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Diagenesis and reservoir quality in continental fault-block reservoirs: Evidence from the Second Member of Shahejie Formation, Dongying Sag, Eastern China

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ABSTRACT: Continental fault-block reservoirs in the Second Member of Shahejie Formation in Dongying Sag of Eastern China are difficult to achieve efficient exploration and development due to the complex geological conditions. This study relates to the in-depth analysis on diagenesis and reservoir quality in such deposits. These deposited sandstones have a wide range of porosity and permeability, which indicate both depositional facies and diagenesis control. Diagenetic processes that influenced the reservoir quality of the study area mainly insist of the formation of carbonate cements, and clay minerals, mechanical compaction, quartz cementation, and dissolution of framework grains. The distribution patterns and mineralogy of cements vary spatially, being relevant to reservoir evaluation. Among the diagenetic menerals, carbonate cements occur as the predominant components in the Shahejie sandstones of the study area. In such settings, the quality-destruction processes include mechanical compaction and carbonate cementation, whereas the quality-generation process is dissolution of detrital grains and calcite cements. The major sequence is eodiagenesis with the types and extent of eogenetic alterations related to the near-surface geological conditions. This study demonstrates diagenesis and related reservoir quality evolution can be linked to fine reservoir characterization, and thereby has an important role on hydrocarbon exploration and exploitation in the continental fault-block reservoirs.

KEYWORDS: Diagenesis, continental fault-block reservoirs, reservoir quality, paragenetic sequence, reservoir characterization.

1 INTRODUCTION

Faults are well developed in many continental fault basins in eastern China, forming a number of fault-block reservoirs. Since most of the fault blocks are generally small, structure and distribution of hydrocarbon and water seem to become relatively complex. Therefore, sandstones in continental fault-block reservoirs vary significantly and reservoir heterogeneity becomes severe, which bring difficulties in hydrocarbon exploration and exploitation.

Diagenesis exerts an important control on the quality and heterogeneity of most clastic reservoirs, and usually accentuates the variations in physical properties [1], [2]. Sandstone diagenesis is on the basis of the formation of depositional sandstones [3]. Carrying out analysis on factors affecting the diagenetic history and summarizing diagenetic model plays an importantl role in predicting distribution of favorable reservoirs and formation of diagenetic traps. The general trend of

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diagenesis is to make the combination of rocks towards a more stable and balance direction in aspects of composition and texture. For this reason, sedimentary rocks will experience changes in mineral composition and adjustments on the rock fabric during the whole series of diagenetic stage.

The studied rocks occur in the Western Dongying Sag of Bohai Bay Basin in eastern China with an aerial extent of about 15.3 km^2. The Second Member of Shahejie Formation (S2) of the study area has long been a site of hydrocarbon exploration and exploitation in China; however, diagenesis and related reservoir quality have not been studied in detail due to the complex geological conditions in these fault-block reservoirs. It is here demonstrated that the diagenesis and reservoir quality contribute to a better understanding of the spatial and temporal distribution of porosity and permeability in such fault-block reservoirs. Also, the research results are expected to resolve the problems of low degree of recovery and low production rate to enrich the knowledge of fine reservoir characterization.

2 METHODS

Sandstone samples were prepared by counting 300 points per thin section, which were vacuum impregnated with red epoxy prior to thin-section preparation. A Quanta 200 scanning electron microscope (SEM) was performed to study cement morphology, paragenetic relationships, and the pore-system geometry in the representative samples, which was coated with a thin layer of gold.

3 RESULTS AND DISCUSSIONS

3.1 DIAGENETIC ALTERATIONS

The S2 Sandstone samples show evidence of variable degrees of mechanical compaction, which refers to the formation of deposits due to the overlying sediments in the heavy load. With sandy sediments deposition after the burial depth increases, mechanical compaction of the detrital grains also from the point contact to point - line contact dominated (Fig. 1A), and plastic particles being deformed are visible in the study area. Chemical compaction, which is manifested by intergranular pressure and lattice formation of quartz cements, is less common.

Carbonate cementation refers to minerals or cements precipitation out of solution from the pores and then the consolidation of loose sediments. It plays an important role in transferring sediments into sedimentary rocks, but also is one of the main reasons of reducing the porosity and permeability of continental reservoirs [4], [5], [6]. Calcite mainly fills the intergranular pores as dominant pore occluding carbonate cement in this area (Fig. 1B), where as dolomite and ankerite occur partially in trace amounts (Fig. 1C).

