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Evidence for rapid precipitation of calcium carbonate in South China at the beginning of Early Triassic

Baozhu Deng [a], Yongbiao Wang [a,*], Adam Woods [b,*], Sheng Li [a], Guoshan Li [a], Weihan Chen [a]

[a] State Key Laboratory of Geological Processes and Mineral Resources, School of Earth Sciences, China University of Geosciences, Wuhan 430074, China
[b] Department of Geological Sciences, California State University, Fullerton, CA 92834-6850, USA

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ABSTRACT

'Anachronistic facies' are sedimentary features and fabrics that are very common in the early history of the Earth, but mainly occur following mass extinctions during the Phanerozoic. Anachronistic facies are typically found in carbonates, commonly have a microbial origin, and reflect an unusual oceanic chemistry. The aftermath of the end-Permian mass extinction is one of the periods when anachronistic facies were common and occur in sedimentary rocks from around the world. In South China, different types of anachronistic facies appear in an orderly succession over time. Microbialites are often the first anachronistic sediments that formed after the end-Permian mass extinction in shallow platform settings, and are subsequently followed by oolites and oncolites, which are sometimes intercalated with vermicular limestones. Because different types of anachronistic facies represent different depositional environments, this succession pattern in the strata records the evolution of marine environments following the end-Permian mass extinction. Based on sedimentological analysis of the Yangjiawan section, Hunan Province, South China, this study suggests that the transition from microbialite to oolitic limestone was associated with a rise of sea level and an increase in hydrodynamic energy; the shift from oolite to oncolite reflects a sustained, rapid rise of sea level. The occurrence of vermicular limestone is considered to be the product of an ephemeral, restricted environment. Anachronistic facies reach a thickness of 75 m at the Yangjiawan section, while over nearly the same time interval, argillaceous limestone reaches a thickness of only 40 cm of Beds 27–29 at the Global Stratotype Section and Point (GSSP) section at Meishan in Zhejiang Province. This difference in thickness indicates strongly elevated sedimentation rates in shallow-water platform settings after the end-Permian mass extinction. High rates of carbonate precipitation are indicative of calcium carbonate supersaturation within shallow watermasses, which may have resulted from the upwelling of alkaline, anoxic deep waters, accompanied by high rates of evaporation as a consequence of extremely high temperatures at the time. Nevertheless, it is the global sea-level rise in the Early Triassic that provided the accommodation space necessary for the precipitation of the great thickness of anachronistic carbonate sediments at the Yangjiawan section.

1. Introduction

The term “anachronistic facies” was originally assigned to flat-pebble conglomerates (Sepkoski et al., 1991), but subsequent works on a variety of anomalous sediments or biosedimentary structures, such as intraclastic limestone (Wignall and Twitchett, 1999), wrinkle structure (Pruss et al., 2004; Mata and Bottjer, 2009), microbialite (Baud et al., 2007), carbonate seafloor precipitate (Woods et al., 1999), vermicular limestone (Zhao et al., 2008), and oolite (Groves and Calner, 2004; Li et al., 2013, 2015; Woods, 2013; Deng et al., 2015), have broadened the scope of sedimentary features and fabrics of anachronistic facies. Anachronistic facies are primarily preserved in carbonate sediments, although some types (i.e., microbially induced sedimentary structures) also occur in marine and terrestrial siliciclastic successions (Chu et al., 2015; Tu et al., 2016; Xu et al., in press). These unusual biosedimentary structures usually reflect extraordinary environmental conditions in ancient oceans and are frequently associated with microbial activity. Because increasing evidence indicates that microbially induced processes are involved in ooid formation (Pacton et al., 2012; Li et al., 2013, 2015; Woods, 2013; Diaz et al., 2015), widespread Lower Triassic ooids have also been regarded as anachronistic facies in recent studies (Groves and Calner, 2004; Li et al., 2013; Deng et al., 2015). Anachronistic facies are very common in sedimentary rocks in the Precambrian, Cambrian, and Ordovician (Sepkoski et al., 1991) and have decreased remarkably since then. Similar sedimentary structures and fabrics, however, appear in the aftermaths of major

* Corresponding authors.
E-mail addresses: wangyb@cug.edu.cn (Y. Wang), awoods@fullerton.edu (A. Woods).

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mass extinction events (Whalen et al., 2002; Sheehan and Harris, 2004; Calner, 2005; Baud et al., 2007). Owing to their indication of peculiar global environmental conditions, anachronistic facies are a hot topic in geobiology and carbonate sedimentology (Wignall and Twitchett, 1999; Woods et al., 1999; Pruss et al., 2005; Zhao et al., 2008; Kershaw et al., 2012; Chen and Benton, 2012; Wu et al., 2014; Kershaw, 2015). Anachronistic facies change in type and richness in the sedimentary record, reflecting the evolution of the marine environment over geologic history. However, it is still difficult to confirm the origins of some anachronistic facies and their usefulness as environmental indicators because of the lack of modern analogues, as well as their absence for much of Phanerozoic history. For example, the origin of vermicular limestone still remains enigmatic (Zhao et al., 2008; Woods, 2014), although various formation mechanisms have been proposed (Baud, 1976; Huang, 1984; Jiang et al., 1992; Qian, 1995; Pruss et al., 2004; Zhao et al., 2008).

