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Reservoir Characteristics and Sensitivity Evaluation of Chang 9 in the Southern Wangwazi Area of Wuqi Oilfield

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Abstract

To clarify the geological characteristics and sensitivity laws of the Chang 9 reservoir in the Wangwazi South area of the Wuqi Oilfield and to facilitate efficient development of the block, this paper conducts research by comprehensively applying methods such as core observation, thin section identification, mercury injection experiments, and sensitivity flow experiments. The results show that the study area is located on the western edge of the Yishan Slope in the Ordos Basin. The Chang 9 oil layer group reservoir is mainly composed of gray and dark gray fine-grained lithic feldspar sandstone, followed by feldspar lithic sandstone. The porosity is concentrated in the range of 1% to 5%, and the permeability is distributed between 0.05 and 0.4 mD, belonging to a very low porosity and tight reservoir. The pore types are mainly feldspar dissolution pores and intergranular pores, presenting a small pore and fine throat structure. The sensitivity evaluation shows that the reservoir has moderate to weak speed sensitivity (critical flow rate 3.72 m/D), moderate to weak water sensitivity, moderate to weak salt sensitivity (critical salinity 21.51 g/L), weak acid sensitivity, and weak to moderate to weak alkali sensitivity (critical pH value 11). Clay mineral migration and precipitation are the main damage mechanisms. The research results clarify the core characteristics and damage laws of the reservoir, providing geological basis for the formulation of reservoir protection plans and the optimization of development technologies, and also enrich the theoretical research on the Chang 9 reservoir in the Yanchang Formation of the Ordos Basin.

Keywords

Long 9 Reservoir; Reservoir Characterization; Reservoir Classification; Sensitivity.

1. Introduction

As one of the important oil and gas-bearing basins in China, the Yanchang Formation's Chang 9 oil formation is a key oil-bearing series in the basin, and its exploration and development are of great significance for regional energy supply. The southern Wangwazi area of Wuqi Oilfield is located at the western edge of the Yishan Slope in the Ordos Basin, with a unique structural setting. As the main development interval in this area, the Chang 9 reservoir has become a key target for oil and gas exploration in recent years. However, affected by the complex sedimentary environment and diagenesis, the reservoir exhibits characteristics of low porosity, low permeability, and complex pore structure. In addition, the prominent reservoir sensitivity problem is prone to cause reservoir damage during the development process, which seriously restricts the improvement of block development efficiency and recovery factor.

At present, the systematic research on the Chang 9 reservoir in the southern Wangwazi area is relatively weak. The petrological characteristics, physical property laws, and sensitivity mechanisms of the reservoir have not been fully clarified, bringing challenges to reservoir protection and the optimization of development schemes. Based on this, this study comprehensively used various technical means such as core observation, thin section identification, mercury intrusion porosimetry, and sensitivity flow experiments to conduct a systematic study on the petrological characteristics, physical parameters, pore structure, and sensitivity characteristics of the Chang 9 reservoir in this area. It clarifies the core geological characteristics and damage mechanisms of the reservoir, provides a geological basis for formulating scientific and reasonable reservoir protection measures and optimizing development technical parameters, and enriches the exploration and development theory of the Chang 9 reservoir in the Yanchang Formation of the Ordos Basin, supporting the efficient and sustainable development of the block [1] .

2. Regional Geological Overview

The southern Wangwazi area of Wuqi Oilfield is located in Wangwazi Township and Tiebiancheng Town, Wuqi County, Shaanxi Province. It borders Dingbian County in the northwest, Zhidan County in the east, Jingbian County in the northeast, and Huachi County, Gansu Province in the southwest. The total exploration and development control area is 141 km^2. Tectonically, it is located at the western edge of the Yishan Slope in the Ordos Basin, presenting a gentle monocline tilting westward. The locally developed low-amplitude nose-shaped uplifts are conducive to oil and gas accumulation.

