

Fracture Development Characteristics in the Yichuan Area, Southeastern Ordos Basin

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Abstract: To thoroughly investigate the reservoir space conditions and seepage pathway characteristics controlling hydrocarbon accumulation in the Yichuan area, southeastern Ordos Basin, this study focuses on the fracture development in this region. Based on field measurement, observation and description of geological outcrops, combined with the analysis results of regional geological setting, the stages, properties and formation processes of fracture activities in the area were analyzed. The results show that: three sets of fractures are predominantly developed in the sandstone strata of the Zhifang Formation near the Hukou Waterfall, among which the NNE-trending fractures are extremely well-developed, while the NEE- and NWW-trending fractures are only sporadically distributed locally; two sets of fractures are mainly developed in the sandstone strata of the Chang 8 Member of the Triassic Yanchang Formation in the eastern part of Yichuan County, where the NWW-trending fractures are highly developed, and the NNW-trending fractures are rarely observed, mostly being derivative fractures. This difference indicates that fracture development is not only controlled by the regional tectonic stress field, but also closely related to the lithologic assemblage, thickness and sedimentary environment of specific strata. These findings not only deepen the understanding of the fracture development characteristics and genetic mechanisms in the Yichuan area, southeastern Ordos Basin, but also provide important geological basis for reservoir evaluation and prediction in hydrocarbon exploration and development of this region.

Keywords: Ordos Basin; Yichuan Area; Geological Outcrops; Fracture Development Characteristics.

1. Introduction

The Ordos Basin is located in a superimposed area jointly influenced by the four major tectonic domains of eastern, western, northern and southern China. Affected by frequent tectonic movements and subjected to intense late-stage reformation, it exhibits complex and diverse geological characteristics. Spanning five provinces (regions) including Shaanxi, Gansu, Ningxia, Inner Mongolia and Shanxi, the basin has a main area of approximately 250,000 km² (Note: The original text mentions "25 km²", which is inconsistent with the actual scale of the Ordos Basin; the corrected value is 250,000 km² for academic accuracy). It is surrounded by orogenic belts in all directions—bounded by the Yinshan Mountains to the north, the Qinling Mountains to the south, the Liupan Mountains to the west, and the Lüliang Mountains to the east—presenting a rectangular outline. As a Mesozoic sedimentary basin formed by long-term evolutionary superimposition on the North China Craton, it is also the second-largest petroliferous basin in China. [1-2]

According to the current tectonic morphology of the Ordos Basin and combined with the tectonic evolution history of the basin floor, the basin can be divided into six first-order tectonic units: the Yimeng Uplift, the Western Shanxi Flexural Fold Belt, the Weibei Uplift, the Tianhuan Depression, the Western Margin Thrust Belt and the Northern Shaanxi Slope. The internal structure of the basin is simple, with gentle tectonics, stable subsidence and weak activity. In contrast, the evolution of the surrounding units (the Yimeng Uplift, Weibei Uplift, Western Margin Thrust Belt and Western Shanxi Flexural Fold Belt) is closely related to the adjacent orogenic belts. Surrounded by active orogenic belts, these peripheral areas are characterized by north-south uplift, westward thrusting and eastward uplifting, resulting in complex tectonic configurations.

The outcrops in the Hukou area of Yichuan, located in the southeastern Ordos Basin, are well-exposed with highly developed fractures. These outcrops provide unique field geological conditions for investigating the developmental characteristics, distribution patterns of fractures in this region and their impacts on the permeability of hydrocarbon reservoirs.

Taking the Yichuan area as the research target, this study conducts field investigations and detailed measurements at the joint observation sites of the Zhifang Formation near Hukou Waterfall and the Chang 8 Member of the Yanchang Formation in the eastern part of Yichuan County. The aims are to systematically analyze the developmental parameters of fractures in the region, including strike, dip direction, dip angle, density and filling characteristics, and to explore the relationship between fracture formation mechanisms and tectonic stress fields. This research will deepen the understanding of fracture development characteristics and genetic mechanisms in Yichuan area and the southern Ordos Basin, and provide important geological basis for the exploration and development of hydrocarbon resources in the southeastern Ordos Basin.

2. Regional Geological Overview

Yichuan is located in the southeastern part of Yan'an City, Shaanxi Province, lying in the transition zone between the Western Shanxi Flexural Fold Belt and the Northern Shaanxi Slope on the eastern margin of the Ordos Basin. Its geographical coordinates range from 109°41' E to 110°32' E and from 35°42' N to 36°23' N. The terrain of this area slopes from west to east: the western part is a loess ridge and hill region, while the eastern part is adjacent to the Yellow River Gorge, featuring complex landforms with crisscrossing gullies and valleys.

