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Analysis on the Control of Natural Fracture Network on Reservoir Seepage Characteristics in Ordos Basin

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ABSTRACT

Natural fracture network not only greatly changes the permeability and fluid distribution of reservoir, but also affects the flow velocity of fluid. According to the causes of cracks, they can be divided into two types: regional cracks and structural cracks. The former is related to the overall structure and sedimentary process of the basin, while the latter is due to local stress concentration caused by crustal movement. The existence of these fractures makes the reservoir show significant heterogeneity, especially the connectivity and directionality of the fractures, which has a key impact on the plane permeability ratio of the reservoir. In addition, the fracture opening has a direct impact on reservoir permeability and plane permeability ratio, and controls the distribution and flow path of fluid in the reservoir. It is pointed out that when the direction of natural fracture is parallel to the direction of maximum horizontal principal stress, the permeability efficiency of fluid can be effectively improved. The formation of complex fracture network further improves the permeability and production of reservoir and provides a better flow channel for the effective development of oil and gas resources. Therefore, it is very important to understand and predict the characteristics of natural fracture network for optimizing oil and gas field development strategy. This study reveals the important control effect of natural fracture network on reservoir seepage characteristics, which provides theoretical support and technical guidance for improving the development efficiency and reducing the development cost of oil and gas resources in Ordos Basin.

KEYWORDS

Ordos Basin; Natural fracture network; Reservoir seepage; Permeability; Fracture connectivity; Crack opening; Crack direction

1. INTRODUCTION

Ordos Basin, as the second largest sedimentary basin in China, is not only complicated in geological structure, but also rich in oil and gas resources. These resources play an important role in ensuring national energy security and promoting economic and social development [1]. However, the reservoirs in Ordos basin are mainly ultra-low permeability sandstone, which makes the effective development of oil and gas resources face severe challenges.

The existence of natural fracture network plays an important role in ultra-low permeability sandstone reservoirs. As a channel of fluid flow, fractures greatly affect the seepage characteristics of reservoirs. They not only change the permeability of reservoir, but also affect the distribution and flow velocity of fluid [2-3]. Therefore, it is of great significance to study the characteristics of natural fracture network and its control on reservoir seepage characteristics in Ordos Basin for improving the development efficiency of oil and gas resources and reducing the development cost. This paper systematically analyzes the characteristics and distribution law of natural fracture network in Ordos

Basin and its influence on reservoir permeability, seepage velocity and fluid distribution, and reveals the controlling effect of natural fracture network on reservoir seepage characteristics.

2. GEOLOGICAL SURVEY OF ORDOS BASIN

The Ordos Basin, covering a total area of approximately 370,000 square kilometers, is China's second-largest sedimentary basin. The structural characteristics of the Ordos Basin are primarily influenced by the ancient Qilian Ocean, the ancient Qinling Ocean, the Tethys Ocean at different periods, the Paleo-Asian Ocean, and the Paleo-Pacific surrounding it. The basement structure of the basin is generally controlled by four first-level faults, dividing it into five secondary structural units. The lithology of each structural unit extends from the Archean to Paleoproterozoic strata around the margins into the basin interior. High aeromagnetic anomaly zones are mainly reflected by Archean blocks, while negative aeromagnetic anomaly zones are primarily indicated by Paleoproterozoic sedimentary metamorphic rocks, exhibiting a feature of northeast transverse segmentation.

The formation and evolution of the Ordos Basin is an extremely complex process that can be divided into three main stages: Paleozoic, Mesozoic, and Cenozoic [4-5]. During the Paleozoic era, the Ordos region was characterized by a shallow marine depositional environment influenced by the North China Sea and the Qilian Sea. In the early Mesozoic era, the Ordos Basin began to develop under arid and hot climatic conditions with poorly developed vegetation, leading to the deposition of mainly fluvial-lacustrine red fine clastic rocks. By the late Mesozoic era, the basin reached its peak period, coinciding with the rise and eventual extinction of dinosaurs. During the Cenozoic era, the basin transformed into an erosional area; the Paleogene and Neogene periods saw the flourishing of angiosperms, while the Quaternary period was marked by the appearance of humans and multiple glacial episodes [6]. The Ordos Basin is rich in hydrocarbon resources, ranking first nationally in proven reserves of natural gas, coalbed methane, and coal, and fourth in oil resources.

