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Paleoproterozoic microbially induced sedimentary structures from lagoonal depositional settings in northern China

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ABSTRACT

Microbially induced sand cracks/crack-fills occur extensively on the top surface of fine sandstone beds of the Paleoproterozoic Zhaojiazhuang Formation, Changcheng Group (>1.7 Ga) around the Cangyan Mountain, Hebei Province, northern China. Detailed field and microscopic petrographical evidence reveal that these sand cracks/crack-fills possibly resulted from dehydration and desiccation of microbial mats. The age and peculiar morphology of these microbially induced sedimentary structures do not allow comparison with trace fossils or purely physical desiccation cracks. The fine sandstone beds on the surfaces of which these microbially induced sedimentary structures formed were deposited in a lagoon/brackish depositional setting (marine to non-marine transitional setting) with episodic injection of marine water. As such, these microbially induced sedimentary structures suggest the colonization of the marine to non-marine transitional settings in the Paleoproterozoic period, and that the search for evidence of early microbial life should be sought in the marine to non-marine transitional settings. These broad habitats suggest these microbes could have been eurytopic organisms capable of adapting to varying extents of salt and oxygen content variations, like their modern counterparts.

1. Introduction

Microbes were the dominant life forms during the Paleo- and Mesoproterozoic periods (Walter, 1976; Knoll, 2003). However, tracing convincing microbial evidence during this period has been difficult because microbes themselves are seldom preserved (Noffke and Paterson, 2008) and tend to degrade (Jones, 2000). Direct evidence for microbial life has been preserved as very rare and fragmentary microbial remains in chert, attributable to permineralization and preservation prior to decay (Schopf, 1999). In the absence of cherty rocks, microbially induced sedimentary structures (MISS)—biochemical and biophysical structures formed and/or preserved as a result of interaction between benthic microbes, such as bacteria and algae, and ambient carbonate or sandy grains by means of their cohesive extracellular polymeric substances (Noffke et al., 2001; Noffke, 2010). MISS in siliciclastic and carbonate rocks have been targeted as proxies hosting indirect evidence of microbial life. As a result, siliciclastic (and carbonate) rocks have been extensively and intensively investigated since 1980s to provide better understanding of microbial roles in the formation of resultant MISS and preserved proxy structures in the clastic record (e.g., Lan and Chen, 2012, 2013; Lan et al., 2013 and references therein). MISS have been widely documented from Paleo- and Mesoproterozoic siliciclastic successions worldwide, with the most common features being microbially induced sand crack-fills (Eriksson et al., 2004; Schieber et al., 2007; Lan and Chen, 2012, 2013; Lan et al., 2013 and references therein).

Interaction between sandy grains and biofilm that is composed of individual cells and their extracellular polymeric substances produces cohesive siliciclastic sediments (Noffke and Awramik, 2013). These sediments with the involvement of microbes behave like muddy sediments and thus produce a variety of cracks upon dehydration and desiccation of microbial organic materials. The major difference between microbially induced sand cracks and purely physical desiccation cracks lies in the binding and dehydration agents. Microbial sediments are water-containing microbial organics, whereas the latter have water-rich clay minerals, the amount of which is almost negligible in sandstone. In this case, the occurrence of microbially induced sand cracks provides indirect evidence for the former existence of cohesive biofilms in sandy deposits.

Microbially induced sand cracks frequently develop on ripple troughs or depressions on sandstone bed surface (Schieber et al., 2007; Lan and Chen, 2012) and exhibit a special fusiform, circular, sigmoidal or '8'-shaped morphology resembling metazoan trace fossils (cf., *Manchuriophycus*; e.g., Schieber et al., 2007). Because of their similar superficial morphology, microbially induced sand cracks have been misread as trace fossils (e.g., Seilacher, 2007), which mislead paleontologists in the exploration of the origin and evolution of the metazoans. Such misunderstandings are also applicable to the MISS in the Paleo- and Mesoproterozoic strata of North China which have incorrectly been treated as trace fossils based solely on macroscopic morphological analyses (Luo and Zhu, 2010; Lan et al., 2013). When detailed microscopic

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internal microstructure analyses were conducted, however, positive correlations were noted with several detailed studies published on the peculiarities of MISS and how to distinguish them from trace fossils (e.g., Seilacher, 2007; Luo and Zhu, 2010; Lan and Chen, 2012; Lan et al., 2013).

In the Paleo- and Mesoproterozoic, MISS-forming microbial mats appeared on Earth's surface wherever their nutritional and hydrological needs were met (Schieber et al., 2007), which effectively encompassed all moist environments. The non-continuous deposition of clastic sediments and episodic nature of the sedimentation regime within these environments allowed enough time for MISS-forming microbial mats to grow and become established (Sarkar et al., 2005; Catuneanu, 2007; Schieber et al., 2007; Noffke, 2010). Evidence for early life from the beginning of the geological record has generally been found within the marine realm, which in preservation terms essentially encompasses shallow marine to peritidal depositional settings for most of the Proterozoic (Schieber et al., 2007; Noffke et al., 2008), given also that the oldest preserved ocean crust is of Jurassic age. This has skewed studies of MISS globally toward such marginal marine environments, rendering little attention paid to other environments. However, increasing evidence shows that microbial life also existed in fresh-water and marine to non-marine transitional paleoenvironments (e.g., Prave, 2002; Noffke, 2010; Callow et al., 2011; Noffke et al., 2013). This study adds another example of microbial life that colonized the Precambrian marine to non-marine transitional lagoonal depositional settings. The broader habitats mean these microbes could have been euryhaline organisms capable of adapting to varying extents of salt and oxygen content fluctuations, as previously recognized.