The surface of the southern Wangwazi area is crisscrossed by gullies and undulating beams and mounds, with an altitude of 1365-1785 m. It belongs to an inland arid climate, with an average annual temperature of 6-7°C and an average annual precipitation of 400-600 mm, mostly concentrated in autumn. The groundwater resources are relatively abundant. The local economy is mainly based on agriculture and animal husbandry, with harsh natural conditions. In recent years, oil exploitation has become a pillar industry driving the rapid development of the local economy. Transportation is dominated by highways. Highways pass through 5 villages in the river valley from south to north, connecting with the highway in Youfang Township, Dingbian County. Rural highways extend in all directions, with convenient transportation, providing favorable conditions for oilfield exploration and development.

3. Reservoir Characteristics

3.1. Petrological Characteristics

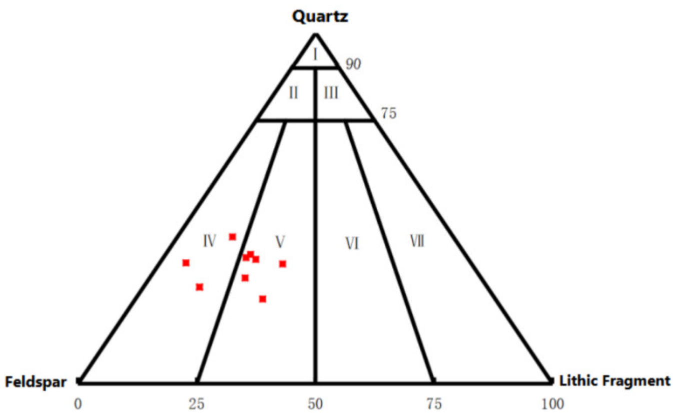


Figure 1. Sandstone Classification Map of the Southern Wangwazi Area, Wuqi County (Chang 9)

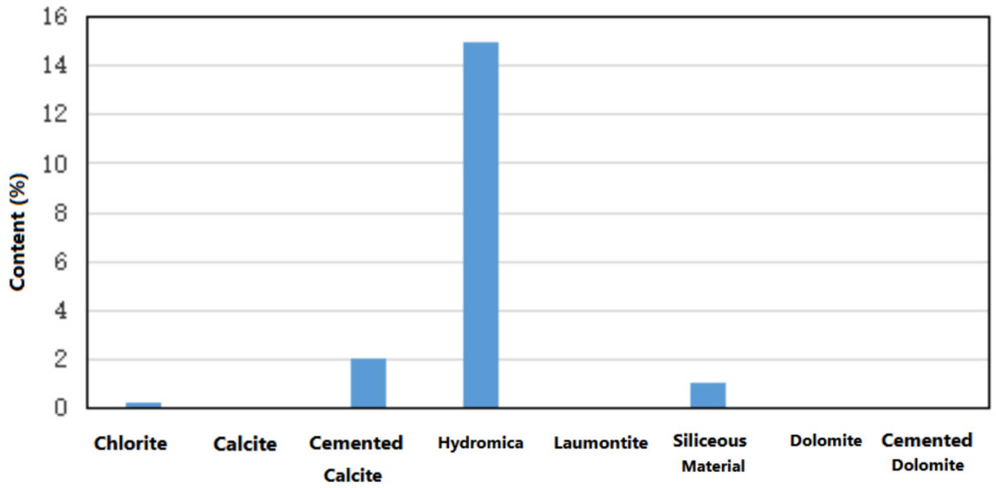
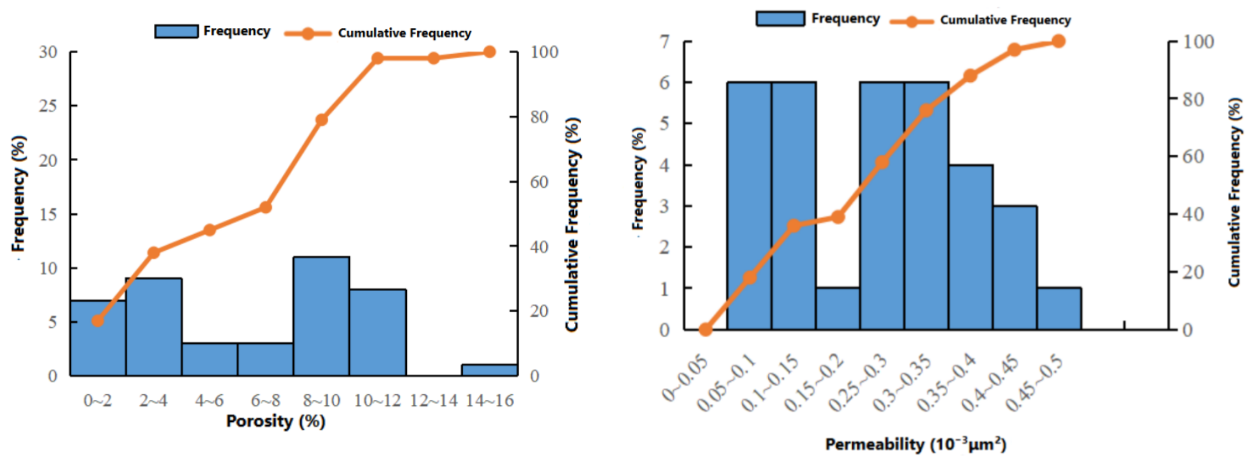


