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Characteristics and Transport Properties of Oil Source Faults in Shixi Uplift, Junggar Basin

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ABSTRACT

Based on the comprehensive analysis of regional tectonic evolution and stratigraphic development characteristics , it is believed that a large number of strike-slip faults are developed in the Mosuowan Uplift and Shixi in the Junggar Basin. This study will reveal the relationship between the mechanism of oil-source fault transportation and oil and gas sealing and the accumulation of oil and gas outside the source through the analysis of the distribution characteristics and conductivity of oil-source faults in the Shixi Uplift. The Shixi Uplift developed two faults in the Hercynian and Early-Middle Yanshanian periods to the Permian, and partly to the bottom of the Triassic and Jurassic; the faulted strata in the Early Yanshanian period ranged from the Permian to the bottom of the Sangonghe River in the Jurassic, and partly cut downward into the Carboniferous; the faulted strata in the Middle Yanshanian period were mainly above the unconformity surface from the Jurassic to the bottom of the Cretaceous. The two- stage fault configuration relationship is good, providing good transportation conditions for oil and gas migration. At the same time, based on the analysis of fault ridges, mudstone smear factor (SSF) and fault mud ratio (SGR) , the fault drainage performance evaluation of the Shixi Uplift and the fault-sand combination control mechanism are established.

KEYWORDS

Oil Source Fault; Shixi Uplift; Fault Activity; Vertical Conductivity; Lateral Conductivity.

1. INTRODUCTION

The distribution of oil-source faults controls the distribution of oil and gas. However, not all oil-source faults and all parts of the same oil-source fault have oil and gas distribution. In addition to being affected by the development of reservoirs and traps, the oil-source faults themselves also play a key role in the transport performance of oil and gas. The oil-source fault transport system is an important part of the oil and gas migration system. It has a vital impact on the migration and accumulation of oil and gas. Faults are a key to the study of hydrocarbon accumulation in oil and gas basins, as oil and gas transport channels. Exploration examples have confirmed that oil-source faults, as complex geological bodies, play different roles in oil and gas migration and accumulation under different conditions. When the fault is open, it mainly plays a transport role, and when it is static, it mainly plays a sealing role. At the same time, the transport role played by the fault when it is open is divided into vertical transport and lateral transport. Correctly understanding the relationship between the transport performance of oil-source faults and the accumulation outside the source is the focus of oil and gas exploration. Systematic dissection of the fault characteristics of Shixi salient and its development and evolution mechanism. Through detailed analysis of fault activity and conductivity, the mechanism and control of fault transmission and sealing of oil and gas are revealed, and based on the dynamic analysis of fault-sand combination, the tight sandstone oil and gas reservoir transmission system in the study area is established and favorable areas are predicted, which provides a strong basis for the subsequent expansion of the tight sandstone oil and gas exploration scope and the realization of efficient exploration of tight sandstone oil and gas controlled by faults.

2. REGIONAL GEOLOGICAL OVERVIEW

The Junggar Basin is a regional tectonic unit surrounded by fold belts such as the Tianshan Mountains, Bogda Mountains, Kelami Mountains, Hara Alat and Zhaier Mountains (Fig. 1) . The basin is a multi-cycle superimposed sedimentary basin from the late Paleozoic to the Mesozoic Cenozoic that developed on the Precambrian crystalline basement and the Hercynian fold basement. It has undergone three major tectonic movements, namely the Hercynian, Indosinian-Yanshan and Himalayan movements [1] . It can be divided into the following evolutionary stages: basement formation before the Carboniferous, transitional development from the Carboniferous to the Permian, inland lake basin from the Mesozoic to the Paleogene, and intense compression from the Neogene to the Quaternary [2] . The Shixi Uplift is a secondary structural unit located in the central depression of the Junggar Basin, which was developed on the basis of the Carboniferous basement. It is adjacent to the Dongdaohaizi Depression in the east, the West Depression of Well 1 in the west, and the Mosuowan Uplift in the south. The Jurassic was deposited during the intracontinental depression period. From bottom to top, it is the Lower Jurassic Badaowan Formation (J1b), Sangonghe Formation (J1s), the Middle Jurassic Xishanyao Formation (J2x), Toutunhe Formation (J2t), the Upper Jurassic Qigu Formation (J3q), and Kalaza Formation (J3k). The main strata studied in this paper are the Sangonghe Formation and the Badaowan Formation. The Sangonghe Formation is mainly composed of sandstone and mudstone. It is relatively close to the Lower Jurassic Badaowan Formation and the Permian source rock. The oil and gas accumulation conditions are favorable. It is the main production stratum in the hinterland of the Junggar Basin [2] . The Badaowan Formation is mainly composed of sandstone, mudstone and coal seams, and is the main coal-bearing stratum in the Jurassic System of the Junggar Basin.

