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Calcified microbial reefs in Cambrian Series 2, North China Platform: Implications for the evolution of Cambrian calcified microbes

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ABSTRACT

This study focuses on the microbial reefs of the Zhushadong Formation (Cambrian Series 2) in Shandong Province, China in order to understand the evolution of calcified microbes in the North China Platform during the Cambrian Series 2 and 3. The microbial reefs occur in a thin unit, ca. 3 m thick, over an area of 1 km^2. They consist of three types of thrombolite based on their mesostructures: rimmed, grainstone-patch, and dendritic. The thrombolites mainly occur in various coarse-grained carbonate facies, including crudely stratified oolitic grainstone, stromatolitic grainstone, and disorganized limestone conglomerate. Calcified microbes in the thrombolites include *Epiphyton*, *Kordephyton*, a tubiform microbe, *Bija*, *Tarthinia*, *Renalcis*, *Amgaina*, and *Razumovskia*. The Zhushadong thrombolites were formed within a grainstone shoal, and experienced repeated burial and exposure. The rimmed thrombolite and grainstone-patch thrombolite experienced abundant input of carbonate grains (forming grainstone patches). In contrast, the dendritic thrombolite formed solely by calcification of microbes that mainly include *Epiphyton*, *Tarthinia*, and the tubiform microbe. The outer crusts of the rimmed thrombolite were formed by *Amgaina*, under high energy conditions.

The diverse calcified microbes of the Zhushadong Formation form the earliest assemblage of their type in the North China Platform. Their descendants, mostly *Epiphyton*, subsequently thrived, forming a ca. 180 m thick microbialite–oolite-dominated succession during the Cambrian Series 3 (Zhangxia Formation). Although the reefs in the Zhushadong Formation are much smaller than those of the overlying Zhangxia Formation, their calcified microbes are more diverse. This most likely reflects changes in depositional environments (e.g., abundant siliciclastic input and tidal effects vs. those of a stable carbonate platform), and/or global changes within reef environments (e.g., end-Cambrian Series 2 extinction of archaeocyaths and calcified microbes). A decrease in diversity of calcified microbes in the North China Platform, where archaeocyaths were absent, may help to account for evolutionary trends in calcified microbes that occurred independently of archaeocyath influence.

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1. Introduction

Calcified microbes firstly appeared in the Precambrian and diversified greatly from the base of the Cambrian (Turner et al., 1993; Zhuravlev, 1996; Riding, 2001; Kah and Riding, 2007). During the early Cambrian (Terreneuvian and Series 2), calcified microbes formed reefs together with archaeocyaths in various localities including Siberia, Laurentia, North Africa, South China, Australia, Europe, and Antarctica (Rowland and Gangloff, 1988; Rowland and Shapiro, 2002; Gandin and Debrenne, 2010; and references therein). Although the diversity of calcified microbes decreased during the late Cambrian Series 2 along with the extinction of archaeocyaths (end-Cambrian Series 2 extinction event), microbes still constructed reefs during the Cambrian Series 3 without reef-building metazoans (Zhuravlev, 1996; Zhuravlev and Wood, 1996; Pratt et al., 2001; Riding, 2001).

The end-Cambrian Series 2 extinction event was most likely caused by global environmental change such as anoxic oceanic conditions (Sinsk Event) and global regression (Hawke Bay Event) (Zhuravlev and Wood, 1996). These global events are thought to have resulted in modification of the calcified microbial community. For example, Zhuravlev (1996) suggested that loss of the ecological niche created by framework-building archaeocyaths, and homogenization of microbial communities due to the extinction of tiny grazers, could have caused the decrease in calcified microbe diversity. However, just how these mechanisms and global events reduced the diversity of calcified microbes has not been studied in detail.

In order to examine the relationships between the end-Cambrian Series 2 extinction event and decrease in the diversity of calcified microbes, this study focused on the Cambrian Series 2 microbial reefs

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in the North China Platform, where a variety of microbial reefs flourished and formed extensive deposits during the Cambrian Series 3 (Woo et al., 2008; Woo and Chough, 2010; Howell et al., 2011). New discoveries of calcified microbes in the Cambrian Series 2 deposits, and comparison with those of the Cambrian Series 3, help to clarify the evolutionary history of calcified microbes on the North China Platform. Furthermore, the absence of archaeocyaths from the North China Platform (Chough et al., 2010; Gandin and Debrenne, 2010) could provide a unique opportunity for elucidating the direct effects of the environmental changes that are suggested to have caused end-Cambrian Series 2 calcified microbe extinctions, independently of archaeocyath extinction.

