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Research article

Petroleum geological features and exploration prospect of deep marine carbonate rocks in China onshore: A further discussion☆

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Abstract

Deep marine carbonate rocks have become one of the key targets of onshore oil and gas exploration and development for reserves replacement in China. Further geological researches of such rocks may practically facilitate the sustainable, steady and smooth development of the petroleum industry in the country. Therefore, through a deep investigation into the fundamental geological conditions of deep marine carbonate reservoirs, we found higher-than-expected resource potential therein, which may uncover large oil or gas fields. The findings were reflected in four aspects. Firstly, there are two kinds of hydrocarbon kitchens which were respectively formed by conventional source rocks and liquid hydrocarbons cracking that were detained in source rocks, and both of them can provide large-scale hydrocarbons. Secondly, as controlled by the bedding and interstratal karstification, as well as the burial and hydrothermal dolomitization, effective carbonate reservoirs may be extensively developed in the deep and ultra-deep strata. Thirdly, under the coupling action of progressive burial and annealing heating, some marine source rocks could form hydrocarbon accumulations spanning important tectonic phases, and large quantity of liquid hydrocarbons could be kept in late stage, contributing to rich oil and gas in such deep marine strata. Fourthly, large-scale uplifts were formed by the stacking of multi-episodic tectonism and oil and gas could be accumulated in three modes (i.e., stratoid large-area reservoir-forming mode of karst reservoirs in the slope area of uplift, back-flow type large-area reservoir-forming mode of buried hill weathered crust karst reservoirs, and wide-range reservoir-forming mode of reef-shoal reservoirs); groups of stratigraphic and lithologic traps were widely developed in the areas of periclinal structures of paleohighs and continental margins. In conclusion, deep marine carbonate strata in China onshore contain the conditions for widely and intensively preserving hydrocarbons, so large oil or gas fields are expected.

Keywords: China onshore; Marine carbonate rocks; Deep zone; Source kitchen; Intensive reservoirs; Resource potential; Exploration prospect

1. Introduction

The marine carbonate rocks in China, unlike those in other countries, are mostly distributed in lower structures of basins. They are ancient and deeply buried, with a large time span, a multiple hydrocarbon-bearing series of strata and a complex reservoir-forming history [1,2]. In recent years, with the deepening of geologic recognitions and the progress of exploration technologies, a series of significant breakthroughs have been made in the exploration of deep marine carbonate reservoirs in China. For instance, firstly, with more efforts in the two palaeohighs in the Tarim Basin (northern Tarim Palaeohigh, Tazhong Palaeohigh), an Ordovician Yingshan Fm karstic fracture-vug type large oilfield was discovered in the Halahatang area on the slope at the southern fringe of the northern Tarim Palaeohigh, and significant breakthroughs were made in several target zones like Ordovician Lianglitage Fm reef-shoal and Yingshan Fm karst on the northern slope of the Tazhong faulted zone. Secondly, through exploration in the

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reef-shoal in the platform fringe zone of Kaijiang-Liangping trough in the Sichuan Basin, some large gas fields like Tieshanpo, Luojiazhai, Puguang and Longgang were discovered. Besides, by further exploration in the Lower Paleozoic-Sinian carbonate rocks in the Palaeohigh of central Sichuan Basin and its slope area, strategic breakthrough was made − a large Cambrian Longwangmiao Fm integral gas reservoir was discovered. Thirdly, by virtue of enhanced exploration to the carbonate weathered crust karst reservoir in the Ordos Basin, a new breakthrough was made in the karstic zone in the western Jingbian gas field, and a new gas-bearing series of strata were discovered in the $Mawu_{4-10}$ member of Ordovician ($O_1m_5^4$−$O_1m_5^{10}$). Based on the recent exploration results, the buried depth of hydrocarbon-bearing series of strata is universally deeper than 4000 m, or even 7000 m in the Tarim Basin, exhibiting favorable prospects of deep-ultra-deep marine carbonate reservoirs.

2. Trend of marine carbonate exploration

2.1. Definition of deep zone

The definition of a deep zone doesn't follow any strict criteria in the world, but varies depending on countries. Generally, oil and gas reservoirs with a buried depth of more than 15 000 ft (4500 m) are defined as deep reservoirs.

