Palaeogeography, Palaeoclimatology, Palaeoecology 412 (2014) 124–140

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Early Middle Triassic stromatolites from the Luoping area, Yunnan Province, Southwest China: Geobiologic features and environmental implications

Mao Luo [a,c,f], Zhong-Qiang Chen [b,*], Laishi Zhao [c], Steve Kershaw [d], Jinyuan Huang [e], Liangliang Wu [f], Hao Yang [b], Yuheng Fang [b], Yuangeng Huang [b], Qiyue Zhang [e], Shixue Hu [e], Changyong Zhou [e], Wen Wen [e], Zhihai Jia [g]

[a] School of Earth and Environment, The University of Western Australia, Western Australia 6009, Australia
[b] State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences, Wuhan 430074, China
[c] State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan 430074, China
[d] Institute for the Environment, Halsbury Building, Brunel University, Uxbridge, United Kingdom
[e] Chengdu Center of China Geological Survey, Chengdu 610081, China
[f] State Key Laboratory of Organic Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 610081, China
[g] School of Resources and Environmental Engineering, Hefei University of Technology, Hefei 230009, China

ARTICLE INFO

Article history:
Received 28 December 2013
Received in revised form 7 July 2014
Accepted 28 July 2014
Available online 12 August 2014

Keywords:
Stromatolite
Rod aggregate
Filamentous structures
Early Middle Triassic
Luoping
SW China

ABSTRACT

An early Middle Triassic stromatolite deposit is documented from the Guanling Formation of the Luoping area, Yunnan, SW China. The Luoping stromatolite shows five types of constructional microbial forms in various magnifications: 1) typical stratified columnar structures, up to 20 cm high, with crinkled laminae. Dark coloured laminae, 1 mm thick, are composed of upright filamentous tubes, averagely 29.4 μm in diameter, showing a vertical growth fabric. 2) Laminoid fenestrae, 0.5–1 mm wide, and 3) prostrate filaments, which are reflected by strong fluorescence in sharp contrast to dolomite cement in fluorescent images. 4) Rod-like aggregates, 4.6–18 μm in diameter, composed of minute dolomite rhombs, are very common in stromatolitic laminae; they resemble present-day cyanobacterial trichome, and thus may represent putative fossilized cyanobacteria. 5) Moreover, small pits, coccoid-like spheroids, calcified biofilms, and fibrous structures are also common in stromatolitic laminae. The last two may represent calcified extracellular polymeric substances (EPS) that contributed to the development and lithification of stromatolites. Authigenic quartz grains are common and may also have involved biological processes in stromatolite formation. Of these microbial functional-groups driving accretion and lithification processes of stromatolite documented in literature, both lithified cyanobacteria/oxygenic phototrophs and possible sulfate-reducing bacteria (SRB), which induced microbial formation of dolomite and contributed to the accretion of the Luoping stromatolite, are suggestive of biogenic origin. The Luoping stromatolite differs from the Permian–Triassic boundary microbialites (PTBMs) in having abundant filamentous structures and growing in an oxic marine environment. Both sedimentary facies analysis and abundant fossilized cyanobacteria may indicate proliferation of oxygenic phototrophs in a normal, oxic habitat during the middle Anisian (early Middle Triassic), a period when hospitable environments, coupled with biotic diversification, prevailed in South China and set an agenda for the full recovery of marine ecosystems in middle–late Anisian. However, the post-extinction stromatolites and other anachronistic facies are not necessarily indicative of anoxic or oxic conditions, and their environmental settings are much more complex than previously thought.

1. Introduction

Stromatolites usually occur as the laminated microbial deposits and are the most common life forms in marine ecosystems during the Precambrian (Awramik, 1971; Awramik and Margulis, 1974; Riding and Liang, 2005; Noffke and Awramik, 2013). They have also proliferated in the aftermaths of several major Phanerozoic mass extinctions and still occur in present-day oceans and hypersaline lakes (Riding, 2006; Mata and Bottjer, 2011; Reitner et al., 2011). Increasing evidences show that stromatolites provide us a unique window to probe the history of photosynthesis, the evolution of early atmosphere and microbe-environment interactions in the geological past (Awramik, 1992, 2006; Kah and Riding, 2007; Kershaw et al., 2007, 2009, 2012; Mata and Bottjer, 2011, 2012; Noffke and Awramik, 2013).

