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Seismic Interpretation Study of the Jiufotang Formation in Block A

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Abstract: The area A is located in the Songliao Basin, and the Lower Cretaceous Jiufotang Formation is the main target layer for oil and gas exploration. Intense The Yanshanian tectonic activity strongly reformed the local strata, resulting in a highly fragmented structural pattern and dense fault development in the area. Relying solely on conventional geological analysis cannot accurately restore the regional tectonic pattern, which poses a major obstacle to the ongoing oil and gas exploration work. In order to deal with these challenges, this study carried out a comprehensive seismic interpretation of the Jiufotang Formation strata and tectonic morphology based on the fully covered 3D seismic data set, combined with local drilling and logging information. A set of geophysical analysis process is adopted, including seismic horizon tracking and fine section structural anatomy to determine faults. The interpretation results show that the study area follows a typical half-graben tectonic framework: the western section is dominated by syncline depressions, and the eastern section is dominated by fault blocks. Two different sets of fault combinations control the entire block. The first set is composed of large normal faults distributed in the northeast direction, which dominates the overall structural layout. The second set refers to the near east-west secondary faults. These faults have many control effects: controlling the sedimentary filling process, acting as a migration channel for hydrocarbon fluids, and forming a lateral closed boundary for oil and gas accumulation. The east and west wing structural belts are selected as the high potential favorable zones for further exploration. This work deepens the understanding of the local structural geological characteristics of the target block and provides a solid geological basis for future drilling deployment and quantitative evaluation of oil and gas resources.

Keywords: Seismic Interpretation; Fault Distribution; Structural Trap.

1. Introduction

The previous drilling data of the exploration wells in Block A confirmed that the Lower Cretaceous Jiufotang Formation developed high-quality source and reservoir sections and had good local oil and gas exploration prospects.[2]

Due to the backward exploration work in the past, the geological evaluation of the block only relies on two-dimensional seismic data. Low-resolution seismic records such as cannot clearly define the distribution pattern of fault groups and the geometry of layered structures. At the same time, the accurate identification and implementation of structural traps are still difficult to achieve, forming a prominent bottleneck restricting the further exploration and development of the area.

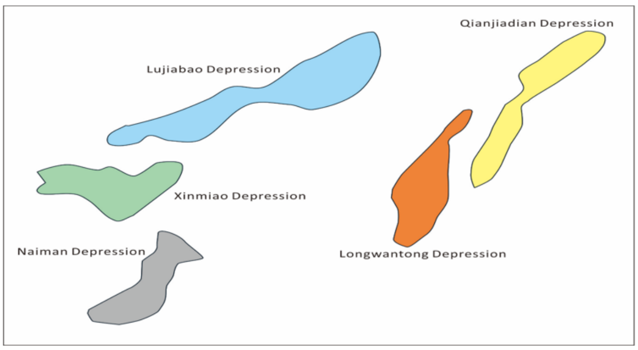

Figure 1. General map of sags in Basin

For a long time, many domestic scholars have conducted in-depth research on the Jiufotang Formation in multiple sags in the basin, mainly focusing on sedimentary facies distribution, sequence stratigraphic framework and hydrocarbon accumulation rules. Nevertheless, there are few targeted studies on the fine structural characteristics, fault system and trap morphology of Block A supported by high-precision 3D seismic information, and the related research is relatively insufficient.

In this context, this work combines the full 3D seismic body with the field drilling and logging data sets to carry out fine seismic interpretation.Its core goal is to sort out the overall structural framework of the study area, clarify the spatial distribution of faults and the development characteristics of favorable traps, and further elaborate the regulation of faults on the process of oil and gas accumulation. This study makes up for the blank of the existing local structure research, and provides a theoretical basis and practical geological data for guiding the subsequent oil and gas exploration activities in Block A.

2. Geological Setting

From the perspective of regional tectonic evolution, the basin was formed in the late Mesozoic extensional rifting related to the Yanshan orogenic belt. A set of semi-graben secondary depression extending to the northeast traverses the basin.

The structural pattern of target block A is dominated by a main boundary fault on its east side. Geologically, it is a typical east-inclined half-graben unit, and its western flank is an overlap stratum. On the terrain, the east slope is steep, the west side is gentle; the terrain is generally uplifted to the north and deepened to the south.

Three different stages mark the tectonic evolution of the basin. The first stage corresponds to the early rapid subsidence, which laid the foundation of the half-graben system. Subsequently, it entered a long stable sedimentary period, and the half-graben reached the maximum development scale. The last stage is the overall uplift of the region and the extensive erosion of the entire basin. Each stage of tectonic evolution interval imposes different constraints on the filling pattern of sediments and the development law of faults in the study area.