Figure 2. Histogram of Interstitial Material Composition Content of Chang 9 Sandstone

The rock types of the Chang 9 sandstone in this area are mainly gray and dark gray fine-grained lithic arkose, followed by feldspathic litharenite. The particle size generally ranges from 0.03 mm to 0.5 mm, with a maximum particle size of 0.6 mm. Most of the colors are light gray. The average content of quartz clasts in the sandstone is 23.4%; the average content of feldspar is 35.6%; the average content of lithic fragments is 21.5%. Bedding is well-developed, and mica and other minerals are enriched and distributed in parallel on the bedding plane; mica is mainly biotite, which is hydrated; the lithology is dense with no obvious visible pores; the interstitial materials mainly include illite, chlorite, and ferrocalcite, with rare siliceous minerals (Figures 1 and 2).

3.2. Physical Properties



(a)Porosity Distribution Histogram of Chang 9 Oil Formation

(b)Permeability Distribution Histogram of Chang 9 Oil Formation

Figure 3. Frequency Distribution Histogram of Chang 9 Reservoir in the Southern Wangwazi Area

(1) Porosity and Permeability Distribution Characteristics

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The maximum porosity of the Chang 9 reservoir is 14.5%, the minimum is 1.1%, the average is 6.5%, and the median is 7.5%, with porosity concentrated between 1% and 5%; the maximum horizontal permeability is 0.49 mD, the minimum is 0.08 mD, the average is 0.25 mD, and the median is 0.3 mD, with permeability concentrated in the range of 0.05-0.4 mD. The results indicate that the Chang 9 reservoir in this area is an ultra-low porosity and tight reservoir.

(2) Porosity-Permeability Correlation

According to the internal relationship between the physical properties of porous reservoirs, the porosity and permeability of the Chang 9 reservoir in the study area show a good linear correlation, manifested as permeability increasing with the increase of porosity (Figure 4). Due to the influence of factors such as pore type and pore structure, there are relatively discrete data points in the fitting graph (Φ - surface porosity, %).

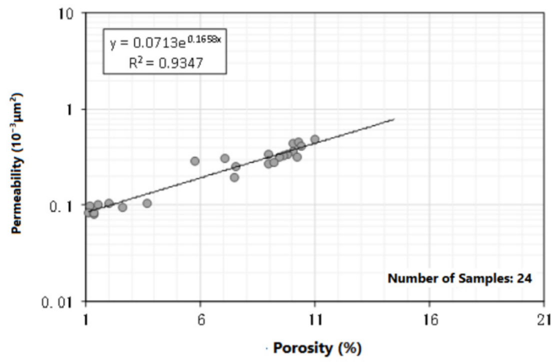

Figure 4. Permeability-Porosity Correlation Diagram of Chang 9 Formation

3.3. Pore Types and Structural Characteristics

(1) Pore Types

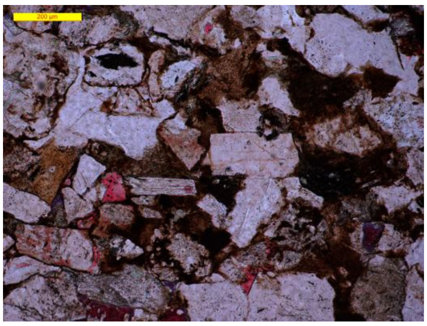

Figure 5. Feldspar Dissolution Pores (Well Y95, 2412.21 m, Chang 9 Formation)