In the *Calculation Specifications for Petroleum Reserves* issued by the National Mineral Reserves Committee (China) in 2005, a buried depth of 3500−4500 m is defined as a deep zone and buried depth >4500 m as an ultra-deep zone. In drilling engineering, 4500−6000 m is adopted as a deep zone, and more than 6000 m as an ultra-deep zone. Due to the difference in geothermal fields and exploration practice of eastern and western China, deep and ultra-deep zones are cognized as 3500−4500 m and more than 4500 m respectively in eastern China, and 4500−5500 m and more than 5500 m in western China. Even as per the traditional definition of a deep zone in western China, the marine carbonate discoveries made over the years in China are also included as deep zones.

2.2. Trend of marine carbonate exploration

2.2.1. Marine carbonate exploration in the world

Marine carbonate reservoirs take a dominant position in the world oil and gas production. According to the statistics of IHS in 2000, marine carbonate hydrocarbon resources account for about 70% of the total in the world, and the proved recoverable oil and gas reserves account for 50% of the total. In 2011, the oil and gas output of marine carbonate reservoirs accounted for about 63% of the total oil and gas output of the world.

Triggered by the international increasing energy supply and demand contradiction, carbonate reservoirs attract the global sights with more and more investment. Deep carbonate reservoirs have become the hotspot of petroleum exploration and development in the world. As is shown in the statistics on the buried depth of main pay zones in the large carbonate fields discovered before 2009, prior to 2000, the number of large fields with a buried depth of main pay zone exceeding 4000 m accounts for 14.8% of the global large carbonate fields; after 2000, this proportion has risen to 58.6% (Fig. 1). Deep carbonate reservoirs have become an important target to discover large fields in the world. For example, in the hotspot areas like the Latin American and the Far East, where some carbonate fields were discovered recently, the buried depth of main pay zones is generally more than 4000 m. Some large fields have main pay zones exceeding 5000 m, e.g., the Yoloten-Osman giant gas field discovered in Turkmenistan in 2004, and the Kish-2 giant gas field discovered in Iran in 2005.

2.2.2. Marine carbonate exploration in China

Compared with the basins in the world, those hydrocarbon-bearing basins in China are dominantly superimposed basins, and the marine carbonate strata are mostly distributed in the lower structures and they are ancient and deeply buried. The exploration of marine carbonate strata in China have experienced a complicated and hard process from the exploration of Lower Triassic Jialing Jiang Fm in the Sichuan Basin at an early stage, to the discovery of buried hills in the Bohai Bay Basin and Jingbian gas field in the Ordos Basin, and to the discovery of Lunnan-Tahe oilfield in the Tarim Basin.

Now, marine carbonate exploration in China is extending gradually from middle-deep zones to deep-ultra-deep zones. Based on the statistics on exploration depth in China, the depth of major reservoirs discovered prior to 2000 is generally less than 4500 m. For example, in the Renqiu oilfield discovered by carbonate buried hill exploration in the Bohai Bay Basin and the Jingbian gas field discovered by carbonate weathered crust reservoir exploration in the Ordos Basin, the buried depth of all major reservoirs is less than 4000 m. In recent years,

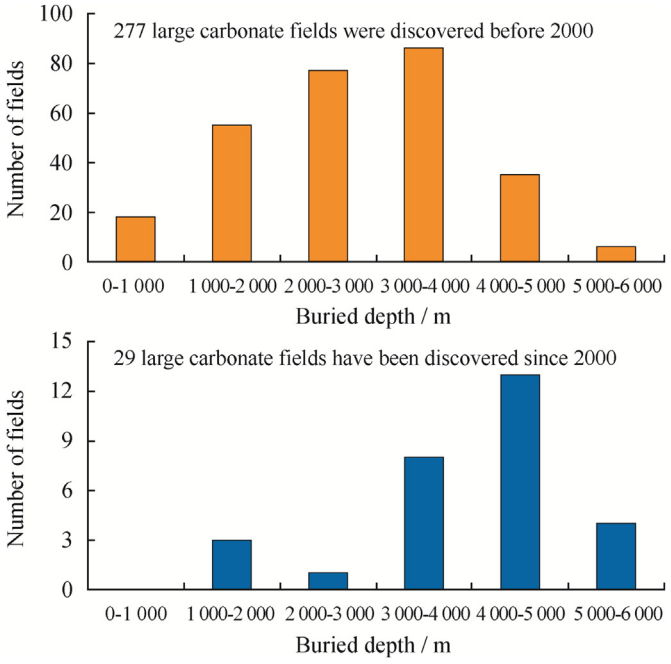

Fig. 1. Buried depth of large carbonate fields discovered in the world before and after 2000.