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Full Length Article

Formation and evolution of intraplatform basin from the late Sinian to early Cambrian in Sichuan Basin, China

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ABSTRACT

Based on the drilling, logging, seismic and outcrop data, the formation and evolution of the late Sinian to early Cambrian intraplatform basin in Sichuan Basin was studied. Through the analysis of the total residual thickness of Member 3 + Member 4 of Dengying Formation, the total thickness of Maidiping Formation + Qiongzhusi Formation, and lithofacies characteristics of Maidiping Formation, the distribution of the intraplatform basin was defined and its controlling effect on natural gas distribution of Dengying Formation was revealed. The intraplatform basin was characterized by small total residual thickness of Member 3 and Member 4 of Dengying Formation, the large total thickness of Maidiping Formation and Qiongzhusi Formation, and the deep-water phosphorous-carbonaceous-siliceous mudstone in Maidiping Formation. Horizontally, the intraplatform basin was mainly distributed in Qingchuan-Ziyang-Yibin area, and experienced four evolution periods. During the period of Member 1 and Member 2 of Dengying Formation, the Sichuan Basin was a rimmed carbonate platform with the well developed mounds and shoals on the platform margin and its interior. The intraplatform basin in western Sichuan Basin was initially formed due to the first episode of Tongwan movement. During the period of Member 3 and Member 4 of Dengying Formation, the depositional center was formed in Moxi, Changning and Zhengxiong area due to extension and rifting of the Upper Yangtze Craton, thereafter, the Sichuan Basin evolved into a rimmed carbonate platform with an intraplatform basin. The second episode of Tongwan movement between Sinian and Cambrian led to the overall uplift and exposure of Sichuan Basin characterized by weathering denudation at high position and downward fluid erosion at low position. During the period of Maidiping Formation, three lithofacies zones were developed horizontally, and the third episode of the Tongwan movement between Maidiping Formation and Qiongzhusi Formation modified the sedimentary geomorphology locally. During the period of Qiongzhusi Formation and Canglangpu Formation, continuous deposition made the Sichuan Basin evolve into a gentle siliciclastic ramp. The evolution of the intraplatform basin not only promoted formation of high-quality platform-margin dolomite reservoirs of Member 4 of Dengying Formation, but also controlled distribution of the high-quality source rocks of Maidiping Formation and Qiongzhusi Formation. The dolomite of Dengying Formation in the surrounding area of the intraplatform basin was the most favorable hydrocarbon exploration area because of its good source-reservoir configuration.

1. Introduction

Since the discovery of Weiyuan gas field in Sichuan Basin in 1964, PetroChina has conducted a serial of explorations on the dolomite reservoir of Dengyin Formation in Sichuan Basin. From the 1970s to the 1990s, 11 structures including Longnvsi, Anpingdian, Ziyang, etc. were explored, only finding Ziyang gas field (with probable reserves of 10.2×10^9 m^3 and possible reserves of 33.8×10^9 m^3) (Hou et al., 1999; Zhang and Zhang, 2002; Chen, 2010; Du et al., 2014; Xu et al., 2014; Zou et al., 2014). In 2011, the test of Well GS1 in Member 2 of Dengying Formation in central Sichuan Basin obtained natural gas with a production of 1.02×10^6 m^3/d. After nearly 3 years of overall evaluation and fast exploration, by the end of December of year 2013, 23 out of 27

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completed wells in Gaoshiti-Moxi area had obtained commercial gas flow, with preliminary probable natural gas reserves of nearly 500×10^9 m^3 (Du et al., 2014; Xu et al., 2014), exhibiting great exploration potential of the dolomite of Dengying Formation. During the hydrocarbon exploration of the Sinian to Lower Paleozoic strata, an intraplatform basin during the late Sinian to early Cambrian was discovered in western and southern Sichuan Basin, where there was a direct unconformity contact between the Cambrian Terreneuvian MaidiPing Formation and Member 2 of the Upper Sinian Dengying Formation, while Member 3 and Member 4 of Dengying Formation were absence. Besides, the thickness of Maidiping Formation and the Qiongzhusi Formation in the intraplatform basin amounted to about 700 m, with the lithology of black pelite, silty mudstone, and limestone with siliceous dolomite, indicating good hydrocarbon generation capability (Liu et al., 2013; Song et al., 2013; Zhong et al., 2013; Wang et al., 2014). Moreover, Weiyuan, Ziyang gas fields and most high-production wells in Moxi-Gaoshiti area were distributed on both margins along the intraplatform basin. The natural gas in Dengying Formation mostly from the Lower Cambrian source rocks, implied that the high-quality source rocks in the intraplatform basin and Dengying dolomite reservoir had a favorable source-reservoir configuration, and distribution of natural gas reservoirs of Dengying Formation was controlled by the intraplatform basin.