2. Geological setting

The study area is located along the Gantao River around the Cangyan Mountain, about 90 km southwest of Shijiazhuang, the capital city of Hebei Province (Fig. 1a, b). Following its formation during the Lüliangian Orogeny at 2.0–1.8 Ga, the North China Craton underwent a series of extentional and rifting events at 1.8–1.6 Ga which resulted in the formation of a series of marginal rift basins (Lu et al., 2008). These aulacogens accommodated onshore shallow marine and marginal marine deposits under a regional transgressive setting (Qiao and Gao, 2007).

The Cangyan Mountain area was an aulacogen during the Proterozoic period and is now situated in the Eastern Block of the North China Craton (Fig. 1c; Zhao et al., 2005; Lu et al., 2008). Rock components in the Cangyan Mountain area include Paleoproterozoic metamorphic basement and overlying Paleoproterozoic unmetamorphosed sedimentary cover (Fig. 2). The metamorphic basement is represented by metamorphic andesite of the Nansi Formation. The sedimentary rocks are dominated by siliciclastic and carbonate rocks attributable to the Changcheng Group and underlying Zhaojiazhuang Formation. The Zhaojiazhuang Formation was established by Du (1984) when he

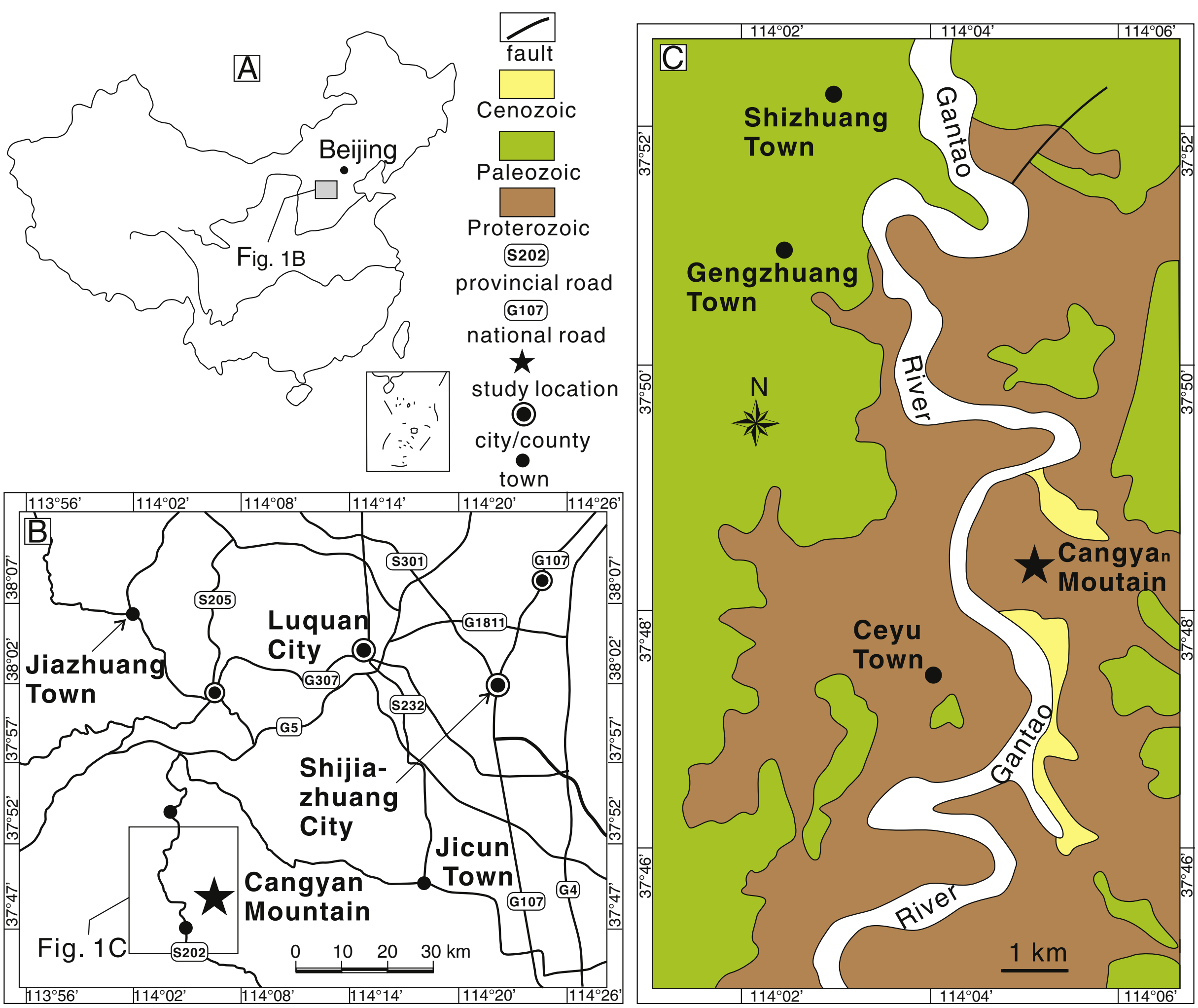

Fig. 1. (a) Map showing the approximate position of the study area. (b) Simplified traffic map around the study area. (c) Simplified geological map around the study location (modified from HBG, 1967).