The abundance of stromatolite deposits has undergone conspicuous perturbations since the Proterozoic (Awramik, 1971; Riding and Liang, 2005; Riding, 2006; Mata and Bottjer, 2012; Noffke and Awramik,

* Corresponding author. Tel.: +86 27 67883068; fax: +86 27 67881234.
E-mail address: zhong.qiang.chen@cug.edu.cn (Z.-Q. Chen).

http://dx.doi.org/10.1016/j.palaeo.2014.07.028
0031-0182/© 2014 Elsevier B.V. All rights reserved.

2013). This fluctuation was largely coupled with ecologic turnovers through geological time, characterized by major environmental changes and ecologic crises. For instance, two of the big five Phanerozoic mass extinctions (in Late Devonian and end-Permian, respectively) facilitated the proliferation of microbialites during biotic recovery interval (Mata and Bottjer, 2012). Microbial bloom is suggested to be coupled with extremely low metazoan diversity, which thoroughly decreased the grazing activity and competition and meanwhile decreased bioturbation that facilitated the development of microbialites (Mata and Bottjer, 2012). However, such inference is open to doubt because recent studies on both Permian–Triassic boundary microbialites (PTBMs) and modern stromatolite deposits reveal abundant infaunal metazoans living within microbial niches (Forel et al., 2012; Forel, 2013; Tarhan et al., 2013). Alternatively, the extremely high saturation rate in seawater may also have facilitated the growth of microbialites in Early Triassic (see Kershaw et al., 2012 and references therein).

The resurgence of microbial communities represented by microbialites (stromatolites, thrombolites and other forms) occurred through the entire Early Triassic, with peaking in early Griesbachian, late Griesbachian–early Dienerian, Smithian, and late Spathian, respectively (Baud et al., 1997, 2005, 2007; Pruss and Bottjer, 2004; Pruss et al., 2006; Woods and Baud, 2008; Mata and Bottjer, 2012). The environmental range in which stromatolites developed in each stage, and the palaeoenvironmental implications of those biosedimentary structures have been documented in detail (Schubert and Bottjer, 1992; Sano and Nakashima, 1997; Wignall and Twitchett, 2002; Richoz et al., 2005; Hips and Haas, 2006; Pruss et al., 2006; Baud et al., 2007; Farabegoli et al., 2007; Kershaw et al., 2011; Mata and Bottjer, 2011, 2012; Ezaki et al., 2012). The PTBMs were deposited in a wide range of environments from shallow marine shelf to outer ramp settings and locally seamount environment (Sano and Nakashima, 1997; Hips and Haas, 2006; Kershaw et al., 2012). Their formation is often interpreted as the outcome of combined reduction in metazoan diversity and rising seawater saturation state in respect to $CaCO_3$ (Riding and Liang, 2005; Kershaw et al., 2007, 2012; Woods et al., 2007). However, the biogenic mechanisms involved in microbialite formation still remain poorly understood. In particular, the functioning microbial groups and structures that contribute to the accretions of Early Triassic stromatolites have long been disputed. Recent studies show that the Anisian (early Middle Triassic) saw a stable ecosystem indicated by stable carbon isotopic excursion (Payne et al., 2004) and a full recovery of marine ecosystems (Hu et al., 2011; Chen and Benton, 2012). The Anisian stromatolite therefore may provide a comparison with their Early Triassic counterparts in composition and further indicate how the variation of oceanographic conditions influences the microbial development and precipitation of microbial carbonate. A comparative study may also shed light on the formation mechanism of the PTBMs and microbialites from other intervals of the Early Triassic.

Here we report a new stromatolite deposit from the early Middle Triassic of the Shangshikan section of Luoping County, Yunnan Province, Southwest China (Fig. 1). This study aims to (1) describe microbial structure and composition of the Luoping stromatolite; (2) elucidate stromatolite's accretion and formation processes; (3) compare the Luoping stromatolite with the Early Triassic and modern counterparts and (4) discuss in a broad context its possible palaeoenvironmental implications.