3. CHARACTERISTICS OF NATURAL FRACTURE NETWORK

3.1. Types and Causes of Cracks

The natural fracture network in Ordos basin is complex and diverse. According to the causes and characteristics of fractures, it can be mainly divided into two categories: regional fractures and structural fractures. Table 1 summarizes two main fracture types and their causes in Ordos Basin.

Table 1. Types and genesis of fractures in Ordos basin

Crack type	Genesis description
Regional cracks	It is closely related to the overall structural development and sedimentary process of the basin, formed by factors such as stretching, compression or shearing of the crust and differential compaction of sedimentary layers, and has certain directionality, which is consistent with the structural line or sedimentary direction of the basin [7].
Tectonic fracture	Due to the local stress concentration caused by crustal movement, such as fault activity and fold deformation, it develops in areas with strong structural deformation, such as fault zone and fold axis, and its strike, dip angle and opening are controlled by local tectonic stress field and mechanical properties of rocks [8].

3.2. Crack Size and Distribution

The scale of natural fractures in Ordos basin varies greatly, from large-scale macro-fractures to micro-fractures. Macrofractures are usually visible to the naked eye, which have a significant impact on the seepage characteristics of reservoirs; However, microscopic fractures need to be observed clearly under a microscope, which plays an important role in the microscopic seepage characteristics of reservoirs.

Within the scope of oil reservoir, the distribution of natural fractures has certain regularity. Generally speaking, the fracture density is higher in areas with strong structural deformation, but lower in areas with relatively stable structure [9]. In addition, the characteristics of fracture spacing and filling degree are also controlled by local geological conditions and tectonic stress field. For example, near the fault zone, cracks are often dense and the filling degree is low; However, in areas far from the fault zone, the cracks are relatively sparse and the filling degree is high.

3.3. Fracture Geometry and Parameters

The natural fractures in Ordos basin have various geometric forms, including linear, tortuous and bifurcated. Linear fractures usually develop in areas with relatively uniform rock mechanical properties, while tortuous and bifurcated fractures are more common in areas with complex rock mechanical properties or changeable tectonic stress fields.

Fracture parameters are important indicators to describe fracture characteristics, including fracture inclination, opening, length, quantity, linear density and so on. The dip angle of fracture reflects the angle between fracture and horizontal plane, which has an important influence on the vertical seepage of fluid. The opening of the fracture determines the flow of fluid through the fracture; The length and number of fractures directly affect the connectivity and seepage efficiency of fracture network; The linear density is an index to describe the number of cracks per unit length and reflects the development degree of crack network.

4. CONTROL EFFECT OF NATURAL FRACTURE NETWORK ON RESERVOIR SEEPAGE CHARACTERISTICS

4.1. Relationship between Permeability and Fracture

In Ordos basin and other sedimentary basins, the natural fracture network significantly affects the seepage characteristics of reservoirs, which not only increases the effective porosity, but also greatly improves the reservoir permeability. These fractures are usually directional, resulting in anisotropy of permeability-that is, the permeability is high along the fracture direction and low in the vertical direction. Fracture provides an efficient fluid transmission path, especially in the case of low matrix permeability, fracture becomes the main fluid channel; However, in the case of high matrix permeability, the effect of cracks on improving permeability is relatively reduced. The existence, connectivity and directionality of fractures have a key influence on the fluid flow behavior of reservoirs.

