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Original research paper

Reservoir diagenesis research of Silurian Longmaxi Formation in Sichuan Basin, China☆

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Abstract

The reservoir diagenesis of Silurian Longmaxi Formation in Sichuan Basin was studied based on a large number of thin section identification, scanning electron microscopy analysis, X-ray diffraction tests, and some other experiments. Seven diagenetic processes were identified, including compaction, cementation, clay mineral transformation, replacement, dissolution, organic matter thermal maturation, and tectonic disruption. Three kinds of cements (quartz, carbonate and sulfide) were recognized, while the source material of quartz cements and the main factor of forming abundant carbonate cements were summed up. According to the single well analysis of the Well N3, it shows that the best, the suboptimal and the none shale reservoir sections were subjected to different diagenetic transformations. As to best shale reservoir, except for compaction, all the main inorganic diagenesis were significantly related to organic matter maturation. Through comprehensive analysis of diagenetic indicators, it is observed that the reservoir has already been in period B of middle diagenetic stage to late diagenetic stage. The inorganic diagenesis has a significant impact on shale reservoir, because it not only controls the conservation, development, and evolution of porosity, but also the mechanical property and the adsorption capacity of rocks. The organic diagenesis is the source material of shale gas, and it generates a large number of nanoporosity in organic matter, which increases the total porosity and the adsorption capacity of the reservoir.

Keywords: Sichuan Basin; Longmaxi Formation; Shale reservoir; Diagenesis

1. Introduction

Silurian Longmaxi Formation is one of the major black rock series of the Paleozoic layers in the Sichuan Basin. Nowadays, with the development of shale gas exploration, it became the main gas producing shale in the Sichuan Basin [1]. Previous studies showed that the best reservoir in the Longmaxi shale is located in the bottom of the layer, with the characteristics of high GR value (higher than 150API), high TOC content (greater than 2%), and high gas content (greater than 2 m^3/t). It also had complex mineral composition, various rock types, poor pore structure, complex pore types, low porosity, and extremely low permeability and heterogeneity [1−10]. All these geological features show a strong particularity and complexity compared to conventional reservoirs.

Some research has been carried out, but specific work on diagenesis of Longmaxi Formation has not been put into practice yet. Aplin et al. [11] mentioned that many important physicochemical properties of mudstones are

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strongly influenced by the mineralogy and size of the deposited grains, and by diagenetic changes. Therefore, such work will not only expand the understanding of the shale reservoir's geology and clarify the main diagenetic alterations and diagenetic stage, but it can also help find out the controlling factors and degree of diagenesis in terms of shale reservoir. Finally, deeper knowledge aids to provide reliable geological basis for shale gas development. In this paper, we focus on the diagenesis of Longmaxi Formation through the samples from coring wells and outcrops within the basin. Core samples were extracted approximately every meter, and the same set of sample were used in the same experiments including thin section identification, scanning electron microscopy, x-ray diffraction, organic carbon analysis, vitrinite reflectance measurement (equivalent vitrinite reflectance), and conventional porosity analysis. The equipment used including Axio Imager A2 polarizing microscope, XL30 scanning electron microscope, X'Pert MPD X-ray diffractometer, and CS-230 carbon/sulfur analyzer. All these analysis and testing were completed in accordance with the national and industry standards recommended. In addition, the gas content test in field was completed by Weatherford with the sampling density of 1–2 samples per 10 m.

2. Diagenesis of Longmaxi Formation

Worden et al. [12] summarized that diagenesis comprises a broad spectrum of physical, chemical, and biological post-depositional processes by which original sedimentary assemblages and their interstitial pore waters react in an attempt to reach textural and geochemical equilibrium with their environment. These processes are continuously active as the ambient environment evolves in terms of temperature, pressure, and chemistry during the deposition, burial, and uplift cycle of the basin history. Based on a large number of thin section identification, scanning electron microscopy analysis, X-ray diffraction tests, and some other experiments, it showed that the Longmaxi Formation suffered multiple diagenetic changes, including compaction, cementation, clay mineral transformation, replacement, dissolution, organic matter thermal maturation, and tectonic disruption (Table 1). Of all the aforementioned, compaction and cementation reduced the rock's porosity. Meanwhile, dissolution, organic matter thermal maturation, and tectonic disruption increased the porosity, while replacement and clay mineral transformation had a minor effect on reservoir porosity.

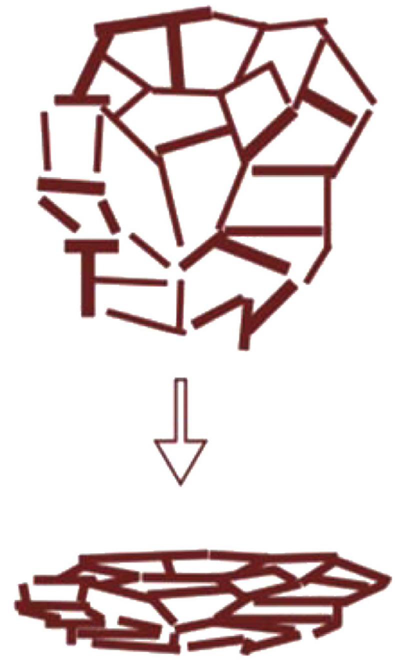

Fig. 1. Compaction of clay [13].

2.1. Compaction

Newly deposited mud consists of an open framework of clay mineral platelets with some silt, sand, pellets, and perhaps a small percent of organic matter; its original porosity value ranges between 60% and 80%. It collapses and deforms gradually as the burial proceeds (Fig. 1), hence, the porosity drops to less than 40% in the first few 100 m while the pore water is expelled. As it goes deeper, the final porosity reduced to only a few percent [13]. Thus, it can be inferred that compaction is the main reason for densification of the Longmaxi Formation. The common compaction signatures in the Longmaxi Formation include directional distribution of sheet-like minerals (Fig. 2) and the ruptured rigid particles.

Table 1
Diagenetic alteration of Longmaxi Formation.

Diagenesis		Diagentic alteration	Effect on porosity
Compaction		Clay mineral and mica bedding orientation	Negative
Cementation	Quartz	Quartz overgrowth, quartz cements precipitation in pore space	Negative
	Carbonate	Calcite and (or) dolomite precipitation in pore space	Negative
	Sulfide	A small amount of granular, nodular and berry pyrite precipitation in pore space	Negative
Clay mineral transformation		Smectite conversion to illlite	Minor
Replacement		Carbonate and (or) clay mineral growth within the body of feldspar	Minor
Dissolution		Feldspar and (or) calcite destroyed by interaction with acid fluid leaving behind a cavity	Positive
Organic matter thermal maturation		forming hydrocarbon and organic pore	Positive
Tectonic disruption		Forming fractures to connect pores	Positive