The strata exposed in the area mainly include the Paleozoic

Cambrian and Ordovician Systems, the Mesozoic Triassic, Jurassic and Cretaceous Systems, as well as the Cenozoic Tertiary and Quaternary Systems. Among them, the Mesozoic Triassic Yanchang Formation, Jurassic Yan'an Formation and Zhifang Formation are the main hydrocarbon-bearing reservoir strata in the region, and also the key target strata for this fracture study.[3-4]

The geological structural evolution of the Yichuan area is strongly controlled by the overall tectonic movements of the Ordos Basin. In particular, tectonic activities since the Yanshanian Period have exerted a significant influence on the formation and distribution of fractures in this area. The major fault structures developed in the region are dominated by the near-east-west, northeast and northwest trends. These faults not only control the distribution of sedimentary facies, but also provide stress conditions and pathways for fracture development. In addition, the widely distributed joint structures in the area, as an important component of the fracture system, have their developmental characteristics closely related to the regional tectonic stress field, serving as crucial carriers for studying the tectonic evolution history.

During the field investigation of fractures in the Yichuan area, southeastern Ordos Basin, conducted by our research group, representative geological sections and outcrop sites were selected as the key study areas. Systematic collection of basic data including fracture occurrence, density, filling characteristics and associated structures was carried out through field measurement, sketch recording and sample collection. The investigation scope covers the main hydrocarbon-bearing reservoir strata in the region. Specifically, focusing on the Mesozoic Triassic Yanchang Formation, Jurassic Yan'an Formation and Zhifang Formation, combined with their exposure conditions and regional tectonic setting, the study strives to comprehensively reflect the differences in fracture development among different strata and different structural positions.

The fieldwork was carried out in strict accordance with geological survey specifications. For each observed fracture, detailed records were made of its strike, dip direction and dip angle. The number of fractures per unit area was counted to calculate the fracture density. Meanwhile, attention was paid to observing the flatness of fracture surfaces, the presence of striations, as well as the composition and cementation degree of fillings, laying a solid foundation for subsequent laboratory experimental analysis and comprehensive research.

3. Fracture Development Characteristics in the Yichuan Area

Field investigations and observations of outcrop fractures were conducted separately on the Zhifang Formation near Hukou Waterfall and the Yanchang Formation in the eastern part of Yichuan County, within the Yichuan area. Through systematic measurement and statistical analysis, the developmental patterns of fractures in different tectonic units and strata were revealed.

3.1. Fracture Development Characteristics of the Zhifang Formation near Hukou Waterfall

The outcrop at this site is located near Hukou Waterfall. Its lower part consists of medium-thin bedded purple-red argillaceous siltstone intercalated with mudstone, while the upper part is dominated by extremely thick-bedded massive

fine sandstone. The entire sequence represents a set of fluvial facies sandstones, locally intercalated with interchannel facies mudstone. Three sets of joints are developed within the sandstone strata at this site. Among them, the set of NNE-trending fractures is extremely well-developed, whereas the NEE- and NWW-trending fractures are only sporadically distributed locally (Fig. 1 a, b, c).

The lower argillaceous siltstone sequence is composed of a series of medium-thin bedded silty mudstone, with a total thickness of approximately 5 meters and a single sandstone bed thickness ranging from 20 to 50 cm. Purple-red mudstone beds of 2–3 cm in thickness are intercalated between sandstone beds. NNE-trending fractures are highly developed within this sequence, with lengths ranging from 20 to 30 meters and a density of 0.2–0.3 fractures per meter. The fracture surfaces are smooth and rarely cut through the underlying thick-bedded sandstone. NEE-trending fractures are poorly developed in this siltstone sequence and can only be observed occasionally adjacent to the NNE-trending fractures. NWW-trending fractures are also developed in this medium-bedded sandstone sequence, with lengths of 3–5 meters and a density of 0.5–1 fracture per meter. The fracture surfaces are rough and exhibit relatively wide apertures, mostly due to fluvial scouring. Most of these NWW-trending fractures are restricted by the NNE-trending fractures, indicating that this fracture set was formed later.