Quartz overgrowths constituent the main siliceous cementation and always occur on quartz grains with clean surfaces. Generally, quartz overgrowths seem to follow pore-filling growth direction, which occupy the pore space (Fig. 1D), change the pore structure and significantly reduce the reservoir properties. Quartz overgrowths transform sandstone pore structure and cut the original good connectivity pore throats into a series of systems ranging in size pore systems, which greatly reduce their pore throat sorting level. Some angular authigenic quartz outgrows are visible in local area observed in SEM.

In the sandstone reservoirs, the clay mineral cements are difficult to identify in the polarizing microscope due to the limited magnification. However, SEM for mineral identification, basically kind of morphology identification, is easy to compensate these deficiencies according to the typical mineral crystal morphology and crystal polymer morphology to determine minerals [7], [8]. By scanning electron microscopy, clay minerals in this study area mainly involve mixed-layer illite-smectite, kaolinite, illite and minor chlorite. Under controls by parameters such as subsurface pore fluid properties, paleosalinity, debris composition, and diagenesis, these authigenic clay minerals in different depositional and diagenetic environments can form different combination and types, showing the evolution of clay minerals in varying degrees. As an important bridge between inorganic and organic world, clay minerals and their evolution are of extremely importance in the porosity evolution of oil and gas bearing basins. Mixed-layer illite-sectite (I/S), which is the most common clay mineral in the S2 Sandstones, exhibits fiber flake-like textural form with the observation of SEM (Fig. 1E). Chlorite occurs dominantly as leaf-shaped with less content in this study area. Kaolinite occurs as booklets and vermicular aggregates that fill in adjacent pore space (Fig. 1F). SEM observation reveals that the crystal of kaolinite can be often found among a large number of pore spaces. So it is rare to see that kaolinite has completely blocked pores although the pore-filling kaolinite often occupies parts or most of the pore spaces. Illite occurs as scattered patches, which is derived from diagenetic evolution of mixed-layer I/S, as coatings around framework grains or pore-occluding cement (Fig. 1G). Chlorite occurs as pore-filling and thin fringes around detrital grains with a minor content (Fig. 1H). Sandstone cementation is strongly controlled by continental components and its provenance, sediments and sedimentary environments, grain coating of clay minerals, presence and alternation of pore water, impact of hydrocarbon, and so on. The formation conditions of clay minerals are varied, depending on mineral composition of sandstones, the pore fluid properties, temperature and hydrogen ion concentration [9], [10], [11].

Dissolution of minerals in sandstones corresponds to authigenic mineral precipitation, which is common in S2 Sandstones. According to the scanning electron microscope and thin section observation, partial dissolution of feldspars, lithic fragments and carbonate cements can be seen. In contrast with the cementation, dissolution plays an important constructive role on the reservoir space (Fig. 1I). The occurrence of dissolution is the combined effect of chemical, physico-chemical and biochemical factors, leading to a better porosity and permeability in the reservoirs.