The newly found Yangjiawan section of Hunan Province, South China, contains a sequence of anachronistic limestones that overlies the end-Permian mass extinction horizon, and includes (in stratigraphic order) a microbialite, vermicular limestone, oolite, and oncolite unit. These different types of anachronistic facies are interpreted to have formed under different water depths and hydrodynamic conditions and were deposited during the global transgression following the end-Permian mass extinction. Therefore, these unusual facies and fabrics provide an excellent opportunity to compare the conditions under which each of the different types of anachronistic facies formed. The depositional cycles composed of oolites and oncolites are well-developed in the stratigraphic succession, which provides good examples to distinguish between oncoids and ooids in Lower Triassic depositional environments.

Anachronistic facies are mostly produced under marine conditions with waters that are supersaturated with respect to calcium carbonate (Riding, 2000; Arp et al., 2001), and therefore possess high rates of sedimentation. High rate of carbonate precipitation often leads to great thicknesses of anachronistic sediments during marine transgressions when sea level rises (Kershaw et al., 2011). In comparison with other areas, anachronistic facies at the Yangjiawan section exhibit a greater variety and a greater thickness of anachronistic limestones, providing new insight into the fluctuations of sea level following the end-Permian mass extinction.

2. Geological and stratigraphic settings

The South China block was located near the equator during the Early Triassic; its western shelf was adjacent to the Paleo-Tethys Ocean, and the eastern margin was open to western Panthalassa (Fig. 1A). The Yangtze platform was the principle carbonate setting on the South China block, which was restricted by the Cathaysian Landmass (Oldland) to the east and the Kamdian Landmass (Oldland) to the west. The Yangjiawan section is located in Cili County of Hunan Province, and was paleogeographically situated in the central part of the Yangtze platform (Fig. 1B) (Feng et al., 1997).

Upper Permian to Lower Triassic strata are well exposed in the Yangjiawan section. The Late Permian stratigraphic sequence is composed of sponge reef limestone in the lower part and algae-foraminifer bioclastic limestone in the upper part. The end-Permian mass extinction led to the disappearance of most marine species and was followed by the formation of a 75-m-thick sequence of anachronistic limestone. A variety of anachronistic facies, including microbialite, oolite, oncolite, and vermicular limestone, occur in this interval (Fig. 2). Microbialite was the first to form, immediately after the end-Permian mass extinction, and was subsequently succeeded by oolitic and oncolitic limestones that are intercalated with vermicular limestone. The microbialites can be subdivided into thrombolites in the lower part and stratiform stromatolites in the upper part. The microbialites are terminated by the first appearance of small ooids (1–1.5 mm in diameter) which are overlain by thin-bedded vermicular limestone. The upper part of the anachronistic limestone succession consists of many depositional cycles, each of which is made up of small ooids (mostly <1.2 mm in diameter), large ooids (2–3 mm in diameter), and oncoids. Thin-bedded argillaceous limestone overlies the anachronistic carbonates (Fig. 2).

The end-Permian mass extinction boundary, characterized by a sharp and irregular surface, is located between the algae–foraminifer bioclastic limestone of the Upper Permian Changxing Formation and the overlying microbialite unit of the Lower Triassic Daye Formation. The conodonts *Hindeodus parvus* and *Isarcicella staeschei*, which are indicative of the early Griesbachian (Early Triassic) in age, were discovered in the middle of the microbialite, and within the vermicular limestone, respectively, in the adjacent Kangjiaping section (Wang et al., 2009), implying that the P–Tr boundary is located at a horizon 3.5 m above the mass extinction boundary, and that most of the anachronistic limestone was deposited during the Early Triassic.

3. Types of anachronistic limestone

3.1. Microbialites

An 8-m-thick microbialite succession formed directly on the Changhsingian bioclastic limestones with a sharp contact between the two units. The microbialites can roughly be classified into 3-m-thick thrombolites in the lower part and 5-m-thick stratiform stromatolites in the upper part (Fig. 2). The stratiform stromatolites are intercalated with skeletal grainstone that contains microgastropods, ostracodes, bivalves, and calcareous tubeworms. These fossils are less diverse but more abundant (Fig. 3) when compared with the communities that were present in the area prior to the end-Permian mass extinction. Most fauna in the skeletal grainstones are considered to be disaster species that became abundant following the end-Permian mass extinction and are widespread in South China (Jiang et al., 2010; He et al., 2012; Hautmann et al., 2015; Yang et al., 2015a, 2015b).

3.2. Microbial oolitic limestone

Oolites comprise two stratigraphic intervals. The lowermost oolite directly caps the underlying stratiform stromatolites, while the second oolitic limestone occurs within the upper part of the succession and contains several depositional cycles that include oncoids.

The lowermost oolite is 4.5 m thick and is composed primarily of well-sorted ooids ranging from 1 to 1.5 mm in diameter (Fig. 4A–B). Most ooids are spherical, with interstices filled with sparry cement and no micritic matrix. Most ooid nuclei are too small to identify, although some are likely microfossil fragments; well-preserved fossils are rarely seen in the lowermost oolite.

The second oolite unit contains depositional cycles in which ooids alternate with oncoids; the ooids may be small or large in diameter. The small ooids resemble the ooids from the lowermost portion of the study interval that directly cap the underlying microbialite (diameter ranges from 1–1.5 mm), but the larger ooids look distinctly different with regards to their texture. The large ooids average 2–3 mm in diameter and usually contain abundant microgastropods or bivalve fragments that served as nuclei for the ooids (Fig. 4C). The upper oolitic limestones were deposited on a lime mud-rich sea floor rich that also resulted in the formation of minor numbers of oncoids (Fig. 4D).

3.3. Vermicular limestone

Thin-bedded vermicular limestone, ~1 m thick, was deposited on the top of the lowermost oolite but disappears at the beginning of the depositional cycles of oolites and oncolites. In outcrop, the vermicular limestone comprises dark gray “wormlike” vermicular bodies

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