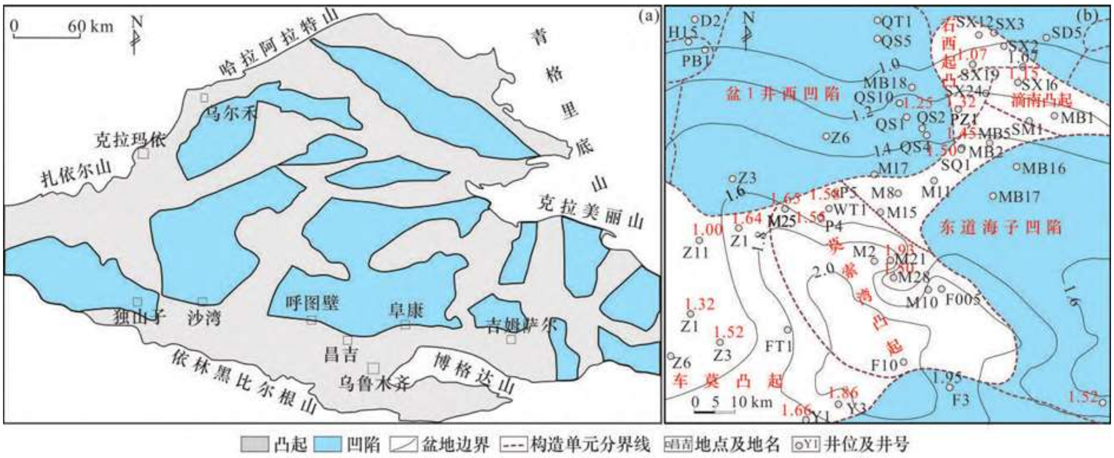

Fig.1 Location map of the study area

3. FAULT DISTRIBUTION CHARACTERISTICS

3.1. Division of Fault Activity Stages

A detailed interpretation of the faults in the Mosuowan bulge in the central area of the Junggar Basin, combined with previous research results, shows that the Shixi bulge area has developed two stages of faults , medium and shallow (Fig. 2) . The Hercynian fault disconnects the Carboniferous to the Permian, and partially disconnects to the bottom of the Triassic and Jurassic. The Early Yanshanian fault is from the Permian to the bottom of the Sangonghe River in the Jurassic, and partially cuts into the Carboniferous. The upper part of the fault is steeper than the lower part, which can directly connect to the Permian source rock and relay to the basement Carboniferous with the Hercynian reverse fault. The fault layer is mainly above the unconformity surface from the Jurassic to the bottom of the Cretaceous, with a steeper cross section, and relays with the Early Yanshanian fault [3].

