



New knowledge of hydrocarbon generating theory of organic matter in Chinese marine carbonates



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Abstract: The marine carbonates of the Tarim Basin are taken to study the relationship between source rock and oil and gas reservoirs and discuss the possibility and mechanisms of mature and low-TOC (less than 0.5%) marine carbonates being source rock. By studying the matching relationship between source rocks in Tarim Basin and hydrocarbon reservoirs in Tahe oilfield and analyzing the hydrocarbon-generating organism combination and its correlation with geochemical characteristics of oil and gas reservoirs, this study established a method to evaluate hydrocarbon generation substance of marine carbonate source rocks. It is concluded that the crude oil of the Tahe oilfield in the Tarim Basin is not derived from muddy source rocks, but has the obvious characteristics derived from carbonate source rocks. It revealed that the underestimated hydrocarbon-generating substance (organic acid salts) in the highly evolved marine carbonate rocks and high quality hydrocarbon-generating organism are the key to high-evolution carbonate rocks being as source rock. Organic acid salts have high hydrocarbon conversion rate and are mainly cracked into natural gas at high temperature. The development model of the source rocks of the Cambrian-Lower Ordovician carbonate source rocks in the Tarim Basin is dominated by the shelf model.

Key words: Tarim Basin; carbonate rocks; hydrocarbon source rock; hydrocarbon-generating organism combination; organic acid salts; hydrocarbon generating theory

Introduction

Before the breakthrough of Chinese continental oil and gas exploration, it had been universally believed that source rock in marine formations is the most important source of conventional oil and gas in the exploration circle. For source rock in marine formations, the conventional mudstone source rock and high TOC (> 0.5%) carbonate source rock were the mainstay, and great achievements have been made in the exploration of marine oil and gas based on this theory. The discovery of the largest marine oilfield in the Tarim Basin—the Tahe Oilfield, the discovery of Lower Paleozoic gas in Ordos Basin, and the second exploration breakthrough of natural gas in the marine lower assemblage in the Sichuan Basin demonstrate the huge exploration potential of marine oil and gas in China. However, with the deepening of oil and gas exploration, it is found that some large-scale marine oil and gas fields have no

corresponding massive mudstone source rock and high TOC carbonate source rock. Currently, more and more exploration and geological evidences show that only taking high TOC mudstone and carbonate as source rock can't explain reasonably many questions of the exploration of marine oil and gas, thereby directly affecting fine exploration and resource evaluation of marine oil and gas. On one hand, oil explorers and petroleum geologists have been still looking for high-quality source rock; on the other hand, people started to doubt the idea that only the conventional high TOC source rock (argillaceous source rock) is hydrocarbon source of marine oil and gas. In ancient marine formations, there might be source rocks other than high TOC source rock, therefore, it is necessary to find out the possibility of carbonate with high thermal evolution level and low TOC value acting as source rock.

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With the discovery and deepening exploration of Lunan-Tahe, Tazhong Oilfields in the Tarim Basin, Jingbian gas field in the Ordos Basin, and other large oil and gas fields, a lot of researches on marine source rock have been conducted, however the source of oil and gas is still unclear and there are serious divergences on oil and gas source^[1–9]. Based on the geological and geochemical analysis of the Paleozoic sedimentary strata in China, the possibility of carbonate with high thermal evolution level and low TOC value acting as source rock has been discussed in combination with petroleum geochemical characteristics, hydrocarbon generation organism combination, hydrocarbon conversion, and geological process.

