Evaluation and formation model of Cambrian high-quality source rocks in the southeast margin of North China Plate

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Abstract. In response to the question of whether effective Cambrian source rocks are developed in the North China Plate, field investigations on the southern margin of North China have been carried out. High-quality marine argillaceous source rocks of continuous thickness of 35 m in the Lower Cambrian were discovered in the south-eastern margin of North China Plate. Phosphorus nodules are common in the source rocks. The TOC is 1.19% ~ 29.70%, with the average of 7.31%. The organic matter comes from low-level biological algae. Because the carbon isotope of kerogen is relatively more negative, it is judged to be mainly benthic algae. The converted vitrinite reflectance (Ro) from measured bitumen reflectance is 2.24% ~ 3.45%, which is an over-mature source rock. The Lower Cambrian source rocks in the southern margin of North China occurred under the background of rising sea levels. After the glaciers on the southern margin of the North China Plate melted, the Qinling rift trough developed and the stratum subsidence caused rapid transgression of seawater from southeast to northwest. At this time, algae multiply in large numbers, and after death they accumulate with phosphorus-containing materials to form phosphorus-containing organic matter. Benthic algae mainly live in deep-water shelf not affected by waves and tides. Therefore, the development of source rocks is mainly in the deep water shelf.

1. Introduction
High-quality Cambrian source rocks have been discovered in the Tarim and Yangtze plates, and oil and gas exploration has been conducted on this set of source rocks, and a series of oil and gas fields have been discovered, such as Hetianhe gas field and Tahe oil field in Tarim Bain, Weiyuan gas field and Anyue gas field in Sichuan Basin, etc. The North China Plate is located between the Tarim and the Yangtze. Does the Cambrian source rock also exist in the North China Plate? How about its quality and what is the formation process? These issues are currently unclear. In response to the above problems, we took the Hefei Basin on the southeastern margin of the North China Plate as the research object, and discovered a complete set of Cambrian source rocks in the Meishan section of the Hefei Basin (Figure 1). Systematic sampling and comprehensive geochemical analysis of source rocks had been carried out, and some insights in source rock evaluation and formation model had been obtained.
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Figure 1. Distribution of gas fields and petroleum systems in Leshan-Longnvsi paleo-uplift

2. Discovery of Cambrian high-quality source rocks in Meishan section

The Meishan section is located in the eastern part of the southern margin of the North China Block and the northern side of the Dabie Orogenic Belt. It is located in the forty-mile Changshan belt at the junction of Huoqiu County, Anhui Province and Gushi County, Henan Province. It belongs to the collisional junction of the North China Plate and the Yangtze Plate (Figure 1). Thick moraine conglomerates are generally developed beneath the lower Cambrian, which is named Fengtai Formation, also known as Fengtai Conglomerate [1]. Above the Fengtai conglomerate, there are thick layers of Cambrian source rocks, which are a set of source rocks formed after glacier melting by climate warming. The effective thickness of the source rocks is 35m. The source rock is black shale, and phosphorus nodules are common in the source rock (Figure 2). Above the source rock is the Cambrian Houjiashan Formation, which is a lithological combination of interbedded limestone and dolomite (Figure 3).

Figure 2. Photograph of Cambrian source rock on outcrops in the southern margin of North China
(A: The lower part of the source rock; B: Middle part of source rock, with a truck as the scale; C: Phosphorus nodules in source rock; D: The upper part of the source rock, with the highest organic carbon content)
At the beginning of this century, researchers discovered a set of thick continuously deposited Cambrian source rocks on top of the Fengtai conglomerate in the outcrop area of the Hefei Basin [2-5], but the profile was incomplete, and the samples were mostly weathered. The top and bottom boundaries of the source rock cannot be determined, which brings some uncertainty to the evaluation of the Cambrian source rock. In recent years, due to mining in the area, fresh strata have been exposed, giving us a new understanding of Cambrian source rocks. We not only obtained fresh samples of the source rock, but also discovered the boundary between the top and bottom of the Cambrian source rock and determined the exact thickness of the source rock.