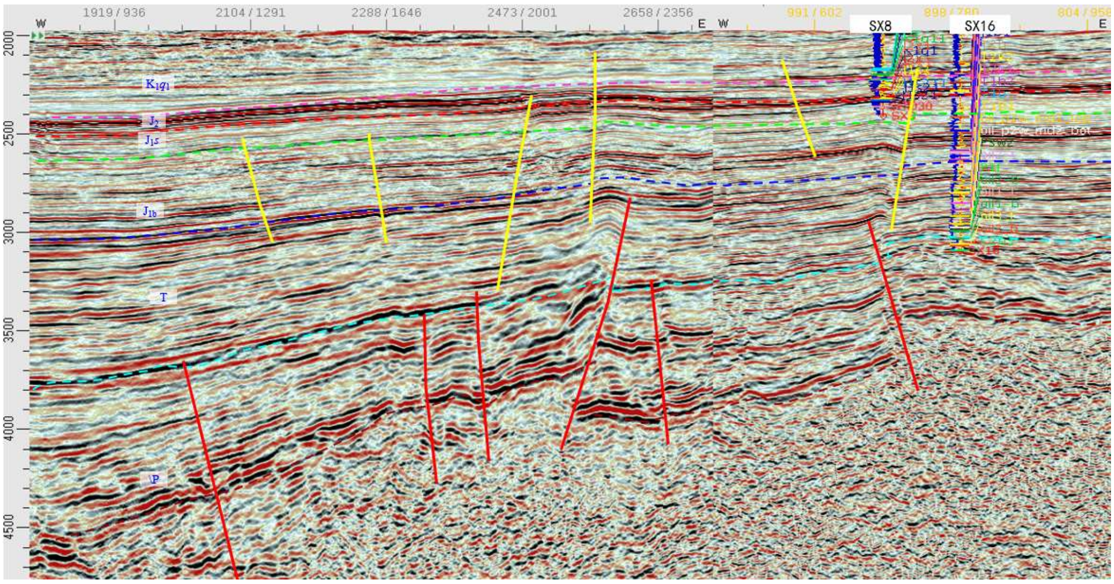

Fig. 2 Seismic geological interpretation section through SX8 well to SX16 well

3.2. Fault Type and Distribution

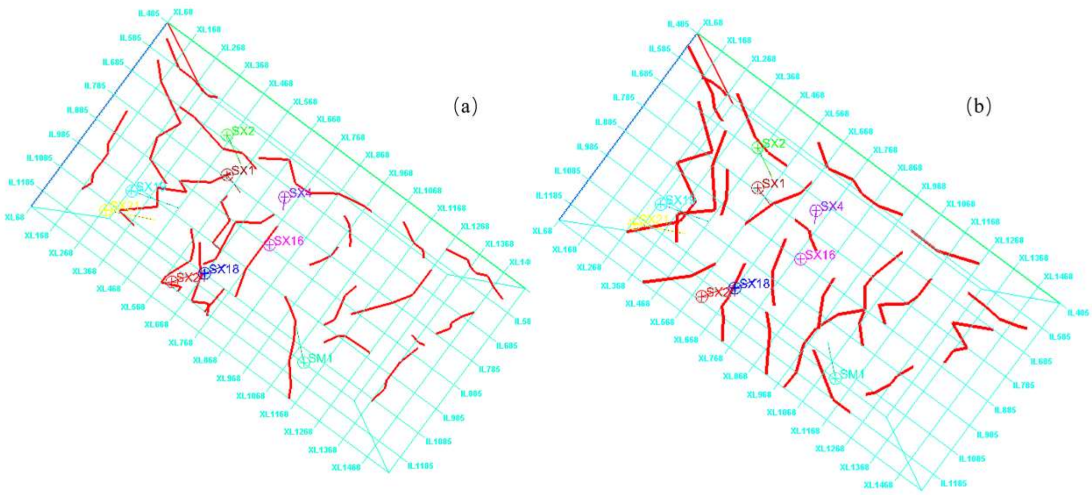

Fig. 3 Fracture outline diagram (a) Outline of the Early Yanshanian fault ; (b) Outline of the Hercynian fault

The Hercynian faults in the study area are mainly reverse faults, mainly developed in the Carboniferous-Permian system, and some faults cut into the Triassic system. The fault strikes are mainly northwest and northeast. The faults began to form at the end of the Carboniferous period. The northeast faults were mainly controlled by the northwest compression stress generated by the uplift of the Zaire Mountains, and the northwest faults were mainly controlled by the northeast compression stress generated by the uplift of the Karamay Mountains [4] . The shallow early and middle Yanshanian fault system mainly developed in the Jurassic system, and some of them cut into the Triassic system downward and disconnected the bottom of the Cretaceous system upward. The fault system is all normal faults, and the scale of the fault is smaller than that of the deep fault system. The fault distance is generally tens of meters to tens of meters, and some of them make the strata flexural. These faults are one-time faults, formed in the middle Jurassic period (Yanshan Movement Episode I), resulting in different thicknesses of Xishanyao Formation strata preserved in the upper and lower plates of some faults. The fault strikes are mainly concentrated in the northeast and northwest directions [5] . The shallow fault system is a normal fault with strike-slip properties, and is a tension-torsion fault system. This is why shallow faults are locally dense, have small fault throws, steep cross-sections, and poor closure .

