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Study on the Reservoir Characteristics of the Triassic Yanchang Formation in the Majiahe Area, Ordos Basin

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Abstract: This study thoroughly analyzes the petrological and physical properties of the Chang 4+5 and Chang 6 reservoirs of the Triassic Yanchang Formation in the Majiahe area of the Ordos Basin. The lithology in the study area is mainly composed of gray fine-grained feldspathic sandstone, followed by medium to fine-grained and silt to fine-grained feldspathic sandstone. The overall petrological characteristics indicate low compositional maturity and high structural maturity, reflecting the complexity of the depositional environment. The reservoir properties exhibit extremely low porosity (very low to ultra-low porosity) and permeability (very low to ultra-low permeability), with significant heterogeneity in the reservoirs.

Keywords: Majiahe Area; Petrological Characteristics; Reservoir Properties; Reservoir Heterogeneity

Introduction

Reservoirs serve as crucial reservoirs for storing oil and gas and are pivotal in controlling their accumulation and distribution. This paper focuses on the Majiahe area of the Ordos Basin, where samples of sandstone from the Chang 4+5 and Chang 6 members were collected. Thin section observations, X-ray diffraction (XRD), scanning electron microscopy (SEM), and mercury intrusion porosimetry (MIP) tests were conducted on these samples to comprehensively analyze the reservoirs in the study area[1].

1. Geological Overview of the Study Are

The Majiahe area is located in the central part of the northern Shaanxi slope of the Ordos Basin, covering parts of Ganquan County and Baota District. The structural area of the region is approximately 70 square kilometers. The study area features a gentle west-dipping monocline structure with an inclination of about 0.5°. The internal structure is relatively simple and geologically stable, with no fault distribution. There are only 2-3 low-amplitude, nearly east-west trending nose-like uplifts with a height of less than 10 meters.

2. Study of Reservoir Characteristics

2.1 Petrological Characteristics

Through the analysis of cast thin sections, the mineral content in the study area was determined as follows: feldspar approximately 53.4%, quartz approximately 20.5%, lithic fragments about 5.7%, and mica content varying significantly from 1.0% to 15.0%, with an average of 6.3%. This indicates the diversity in the lithology of the source area and its physical and chemical stability. The rock type ternary diagram (Figure 1) shows that the reservoir rocks in this area are classified as feldspathic sandstone, The sandstone is predominantly gray[2].

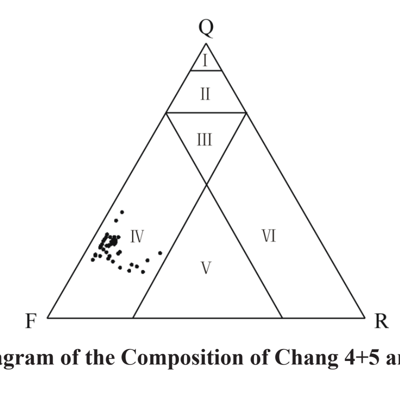

Figure 1: Ternary Diagram of the Composition of Chang 4+5 and Chang 6 Sandstones

2.2 Reservoir properties

Physical property analysis was conducted on core samples from the Chang 4+5 and Chang 6 reservoirs in the Majiahe area of the Ordos

Basin, revealing similar porosity and permeability characteristics in these reservoirs.[3] comprehensive analysis of test data from 62 core samples from 17 wells showed that the average physical properties of the Chang 4+5 and Chang 6 reservoirs were close. it can be observed that the average porosity of the Chang 4+5 reservoir was 10.43%, indicating relatively low porosity related to reservoir heterogeneity, with porosity mainly concentrated between 8% and 15%. The average permeability was approximately $1.39\times10^{-3}\mu m^2$, with permeability mainly concentrated between $0.3\times10^{-3}\mu m^2$ and $4.0\times10\text{-}^{3}\mu m^2$. The average porosity of the Chang 6 reservoir was 10.24%, indicating vertical heterogeneity of the reservoir, with porosity mainly concentrated between 8% and 15%. Permeability was mainly distributed between $0.3\times10^{-3}\mu m^2$ and $4.0\times10^{-3}\mu m^2$, reflecting the presence of favorable pathways for oil and gas migration in the Chang 4+5 and Chang 6 reservoirs. Detailed layer statistics are shown in Table 1.

Table 1: Porosity and Permeability Statistics of Chang 4+5 and Chang 6 Reservoirs

Strata	Chang 4+5		Chang 6	
Properties	Porosity (%)	Permeability ($10^{-3}\mu m^2$)	Porosity (%)	Permeability ($10^{-3}\mu m^2$)
Sample Count	251	251	424	424
Maximum Value	18.77	6.79	18.05	7.78
Minimum Value	2.09	0.04	1.63	0.04
Average Value	10.43	1.39	10.24	1.26

2.3 Study on Macroscopic Heterogeneity of Reservoirs

This section of the paper focuses on the study of macroscopic heterogeneity of reservoirs, which includes within-layer heterogeneity, inter-layer heterogeneity, and planar heterogeneity.