2. Geological setting

The North China Platform is a typical epeiric platform that existed throughout the Cambrian Series 2–Middle Ordovician (Meng et al., 1997; Kwon et al., 2006). The platform formed on a stable craton, the Sino-Korean Block, which was located near the margin of Gondwana during the Early Paleozoic (McKenzie et al., 2011). Paleomagnetic analyses suggest that the Sino-Korean Block was situated near the paleoequator during the Cambrian (Zhao et al., 1992; Huang et al., 2000; Yang et al., 2002). A 1800 m-thick mixed siliciclastic–carbonate succession was deposited in the North China Platform (Meng et al., 1997). In the central part of the North China Platform (Shandong Province, China), the carbonate-dominated Zhushadong Formation (10 to 50 m thick) unconformably overlies the Precambrian basement (Meng et al., 1997; Chough et al., 2010) (Fig. 1A). This formation passes laterally into the siliciclastic Liguan Formation (37 m thick) in eastern-most Shandong (Fig. 1B). Various limestones and dolostones including laminated/homogeneous dolo-mudstone, bioturbated dolo-wackestone, cross-stratified oolitic grainstone, limestone conglomerate, microbial laminites, and stromatolites occur in the Zhushadong Formation (Fig. 2). This assemblage of deposits represents carbonate dominated environments such as peritidal flats and ooid shoals, reflecting uneven topography and local variations in the carbonate factory (Lee and Chough, 2011). The Zhushadong Formation was deposited during the upper Tsanglangpuan Stage (*Megapalaeolenus* Zone), which can be correlated with informal Stage 3 of the Cambrian Series 2 (Geyer and Shergold, 2000; Peng et al., 2012).

3. Methods

The study area (Sunmayu section) is located in the southeastern part of Shandong Province (Fig. 1A). The Zhushadong Formation in this area is up to 50 m thick, and unconformably overlies Precambrian granitic gneiss (Fig. 2A). Thrombolites, containing clotted mesostructures (Aitken, 1967; Shapiro, 2000), mainly occur in a 3 m thick interval that occurs 31 m above the basement, and were examined in two sections (Sections 1 and 2), about 1.1 km apart (Fig. 2). Within Section 1, three sub-sections, 20 to 30 m apart, were selected to describe the lateral variations (Sections 1-1, 1-2, and 1-3). These sections were measured at a 1:50 scale (Fig. 2B, C). Sketches and line drawings of the thrombolites were made in the field, and slabs and thin sections were prepared in the laboratory to identify meso- and microscale fabrics.

4. Microbial reefs in the Zhushadong Formation

4.1. Macro- and mesoscale characteristics

Several types of dm- to m-scale thrombolite occur in the coarse-grained carbonate facies, including crudely stratified oolitic grainstone, stromatolitic grainstone, and disorganized limestone conglomerate (Fig. 2). Three types of thrombolite are recognized based on their mesostructures (cf., Shapiro, 2000; Chen and Lee, 2014): rimmed, grainstone-patch, and dendritic thrombolites (Table 1). Thrombolites are described here as microbial reefs, following the reef definition of Wood (1999): "a discrete carbonate structure formed by in-situ or bound organic components that develops topographic relief upon the sea floor".

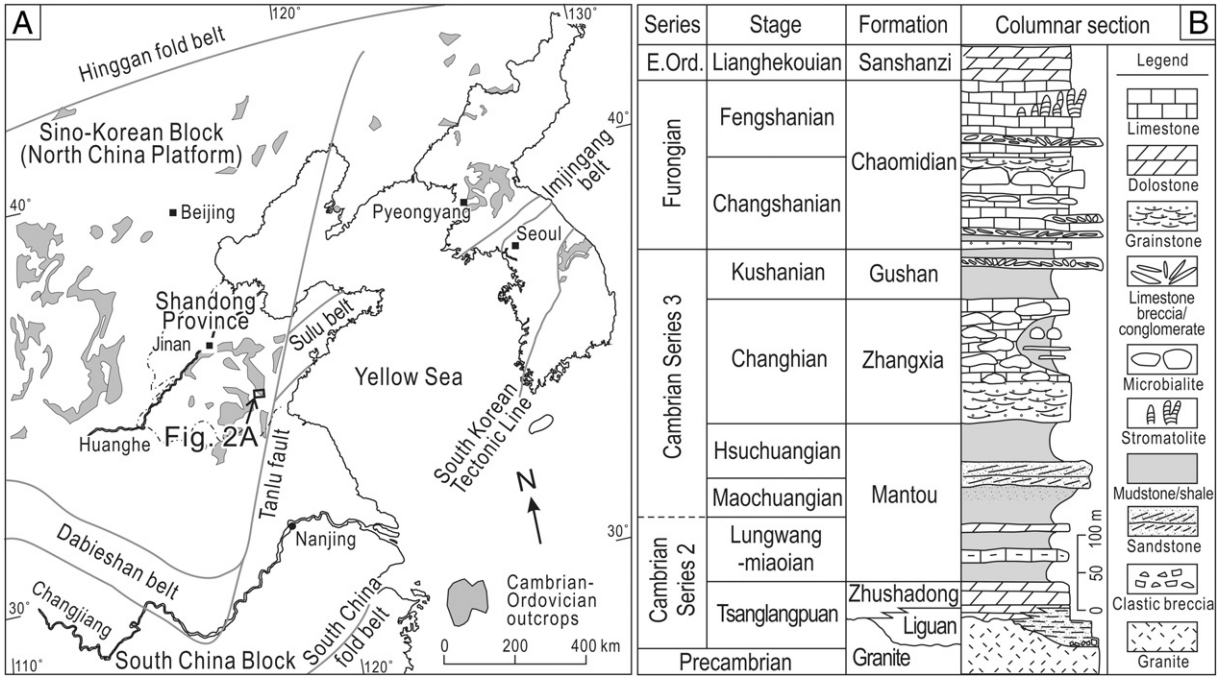

Fig. 1. Geological setting of the study area. (A) Cambrian–Ordovician outcrops in the North China Platform. Study area is marked with an arrow. (B) Summary of the Cambrian succession in Shandong Province, China.
Modified after Chough et al. (2010).

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