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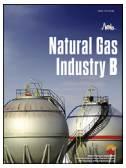

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Sedimentary mode and reservoir distribution of the Cambrian carbonate & evaporate paragenesis system in the Sichuan Basin

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Abstract

The Cambrian carbonate & evaporite paragenesis system in the Sichuan Basin is made up of the Longwangmiao, Gaotai and Xixiangchi Fms. So far, great breakthrough has been made only in the Longwangmiao Fm instead of the latter two, and the Anyue Gasfield was discovered in the center of this basin. In this paper, therefore, the Cambrian carbonate & evaporite paragenesis system in the Sichuan Basin was analyzed in terms of its structural−sedimentary setting, sequence stratigraphic framework, sedimentary facies and the distribution of evaporites by using various geologic, logging and seismic data. Then, the geological model of sedimentary facies was established and the distribution range of favorable reservoirs was predicted. Based on these studies, the following results are obtained. Firstly, the palaeotectonic framework is characterized by the style of "one depression between two uplifts" in the setting of a large SE dipping slope, and the stratigraphic filling is in the structure of "onlapping at the bottom and truncation at the top" which is thin in the west and thick in the east. Secondly, three third-order sequence cycles which, on the whole, become shallow upward are developed from bottom to top, and gypsum-salt rocks are mainly located at the high system tract (HST) of third-order sequences and concentrated in the Wanzhou−Yibin sag. Thirdly, the geological model of sedimentary facies is composed of three major sedimentary structural layers from bottom to top, namely the evaporative carbonate ramp, the evaporative diamictic restricted platform and the evaporative restricted platform. The sedimentary environment changes from the open to the closed and the penesaline for a long time, and then back to the open. The distribution of shoals changes from the pattern of "dual banks" in a large area to more scattered shoals and banded shoals, while the evaporative lagoon and tidal flat shrink. Fourthly, the reservoir distribution is complicated and mainly controlled by the sedimentary pattern of palaeotectonics, the grain shoals and the exposed surfaces of sequences with different orders. The favorable areas for reservoir development are located above the paleo-uplift and its surroundings, at the slope-break belt in the platform and in the periphery of platform margin.

Keywords: Sichuan Basin; Cambrian; Carbonate & evaporite paragenesis; Palaeotectonic framework; Stratigraphic sequence; Gypsumsalt rocks; Sedimentary model; Reservoir distribution

Cambrian formations in the Sichuan Basin, with a thickness of 100−2000 m, are significantly different in stratigraphic classification and nomenclature in subregions [1−3]. They include (from bottom to top) the Lower Cambrian Maidiping, Qiongzhusi, Canglangpu and Longwangmiao Fms, the Middle Cambrian Gaotai Fm and the Middle−Upper Cambrian Xixiangchi Group in the central Sichuan Basin, the Lower Cambrian Jiulaodong Fm, the Middle−Lower Cambrian Yuxiansi Fm and the Middle−Upper Cambrian Xixiangchi Group in southern Sichuan Basin, and the Lower Cambrian Maidiping, Qiongzhusi, Canglangpu and Longwangmiao Fms, the Middle Cambrian Douposi Fm and the Middle−Upper Cambrian Longwangmiao or Erdaoshui Fm and Xixiangchi

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Group in southwestern SW Sichuan Basin. The stratigraphic classification and nomenclature for the Lower Cambrian and the Middle−Lower Cambrian are basically the same in eastern and southwestern SW Sichuan Basin, while the Middle−Upper Cambrian includes Maotian, Houba, Pingjing or Shilengshui Fm and Xixiangchi Group. The stratigraphic classification and nomenclature for Cambrian in the central Sichuan Basin are adopted in this paper.

According to the researches of many scholars [4−8], in the Sichuan Basin, the Lower Cambrian Maidiping and Qiongzhusi Fms are defined as excellent source rocks, consisting dominantly of siliceous or carbonaceous shale and dark mudstone of continental shelf, the Canglangpu Fm is the shore shelf-diamicitc platform facies deposition, while the Longwangmiao Fm, Gaotai Fm and Xixiangchi Group are a representative of carbonate−evaporite paragenesis system (namely, a marine sedimentary system made up of carbonate rocks, sulfate rocks, halides and thin fine sandstones and mudstones of unequal amount). A certain scale of gas reserves have only been discovered in the Longwangmiao Fm and Xixiangchi Group of the Cambrian carbonate−evaporite paragenesis system in Ziyang−Weiyuan and Moxi−Gaoshi areas currently, while in other areas, the logging interpretation or gas well testing from wells penetrated the system mainly suggest that the system is often characterized by water layers, water-bearing lower-yield gas layers or dry layers, where the exploration process is restricted seriously by unclear distribution and formation of reservoirs. Although numerous substantive results in the characteristics, formation and distribution of the Longwangmiao Fm reservoirs have been achieved [8−21], and some researches about the lithology, distribution and genetic model of Cambrian gypsum-salt rocks have been conducted [22−29], the sedimentary facies distribution, favorable reservoir distribution and the main controlling factors of the carbonate−evaporite paragenesis system have not been figured out yet. In this study, these outstanding aspects are highlighted in so that further exploration of the system can be carried out effectively.