4. EVALUATION OF FAULT CONDUCTIVITY

4.1. Evaluation of the Transport Capacity of Convergent Ridges on Cross Sections

There are three main methods for determining the dominant transport pathways on a fault plane, namely, the section burial depth contour method, the three-dimensional structural morphology of the fault plane, and the fault plane paleofluid potential method. In terms of the mechanism of oil and gas migration, the fault plane paleofluid potential method can best reflect the convergence and divergence characteristics of oil and gas along the fault plane. Currently, the more commonly used and effective methods are the section burial depth contour method and the section three-dimensional structural morphology method. The section burial depth contour method is the most widely used method in the study of fault deformation and oil and gas migration. It assumes the fault zone as a surface and mainly determines the variation law of the burial depth of the strata on the section along the fault strike through three-dimensional seismic data. The position where the overall trend of the burial depth contour line is concave upward is usually the "saddle" of the fault plane, which is a relatively high potential area, corresponding to the concave fault unit, and has a divergent effect on oil and gas; the position where the burial depth contour line is concave downward is usually the "ridge" of the fault plane, which is a low potential area of the section and has a convergent effect on oil and gas. Therefore, the position of the section ridge is the position of the dominant oil and gas migration channel on the fault plane [6] . In addition, with the improvement of oil and gas exploration technology, geological modeling and oil and gas migration and closure research are gradually developing in the direction of three-dimensional visualization. The three-dimensional morphology of the fault can be intuitively displayed through the three-dimensional geological modeling software Petrel . The "saddle" and "ridge" of the section can be quickly determined by the three-dimensional morphology of the fault surface and the change in burial depth, and then the dominant migration channel for oil and gas convergence can be determined.

The three-dimensional morphology of the fault planes of the Hercynian fault and the Early Yanshanian fault was interpreted respectively, and several gas-dominated convergence ridges were identified. From the positional relationship with the convergence ridges, the closer the sand bodies are to the convergence ridges, the more favorable they are for the formation of gas enrichment (Fig.4) .

The essence of oil and gas migration is migration from high potential difference to low potential difference. The cross-section convergence ridge is the line connecting the low potential areas in a certain direction vertically on the fault. Oil and gas migrate from the surrounding high potential areas to the low potential areas of the convergence ridge in a convergence flow-like manner. The greater the curvature of the convergence ridge, the greater the potential energy difference of oil and gas from the concave ridge to the convex ridge, and the stronger the ability to gather oil and gas; conversely, the smaller the curvature of the convergence ridge, the smaller the potential energy difference, and the poorer the convergence ability. Therefore, the high-steep cross-section convergence ridge is conducive to the convergence of oil and gas for vertical migration, and has a strong transport capacity; the low-slow cross-section ridge has a poor ability to gather oil and gas and a weak transport capacity. This study considered the scale of the convergence ridge and conducted a qualitative evaluation (Fig.5) .