The upper thick-bedded sandstone sequence has a total thickness of approximately 20–30 meters. NEE-trending fractures are extremely well-developed within it, with lengths ranging from 50 to 120 meters and a density of 0.2–0.5 fractures per meter. The fracture surfaces are smooth and cut through all sandstone beds. NWW- and NEE-trending fractures are generally poorly developed within this thick-bedded sandstone sequence. NWW-trending fractures in this siltstone sequence are only occasionally observed near NNE-trending fractures, with lengths of 2–3 meters and a density of 1–2 fractures per meter. The fracture surfaces are rough, and they rarely cut through the entire stratum.

The above-mentioned joint development characteristics indicate that NEE-trending shear fractures are extremely well-developed at this site, whereas NNE-trending fractures are only occasionally observed adjacent to NEE-trending fractures and should be regarded as secondary fractures derived during the development of NEE-trending fractures. NWW-trending shear fractures are moderately developed, but their growth is restricted by NEE-trending shear fractures. Based on the development characteristics of nearly NS-trending basement faults in this region, NNE-trending fractures may have formed under the southwest-northeast trending shear-compression during the Indosinian Period, with basement faults exerting a controlling effect on the formation of this fracture set. In addition, the direction of the acute angle between these two fracture sets is northwest-southeast trending. Combined with the analysis of regional geological setting, it is indicated that these two joint sets may have formed during the Yanshanian Period.

3.2. Fracture Development Characteristics of the Chang 8 Member of the Yanchang Formation in the Eastern Part of Yichuan County

The outcrop at this site is located in the eastern part of Yichuan County. Its lower part consists of the extremely thick-bedded grayish-green mudstone of the Chang 9 Member,

the middle part is medium-bedded argillaceous siltstone intercalated with mudstone, and the upper part is dominated by extremely thick-bedded massive grayish-green fine sandstone. The entire sequence from bottom to top represents a set of transitional deposits of lacustrine facies to delta front

facies. Two sets of joints are developed within the sandstone strata at this site: the set of NWW-trending fractures is extremely well-developed, whereas the NNW-trending fractures are only sporadically distributed locally.



Figure 1. Fracture Characteristics of the Zhifang Formation Outcrop near Hukou Waterfall

The lower thick-bedded mudstone sequence has a total thickness of approximately 5 meters with indistinct bedding. A small number of NWW-trending fractures are developed within this mudstone sequence, with lengths ranging from 20 to 30 meters and a density of 0.2–0.3 fractures per meter. The fracture surfaces are smooth and often cut through the entire mudstone sequence. An extremely small number of NNW-trending fractures are also developed within this medium-bedded sandstone sequence, with lengths of 2–5 meters and rough surfaces; these are derivative fractures of the NWW-trending fractures.

The middle part is composed of medium-thin bedded grayish-green argillaceous siltstone of the Chang 9 Member, with a total thickness of approximately 5 meters. NEE-trending fractures are extremely well-developed within it, with lengths ranging from 50 to 120 meters and a density of 2–3 fractures per meter. The fracture surfaces are smooth, and most of them cut through all sandstone beds in an arcuate pattern from bottom to top.

The upper thick-bedded grayish-green sandstone sequence has a total thickness of approximately 20–30 meters, intercalated with medium-thick bedded sandstone. NWW-

trending fractures are extremely well-developed within this sequence, with lengths ranging from 50 to 120 meters and a density of 0.3–0.5 fractures per meter. The fracture surfaces are smooth, and the fracture density is slightly higher at the base of the strata; only large-scale fractures can cut through the entire sandstone sequence. NNW-trending fractures are rarely developed within this thick-bedded sandstone sequence.

The above-mentioned joint development characteristics indicate NWW-trending shear joints are extremely well-developed in this region, whereas NNW-trending shear-tension joints, as derivative structures of the NWW-trending fractures, are poorly developed. There are significant differences in the occurrences of fractures between these two sets and those in the underlying Zhifang Formation, indicating that the fractures in the underlying strata exert little influence on the fracture development of the Yanchang Formation in the study area. The direction of the acute angle enclosed by these two fracture sets is northwest-southeast trending. Combined with the analysis of regional geological setting, it is inferred that these joint sets may have formed during the Yanshanian tectonic period. [5-9]

