Characteristics of Tight Sandstone Cement in Panke Area

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Abstract. In order to improve the success rate of oil and gas exploration and further study the impact of tight sandstone cements on reservoirs, this paper uses a large number of rock thin sections, scanning electron microscopy, and physical property analysis to analyze the cements of the Chang 6 reservoir in the Panke area, southern Ordos Basin. Features have been studied in depth. The results show that the cements in the study area mainly include: authigenic cements such as illite and chlorite, carbonate cements such as iron calcite and iron dolomite, and siliceous cements. As the depth of the stratum increases and the temperature rises, the content of illite gradually increases; the main distribution area of chlorite cement is shallower than that of illite; with the increase of buried depth, the content of carbonate cement has a increase trend; The content of siliceous cement in the deeper stratum is higher than that in the shallow layer.

1. Introduction

Compared with conventional reservoirs, the cements of tight sandstone reservoirs present the characteristics of rich content, diverse types, complex components, and high degree of diagenetic evolution [1,2]. Because the existence of cement is closely related to the pore development of tight sandstone reservoirs, it can be used as an important basis for predicting the "sweet spot" of tight sandstone, which has attracted widespread attention.

In order to further clarify the impact of cements in tight sandstone reservoirs on storage performance, this paper analyzes the content, occurrence and distribution characteristics of cements through rich rock slices, high-pressure mercury intrusion and physical property analysis data, and hopes to be a tight sandstone. The prediction of "sweet spot" reservoirs provides a more powerful basis.

2. Geological profile

The Panke area is located in the southern part of the Ordos Basin, in Ningxian County, Gansu Province. A large set of semi-deep lake-deep lake system massive sandstones developed in the Triassic Yanchang Formation Chang 6 oil-bearing group is a regional reservoir. Because it is located in the upper part of the Chang 7 source rock, it has a unique advantage of near-source hydrocarbon supply, and it contains huge unconventional oil and gas resources. Exploration in this area began in the 1950s, and the
Silangmiao, Miaowan, Malan and other oil fields have been discovered so far, and the Chang 6 oil-bearing formation is the main oil-bearing series for exploration and development in this area.

Due to the dual transformation of sedimentation and diagenesis, the composition of the Chang 6 oil layer in the study area is a typical tight sandstone reservoir with an average porosity of 8.33% and an average permeability of only $0.12 \times 10^{-3} \mu m^2$. It can be seen from the multiple oil fields that have been discovered that even such a tight reservoir can store a large amount of oil resources. The reservoir performance of tight sandstone reservoirs is mainly reflected in three aspects: storage space, pore structure and physical properties. The existence of cement is closely related to the preservation and development of storage space. Analyzing the characteristics of cements is of great significance for in-depth understanding of the development of "sweet" reservoirs.

3. Types of cements and their characteristics

Cement is a comprehensive product of sedimentation and diagenesis [3,4], and is the main type of cement in Panke area. Based on the analysis and statistics of 78 wells, 314 rock slices and scanning electron microscopy experimental samples in the study area, it is believed that the content of cement in Chang 6 sandstone in Panke area varies greatly, with the highest being 35%, the lowest being 3.4%, and the average being 14.16%. Mainly include authigenic clay cement, carbonate cement, siliceous cement and feldspar cement, etc. (Figure 1).

![Figure 1 The main fillings and their content histogram of Chang 6 in Panke area](image)

3.1. Autogenous illite cement

Illite is the most abundant cement in the study area, with an average content of 6.5% (Figure 1). The statistical results show that illite is mainly distributed in the stratum with a buried depth of 1300m~1900m, and as the buried depth of the stratum increases and the temperature rises, the illite content gradually increases (Figure 2a). From the photos under the microscope, it can be observed that a large amount of illite is filled in the pores of the study area, and the common production methods are honeycomb, filamentous, and occasionally bridge-shaped (Figure 3a, b, c). Honeycomb illite is transformed from smectite (Formula 1). Under normal circumstances, as the buried depth increases and the temperature rises, montmorillonite dehydration occurs. When the temperature reaches 60~110°C, illite petrification of montmorillonite will generally occur. Studies have shown that the diagenetic temperature in the southern Ordos Basin is basically above 80°C[5,6]. Therefore, as long as there is montmorillonite in the formation, it will be converted into honeycomb illite in a large amount. The filamentous and bridging illite are transformed from kaolinite. When organic acids produced by organic matter enter the formation water, potassium feldspar is dissolved to form kaolinite (Formula 2). When the diagenetic temperature exceeds 120°C, the PH value of the medium of kaolinite increases, and K⁺ ions are added, and it will transform into filamentous or bridging illite (Formula 3). Once this reaction starts, it will not stop until either of the kaolinite and potash feldspar is basically exhausted. From this
point of view, the illiteization of kaolinite and the dissolution of potassium feldspar have a mutual promotion effect.

\[ 4.5K^+ + 8Al^{3+} + \text{Smectite} \rightarrow 4\text{KAlSi}_3\text{O}_8 + 2K^+ + 2Ca^{2+} + 2Mg^{2+} + 2.5Fe^{3+} + 3Si^{4+} + 10H_2O \]  
(Formula 1)

\[ 4\text{KAlSi}_3\text{O}_8 \text{ (Potash feldspar)} + 2H^+ + H_2O \rightarrow Al_2(\text{Si}_2\text{O}_5)(OH)_4\text{ (Kaolinite)} + 4\text{SiO}_2 \text{ (Siliceous)} + 2K^+ \]  
(Formula 2)

\[ 3\text{Al}_2(\text{Si}_2\text{O}_5)(OH)_4\text{ (Kaolinite)} + 2K^+ \rightarrow 2\text{KAl}_2\text{Si}_3\text{O}_{10}(OH)_2\text{ (Illite)} + 2\text{SiO}_2 \text{ (Siliceous)} + H_2O \]  
(Formula 3)