4.2. Fracture Connectivity and Seepage Velocity

Fracture connectivity is one of the important indexes to evaluate the influence of natural fracture network on reservoir permeability. A well-connected fracture network can form more seepage channels, thus improving reservoir permeability. The research shows that with the increase of fracture connectivity, the average permeability of reservoir will also increase accordingly [10]. The relationship between reservoir average permeability and fracture connectivity is shown in Figure 1.

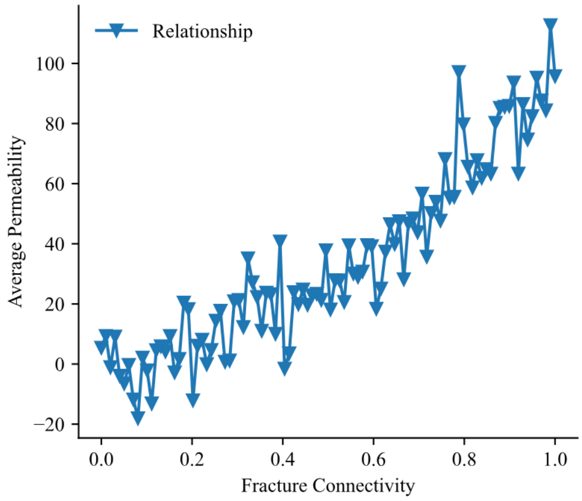

Figure 1. Relationship between average permeability of reservoir and fracture connectivity

Plane permeability ratio refers to the permeability difference of reservoirs in different directions. The existence of natural fracture network will aggravate this difference, because fractures usually have certain directionality, which leads to higher permeability of fluid in the direction of fracture development than in other directions. Therefore, the fracture connectivity has a significant impact on the plane permeability ratio, and the better the connectivity, the greater the plane permeability ratio.

Fracture cutting depth refers to the extension degree of fractures from the reservoir surface to the inside. Fractures with large depth can penetrate more reservoir matrix and form wider seepage channels, thus improving reservoir permeability in the direction of fracture development. At the same time, due to the directionality of cracks, the increase of cutting depth will also lead to the increase of plane permeability ratio.

4.3. Fracture Opening and Fluid Distribution

The aperture of cracks is one of the key factors affecting the permeability of reservoirs. Research has shown that reservoir permeability significantly increases with the increase of fracture opening. Especially when the crack opening is greater than 0.007 cm^2, the contribution of cracks to reservoir permeability can reach tens to hundreds of times, and the lower the matrix permeability, the greater the increase in permeability [11]. This indicates that the opening of cracks not only directly affects the flow channels of fluids, but also significantly improves the overall permeability of the reservoir. Figure 2 shows the relationship between crack opening and fluid distribution.

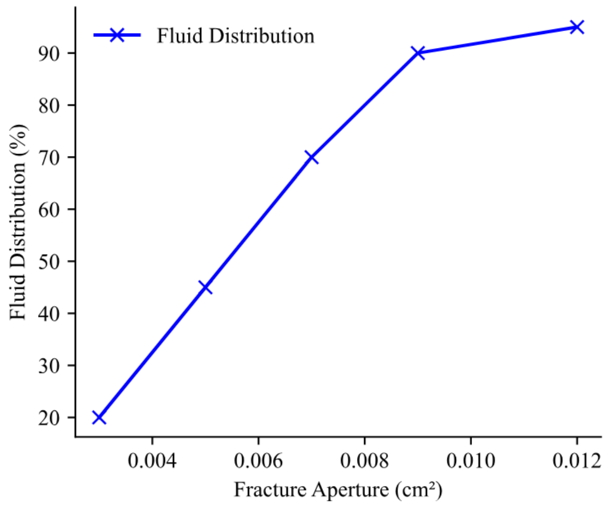

Figure 2. Relationship between fracture opening and fluid distribution

The inhomogeneity of fracture opening will lead to the increase of reservoir plane permeability ratio. In the area with larger fracture opening, the permeability is significantly higher than that in the area with smaller fracture opening, thus forming obvious permeability ratio. This level difference will lead to more complicated fluid flow paths in the reservoir, and the fluid tends to flow through fractured channels with high permeability, while the fluid flow in low permeability areas is relatively limited. Fracture opening has a significant effect on the distribution of fluid in reservoir. Cracks with large opening can provide wider flow channels, making it easier for fluids to gather and flow in these cracks. On the contrary, cracks with small opening have little contribution to the flow of fluid, and the distribution of fluid in these areas is relatively small. This uneven fluid distribution will lead to the difference of fluid migration speed and direction in the reservoir, and then affect the oil and gas production efficiency.