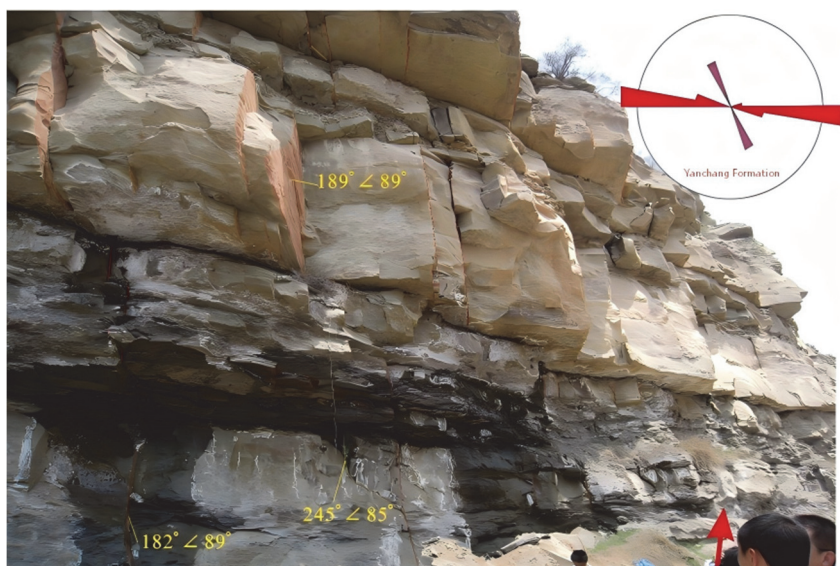


Figure 2. Fracture Characteristics of the Chang 8 Member of the Yanchang Formation Outcrop in the Eastern Part of Yichuan County

4. Conclusion

Based on the systematic field investigation, measurement and analysis of outcrop fractures in the Jurassic Zhifang Formation near Hukou Waterfall and the Triassic Chang 8 Member of the Yanchang Formation in the eastern part of Yichuan County, located in the southeastern Ordos Basin, this study draws the following main conclusions:

First, there are significant differences in fracture development characteristics among different strata in the Yichuan area. Three sets of joints are predominantly developed in the sandstone strata of the Jurassic Zhifang Formation near Hukou Waterfall. Among them, the NNE-trending fractures are extremely well-developed; in the lower medium-thin bedded argillaceous siltstone, their lengths can reach 20–30 meters with a density of 0.2–0.3 fractures per meter, and the fracture surfaces are smooth. In contrast, the NEE- and NWW-trending fractures are only sporadically distributed locally; the NWW-trending fractures are relatively short (3–5 meters in length) but have a relatively high density (0.5–1 fracture per meter). However, two sets of joints are mainly developed in the sandstone strata of the Triassic Chang 8 Member of the Yanchang Formation in the eastern part of Yichuan County. The NWW-trending fractures are extremely well-developed; in the upper thick-bedded sandstone, their lengths reach 50–120 meters with a density of 0.3–0.5 fractures per meter, and the fracture surfaces are smooth. The NNW-trending fractures are rarely developed and mostly occur as derivative fractures. These differences indicate that fracture development is not only controlled by the regional tectonic stress field, but also closely related to the lithologic assemblage, thickness and sedimentary environment of specific strata.

Second, the formation of fractures in the study area is closely associated with regional tectonic movements. The NNE-trending fractures in the Zhifang Formation near Hukou Waterfall may have formed under the southwest-northeast trending shear-compression during the Indosinian Period, and their development was controlled by basement faults. The direction of the acute angle enclosed by the NEE- and NWW-trending fracture assemblage indicates that these fractures may have formed during the Yanshanian Period. Combined with the analysis of regional geological setting, the acute angle orientation of the NWW- and NNW-trending fracture assemblage in the Chang 8 Member of the Yanchang Formation in the eastern part of Yichuan County also suggests that these fractures were mainly formed during the Yanshanian tectonic period. This demonstrates that the Yanshanian tectonic movement was the key dynamic factor for fracture development in the study area, exerting a significant influence on the occurrence and distribution of fractures in different strata.

Finally, fracture development exhibits distinct directionality and a clear primary-secondary hierarchy. Both

in the Zhifang Formation and the Chang 8 Member of the Yanchang Formation, one set of fractures with a dominant strike is extremely well-developed, constituting the main body of the fracture system. In contrast, fractures with other strikes are mostly secondary or derivative fractures, only sporadically distributed locally or having a low density. The fractures with dominant strikes are generally formed under the action of major tectonic stress, which are of great significance for improving reservoir permeability. Derivative fractures may further connect the main fractures, forming a more complex fracture network. These findings not only deepen the understanding of fracture development characteristics and genetic mechanisms in the Yichuan area, southeastern Ordos Basin, but also provide important geological basis for reservoir evaluation and prediction in the exploration and development of hydrocarbon resources in this region.

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