Figure 2 Characteristics of different fillings of Chang 6 in Panke area

3.2. Autogenous chlorite cement

According to the statistics of thin slice identification results, the content of chlorite cement is 1.7% (Figure 1), which is mainly distributed in the stratum with a buried depth of 1150m~1700m (Figure 2b), which is shallower than the main distribution area of illite, showing its formation. The required temperature is lower than that of the illite cement. Chlorite is a silicate mineral rich in iron and magnesium. According to the source of iron and magnesium, the genesis of chlorite can be summarized into three types: ①The hydrolysis of iron-rich and magnesium minerals forms chlorite[7,8]. ②Dissolution, for example, the dissolution of feldspar produces a large amount of iron and magnesium ions. When the pore fluid red iron and magnesium ions are saturated, chlorite will be precipitated. ③Sedimentary genesis, such as the advancement of the delta front will bring abundant dissolved iron and produce chlorite.

There are many possibilities for the formation of chlorite cement in the study area. Its occurrence mainly includes pore liner and pore filling, especially chlorite with pore liner. Pore liner chlorite is formed after mechanical compaction results in the contact of the debris particles, and grows perpendicular to the surface of the debris particles in contact with the pores. It is often used as a film that wraps the particles, so it is also called chlorite film (Figure 3d). The pore-filled chlorite crystals are relatively large, with a high degree of self-shape, and there is no obvious vertical or parallel relationship between the crystals and the elastic particles. Multiple chlorite crystals aggregate together and fill in the residual intergranular pores or secondary dissolved pores in the form of rosettes or scattered flakes (Figure 3e, f).
Figure 3 Microscopic photos of fillings of Chang 6 in Panke area
(a) Honeycomb illite, N72 well, 1283.07m, scanning electron microscope; (b) Intergranular distribution of filamentous illite, N24 well, 1444.49 m, scanning electron microscope; (c) Residual intergranular pores, intergranular See Yilishiqiao, Z55 well, 1238.5m, scanning electron microscope; (d) Extremely developed chlorite membrane, Z85 well, 1820.5m, cast thin section; (e) Residual intergranular pores, chlorite is granular Ring edge, Z55 well, 1240.5m, scanning electron microscope; (f) Soft component deformation, chlorite flake filling pores, Z42 well, 1761.42m, thin cast body; (g) Feldspar sandstone, dense iron calcite Cementation, N108 well, 1209.99m, cast thin section; (h) Iron dolomite cementation, Z14 well, 1381.21m, cast thin section; (i) Quartz secondary enlargement, N80 well, 1633.85m, scanning electron microscope.

3.3. Carbonate cement
The content of carbonate cement in the study area varies greatly, ranging from 0.5% to 15%, with an average content of 5.0% (Figure 1). Its distribution in the stratum is wider than that of illite and chlorite cements. It is mainly distributed in the stratum with a buried depth of 1100m~1900m, and with the increase of buried depth, its content has a increase trend (Figure 2c). The distribution characteristics of carbonate cements are related to their types and formation period. The carbonate cements in the study area are mainly composed of iron calcite and iron dolomite, with only a small amount of calcite and dolomite (Figure 3g, h). Calcite and dolomite are mainly formed in the early stage of diagenesis, which is speculated to be related to the supersaturation of calcium carbonate and alkaline medium in the lake environment of the study area. Iron calcite and iron dolomite are formed in the late diagenesis stage with deep burial. During this diagenesis period, the acidic substances produced by the hydrocarbon generation of Chang 7 oil shale enter Chang 6 under strong hydrocarbon expulsion pressure, which promotes carbonate cuttings and silicic acid. The salt is corroded, so that Fe$^{2+}$, Ca$^{2+}$, Mg$^{2+}$, CO$_3^{2-}$ ions are gradually enriched and precipitated in the form of carbonate cement, forming a large amount of late iron calcite and iron dolomite. A small amount of calcite and dolomite in the early diagenesis and a large
amount of iron calcite and iron dolomite in the late stage make the carbonate minerals generally show the characteristics of less distribution in the shallow part of the formation and more in the deep part.

3.4. Silica cement
Siliceous cements are widely distributed in the sandstone in the study area, but the content is small, with an average of 0.8% (Figure 1), and mainly distributed in the stratum with a buried depth of 1100m~1900m (Figure 2d). Scanning electron microscopy photos show that there are two types of silica with secondary enlarged edges of quartz (Figure 3i) and authigenic quartz particles. Because the formation of silicon requires Si^{4+} and SiO_{2}, organic acids, CO_{2}, H_{2}S, etc. produced by the thermal evolution of the underlying Chang 7 member source rock enter the overlying Chang 6 member sandstone, resulting in the dissolution of feldspar and other aluminosilicates to provide silicon. It is the most important source of material. Therefore, the content of siliceous cement in the deeper stratum is higher than that in the shallow layer.

4. Conclusion
(1) The cements of Chang 6 oil-bearing formation in Panke area, southern Ordos Basin are diverse in types, complex in composition, and high in diagenetic evolution. Mainly include: authigenic cements such as illite and chlorite, carbonate cements such as iron calcite and iron dolomite, and siliceous cements.

(2) As the burial depth increases and the temperature rises, the illite content gradually increases; the chlorite cement is shallower than the main distribution area of illite; with the increase in the buried depth, the carbonate cement content is increasing; the content of siliceous cement in the deeper stratum is higher than that in the shallow layer.

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