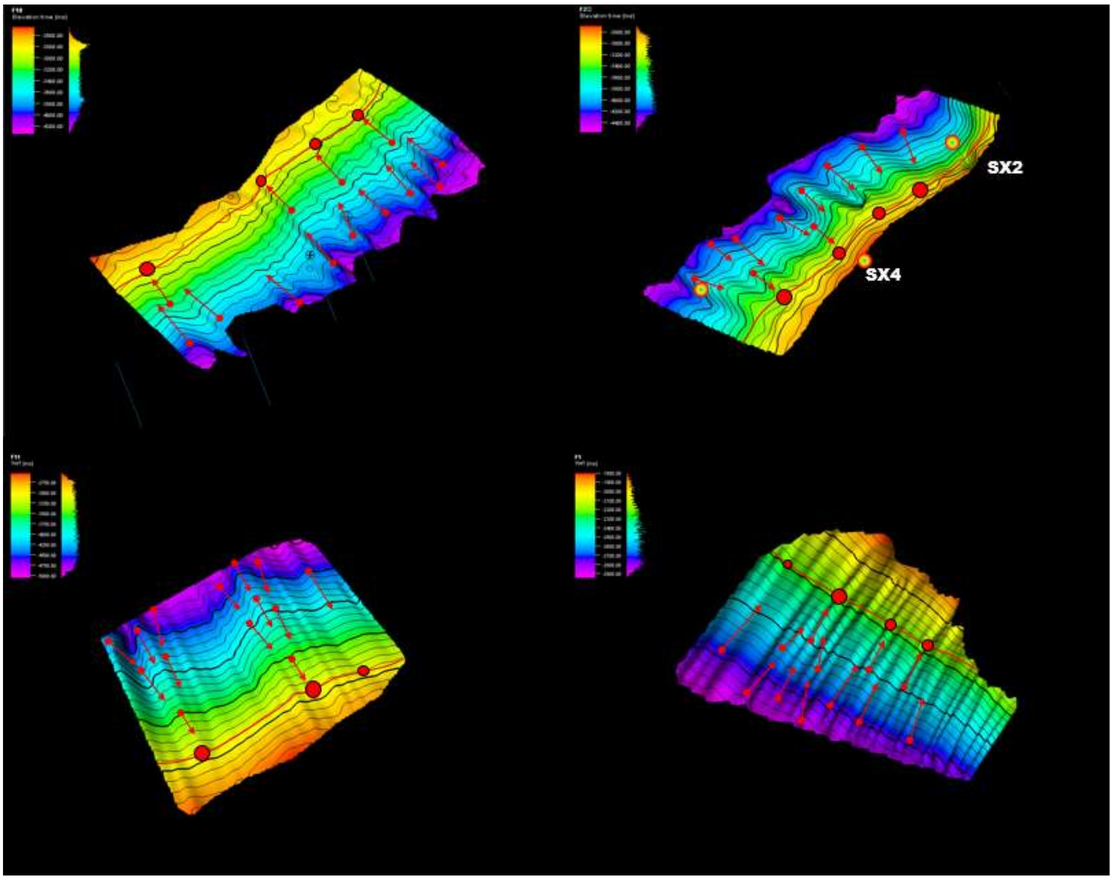

Fig. 4 Typical gas source fault cross-section morphology and convergent ridges in Shixi Uplift

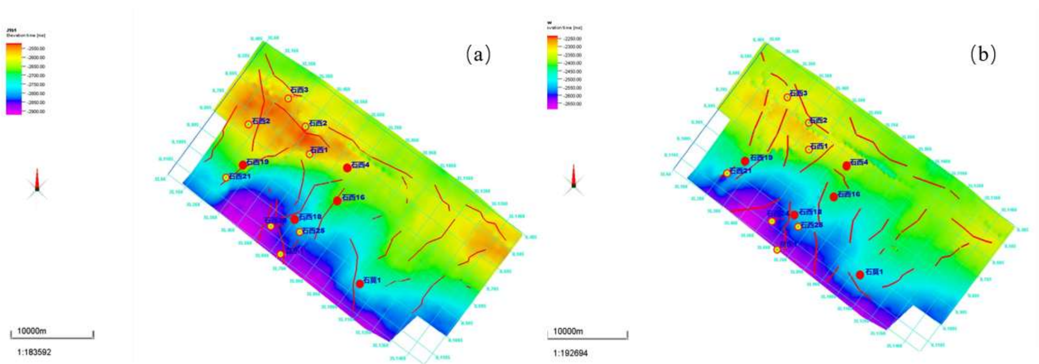

Fig. 5 Outline map of Shixi uplift faults and distribution of dominant lateral filling points of gas source faults

4.2. Mudstone Smear Factor

Lindsay et al. (1993) proposed the shale smear factor (SSF) method [7](Fig.6). It refers to the ratio of the fault displacement to the thickness of the shale layer. As the displacement distance between the two sides of the fault increases, the continuity of the shale smear layer may be broken. The larger the ratio of the two, the worse the continuity of the smear layer, the easier it is for oil and gas to leak through pores, and the stronger the conductivity of the fault. Conversely, the stronger the sealing property of the fault.

