



# Petroleum geological conditions and exploration importance of Proterozoic to Cambrian in China



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**Abstract:** The discovery of the giant Anyue gas field in Sichuan Basin gives petroleum explorers confidence to find oil and gas in Proterozoic to Cambrian. Based on the reconstruction of tectonic setting and the analysis of major geological events in Mesoproterozoic–Neoproterozoic, the petroleum geological conditions of Proterozoic to Cambrian are discussed in this paper from three aspects, i.e. source rocks, reservoir conditions, and the type and efficiency of play. It is found that lower organisms boomed in the interglacial epoch from Mesoproterozoic–Neoproterozoic to Eopaleozoic when the organic matters concentrated and high quality source rocks formed. Sinian–Cambrian microbial rock and grain-stone banks overlapped with multiple-period constructive diagenesis may form large-scale reservoir rocks. However, because of the anoxic event and weak weathering effect in Eopaleozoic–Mesoproterozoic, the reservoirs are generally poor in quality, and only the reservoirs that suffered weathering and leaching may have the opportunity to form dissolution-reconstructed reservoirs. There are large rifts formed during Mesoproterozoic–Neoproterozoic in Huabei Craton, Yangtze Craton, and Tarim Craton in China, and definitely source rocks in the rifts, while whether there are favorite source-reservoir plays depends on circumstance. The existence of Sinian–Cambrian effective play has been proved in Upper Yangtze area. The effectiveness of source-reservoir plays in Huabei area depends on two factors: (1) the effectiveness of secondary play formed by Proterozoic source rock and Paleozoic, Mesozoic, Cenozoic reservoir rocks; (2) the matching between reservoirs formed by reconstruction from Mesoproterozoic–Neoproterozoic to Eopaleozoic and the inner hydrocarbon kitchens with late hydrocarbon generation. As for Tarim Basin, the time of Proterozoic and the original basin should be analyzed before the evaluation of the effective play. To sum up, Proterozoic to Cambrian in the three craton basins in China is a potential exploration formation, which deserves further investigation and research.

**Key words:** Proterozoic; Cambrian; tectonic setting; major geological events; interglacial epoch; source rock; microbial rock; intracratonic rift; play

## Introduction

Though great oil and gas discoveries have been obtained in the Proterozoic–Cambrian in some regions, such as Central Asia and North Africa<sup>[1–2]</sup>, it is not clear on whether ancient layers are valuable for exploration worldwide. Chinese researchers studied Proterozoic petroleum geology during the 1970s–1980s; however, the studies, restrained by available data, were mainly about the Sinian System in the Sichuan Basin<sup>[3]</sup> and its peripheral regions and the Mesoproterozoic in Jixian county of Tianjin city<sup>[4]</sup>. The discovery of the giant Anyue gas field in the Proterozoic–Cambrian of the Sichuan Basin<sup>[3,5]</sup> proves that there are good prospects for exploring oil and gas in the Proterozoic–Cambrian in China, and gives petroleum explorationists confidence to find oil and gas in ancient layers.

The Sichuan Basin, Tarim Basin and Ordos Basin in China

are all cratonic basins with Archean basement. The Proterozoic–Cambrian strata in these basins have an area of more than  $300 \times 10^4 \text{ km}^2$ , and the layers with proved oil and gas reserves are mainly in the Ordovician and its overlying formations, with little proved reserves in the Proterozoic–Cambrian. Is the discovery of the giant Anyue gas field only a special local case or a regional directive breakthrough? For answering this question, we must solve the following three basic geologic problems: (1) During the Mesoproterozoic and Neoproterozoic periods, the organisms on the earth were lower and simple. Whether could large-scale high-quality source rocks be universally formed? (2) The Proterozoic–Cambrian formations have ancient ages and bigger burial depths, and they experienced multiphase diagenetic reformation. Whether could large-scale effective reservoir beds be developed? (3) Whether is the effective Proterozoic–Cambrian play primary type with self-generation and self-storage, or secondary type

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with old-generation and new-storage?

Our research team has continuously studied the basic petroleum geology of Proterozoic–Cambrian, analyzed source rock development mechanism of source rocks and conditions for forming microbial reservoir rocks during interglacial epoch. Moreover, on the basis of describing the intracratonic rifts, taking source rock evaluation as the center, we evaluated favorable exploration regions. Our studies concluded that the Mesoproterozoic, Neoproterozoic and Cambrian in Huabei Craton, Yangtze Craton, and Tarim Craton all developed large-scale high-quality hydrocarbon kitchens, effective reservoir beds, and primary and secondary plays, so exploration in these regions has feasibility.