The fold metamorphic rock series formed in the lower Hercynian period in the study area is overlying the Mesozoic Cretaceous and Neogene sedimentary layers. The Jiufotang Formation of the Lower Cretaceous is the main exploration target layer in the period of the strongest subsidence of the basin, and the thickness of the stratum fluctuates between 600m and 1200m.

This form can be roughly divided into two parts. The lower sub-section is dominated by dark gray mudstone and siltstone, mixed with sporadic tuffaceous debris, which is the main source rock of the whole block. In contrast, the sandstone and lacustrine mudstone in the upper sub-member appear alternately, which are mainly formed in the fan delta front environment and are the key layers of oil and gas reservoirs.

On the plane, the stratum reaches the maximum thickness along the eastern steep slope zone, and gradually thins to the western gentle slope, accompanied by obvious stratigraphic overlap traces.

At present, 12 exploration boreholes have been completed in this block. A number of wells in the Jiufotang Formation have seen clear oil and gas shows, of which three wells stably produce industrial oil flow. These drilling results fully verify that the study area has favorable geological conditions for oil and gas accumulation.

3. Fault Distribution

These faults have obvious zoning characteristics : dense belts along the east, sparse distribution in the west, strong deep activity, and weak upper activity. The fault activity reached its peak in the early and middle stages of Jiufotang Formation deposition, and the tectonic movement was obviously weakened in the late stage of deposition. This evolution process has laid a good geological foundation for trap oil and gas preservation.

There are two main fault strike groups on the plane. The first group is a NE-trending fault, which is a first-order boundary fault spanning grade I and grade II. These large structures control the tectonic framework and sedimentary filling model of the basin, and fundamentally shape the overall sedimentary and tectonic framework of the sag. The second group is composed of near east-west secondary adjustment faults, mostly small-scale grade III and IV cracks, with limited extension and small displacement. Their main role is to dissect large fault chambers and further divide the local tectonic framework.

The longitudinal section shows that there are obvious differences in the development characteristics of different grades of faults. As the main boundary fault, the first-order fault controls the subsidence of the east side and controls the overall distribution of the stratigraphic sequence. The second-order fault divides the whole study area into three first-order structural sections : steep slope zone, central depression zone and western gentle slope zone.

4. Seismic Interpretation

The whole set of structure and stratigraphic interpretation depends on the full coverage of three-dimensional seismic body. The bin size is 20 m × 20 m, and the main frequency range is 30-45 Hz. These seismic data provide a vertical resolution with sufficient fine structural anatomy. In the pre-processing stage, the standardization and calibration of logging curves were completed by combining the data of 12 exploration wells in the area, which ensured the accuracy.[4]

Well-seismic calibration is the basic premise of reliable seismic interpretation. In this time, five exploration wells evenly distributed in the study area are selected to construct synthetic seismic records. The reflection coefficient is calculated according to the acoustic time difference and density logging curves, and then the seismic traces near each well are matched to accurately calibrate the top and bottom interfaces of the Jiufotang Formation.

The top marker of the Jiufotang Formation corresponds to mid-high amplitude, laterally continuous wave peak reflections, whereas its base boundary generates high-amplitude, highly persistent seismic events. These two distinct marker horizons can clearly separate the Jiufotang Formation from the underlying Yixian Formation. After regional loop correction was implemented, the residual closure error of horizon tracing was controlled below 10 ms, complying with technical specifications for fine seismic structural interpretation.

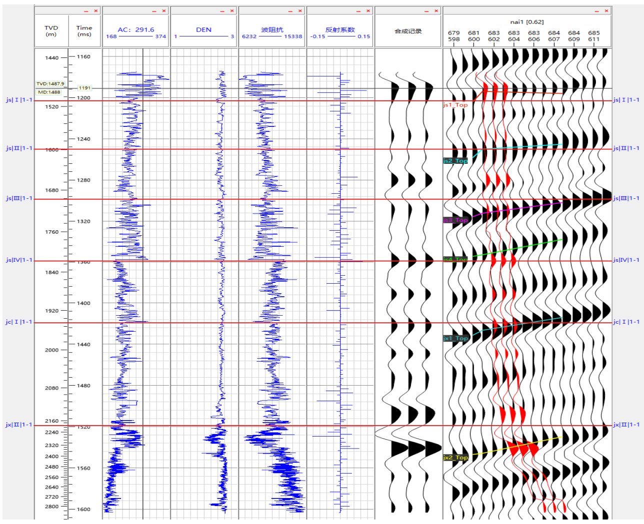
Figure 2. Synthetic seismogram of Well A1