3. Evaluation of Cambrian Source Rocks in Meishan Section

3.1. Abundance of source rocks

The continuous thickness of the source rocks on this profile is about 35m. Among the 50 samples collected, the TOC is 1.19% at the lowest and 29.70% at the highest, with an average of 7.31%, which is a high-quality source rocks with high organic content. It can be clearly seen from the geochemical profile that the organic carbon in the upper part of the source rocks is significantly higher than that in the lower part (Figure 3). In the lower 22m source rock, TOC is 1.19% to 2.49, with an average of 1.90%; in the upper 12m source rock, TOC is 5.08% to 29.7%, with an average of 13.65%.

3.2. Type of organic matter in source rocks

Through the identification of biological types of Cambrian source rocks, the organic matter is dominated by lower biological algae. Some fragment of benthonic algae and Laminarites sp. had been found. The kerogen carbon isotope of the Cambrian source rocks in the southern margin of North China are relatively more negative, compared with Tarim and Sichuan basins (Figure 4). According to the standard of kerogen carbon isotope to identify the type of organic matter [6], the Cambrian source rock in South China and North China is type I. The kerogen exhibits the characteristics of benthic algae. Because planktonic algae consume carbon from the atmosphere and benthic algae consume...
carbon that is decomposed by lower organisms in the sea. So, the carbon isotopes of kerogen produced by benthic algae are more negative than planktonic. This has been confirmed by previous research [7-9].

Table 1. $\delta^{13}$C$_{Kerogen}$ of Cambrian source rocks in the southern margin of North China

| Sample numble | Stratigraphy | Lithology   | $\delta^{13}$C$_{Kerogen}$, ‰ (VPDB) |
|---------------|--------------|-------------|--------------------------------------|
| D22           | Cambrian     | Black shale | -32.7                                |
| D18           | Cambrian     | Black shale | -33.7                                |
| D10           | Cambrian     | Black shale | -33.2                                |
| D6            | Cambrian     | Black shale | -33.6                                |
| D3            | Cambrian     | Black shale | -33.4                                |

Figure 4. Comparison of kerogen carbon isotopes of Cambrian source rocks in the southern margin of North China with the Sichuan and Tarim basins

3.3. Maturity of organic matter in source rocks
The six bitumen reflectance (Rb) measured are 2.83%~4.644%, and the vitrinite reflectance (Ro) converted by the regression formula Ro=0.668Rb+0.346 are 2.24%~3.45%. Due to the high evolution degree of organic matter, most of the organic matter has already undergone hydrocarbon generation and expulsion, so the hydrocarbon generation potential (PG) of the current source rocks is relatively low, ranging from 0.02 to 0.12mg/g, with an average of 0.06mg/g.

4. Development pattern of Source rocks
The formation of the phosphorus-containing bed is due to the phosphorus-rich seawater flowing up the continental slope in the deep ocean, bringing phosphorus-containing materials to the shelf and coastal zone and depositing together with the clastic deposits to form phosphorus rocks or phosphorus-containing deposits. The formation of phosphorus-containing bed includes two situations: low sea level and high sea level. The former phosphorus-containing bed has a smaller distribution range, while the latter has a larger distribution range. After the glaciers on the southern margin of the North China Plate melted, due to the development of the Qinling rift trough, the stratum subsidence led to rapid transgression of seawater from southeast to northwest. The area affected by the transgression is mainly the southern margin of the North China Plate. In the northeast, only some areas encountered
transgression [10]. At this time, the main body of the Ordos Basin belonged to ancient land and did not accept deposition.

![Diagram showing the formation model of Cambrian source rocks in the southeast margin of North China Plate](image)

**Figure 5.** Formation model of Cambrian source rocks in the southeast margin of North China Plate

Therefore, the Lower Cambrian source rocks in the southern margin of North China occurred under the background of rising sea levels. Due to the higher sea level, the phosphorus-containing bed were widely developed and distributed in a larger area. At this time, algae multiply in large numbers, and when they die, they accumulate with phosphorus-containing substances to form phosphorus-containing organic matter. Studies have shown that the organic matter of Cambrian source rocks in the southern margin of North China is dominated by benthic algae (the author will elaborate in future research developments), and benthic algae mainly live in deep-water shelf that is not affected by waves and tides. The development of source rocks is also mainly in the deep-water shelf, and its distribution range is much smaller than that of the phosphorus-containing bed.

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