Through the change of fracture opening, natural fracture network not only controls the permeability and plane permeability ratio of reservoir, but also directly affects the distribution and flow path of fluid in reservoir. The existence of large-opening fractures significantly improves the overall permeability of the reservoir, enabling the fluid to migrate more effectively, while small-opening fractures may become obstacles to the fluid flow. This complex fracture network structure makes the seepage characteristics of reservoirs show strong heterogeneity, which puts forward higher requirements for oil and gas exploitation and development strategies.

4.4. Crack Direction and Seepage Direction

In the reservoirs of the Ordos Basin, the direction of natural fractures has a significant controlling effect on the permeability characteristics. Research has shown that when natural cracks are parallel to the direction of the maximum horizontal principal stress, the permeability of the cracks is the best and the yield increasing effect is the most significant [12]. This is because in this situation, cracks can more effectively serve as channels for fluid flow, reducing the flow resistance of fluids in the reservoir and thus improving the permeability efficiency of fluids.

In the process of seepage, the different directions of cracks have different effects on fluid flow: cracks parallel to the direction of seepage provide unobstructed and fast flow paths for fluids, greatly improving permeability and production; Cracks perpendicular to the direction of seepage mainly serve as collection and dispersion points for fluids. Although their contribution to direct seepage is limited, they can guide fluids into the main fracture network and improve overall seepage efficiency; Cracks that are inclined at a certain angle to the direction of seepage have both fast flow paths and collection and dispersion functions, especially when the angle is between 30 ° and 60 °, they can form a complex hydraulic fracturing fracture network, further improving seepage efficiency.

The complexity of natural fracture network also has an important influence on the seepage characteristics of reservoirs. Complex fracture network can significantly improve reservoir permeability and production. For example, when natural fractures meet bedding plane, a more complex fracture network will be formed, which will increase the fractal dimension of fractures, thus improving seepage efficiency. In addition, the change of strength and stress field of natural fractures will also affect the complexity of fracture network. Low-strength natural fractures are more likely to be activated, thus changing the propagation path of hydraulic fractures and forming a more complex fracture network.

The direction and complexity of natural fracture network have a significant control effect on the seepage characteristics of reservoirs in Ordos Basin. Parallel fractures can significantly improve the permeability efficiency of fluids, while vertical and oblique fractures play an important role in the collection and dispersion of fluids. Complex fracture network can further improve reservoir permeability and production, and provide a more effective flow path for oil and gas development. Therefore, it is of great significance to understand and predict the direction and network characteristics of natural fractures for optimizing oil and gas development strategies.

5. CONCLUSION

In the ultra-low permeability sandstone reservoir in Ordos Basin, the natural fracture network significantly affects the seepage characteristics, and becomes the main fluid channel by increasing the effective porosity and permeability, especially when the matrix permeability is low. The anisotropy of permeability is caused by the directionality of cracks, that is, the permeability is high along the direction of cracks and low in the vertical direction. Good fracture connectivity and large shear depth can form more and wider seepage channels, further improving permeability; At the same time, the increase of fracture opening also significantly improves the permeability, and its inhomogeneity affects the plane permeability ratio. When the cracks are parallel to the direction of the maximum horizontal principal stress or form a complex network, the seepage efficiency and output will be greatly improved if they meet the bedding plane. Therefore, the connectivity, directionality and opening of natural fractures play a decisive role in reservoir seepage characteristics, and understanding these characteristics is very important for optimizing oil and gas development.

