

Research Article

Hydrocarbon accumulation characteristics and enrichment laws of multi-layered reservoirs in the Sichuan Basin

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Abstract

The Sichuan Basin represents the earliest area where natural gas is explored, developed and comprehensively utilized in China. After over 50 years of oil and gas exploration, oil and gas reservoirs have been discovered in 24 gas-dominant layers in this basin. For the purpose of predicting natural gas exploration direction and target of each layer in the Sichuan Basin, the sedimentary characteristics of marine and continental strata in this basin were summarized and the forms of multi-cycled tectonic movement and their controlling effect on sedimentation, diagenesis and hydrocarbon accumulation were analyzed. Based on the analysis, the following characteristics were identified. First, the Sichuan Basin has experienced the transformation from marine sedimentation to continental sedimentation since the Sinian with the former being dominant. Second, multiple source–reservoir assemblages are formed based on multi-rhythmed deposition, and multi-layered reservoir hydrocarbon accumulation characteristics are vertically presented. And third, multi-cycled tectonic movement appears in many forms and has a significant controlling effect on sedimentation, diagenesis and hydrocarbon accumulation. Then, oil and gas reservoir characteristics and enrichment laws were investigated. It is indicated that the Sichuan Basin is characterized by coexistence of conventional and unconventional oil and gas reservoirs, multi-layered reservoir hydrocarbon supply, multiple reservoir types, multiple trap types, multi-staged hydrocarbon accumulation and multiple hydrocarbon accumulation models. Besides, its natural gas enrichment is affected by hydrocarbon source intensity, large paleo-uplift, favorable sedimentary facies belt, sedimentary–structural discontinuity plane and structural fracture development. Finally, the natural gas exploration and research targets of each layer in the Sichuan Basin were predicted according to the basic petroleum geologic conditions, enrichment laws and exploration status.

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Keywords: Sichuan Basin; Sedimentary characteristics; Structural evolution; Multi-layer; Natural gas; Hydrocarbon accumulation characteristics; Enrichment laws; Exploration domains

Oil and gas exploration in the Sichuan Basin has been carried out for more than half a century [1]. Oil and gas reservoirs, both conventional and unconventional, were discovered from the Sinian to the Jurassic, with the dominance of gas reservoirs, including 24 oil and gas pay zones (of which 18 pay zones are marine facies). In 2005, the proven reserves of natural gas were more than $1 \times 10^{12} \text{ m}^3$, and the annual natural gas production

exceeded $100 \times 10^8 \text{ m}^3$. Within the subsequent ten years, both reserves and production increased rapidly.

In order to predict the targets in future exploration and researches in multi-layered gas reservoirs in the Sichuan Basin, we systematically analyzed the general characteristics of deposits in marine and continental formations in the Sichuan Basin. We also investigated the different forms of multi-cycle tectonic movements since the Sinian and their controlling effects on sedimentation, diagenesis, and hydrocarbon accumulation, and discussed the accumulation features and enrichment laws of conventional reservoirs in this area.

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1. Sedimentary characteristics

Since the Sinian, the Sichuan Basin has witnessed sediments of nearly ten thousand meters [2–4], with diverse rock types and sedimentary systems. Marine carbonates were mainly deposited (with a thickness of 4–7 km) during the Sinian–Middle Triassic, marine–continental transitional facies (with a thickness of 300–400 m) were dominant in the early period of Late Triassic, and continental clastic sediments (with a thickness of 2–5 km) were predominant after the middle period of Late Triassic.

1.1. Marine deposits

In the Sinian–Middle Triassic, the Sichuan Basin was a part of the Upper Yangtze Platform with a relatively stable sedimentary environment. Carbonate sediments were predominant, and clastic rocks were also developed in some formations.

1.1.1. Multi-cycled, multi-rhythmed

In the Sinian–Middle Triassic, multiple sedimentary cycles of transgression–regression occurred [5]. In the transgression period, when the continental shelf or open sea platform was predominant, source rocks were formed. In the regression period, when the restricted sea platform was predominant and shoal facies and lagoons were developed, shoals were formed. Multiple sedimentary cycles formed several sets of source–reservoir assemblages in the Sichuan Basin, and they are the basis for the formation of multi-layered reservoirs.