Formation of the intraplatform basin had been explained from the viewpoint of tectonism and karstification. For example, it was believed to be a tensional trough (Liu et al., 2013; Song et al., 2013 Zhong et al., 2013) or rift trough (Du et al., 2014; Wang et al., 2014; Zou et al., 2014) formed by uplifting and denudation during the later period of the Dengying Formation and extension in early Cambrian, or a large nearly-SN-trending erosion valley by karstification at the end of the Sinian (Yang et al., 2014a; Li et al., 2015). And the distribution of the intraplatform basin was described using the thickness of the Cambrian Maidiping Formation to Canglangpu Formation and the thickness of the Cambrian Maidiping Formation and Qiongzhusi Formation or residual thickness of the upper Sinian Dengying Formation (Liu et al., 2013; Song et al., 2013; Zhong et al., 2013; Li et al., 2015; Wang et al., 2014; Yang et al., 2014a). The authors found that the pattern of lithofacies paleogeography of Dengying Formation had a direct effect on formation and distribution of the late Sinian to early Cambrian intraplatform basin. Therefore, the evolution of the intraplatform basin was comprehensively analyzed from the perspective of sedimentary evolution on the basis of previous studies and data of drilling, logging, outcrops and seismic exploration. The result revealed that the first episode of Tongwan movement between Member 2 and Member 3 of Dengying Formation formed the prototype of a marine basin, which was further extended during the period of Member 3and Member 4 of Dengying Formation. The intraplatform basin was shaped by tectonic uplifting and fluid incision at the end of Dengying Formation, filled continuously and withered away during the period of Maidiping Formation and Canglangpu Formation. The distribution of the intraplatform basin was defined by the thickness of Maidiping Formation and Qiongzhusi Formation and lithofacies zoning characteristics and the hydrocarbon geological significance was revealed.

2. Geological setting

The Sichuan Basin was a second-order tectonic unit of Yangtze Craton, including the major part of Sichuan Province and Chongqing City with an area of about 0.18×10^6 km^2. The wells drilling of the Sinian and Cambrian reservoirs mainly were in central and western Sichuan Basin, and outcrops of the Sinian and Cambrian were commonly developed in the periphery of the basin. The intraplatform basin (namely Qingchuan-Ziyang-Yibin intraplatform basin) of the late Sinian to early Cambrian studied in this paper was mainly distributed in the northwestern and southwestern Sichuan Basin as well as the eastern Yunnan Province (Fig. 1).

Basement of Sichuan Basin and its periphery were mainly formed in Archaean and early Proterozoic, and developed steadily in the Mesoproterozoic with central Sichuan Basin as the continental nucleus, around which were some pre-Sinian rifts (Pan et al., 1987; Guo et al., 1996; Gu and Wang, 2014; Yang et al., 2014b), characterized by the tensional faults on seismic profile (Guo et al., 1996; Zhong et al., 2013; Gu and Wang, 2014; Yang et al., 2014b). Some tectonic movements (e.g., Jinning movement) in the middle and late of Mesoproterozoic led to strong folding, magmatic intrusion, and regional metamorphism of the basement, and the continental crust was consolidated and expanded, providing the base for development of caprocks of the Upper Yangtze craton (Guo et al., 1996), among which central Sichuan Basin was a rigid uplift basement, but the western and eastern Sichuan were the plastic depression basement (Song, 1987; Gu and Wang, 2014). The deposits overlying the basement included the Sinian to Middle Triassic marine carbonate rocks and the late Triassic to Eocene continental siliciclastic rocks.

In the early Sinian (the depositional period of Doushantuo Formation), a suite of black shale, silty shale, and thin-bed carbonate rocks with the total thickness of 0–250 m was deposited in the periphery of Sichuan Basin, while pebbly sandstone with smaller thickness was distributed inner the basin. Afterwards, the major of the Upper Yangtze Platform transgressed to form a shallow carbonate platform, in which algal dolomite of 500–900 m thick of Dengying Formation was developed. The overlaying sediments were siliceous-phosphorous dolomite, black siliciclastics, and granular dolomite of the early Cambrian, and dolomite of restricted platform and tidal flat of Mid-Late Cambrian (Fig. 2).

According to the lithological and electrical properties, Dengying Formation could be divided into Member 1 to Member 4. Cambrian including Maidiping Formation, Qiongzhusi Formation, Canglangpu Formation, Longwangmiao Formation, Gaotai Formation, and Xixiangchi Group (Fig. 2). Tongwan movement occurring during the late Sinian to early Cambrian (Liu et al., 2013; Gu et al., 2014; Xing et al., 2015) led to strong denudation or erosion of Sichuan Basin and its surrounding areas. Three regional unconformities could be observed in the drilling, outcrops and seismic profiles (Gu et al., 2014; Wang et al., 2014; Xing et al., 2015), which were responses of three episodes of Tongwan movement. The first episode occurred between Member 2 and Member 3 of Sinian Dengying Formation, and the second episode occurred between Sinian Dengying Formation and Cambrian Maidiping Formation, and the third episode occurred between Lower Cambrian Maidiping Formation and Qiongzhusi Formation.

3. Identification of the intraplatform basin

Previous studies revealed a gulf lagoon was developed in eastern Yunnan Province during Lower Cambrian Maidiping Formation (Chen and Chen, 1987; Qian, 1999), where the sediment was mainly the phosphorous-carbonaceous-siliceous mudstone. Through the analysis of drilling data, Well Zi 4 and Gaoshi Well 17 have similar lithological features to outcrops in the gulf lagoon in East Yunnan Province. Considering thickness of strata and characteristics of seismic responses, this gulf lagoon extended to the north, through Leibo, Yibin, Mianyang, Qingchuan, etc., and connected directly to open ocean, therefore, an intraplatform basin (namely Qingchuan-Ziyang-Yibin intraplatform basin) was developed in the studied area.

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