## 1. Tectonic setting and major geological events during Mesoproterozoic and Neoproterozoic Eras

Compared with Phanerozoic time, the earth evolution, plate movement scale and feature, ancient oceans, atmospheric circulation and microbial systems during Pre-Cambrian all had specialties<sup>[6–8]</sup>, which profoundly affected the Proterozoic petroleum geologic conditions.

### 1.1. Small earth surface area and similar continents

According to the earth expansion theory, continuous asymmetric finite expansion ceaselessly occurred during earth evolution<sup>[9–10]</sup>, and the earth surface area continuously increased with time. Paleomagnetic data show<sup>[10]</sup> that the earth radius during Mesoproterozoic, Neoproterozoic and Cambrian were 76%, 81% and 94% of current earth radius, respectively. The earth surface area during the Proterozoic Era was much smaller than present. This indicates that the distances between all the continents during the Proterozoic Era were not much remote, thus they had consistent or similar deposits and tectonic events. Moreover, during the Proterozoic Era, the ancient climate consistency (for instance, the Huronian glacial epoch at 2.4 Ga and the snowball event at 800–600 Ma etc. all performed as global events<sup>[6,8]</sup>) and relative flatness of continental terrain (super large sedimentary facies belt development and similar filling sequences. For example, the major source rocks in Mesoproterozoic<sup>[2]</sup>, deposits and event stratification records of glacial epoch etc. in Neoproterozoic<sup>[8]</sup> were global) mean that the petroleum geology elements in various major land blocks during Proterozoic Era had similar development settings, and they have more similarities in petroleum geology conditions than diversities.

### 1.2. Lower atmospheric oxygen content and generally worse weathering

Compared with Phanerozoic time, because of lower atmospheric oxygen content during the Proterozoic Era (generally <1% of present atmospheric oxygen content)<sup>[8,11]</sup>, the weathering on significant geologic interfaces was universally weaker. Generally, oxidation, hydrolysis and leaching of source rock by oxygen, water and various acids are important

weathering processes. However, in hypoxic setting, chemical weathering is not easy to occur or much weaker, thus even formations exposed for long during Proterozoic Era, they suffered weaker weathering, and large-scale karst type, and weathering-leaching type of reservoir beds are hard to form.

### 1.3. Enriching radioactive substances are an important factor for over flourishing lower organisms

The Proterozoic earth had smaller volume and crust thickness than the present. Thus, we can judge that compared with the present situation, the Proterozoic volcanic activities were more and bigger. Along with volcanic eruption, considerable radioactive substances from mantle were scattered into atmosphere and then fell into marine water, or accumulated together with deposits<sup>[12]</sup>. According to modern actual live observation and medical cases, excessive radioactive radiation may lead to abnormal creature growth (such as overgrown rats at Chernobyl nuclear leak scene in former Soviet Union) and over-speed growth of cells (such as cancer occurrence). If from the viewpoint of organic materials, these events are all excessive creature flourishing and excessive increase of hydrocarbon matrix. Experiments also indicate that radioactivity can also promote conversion of organic material to hydrocarbons<sup>[13–14]</sup>, especially the conversion from heavy substance to light substance. Industrial development of shale gas implies researchers that the sections with high TOC values and enriching shale gas usually contain higher radioactive substances<sup>[15]</sup>, which also proves that high radioactive substance content can promote organic material enrichment.

### 1.4. The similarity of petroleum geology is more than diversity; the success in one region can guide other regions

Many Proterozoic tectonic events indicate that there were several continents during that period. Though the present continents are remote from each other, the distances between them during Proterozoic period were much smaller than present, thus there are many generality, similarity and comparability of deposit feature, sedimentary facies scale, lateral stability of deposit sequences, geologic process of tectonic event and the related petroleum geologic conditions between various continents. Though the exploration degree and cognition degree for Proterozoic–Cambrian in the cratonic basins are generally lower, the successful exploration in one region can provide reference for evaluating oil and gas resources in other regions while from the development generality of petroleum geology conditions, which is beneficial for deepening our cognitions on Proterozoic Erathem.

## 2. Proterozoic–Cambrian petroleum geologic conditions

Three major cratons (Huabei, Yangtze and Tarim) in China preserve relatively complete Proterozoic–Cambrian strata<sup>[16–17]</sup>. The formation, evolution and development of cratonic rifts in the Mesoproterozoic–Neoproterozoic period had significant

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