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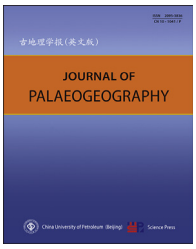

Lithofacies palaeogeography and sedimentology

The sedimentological characteristics of microbialites of the Cambrian in the vicinity of Beijing, China

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Abstract With oil and gas exploration transferring to deeper and more ancient marine strata, more researches have been conducted about the Meso–Neoproterozoic and Cambrian microbial carbonate rocks by petroleum geologists. The Cambrian deposits experienced the first transgression of the Paleozoic, with shallow marine facies depositing in most areas, which are favorable for different kinds of biological reproduction. The Lower Cambrian in Beijing area is lithologically dominated by purple red shales interbedded with limestones, the Middle Cambrian is mainly composed of thick oolitic limestones, and the Upper Cambrian consists of thin limestones and flat-pebble conglomerates. Two beds of microbial carbonate rocks were discovered in the Cambrian outcrops in the vicinity of Beijing. One is from the Zhangxia Formation of Middle Cambrian, and the other is from the Gushan Formation of Upper Cambrian. The microbialites are characterized by combination of multiple stromatolites forming different bioherms. The bioherms are mostly in oval shape and with different sizes, which are 3–4 m long, and 1–3 m high. The surrounding strata beneath the bioherms are oolitic limestones. A central core of flat-pebble conglomerates occurred within each bioherm. Wavy or columnar stromatolites grow on the basis of flat-pebble conglomerates, with dentate erosional surfaces. The bioherm carbonate rocks are interpreted as products from a deep ramp sedimentary environment where potential oil and gas reservoirs can be found. The analysis of sedimentological characteristics of bioherm carbonate rocks and its lithofacies palaeogeography has significant implication for petroleum exploration. Research on geological record of microbialites is beneficial to investigating the Earth evolution, biodiversity, palaeoenvironment and palaeoclimate change, as well as biological extinction event during geological transitions. It also gives warning to human beings of modern biological crisis.

Keywords Cambrian, Stromatolite, Bioherm, Microbialite, Oil and gas reservoir, Marine sedimentary environment, Beijing

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1. Introduction

The marine Cambrian is important for oil and gas exploration in China. Many new discoveries in Ordos Basin, Tarim Basin and Sichuan Basin, especially in oil and gas reservoirs of microbialites attracted strong interests of petroleum geologists. Stromatolites were widely distributed in ancient marine environments (Bhat *et al.*, 2012; Chang and Zheng, 2012). The complicated process of metabolism in microbial community forms special and complex microfabrics of carbonate rocks grains including benthic radial ooids, oncolites and thrombolites *etc*. (Mei *et al.*, 2015). Previous studies indicated that stromatolites were related to microbial mat. For example, the carbonate ramp preserved microbial fabrics in Carawine Formation, Hamersley Group of Archean in western Australia, which represented the special environment of subtidal zone (Murphy and Sumner, 2008). Dupraz *et al.* (2009) summarized the microbial composition of main element circulation in microbial mat which indicated that the integrating activity of key microbial combination with similar metabolism controlled main element circulation such as oxygen, nitrogen, sulfur and carbon circulation. These microbial combinations included: (1) photosynthetic petrification autotrophs (*i.e.* cyanobacteria); (2) aerobic (chemically organic) heterotrophic organisms; (3) fermenting organisms; (4) anaerobic heterotrophic organisms (mainly sulfate-reducing bacteria); (5) sulfide oxidation (sulfide-oxidizing bacteria); (6) anaerobic photoautotrophic microorganisms (*i.e.* purple and green sulfur bacteria); and (7) methane bacteria. The stromatolite biostromes were discovered from the Fengshan Formation of the Cambrian in Xishan area of Beijing (Mei *et al.*, 2015). On the basis of geological survey, two beds of microbial carbonate rocks were discovered from the Cambrian outcrops in the vicinity of Beijing. One is the Zhangxia Formation of Middle Cambrian, and the other is the Gushan Formation of Upper Cambrian. The microbialites were characterized by combination of multiple stromatolites forming different bioherms (Gao *et al.*, 2009; Mei, 2014).

2. Geological setting and methods

In North China, the Cambrian deposited in areas including Beijing, Yinchuan, Xi'an, Hefei, Qingdao and Shenyang cities. The Cambrian is distributed at 42°—30° N and 106°—126° E (Fig. 1) (Pan *et al.*, 2013). It is divided into 10 formations in North China (Table 1). Among these formations, Zhangxia Formation, equivalent to Drumian Stage of international stratigraphic division, belonged to the Middle Cambrian; and Gushan Formation, equivalent to Guzhangian Stage, belonged to the Upper Cambrian. The Lower Cambrian unconformably overlay the Meso—Neoproterozoic (commonly Jixian System or Qingbaikou System) in the vicinity of Beijing (Wu *et al.*, 2016). The boundary between the Cambrian and the Ordovician is conformable mostly in North China, occasionally disconformity occurred in the western North China. During the Xinji depositional period of the Early Cambrian, the first marine transgression began in North China. When sea water flew into the eastern and southern part, land occurred on the north-western area which is named giant North China Palaeoland. It is a peneplanation palaeoland which supplied fine clastic materials to marine area (Li *et al.*, 2014; Scotese, 2009). The deposits from adjacent area were sandy mudstone and muddy dolostone interpreted as tidal flat. The outer is open sea and broad carbonate platform.

The transgression reached its maximum at Zhangxia Age, Middle Cambrian. Consequently, there were oolitic beaches all over the carbonate platform. During the Late Cambrian, carbonate platform was covered by flat-pebble conglomerate beaches. The land shrunk, mud flats vanished, and dolomite flats appeared which indicated the peneplanation went further (Feng *et al.*, 2004; He, 2010).

The purpose of this research is to explain the distribution of the microbialite and its significance for petroleum exploration. Detailed information has been acquired by research on 40 published papers, observation of 12 outcrop profiles (in total about 2400 m long), which locate in Beijing, Shanxi and Shanxi Provinces respectively, and analyses of 35 rock thin sections. The photographs of outcrops were taken by Nikon D700 camera, and interpreted with Microsoft PowerPoint 2010. While the analyses of thin sections were conducted by polarizing microscope of Leica DM4500P YQ08008. The maps and graphs were compiled by CorelDRAW X4.

3. The sedimentary characteristics of the Cambrian bioherm

The studied Cambrian strata are distributed in Xishan area and Northern Mountains (Fig. 1). The strata are exposed particularly well in Yongding River