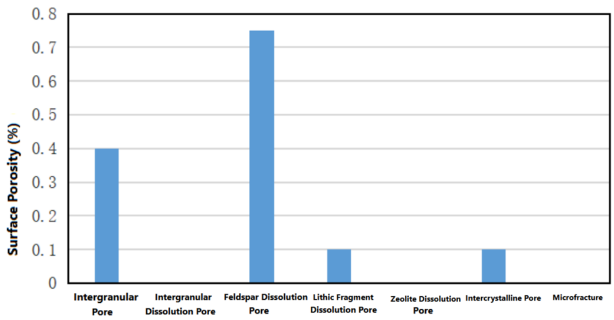

Figure 6. Pore Type Distribution Diagram of Chang 9 Reservoir

The total porosity of the Chang 9 reservoir in this area is 1.3%, among which feldspar dissolution pores are dominant (average 0.75%), accounting for 57.7% of the total porosity, followed by intergranular pores (average 0.4%), accounting for 30.8% of the total porosity (Figure 5). Intergranular pores are primary intergranular pores remaining after mechanical compaction, secondary overgrowth of feldspar and quartz, and filling by various cementation, also known as residual intergranular pores. They include: residual intergranular pores after early film-like chlorite and illite cementation; residual intergranular pores after quartz and feldspar secondary overgrowth; residual intergranular pores after calcite and clay mineral filling and cementation, among which the former has a larger pore diameter, up to 60-100 μm. Pores formed by the dissolution of feldspar, lithic fragments, laumontite, carbonate, etc., under dissolution are the main body of secondary pores, namely dissolution pores [2]. The secondary pores of the sandstone reservoir in the Chang 9 oil formation in this area are mainly intragranular dissolution pores, with fewer intergranular dissolution pores and intra-interstitial dissolution pores. Feldspar dissolution pores are the most important type of pores in the Chang 9 sandstone reservoir of the Yanchang Formation in this area (Figure 6).

(2) Pore-Throat Size and Distribution

The displacement pressure of the Chang 9 oil formation ranges from 0.034 to 20.654 MPa, with an average of 4.732 MPa; the median pressure ranges from 0.307 to 94.164 MPa, with an average of 31.300 MPa; the median pore-throat radius ranges from 0.008 to 0.407 μm, with an average of 0.084 μm; the sorting coefficient ranges from 1.137 to 3.372, with an average of 1.878; the skewness ranges from -0.338 to 0.320, with an average of -0.127; the maximum mercury saturation ranges from 54.405% to 91.777%, with an average of 76.894%; the mercury withdrawal efficiency ranges from 25.006% to 33.113%, with an average of 30.061% (Figure 7).

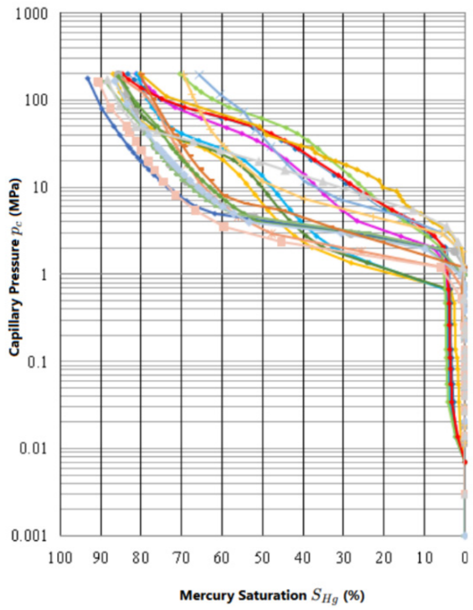

Figure 7. Mercury Intrusion Curve of Chang 9 Reservoir

4. Reservoir Sensitivity Evaluation

Through sensitivity experimental research, the sensitivity characteristics of the Chang 9 reservoir in the southern Wangwazi area were analyzed, and corresponding measures were implemented for reservoirs with different sensitivity characteristics to significantly improve oilfield development efficiency.