1. Global carbonate source rocks

The statistics on different types of source rocks in global petroliferous basins show that the argillaceous rock-dominated source rock accounts for 42% of the total source rock, while the source rock related with carbonate accounts for 58% of all the source rock^[10–11], and the carbonate source rock provides nearly half of oil and gas resource in the world's large oilfields^[12]. High-quality carbonate source rock in the low-medium thermal evolution stage has a TOC value of 8%–2%, while in the high thermal evolution stage, its TOC value rapidly decreases to 1%–4%, so it is speculated the TOC value of source rock with better parental material types decreases substantially in the evolution process. Jarvie systematically analyzed the TOC variations during evolution and considered that the TOC of source rock with good organic matter types could reduce by up to 80% in the high evolution stage; while the TOC value of source rock with poor organic matter types could reduce by up to 20%^[13–14], which is of great significance for the evaluation of high-thermal evolution, low-medium TOC carbonate rock in China. For the carbonate rock with low TOC value in the high thermal evolution stage, the possibility of this kind of carbonate having high TOC value in the low-to-medium thermal evolution stage can't be ruled out.

2. Confusion of China's marine oil and gas exploration and source rock understanding

China's oil and gas exploration for a long time has been concentrated in the continental basins, where the discovery rate of oil and gas resources is 30%–40%. The exploration of marine oil and gas has found 13 large and massive oil and gas fields, but the proven rate of resources is only about 10%, much lower than the China continental and global marine oil and gas exploration rate (69%). The Lower Paleozoic marine carbonate rock formations are even lower in exploration degree, with natural gas exploration rate of only 7%^[15–17].

A lot of researches on the marine source rock previously have reached the following findings^[3–11]: (1) argillaceous source rock is still the main source rock type; (2) the carbonate source rock show the features of low TOC value, and good hydrocarbon parent material type, and the potential of carbon-

ate rock can't be evaluated effectively at present; (3) in source rock with low TOC, there might be unrecognized hydrocarbon generation substances which can generate large amounts of hydrocarbons.

At present, China's marine oil and gas exploration is facing an obvious confusion of mismatch between source and reservoir, and China's three major marine oil and gas basins are taken as examples to illustrate. (1) The source of oil and gas of Tahe oilfield discovered in the Tarim Basin is still unknown, and so far, no conventional organic-rich high-quality source rock in the hydrocarbon generation stage has been found there. The spatial distribution and geochemical characteristics of high TOC value source rock layers found are not completely consistent with those of the hydrocarbons found in the massive oil and gas reservoir^[18–20]; (2) Jingbian large-scale oil and gas fields have been found nearly 20 years, while the geochemical characteristics of natural gas show that the gas is derived from Paleozoic marine source rock^[21–25], neither the geological research nor drilling has found the corresponding high quality hydrocarbon source rock; moreover, horizontal wells drilled in the Middle Ordovician Ma 5 Member black carbonate layer in the east of the central palaeo-uplift and the west part of the Jingbian gas field of the Ordos Basin recently obtained industrial gas flow, the natural gas seems to have originated from the traditionally-understood Permian coal-bearing source rock, but there are no migration and accumulation conditions for injection migration; (3) in the Sichuan Basin, the Paleozoic source rock is very well developed, and the Cambrian Niutitang (Qiongzhusi) Formation and the Silurian Longmaxi Formation both contain high-quality mudstone source rock with high TOC, but, corresponding large-scale natural gas reservoirs have not been found; however, the natural gas of large-scale reservoirs are mainly derived from the Carboniferous-Permian argillaceous and marlitic source rock, and only the Carboniferous gas in the eastern Sichuan Basin is sourced from the Silurian Longmaxi Formation; it is thought the gas source of the Anyue large-scale gas field discovered in the paleo-uplift of central Sichuan Basin in 2013, is related to Qiongzhusi Formation source rock^[26]. From the above discussion, the large scale marine oil and gas reservoirs found in the Tarim Basin have no definite source rocks; in the upper and middle Yangtze region, there develop several sets of high quality source rock, but there aren't corresponding scale of hydrocarbon reservoirs; the Ordos Basin is rich in oil and gas, but the Paleozoic source rock has still not been found. Meanwhile, the geochemical characteristics (including biomarkers and macromolecule compounds) of the discovered large-scale marine oil fields, especially the Tahe oilfield in the Tarim Basin, all show the characteristics of carbonate source rock. Therefore, it is necessary to re-examine the possibility of low TOC value marine carbonate rock in the high thermal evolution stage in China acting as source rock.

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