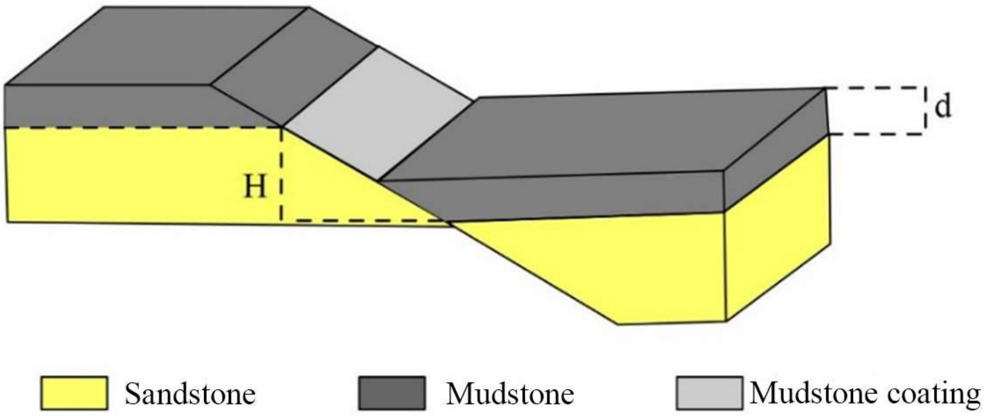

Fig. 6 SSF formula calculation diagram

The calculation formula is:

$$SSF = \frac{H}{d} \quad (1)$$

Where: H is the fault throw, m; d is the thickness of the mudstone layer, m.

The fault throw refers to the distance between the two plates of the fault. If the distance between the two plates is large, the mudstone smear layer will be discontinuous or thinned during the fault activity. In this case, the lateral conductivity of the fault will be greatly enhanced, which is conducive to the lateral migration of oil and gas; but if the fault throw is small, the thickness of the mudstone smear layer in the fault zone will be reduced, and the possibility of being pulled off will also decrease. In this case, the fault has strong blocking properties, which is conducive to the accumulation of oil and gas. The fault throw and mudstone thickness data of the study area were statistically analyzed by fault interpretation data and lithological data. The SSF calculation formula was used to calculate the SSF value of the main fault in the study area (Fig.7). According to the calculation results, the SSF value of the fault in the middle Yanshan period is generally small, because the fault throw in this area gradually decreases from bottom to top, and the middle Yanshan period mainly disconnects the Sangonghe Formation and its upper parts. Relatively speaking, the mudstone of the Sangonghe Formation is more developed than that of the Badaowan Formation. When the fault throw of the early Yanshan period is small and the mudstone thickness is relatively large, its SSF value is generally lower than that of the middle Yanshan period. This result also shows that the lateral transport capacity of the Middle Yanshanian fault is relatively weak, which effectively blocks oil and gas and is one of the favorable conditions for the accumulation of oil and gas in the Jurassic.

