of facies is a mound-like uplift feature. The overlying strata has an overlapping feature and reflection amplitude is intermittent, poorly continuous. By characterizing the volcanic facies, it is found that the volcanic channel at the bottom of the eruption facies usually develops along the basement fault (Figure 4). The appearance of the rocks were nearly upright, cut through the rock strata, and showed an unconformity relationship with the surrounding rocks. The author's point of view is that the volcanic rocks in southwestern Sichuan have fissured eruption along with the deep and large fault distribution area, which is confirmed by the development of the Permian volcanic eruption facies and the basement fault. So far, many wells drilled to the volcanic eruption facies have achieved high production.
Conclusions

The basement faults in Pre-Sinian in the Sichuan Basin are deep buried, seismic characteristics are relatively weak and a low S/N. High-precision imaging processing technology for basement faults can better protect low-frequency signals. According to the comparative analysis of non-seismic and deep seismic data in the Sichuan Basin, it is believed that the gravity and magnetic data can represent the general distribution of the anomalies of deep faults. Using the joint interpretation of seismic and non-seismic data can effectively characterize the deep tectonic patterns and vertical and lateral distribution characteristics of basement faults. The application of basement fault seismic interpretation technology shows that the development of Permian volcanic eruption facies is closely related to basement faults, confirming the geological view of volcanic rocks in the southwestern Sichuan along with the large fault distribution area.

References

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