2.3.1 Within-Layer Heterogeneity

Within a single sand body, within-layer heterogeneity is manifested through various aspects such as the cyclicity of the stratigraphic sequence, variability of permeability between sand layers, distribution of interlayers, and characteristics of intra-layer fractures. The main oil-bearing sand layers in the Chang 4+5 and Chang 6 reservoirs are composed of multiple sedimentary cycles, resulting in pronounced within-layer heterogeneity[4].

In the study area, mud interlayers are commonly encountered within the Chang 4+5 and Chang 6 reservoirs. The frequency, density, and thickness variations of these mud interlayers are shown in Table 2.

Table 2: Statistics of Mud Interlayers within Chang 4+5 and Chang 6 Oil-bearing Strata

Layer	Average Sandstone Thickness per Well (m)	Average Number of Interlayers per Well (layers)	Average Thickness of Interlayers per Well (m)	Individual Interlayer Thickness (m)	Interlayer Frequency (layers/m)	Interlayer Density (f)
Chang 4+5	14.3	1.8	1.3	1.0	0.13	0.09
Chang 6	16.2	2.1	1.8	0.8	0.13	0.11

According to the statistical results, it is evident that the mud interlayer frequency, individual interlayer thickness, and interlayer density of the Chang 4+5 and Chang 6 oil layers in this area exhibit significant similarity, indicating a comparable depositional environment.

2.3.2 Inter-Layer Heterogeneity

Inter-layer heterogeneity refers to the vertical variation in reservoir properties within a single sand layer or sand layer group, directly affecting the degree of water inundation and sweep efficiency of the reservoir. It encompasses differences between individual layers within a sand layer group as well as variations between different sand layer groups.

According to the statistical data (Table 3), the sand thickness ratio of Chang 4+5 is relatively small, at 0.35, while that of Chang 6 is relatively large, at 0.44. This difference suggests variations in sedimentary environment and sediment supply between the two reservoirs. The average thickness of a single sand layer is 3.5 meters for Chang 6 and 2.8 meters for Chang 4+5. The average number of sandstone layers per well is consistent for both oil layers, at 4.8 layers. The average sandstone thickness per well is 13.5 meters for Chang 4+5 and 16.7 meters for Chang 6.

Table 3: Sand-to-Mud Ratio Statistics for Chang 4+5 and Chang 6 Oil Layers

Layer	Average Stratum Thickness (m)	Average Number of Sandstone Layers per Well	Average Thickness of Sandstone per Well (m)	Average Thickness of Single Sandstone Layer (m)	Sand-to-Mud Ratio (f)
Chang4+5	39.0	4.8	13.5	2.8	0.35
Chang6	37.7	4.8	16.7	3.5	0.44

2.3.3 Plane Heterogeneity

Plane heterogeneity reflects the variations in reservoir properties laterally due to differences in sedimentation processes and diagenetic effects. It is mainly analyzed through contour maps of permeability, porosity, and sand body thickness, combined with the influence of sedimentary facies and diagenetic processes. Comprehensive analysis of the plane heterogeneity of Chang 4+5 and Chang 6 is crucial for the effective development and management strategies of oil and gas reservoirs.

2.4 Study on Microscopic Heterogeneity of Reservoirs

For the study of microscopic heterogeneity in reservoirs, the key is to use thin sections, cast thin sections, scanning electron microscopy, and mercury intrusion porosimetry techniques to understand the microscopic pore structure and its distribution characteristics of the reservoir. Through detailed description of the microscopic pore structure of Chang 4+5 and Chang 6 reservoirs in this area, Thin section analysis reveals that the average pore ratio of Chang 4+5 and Chang 6 reservoirs is 7.7%, mainly distributed between 3.5% to 12.0%. This range of porosity directly affects the fluid storage capacity and flow characteristics of the reservoir[4].

Figure2: Line Chart of Pore Types in Chang 4+5 and Chang 6 Reservoirs in Majiahe Area

The primary intergranular pores account for 66.5% of all pores in Chang 4+5 and Chang 6 reservoirs. These pore spaces usually represent favorable reservoir conditions because of their strong connectivity, providing effective channels for fluid flow. Next are dissolution pores, accounting for 31.9%, including intragranular dissolution pores (feldspar dissolution pores, lithic dissolution pores) and intergranular dissolution pores.[5]

3. Conclusion

(1) The reservoirs in this study area mainly consist of gray fine-grained feldspathic sandstone, characterized by relatively homogeneous clastic particles. The predominant grain size (0.1~0.3mm) accounts for over 70% of the total, with moderate to good sorting and subangular to subrounded grain shapes.

(2) The Chang 4+5 and Chang 6 reservoirs exhibit strong heterogeneity, characterized by low porosity and permeability. The pore structure resembles that of medium porosity with micro-fine throat type reservoirs.

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