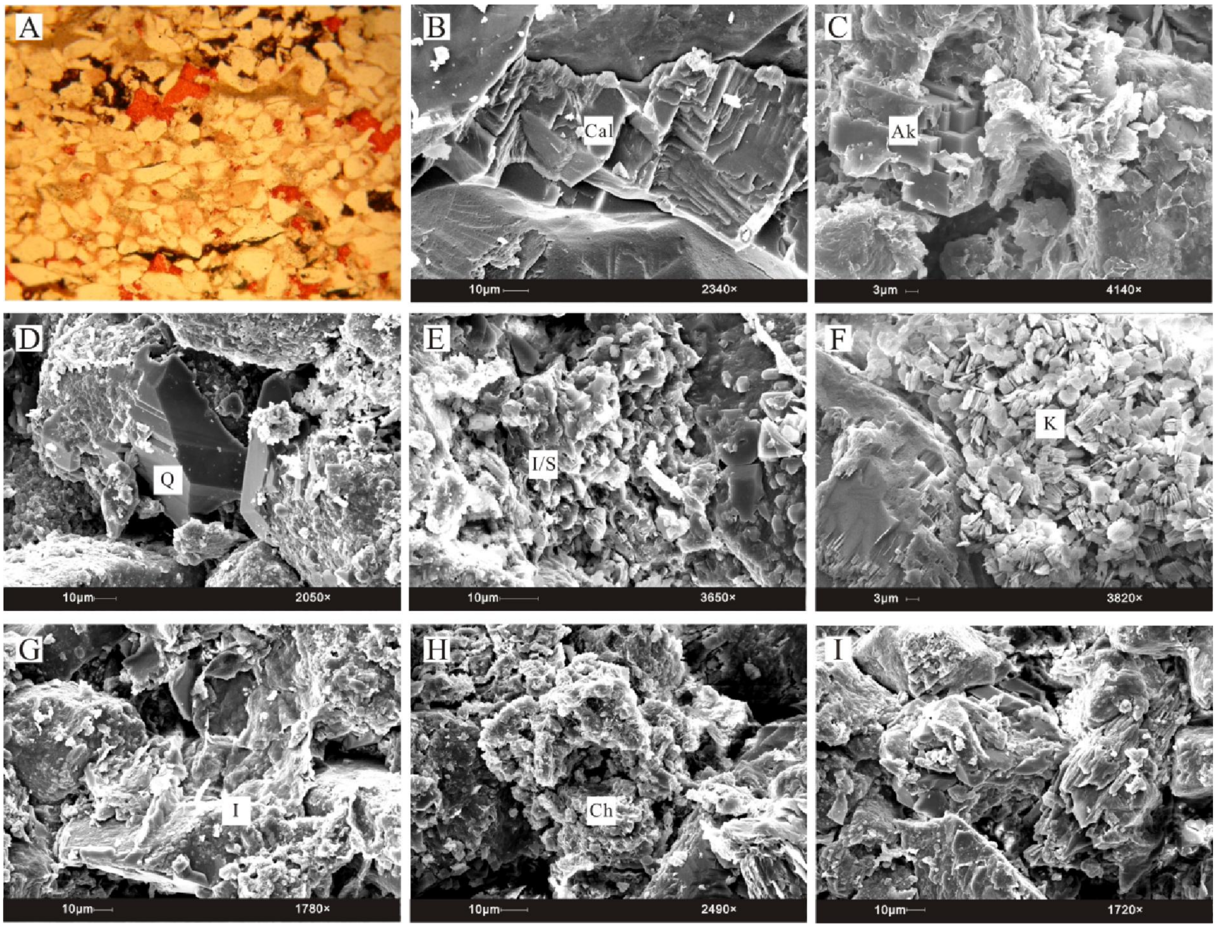

Fig. 1. Thin section and scanning election photomicrographs of the S2 Sandstone subsurface samples

3.2 POROSITY AND PERMEABILITY

The observation of thin section and SEM in the S2 Sandstones reveals that porosity in this area includes primary intergranular, secondary intragranular, intergranular, and mouldic porosity. Micro pores can also be found between clay crystals and within dissolved feldspars. Statistical analysis of reservoir physical properties on core samples shows that there is a large range distribution of porosity and permeability within the study area. Porosity measured by core samples mainly range between 20 to 30% showing a single peak (Fig. 2A), and statistics on permeability occur mainly between 10 to 1000mD (Fig. 2B), reflecting a strong heterogeneity. Also, porosity exhibits a good correlation (r^2=0.8224) with permeability (Fig. 2C), but there is relatively weak correlation between porosity and carbonate contents.

Physical properties of sandstone reservoirs are often controlled by many factors, such as depositional structures and a series of diagenetic process in rock sediments during burial. Sedimentation controls to some extent on the type, shape, size, original condition and spatial distribution of reservoir sands, whereas diagenesis influences reservoir evolution and reservoir physical properties.

According to the statistical data of physical properties in different sedimentary sandstone reservoirs, it shows deposition has relatively good control effect on reservoir properties. The best quality reservoirs appear in distributary channel, whereas mouth bar show a moderate quality and interdistributary display a poor quality (Fig. 2D).

For diagenesis, mechanical compaction and cementation are the main reasons for the destruction of primary porosity. Pore blocking can be seen by carbonate cements in local intervals, which reduce pore space significantly. Dissolution is very common is this area, which is a major constructive factor to improve the reservoir quality.