1.1.2. Vast neritic environments and carbonate platform deposits

The Sinian–Middle Triassic deposits were mostly of neritic or tidal flat facies. Deep-water deposits also existed, but they

were not predominant. Carbonate deposits were dominant, forming a vast platform deposition environment. Generally, the platform contained relatively gentle geomorphology, broad sedimentary facies belts, and small facies belt differentiation. However, this does not mean that the platform was flat; instead, some positive protrusions are favorable for the formation of shoals, while relative depressions are more likely to form a lagoon environment (Fig. 1).

1.1.3. Wide distribution of tide belts

The shore tidal flat was often formed and developed in association with terrigenous province. Long-standing paleocontinents resided in the periphery of the Upper Yangtze region. On the one hand, these paleocontinents provided a source for the sedimentary basins; on the other hand, the paleocontinents, to some degree, controlled the distribution of sedimentary facies. Along the side of paleocontinent, tidal flat deposits were developed in variable scales, generally consisting of debris components.

1.1.4. Extensive development of shoals and reefs in the platform

The margin and inner high-energy belt in the carbonate platform are favorable for the development of reef and shoal bodies. Based on the available data, reefs were developed in the Silurian and Late Permian, while shoals were deposited in several ages, such as Sinian, Cambrian, Ordovician, Permian, and Triassic [6–10]. In general, marginal-platform shoals are large and regular, while intra-platform shoals are dispersive and small.

1.2. Continental deposits

Since the Late Triassic, the Sichuan Basin entered the stage of intra-continental basin evolution, when the continental

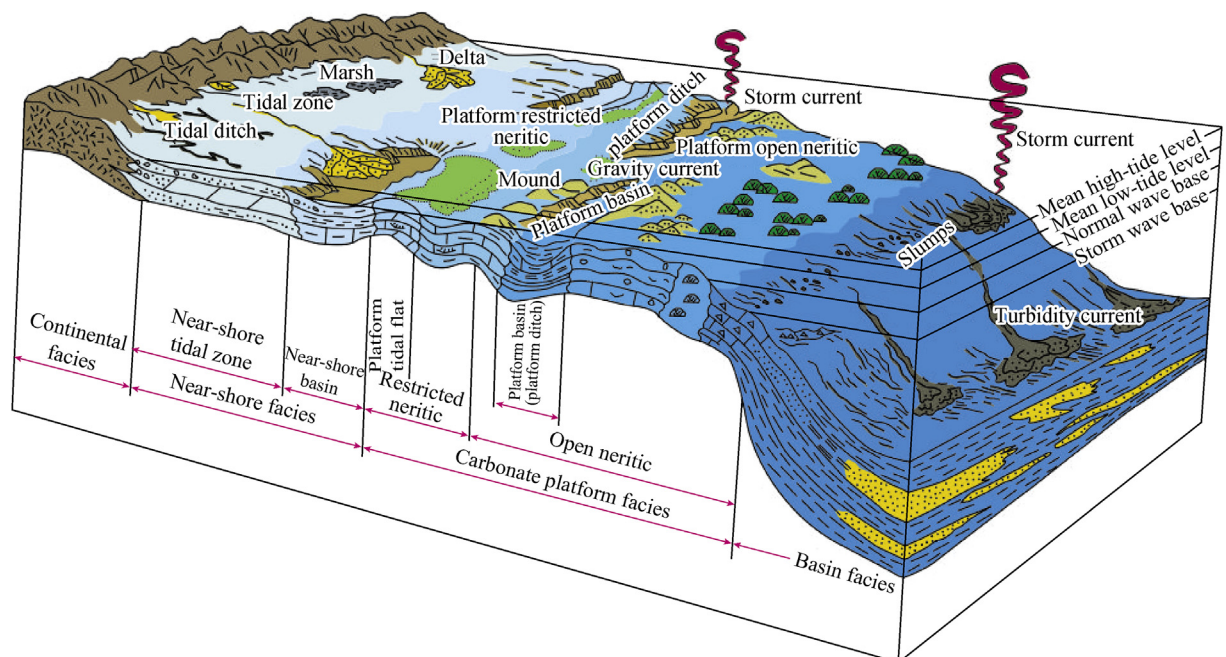


Fig. 1. Model of marine deposits in the Sichuan Basin.

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