Well-seismic stratigraphic correlation lays the groundwork for arranging interpretation lines, with a primary grid spacing set at 200 m by 200 m. Major seismic sections are interpreted first to pick out typical reflector termination features, including stratigraphic onlap and erosional truncation. By analyzing the offset and bifurcation of seismic coherent axes, geologic discontinuities can be distinguished, which further helps define fault occurrence and their planar assemblage styles.[5]

For zones featuring intricate faulted compartments, we densify the interpretation grid down to 100 m × 100 m. This finer mesh prevents tiny blind faults from being overlooked during tracing. Variance cube coherence is also adopted as an auxiliary interpretation tool. Zones with low coherence anomalies can mark potential fault positions in advance. Combining fault breakpoints seen on seismic sections with planar attribute slices allows mutual cross-checking, which optimizes the delineation of fault frameworks and mitigates non-unique solutions commonly encountered when interpreting highly broken fault blocks.[6]

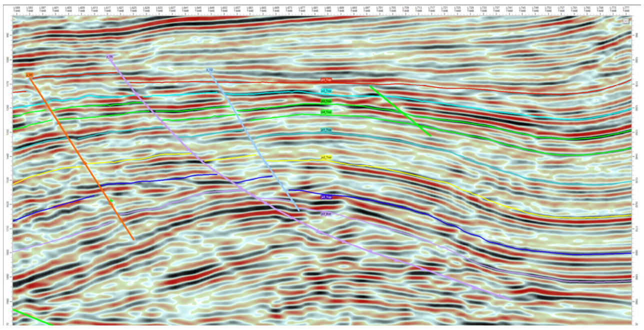

Figure 3. Seismic interpretation profile along sediment source direction in Block A

5. Results of Seismic Interpretation

Based on horizon tracking data of 3D seismic data, the depth structural map of the top surface of the Jiufotang Formation is compiled via time-depth conversion, revealing the overall structural framework of the block. From east to west, the study area is divided into three secondary structural units: eastern steep fault terrace belt, central sag belt and western gentle slope belt. The burial depth of strata ranges from 1400 m to 2550 m, and the subsidence center is located in the south-central part of the block. Step-like fault terraces are developed in the eastern area controlled by the boundary fault. The central part is the deepest sag of the whole area, and strata gradually rise westward in the western area, where a large number of gentle fault nose structures are developed.

Combined with fault distribution and stratigraphic attitudes, fine analysis of structural traps is carried out. A total of 42 effective structural traps are identified, including 7 fault block traps and 4 fault nose traps, with a total trap area of 32.6 km². The spatial distribution of traps is highly differentiated. Traps in the eastern steep fault terrace belt and western gentle slope belt are complete with favorable hydrocarbon accumulation conditions. The central sag belt is severely fragmented by interlaced faults, making it difficult to form large-scale effective traps.

Comprehensive analysis shows that faults play a decisive role in hydrocarbon accumulation in the study area. During active sedimentary periods, NE-trending dominant faults control sediment supply and sedimentary system distribution, facilitating the development of high-quality delta front reservoirs in the eastern steep slope belt. In the stable tectonic stage, inactive sealing faults can trap hydrocarbons and form complete source-reservoir-cap rock combinations together with reservoirs and cap rocks. Meanwhile, faults act as vertical migration pathways, connecting deep hydrocarbon source rocks and shallow reservoirs and providing favorable conditions for hydrocarbon accumulation.

6. Conclusion

(1) The Jiufotang Formation in Block A is developed in the dustpan-like fault depression. Two sets of fault systems are developed, namely, the NE-trending main control normal fault and the nearly EW-trending adjustment fault, which explain 42 faults at all levels. The fault is dense in the east and sparse in the west, and is more active in the lower part of the group. The tectonic activity is concentrated in the early-middle deposition of Jiufotang Formation.

(2) Accurate horizon calibration is completed by synthetic seismograms, and coherence volume attributes are used to assist fault identification. Fine interpretation of horizons and faults of the Jiufotang Formation is realized across the study area, with the horizon closure error controlled within 10 ms. The interpretation accuracy satisfies the requirements for oil and gas exploration deployment.

(3) The study area is divided into three structural units: eastern steep fault terrace belt, central sag belt and western gentle slope belt. A total of 11 fault block and fault nose traps are identified. Faults control sedimentation, serve as hydrocarbon migration pathways and provide lateral sealing. The eastern and western structural belts are the most prospective areas for oil and gas exploration in the block.

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