3.3 Paragenetic sequences of diagenetic processes

Diagenetic stages of clastic reservoirs are the results of interaction among structure change, fluid properties, burial depth and other factors, which determine the degree of maturity of organic matter, and internal composition, structure, properties of sedimentary rocks [12]. Therefore, the determination of diagenetic stages sets an important basis for predicting the formation of oil and gas, and assessing reservoir conditions. Besides, it is of great importance for determining a regional exploration target.

The overall paragenetic sequence of the sandstones is shown in Fig. 3, and the main diagenetic modifications occur in Eodiagenesis. And the diagenetic processes are strongly governed by parameters such as chemical composition of surface waters, detrital composition of the sands, deposition rates, and organic-matter content, which is in turn controlled by pore-water chemistry. Buried depth in the study area is generally between 1950 and 2250m, with mainly semi-consolidated to consolidated, and point - line contact. Precipitation of early calcite, dolomite, and late ankerite cements is visible in S2 Sandstones, resulting in deterioration in reservoir quality. Quartz overgrowth and authigenic quartz crystal occur as core-occluding cements [13]. Clay minerals including mixed-layer illite-smectite, illite, kaolinite, and minor chlorite appear to prevent quartz overgrowth, indicating a preservation of reservoir quality. Feldspar, lithic and calcite can be seen dissolved to form a certain degree of secondary porosity, and thus enhance the reservoir quality to some content.