1. Structural−sedimentary setting

The Sichuan Basin is located at the western margin of the Middle−Upper Yangtze landmass. According to many scholars [3−16], at the end of Sinian, regional extensional rifting and strongly differential uplifting and subsidence were active in the basin as a result of the Tongwan tectonic movement and adjacent landmass splitting, and the basin is surrounded by Motianling, Pengguan, Baoxing and Kangdian ancient lands at its N, NW, W and SW margins respectively, with multiple craton marginal rifted basins developed. Moreover, block faulting activities occurred inside the basin, making strata highly denuded, thus forming two stratigraphic low-relief paleo-uplifts (Ziyang−Weiyuan and Moxi−Gaoshiti) and the nearly SN rift in its primary form along Deyang−Anyue. As block faulting activities were enhanced by the Xingkai tension tectonic movement in Early Cambrian, the Deyang−Anyue rift was formed. Thus, the structural−sedimentary framework of "one depression between two uplifts" was established (Fig. 1). The "one depression" refers to the Deyang−Anyue intra-platform rift, which was filled with the Lower Cambrian Maidiping ($\epsilon_1 m$) and Qiongzhusi ($\epsilon_1 q$) Fm deep-water shelf facies siliceous phosphate dolomite, phosphate black shale, black carbonaceous shale, siliceous rocks and siliceous dolomite. The "two uplifts" refer to the Ziyang−Weiyuan uplift and the Moxi−Gaoshiti low-relief paleo-uplift in the east and west sides of Deyang−Anyue rift, which were primarily filled with $\epsilon_1 m$ and $\epsilon_1 q$ thin shallow-water shelf facies dark gray silty mudstone and argillaceous siltstone interbedded with fine sandstone. During the deposition of Lower Cambrian Canglangpu Fm ($\epsilon_1 c$), due to the Early Caledonian compressional movement, a series of ancient lands along the NW−SW margin of the basin were uplifted, and the merging and combined growth of 2 paleo-uplifts (Weiyuan and Gaoshiti) within the basin gave rise to a large underwater paleo-uplift, which was filled with a set of regression shore shelf-diamictic platform facies deposits, characterized by rift filling and leveling up. In view of sedimentary paleogeography, it presents a large slope dipping from west or northwest to southeast. During the deposition of the Lower Cambrian Longwangmiao Fm ($\epsilon_1 l$)−Upper Cambrian Xixiangchi Group ($\epsilon_3 x$), with the Caledonian compressional movement, the basement fault along Huayingshan and Qiyaoshan was activated, giving rise to a series of syndepositional faults. Specifically, the Huayingshan and Qiyaoshan faults were syndepositional faults with opposite inclinations with a certain size, which changed the sedimentary paleogeographical framework into the "one sag between two uplifts" overlapped on a large SE dipping slope. The "two uplifts" are low uplifts respectively in the west of Huayingshan fault and the east of Qiyaoshan fault. The "one sag" is the Wanzhou−Yibin sag between the faults (Fig. 1), which creates favorable conditions for the later deposition of the evaporative carbonate ramp slope and the evaporative restricted carbonate platform.

2. Stratigraphic filling and geological characteristics

2.1. Stratigraphic filling and sequence stratigraphic framework

Based on cores, outcrops, drilling and seismic interpretation and logging interpretation, and in combination with previous research results [1,2,9−15], a comparative study is made on sequence stratigraphic framework and sedimentary facies (Fig. 2). From bottom to top, the Cambrian is mainly composed of various sedimentary systems including clastic shelf, diamictic shelf, evaporative ramp slope platform, diamictic evaporative restricted platform and evaporative restricted platform, with six third-order sequences (SQ1−6), which correspond to Maidiping Fm, Qiongzhusi Fm, Canglangpu Fm, Longwangmiao Fm, Gaotai Fm and Xixiangchi Group (namely $\epsilon_1 m$, $\epsilon_1 q$, $\epsilon_1 c$, $\epsilon_2 l$, $\epsilon_2 g$ and $\epsilon_3 x$) respectively. The Cambrian carbonate−evaporite paragenesis system consists of three regression third-order sequence cycles (SQ4−6),

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