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4.1. Reservoir Velocity Sensitivity Evaluation

Velocity sensitivity refers to the phenomenon where changes in fluid velocity cause the migration of mineral particles in the formation and blockage of throats, thereby leading to a decrease in reservoir permeability[3].

Based on the velocity sensitivity test results of rock samples in the study area. According to the velocity sensitivity experiments of the samples, the average velocity sensitivity index is 0.38, the average gas permeability is 0.9725×10^{-3} μm^2, the average porosity is 10.725%, the average critical flow velocity is 3.72 m/D, the velocity sensitivity damage rate is 30.91%-45.6%, and the velocity sensitivity index is 0.31-0.46, indicating moderate-weak velocity sensitivity.

Table 1. Velocity Sensitivity Test Data of Reservoirs in the Study Area

Sample No.	Formation	Length	Diameter	Gas Permeability	Porosity	Critical Flow Velocity	Damage Rate	Velocity Sensitivity Index	Velocity Sensitivity Evaluation
		(cm)	(cm)	($\times10^{-3}$μm^2)	(%)	(m/D)	(%)		
P1	Chang 9	6.04	2.49	1.42	14.3	5.21	30.91	0.31	Moderate-weak
P1	Chang 9	6.03	2.49	1.50	14.0	5.25	31.55	0.32	Moderate-weak
P2	Chang 9	3.23	2.48	0.71	7.1	0.70	43.22	0.43	Moderate-weak
T1	Chang 9	4.32	2.49	0.26	7.5	-	45.60	0.46	Moderate-weak

4.2. Reservoir Water Sensitivity Evaluation

According to the water sensitivity experiments of 2 samples in the study block, based on the test data, the average gas permeability is 0.37×10^{-3} μm^2, the average porosity is 10.15%, and the average water sensitivity index of the Chang 9 reservoir is 0.46, indicating moderate-weak water sensitivity (Table 2).

Table 2. Water Sensitivity Test Data of Reservoirs in the Study Area

Sample No.	Formation	Length	Diameter	Gas Permeability	Porosity	Water Sensitivity Index	Water Sensitivity Evaluation
		(cm)	(cm)	($\times10^{-3}$μm^2)	(%)		
T1	Chang 9	2.53	2.53	0.24	7.8	0.43	Moderate-weak
T2	Chang 9	2.04	2.52	0.50	12.5	0.39	Moderate-weak

4.3. Reservoir Salt Sensitivity Evaluation

Table 3. Salt Sensitivity Test Data of Reservoirs in the Study Area

Sample No.	Formation	Gas Permeability	Porosity	Formation Water Permeability	Permeability after Dilution ($\times10^{-3}$μm^2)		Deionized Water Permeability	Critical Salinity	Salt Sensitivity Evaluation
		$\times10^{-3}$μm^2	(%)	$\times10^{-3}$μm^2	50%	25%	$\times10^{-3}$μm^2	g/L	
P1	Chang 9	4.22	11.9	1.192	0.179	0.159	0.095	2.03	Moderate-weak
T1	Chang 9	0.20	8.9	0.053	0.043	0.034	0.026	25.0	Moderate-weak
T1	Chang 9	0.44	11.5	0.056	0.044	0.038	0.033	37.5	Moderate-weak

By means of salt sensitivity experiments, the specific conditions of how changes in the salinity of injected fluids affect formation permeability damage were monitored and analyzed. During this process, data on permeability changes under different salinity conditions were recorded to accurately determine the critical salinity value that causes a decrease in permeability [4-6].

According to the salt sensitivity experiments of 3 samples in the study block, the permeabilities are 4.22×10^{-3} μm², 0.20×10^{-3} μm², and 0.44×10^{-3} μm² respectively; the average porosity is 10.77%, and the average critical salinity causing salt sensitivity damage to the reservoir is 21.51 g/L. It is considered that the Chang 9 reservoir in this block has moderate-weak salt sensitivity (Table 3).