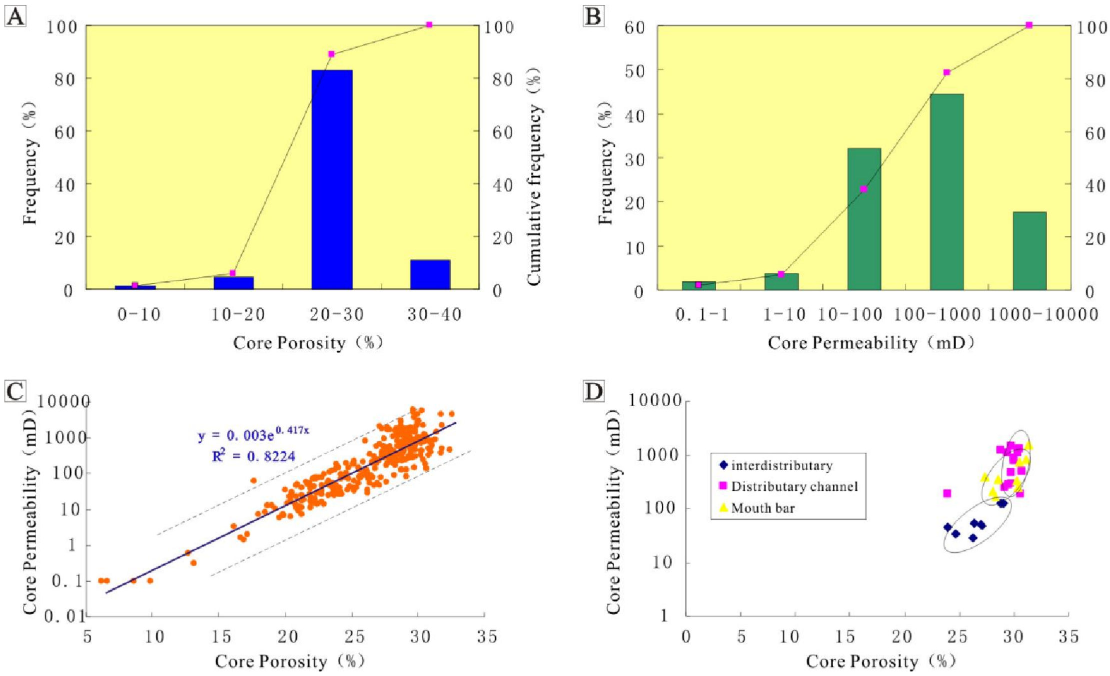

Fig. 2. Maps for the statistical data of physical properties in the study area

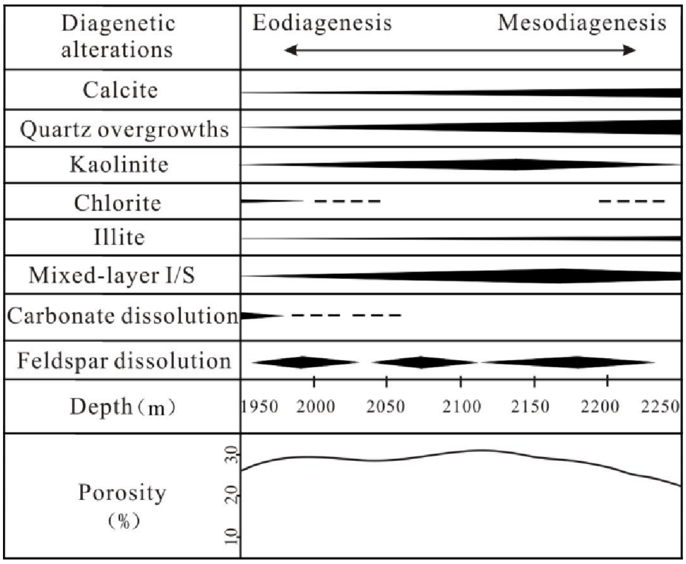

Fig. 3. Paragenetic sequences of diagenetic processes that occurred in the study area

4 CONCLUSION

Fault-block sandstone reservoirs are well developed especially in continental basins of eastern China. Diagenetic alterations that have been linked to the geological conditions include mechanical compaction, precipitation of quartz cements, calcite, dolomite, ankerite, illite, mixed-layer I/S, and kaolinite, and dissolution of carbonates, feldspars, and lithic grains. Diagenesis and depositional facies have controlled the reservoir quality of the study area. Distributary channel and mouth bar sandstones have good-moderate quality, whereas interdistributary sandstones have poor quality. When it comes to diagenetic modifications, sandstones with framework dissolution and precipitation of clay coats are considered to be favorite area with a better potential. Carrying out studies on diagenesis and related reservoir quality are particularly important in the late period in the oil fields development.

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REFERENCES

[1] S. Morad, K. Al-Ramadan, J. M. Ketzer, and L. F. De Ros, “The impact of diagenesis on the heterogeneity of sandstone reservoirs: A review of the role of depositional facies and sequence stratigraphy,” *AAPG Bulletin*, vol. 94, no. 8, pp. 1267-1309, 2010.
[2] S. D. Burley, R. H. Worden, Sandstone Diagenesis: Recent and Ancient. *Blackwell Pub. Ltd*, 2003.
[3] R. L. Folk, Petrology of Sedimentary Rocks. *Hemphill Publishing*, 1980.
[4] R. C. Selley, Elements of Petroleum Geology. *Academic Press*, 1997.
[5] S. Gier, R. H. Worden, W. D. Johns, and H. Kurzweil, “Diagenesis and reservoir quality of Miocene sandstones in the Vienna Basin, Austria”, *Marine and Petroleum Geology*, vol. 25, pp. 681-695, 2008.
[6] A. Karim, G. Pe-Piper, D. J. W. Piper, “Controls on diagenesis of Lower Cretaceous reservoir sandstones in the western Sable Subbasin, offshore Nova Scotia”, *Sedimentary Geology*, vol. 224, pp. 65-83, 2010.
[7] J. A. Kupecz, J. Gluyas, S. Bloch, Reservoir Quality Prediction in Sandstones and Carbonates, *AAPG Memoir 69*, 1997.
[8] N. J. Hancock, A. M. Taylor, “Clay mineral diagenesis and oil migration in the Middle Jurassic Brent Sand Formation, Sandstone diagenesis”, *Journal of the Geological Society of London*, pp. 69-72, 1978.
[9] M. D. Wilson, E. D. Pittman, “Authigenic clays in sandstones: recognition and influence on reservoir properties and paleoenvironmental analysis”, *Journal of Sedimentary Petrology*, vol. 47, pp. 3-31, 1977.
[10] M. E. Tucker, Sedimentary Petrology. *Blackwell Scientific Publications*, 1991.

[11] D. W. Houseknecht, E. D. Pittman, W. D. F. Keller, Origin, Diagenesis, and Petrophysics of Clay Minerals in Sandstones. *SEPM Special Publication 47*, 1992.
[12] F. X. Ying, P. Luo, D. B. He, clastic reservoir diagenesis and diagenetic numerical simulation in petroliferous basin of China. *Petroleum Industry Press*, 2004.
[13] F. Leader, W. Park, "Porosity reduction in sandstone by quartz overgrowth", *AAPG Bulletin*, vol. 70, no. 11, pp. 711-713.