2. Geological, stratigraphic and palaeoenvironmental settings

2.1. Geological and stratigraphic settings

The studied section is located 2 km northeast of the Daaozi Village, 20 km southeast of the Luoping County town, eastern Yunnan Province, Southwest China (Fig. 1). During the early Middle Triassic, the Luoping area, together with border areas between eastern Yunnan and western Guizhou Provinces, was located on the southwestern part of the Yangtze Platform and separated from the Nanpanjiang Basin by a shoal complex (Feng et al., 1997; Lehrmann et al., 2005; Enos et al., 2006). Within the vast Yangtze Platform interior region several spatially and temporally separated intraplatform basins or depressions with exceptional fossil preservations, namely the Panxian, Luoping, Xingyi, and Guanling, have been recognized from the late Anisian, late Ladian and Carnian intervals, respectively (Hu et al., 2011; Benton et al., 2013). These basins shared similar features, including a restricted circulation, density stratification of the water column, and dysoxic to anoxic bottom water during the burial of these exceptionally preserved vertebrate faunas in various stages of the Triassic (Benton et al., 2013). In Luoping, abundant marine reptile faunas were preserved in a basinal setting represented by the upper part of Member II of the Guanling Formation (Hu et al., 2011). The highly fossiliferous, dark coloured micritic limestone of the upper part of Member II can be traced over an area of some 200 km^2 (Benton et al., 2013). However, Member I and lower and middle parts of Member II of the Guanling Formation record similar successions over the entire Yangtze Platform interior region in the Yunnan–Guizhou bordering areas (Enos et al., 2006).

Therein, the stromatolite-bearing unit belongs to the second member of the Middle Triassic Guanling Formation (Zhang et al., 2008). The Guanling Formation is subdivided into two members. Member I is dominated by siliciclastic sediments representing deposition in subtidal to intertidal environment (Hu et al., 1996), while Member II by micritic limestone, bioclastic limestone, oncoidal limestone and dolomite in the lower and middle parts, and by black muddy limestone, cherty limestone, and grey dolomite in the upper part (Fig. 2). Integration of sedimentary facies analysis, palaeoecology and taphonomy indicates that the lower and middle parts of Member II were deposited in the relatively open shallow marine settings, while the upper portion of the member was deposited in a low energy, semi-enclosed intraplatform basin setting with influence of episodic storms (Hu et al., 2011). The Guanling Formation in the Luoping area, overall, records an up-deepening succession (Zhang et al., 2008).

Conodont *Nicoraella kockeli* Zone has been detected from the horizons, about 30 m above the stromatolite-bearing horizon at the upper part of Member II (Fig. 2). This conodont zone includes elements such as *Nicoraella germanicus*, *N. kockeli* and *Cratognathodus* sp., indicative of a Pelsonian age of the middle Anisian (Zhang et al., 2009). The underlying Member I of the Guanling Formation yields bivalves *Myophoria* (*Costatoria*) *goldfussi mansuyi* Hsü, *Unionites spicatus* Chen, *Posidonia* cf. *pannonica* Moj, and *Natiria costata* (Münster), and contains several clay beds. The bivalve assemblage is of early Anisian age in South China (Zhang et al., 2008), while the clay beds have been regarded as correlation markers of the base of the Anisian in southwest China (Enos et al., 2006; Zhang et al., 2009). Given its higher stratigraphic position and just beneath the Pelsonian conodont zone, the stromatolitic unit is tentatively assigned to the Bithynian of early–middle Anisian in age.

2.2. Palaeoenvironmental analysis

At the logged section, Member II of the Guanling Formation comprises Units 1–4 (Fig. 2). Unit 1 (0–38 m) is characterized by thick-bedded dolomitic limestone in the lower part and alternating dolomitic limestone and micrite at the middle and upper parts. Dolomitic limestone is partly fossiliferous and has a sutured mosaic fabric (Fig. 3A) or micritic texture, with framboid pyrites being commonly present at some horizons (Fig. 3B), indicating generally dysoxic to anoxic conditions. Dolomitization tends to obliterate the original physical sedimentary structures of the rock, making the very fine-grained sediments representing either deep basinal facies or shallow restricted low-energy carbonate platform facies. Given that Member I consists mainly of siltstone and sandstone of intertidal to subtidal zones, Unit 1 of the lower Member II was unlikely deposited in a relatively deep basinal