4.4. Reservoir Acid Sensitivity Evaluation

Acid sensitivity refers to the degree of sensitive characteristics exhibited when acidic fluids are injected into the reservoir and react chemically with minerals contained in the reservoir, specifically manifested as a decrease in permeability and a reduction in pore-throat radius[7-8].

According to the acid sensitivity experiments of 4 samples in the study block, by comparing the permeability changes before and after acidification, the acid sensitivity index ranges from 0.06 to 0.25; the acidic mineral calcite in the interstitial materials of the study area is well-developed, which is prone to react with acid to form precipitates such as iron and calcium, thereby blocking pore throats[9]. It is considered that the Chang 9 reservoir in this block has weak acid sensitivity (Table 4).

Table 4. Acid Sensitivity Test Data of Reservoirs in the Study Area

Sample No.	Formation	Gas Permeability	Porosity	Acid			Formation Water Permeability (×10⁻³μm²)		Acid Sensitivity Index	Acid Sensitivity Evaluation
		×10⁻³μm²	(%)	Name	pH Value	Dosage (FV)	Before Acid	After Acid		
P1	Chang 9	4.09	12.8	HCL	15	0.86	0.211	0.183	0.13	Weak
P1	Chang 9	4.36	13.2	HCL	15	0.86	0.255	0.190	0.25	Weak
T1	Chang 9	0.41	13.0	HCL	15	1.00	0.230	0.220	0.06	Weak
T1	Chang 9	0.44	12.0	HCL	15	1.00	0.750	0.650	0.14	Weak

4.5. Reservoir Alkali Sensitivity Evaluation

Alkaline ions in fluids react with cations in formation water, or alkaline fluids react with acidic minerals to form precipitates that block pore throats, resulting in a decrease in permeability [10].

According to the alkali sensitivity experiments of 4 samples in the study block, the average alkali sensitivity index of the Chang 9 reservoir is 0.25, showing weak to moderate-weak alkali sensitivity (Table 5).

Table 5. Alkali Sensitivity Test Data of Reservoirs in the Study Area

Sample No.	Formation	Formation Water Permeability	Porosity	Alkali		Formation Water Permeability After Alkali	Alkali Sensitivity Index	Alkali Sensitivity Evaluation
		(×10⁻³μm²)	(%)	Name	pH Value	(×10⁻³μm²)		
P1	Chang 9	0.213	12.6	KCL	6.0	0.183	0.14	Weak
P1	Chang 9	0.185	12.7	KCL	6.0	0.177	0.01	Weak
T1	Chang 9	0.217	7.8	KOH	11.0	0.142	0.35	Moderate-weak
T1	Chang 9	0.632	4.4	KOH	11.0	0.321	0.49	Moderate-weak

In summary, the reservoir sensitivity in the study block is characterized by moderate-weak velocity sensitivity, moderate-weak water sensitivity, moderate-weak salt sensitivity, weak acid sensitivity, and weak to moderate-weak alkali sensitivity. The critical salinity causing salt sensitivity damage to the reservoir is 21.51 g/L, and the critical pH value causing alkali sensitivity damage is 11.

The results of sensitivity experiments show that the degree of reservoir damage is controlled by multiple factors: reservoir physical properties, lithology, and formation water salinity all affect its sensitivity. When the reservoir physical properties are poor, the proportion of expansive clay minerals is high, or the difference between formation water salinity and working fluid is significant, reservoir sensitivity damage is more likely to be induced.

5. Conclusion

(1) The reservoir of the Chang 9 oil formation in Wangwazi is dominated by gray and dark gray fine-grained lithic arkose, followed by feldspathic litharenite. The porosity is concentrated between 1% and 5%; the permeability is concentrated in the range of 0.05-0.4 mD; the reservoir belongs to an ultra-low porosity and tight reservoir.

(2) By analyzing the influence of the content of clay minerals in the southern Wangwazi area on sensitivity, and then evaluating the reservoir sensitivity, the experimental results show moderate-weak velocity sensitivity, moderate-weak water sensitivity, moderate-weak salt sensitivity, weak acid sensitivity, and weak to moderate-weak alkali sensitivity; the average critical flow velocity is 3.72 m/D; the critical salinity is 21.51 g/L; the critical pH value of the reservoir is 11.

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