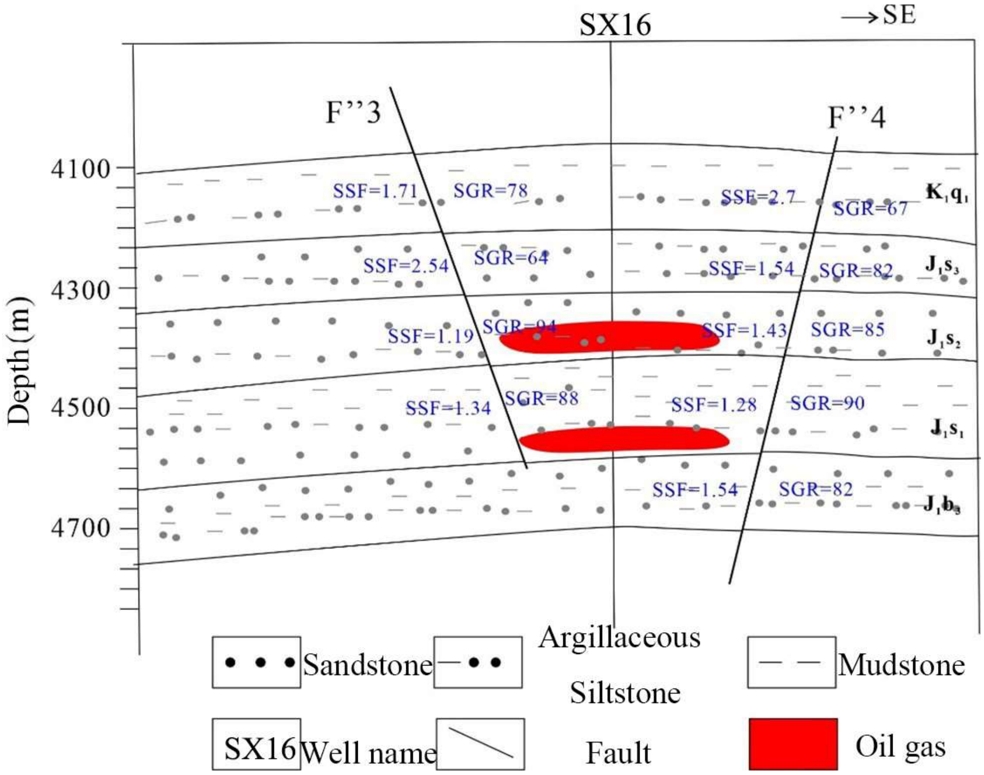

Fig. 7 Quantitative evaluation diagram of the sealing properties of faults SSF and SGR in the middle Yanshan period

4.3. Gouge Ratio

Yielding et al. (1997) proposed the fault gouge ratio (SGR) method[8]. SGR represents the proportion of shale that is squeezed into the fault zone through various mechanisms. Its calculation formula is:

$$\mathrm{SGR}=\frac{\sum(Hi*Pi)}{H}*100\% \tag{2}$$

In the formula: Hi is the thickness of the stratum moved by the fault, (i = 1.2.3.4.), m; Pi is the mud content corresponding to the moved stratum, (i = 1.2.3.4.), %; H is the total fault throw, m.

The mud content of the fault movement formation refers to the ratio of the mudstone volume corresponding to the formation crossed by the fault to the total volume of the formation. The higher the ratio, the higher the degree of mudstone smearing in the fault zone and the higher the lateral sealing of the fault; conversely , if the mud content in the formation is low, the lower the degree of mudstone smearing in the fault zone, the stronger the lateral conductivity of the fault, which is conducive to the lateral migration of oil and gas. The fault mud ratio (SGR) required to obtain the parameters such as the fault distance of each layer and the mud content corresponding to the fault movement formation is obtained through drilling and logging data.

Substituting various data into the SGR formula , the SGR values of the main faults in the study area were calculated (Fig.8). According to Yielding et al [22]SGR is used to distinguish whether the fault is laterally closed or open. The larger the value, the higher the shale content in the surrounding rock, and the worse its conductivity to oil and gas. Conversely, the stronger the conductivity. Combined with the actual situation in the Mosuo Bay area, the SGR evaluation standard was determined (Table 1) .

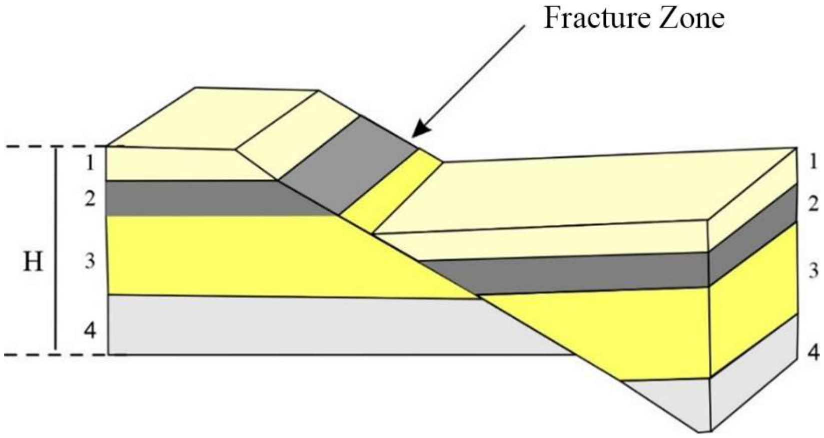

Fig. 8 SGR formula calculation diagram

Table 1. SGR grade evaluation criteria

Conductivity evaluation	good	better	medium	Difference
SGR (%)	< 50	5 0~60	6 0~75	> 75