REFERENCES

[1] Jiang, T. W., & Sun, X. W. (2018). Development Understanding and Technical Countermeasures for Super-Deep Ultra-High Pressure Gas Reservoirs in the Keshen Gas Field of the Kuqa Foreland Basin. Natural Gas Industry, 38(6), 9.

[2] Yang, H. J., Zhang, R. H., Yang, X. Z., Wang, K., Wang, J. P., Tang, Y. G., et al. (2018). Characteristics of Structural Fractures in Super-Deep Tight Sandstone and Their Reservoir Modification Effects: A Case Study of the Cretaceous Strata in the Keshen Gas Field of the Kuqa Depression, Tarim Basin. Natural Gas Geoscience, 29(7), 9.

[3] Wang, J. P., Zeng, L. B., Xu, Z. P., Wang, K., Zeng, Q. L., Zhang, Z. Y., et al. (2024). Impact of Diagenetic Fluids on Filling and Dissolution Alteration of Structural Fractures in Super-Deep Tight Sandstone Reservoirs: A Case Study of the Kelasu Oilfield in the Tarim Basin. Earth Science Frontiers, 31(3), 312-323.

[4] Yao, J. L., Liu, X. P., Zhao, H. T., & Li, X. M. (2019). Reservoir Characteristics and Geoengineering Integrated Countermeasures for Tight Sandstone Gas Reservoirs in Member 8 of the He Formation in the Ordos Basin. China Petroleum Exploration, 24(2), 186-195.

[5] Shi, J. X., Zhao, X. Y., Pan, R. F., Zeng, L. B., & Zhu, Z. P. (2023). Characteristics of Natural Fractures in Ediacaran Dengying Formation Carbonate Rocks and Their Impact on Well Productivity in the Central Sichuan Region. Petroleum and Natural Gas Geology, 44(2), 393-405.

[6] Zhang, H. L., Su, Y. D., Wang, M., & Tang, X. M. (2024). Analysis of Permeability Around Wells Based on Rock Mechanics and Production Evaluation. Petroleum Geophysics, 63(1), 207-216.

[7] Wang, Q., Ye, M. N., Li, N., Ye, Y. F., & Dong, J. X. (2019). Research Progress on Numerical Simulation Models for Shale Gas Reservoirs. Geological Bulletin of China, 46(6), 16.

[8] Zhu, H. Y., Song, Y. J., & Tang, X. H. (2021). Research Progress on Four-Dimensional Stress Evolution and Complex Fracture Propagation in Shale Gas Reservoirs with Additional Wells. Acta Petrolei Sinica, 42(9), 13.

[9] Song, Z. Y., Wang, H., Li, J., Sun, L. N., Zhang, J. T., & Liu, C. (2019). Influence of Coupled Seepage-Stress Effects on Fracture Development in Reservoirs. Journal of Geomechanics, 25(4), 9.

[10] Yang, X. T., Teng, Q., Zhang, Y., Yu, Y. H., Li, W., Feng, J. Y., et al. (2018). Post-Fracturing Evaluation and Production Forecasting Methods for Fractured Tight Sandstone Gas Reservoirs Supported by Geoengineering Integration. China Petroleum Exploration, 23(2), 13.

[11] Du, X. Y., Jin, Z. J., Zeng, L. B., Liu, G. P., Yang, S., Liang, X. P., et al. (2024). Evaluation of Natural Fracture Effectiveness in Deep Lacustrine Shale Oil Reservoirs Based on Imaging Logging. Petroleum and Natural Gas Geology, 45(3), 852-865.

[12] Zhao, X. Y., Wang, D., You, Y. C., Guo, Y. D., Ren, X. J., Han, J. Y., et al. (2022). Characteristics and Formation Mechanism of Natural Fractures in Volcanic Rock Reservoirs of the Songnan Yingcheng Formation. Geological Science, 57(3), 720-732.