From the SGR calculation results, it can be concluded that the SGR value of the Middle Yanshanian fault is relatively high, with medium to good sealing, while the SGR value of the Early Yanshanian fault is slightly lower than that of the Middle Yanshanian fault, with medium or below sealing; the SGR values of the F"3 fault and the F"4 fault are similar, generally high, with good sealing, which is conducive to the formation of oil and gas barriers and easy to form reservoirs.

5. CONCLUSION

(1) The Shixi bulge in the Mosuowan area has two faults, the Hercynian and the Middle Yanshanian. The deep Hercynian fault began to form at the end of the Carboniferous and was active in the Hercynian and Indosinian periods, disconnecting the Carboniferous to the Permian, and partially disconnecting to the bottom of the Triassic and Jurassic. The main strikes are northwest and northeast, and the dip angles are large, ranging from 60 ° to 85 °. The plane extension length is thousands of meters, and the fault throw varies from hundreds to thousands of meters, and the fault throw gradually decreases from bottom to top. The Middle Yanshanian fault was formed in the late Yanshan movement, and the Himalayan activity basically stopped. The shallow early and middle Yanshanian northeast-trending faults are poorly developed, and the main northwest-trending faults are developed. The fault dip angle is slightly smaller than that of the deep faults, and the plane extension length and fault throw are also significantly smaller than those of the Hercynian faults. The fault throw gradually decreases from bottom to top until there is no obvious fault throw.

(2) The vertical conductivity of the two-stage faults in the Shixi Uplift was qualitatively and quantitatively analyzed by analyzing the scale of oil source fault development, the scale of cross-section convergence ridges, and the normal pressure of faults. The analysis results show that the two-

stage faults relay transport, which is of great significance for the migration of oil and gas from the Permian to the Jurassic.

(3) The lateral conductivity of the Hercynian and Middle Yanshanian faults in the study area was evaluated using methods such as shale smear factor (S SF) and fault mud ratio (S GR). The lateral sealing effect of shallow Middle Yanshanian faults is a key condition for the accumulation of oil and gas in the Jurassic.

(4) The strong vertical conductivity of deep oil source faults in the Mosuowan area is conducive to the long-distance vertical migration of oil and gas to shallow layers, while the strong lateral sealing ability of the Yanshanian faults controls the Jurassic reservoir-forming zone.

REFERENCES

[1] Wu QF, Dong G H. Evaluation method and application of oil and gas resources in the Junggar Basin[J]. Xinjiang Petroleum Geology, 1986, 4(4): 13-32.

[2] HE W J. Origin and Evolution of Deep-seated Abnormal Pressure in the Junggar Basin[D]. Qingdao: China University of Petroleum(East China), 2023.

[3] Sedimentary system and controlling factors of the Lower Jurassic Sangonghe Formation in the southern part of the Junggar Basin[J]. Journal of Paleogeography, 2023, 25(3): 628-647.

[4] Liu Wei, Jia Zhong, Li Li. Comprehensive analysis method of fault sealing in complex fault-block oil and gas fields[J]. Fault-Block Oil and Gas Field, 2002(01):25-28+82.

[5] Li Honglin, Zhang Rucai, Wang Bingjie, et al. Quantitative evaluation of the transport capacity of convergent ridges in sections and their role in controlling reservoir accumulation[J]. Journal of Southwest Petroleum University (Natural Science Edition), 2020, 42(03):13-20.

[6] Zhang Wenhua. Some understandings on the role of faults in hydrocarbon migration and accumulation in fault basins[J]. Modern Geology, 1994, 000(002):194.

[7] Liu Zerong, et al. Formation mechanism and structural model of fault-block oil and gas reservoirs[M] Beijing: Petroleum Industry Press, 1998.

[8] Yielding G, Freeman B, Needham D T.Quantitative fault seal prediction[J].AAPG Bulletin, 1997, 81(6):897-917.