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Sedimentary characteristics and origins of Late Pennsylvanian–Early Permian carbonate mud-mounds at the Shangdan section, Inner Mongolia

Zhen Yan [a,b,c], Jian-Bo Liu [a,b,*], Yuan-Lin Sun [a,b], Hai-Feng Wang [a,c], Bao-Qi Huang [a,b]

[a] School of Earth and Space Sciences, Peking University, Haidian, Beijing 100871, China
[b] Key Laboratory of Orogenic Belts and Crustal Evolution (Peking University), Ministry of Education, Beijing 100871, China
[c] Institute of Geology, Chinese Academy of Geological Sciences, Xicheng, Beijing 100037, China

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Abstract

Late Pennsylvania–Early Permian carbonate mud-mounds exposed in the Shangdan section, Inner Mongolia, are commonly massive, showing depositional relief, and are distinct from the thin- to medium-bedded limestones of intra-mounds. Based on the various proportions of lithofacies, four types of mud-mounds are recognized: MM-A (type A carbonate mud-mound) and B (type B carbonate mud-mound) consist of massive lime mudstone and massive wackestone (Subfacies B), respectively; MM-C (type C carbonate mud-mound) are composed of massive wackestone (Subfacies B) in the lower parts, analogous to MM-B, and massive wackestone (Subfacies A) and boundstone in the upper parts, similar to MM-D (type D carbonate mud-mound). Carbonate mud-mounds are deposited in low-energy settings on a ramp, likely below fair-weather wave base, where the depositional settings of MM-A, B, C and D have a shallowing-upward trend. Carbonate mud-mounds have diverse origins of lime mud: allochthonous lime mud in MM-A; lime mud produced by the disintegration of phylloid algae in MM-B, C and D; lime mud linked to cyanobacterial activity in MM-D and the upper parts of MM-C. Different from MM-A and B, which were formed only by mechanical accumulation, MM-C and D resulted from the combinations of mechanical accumulation and microbial binding and solidifying. MM-A, B, C and D significantly expand the global spectrum of Late Pennsylvania–Early Permian carbonate mounds.

Keywords: Depositional setting; Origin of lime mud; Mechanical accumulation; Cyanobacteria; Phylloid algae

1. Introduction

Carbonate mud-mounds are common features in the late Paleozoic rock record, reaching a global peak during the Carboniferous (Lee and Miller, 1995; Krause et al., 2004). Carbonate mounds were dominated by algal mounds during the Bashkirian (Early Pennsylvania) to Sakmarian (Early Permian) (Davies and Nassichuk, 1973; Toomey et al., 1977; Bonem, 1978; Toomey, 1980; Chuvashov, 1983; Lonoy, 1988; Stemmerik and Worsley, 1995; Samankassou, 2003; Samankassou and West, 2003; Krainer, 2007; Wasson and Lohmann, 2015). Few reports, however, have described carbonate mud-mounds in North China during the Early Pennsylvanian–Early Permian. Sedimentary characteristics and formation mechanisms of carbonate mud-mounds, and the origin of lime mud in North China are poorly understood.

Carbonate mud-mounds, commonly deposited in low-energy settings (Brachert et al., 1992; Krainer, 1995; Negra et al., 1995; Belka, 1998; Samankassou, 1998, 1999, 2001; Elrick and Snider, 2002; Pas et al., 2011), are characterized by lime mud (Bosence and Bridges, 1995; Monty, 1995; Riding, 2002) on the slopes or ramps (Bridges et al., 1995; García-Mondéjar and Fernádez-Mendiola, 1995; Gutteridge, 1995; Jeffery, 1997; Berkowski, 2006; Ruggeberg et al., 2007). Lime mud has two origins, including allochthonous lime mud, originated from the surrounding areas (Bosence, 1995; Dorobek and Bachtel, 2001; Pas et al., 2011; Correa et al., 2012), and autochthonous lime mud, linked to microbial activity (Bridges and Chapman, 1988; Camoin, 1995; Monty, 1995; Elrick and Snider, 2002; Pas et al., 2011;

* Corresponding author at: School of Earth and Space Sciences, Peking University, Haidian, Beijing 100871, China.
E-mail address: jbliu@pku.edu.cn (J.B. Liu).

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Tosolini et al., 2012) and the degradation of skeletons (Bosence, 1995; Camoin, 1995; Taberner and Bosence, 1995; Floquet et al., 2012; Tosolini et al., 2012). Research over the last decades showed that the formation of carbonate mud-mounds resulted from a combination of both physical process and microbial activity (Bridges et al., 1995; Calvet and Tucker, 1995; Camoin, 1995; Wanless et al., 1995; Correa at al., 2012).

This study describes ten lithofacies at the Shangdan section, Inner Mongolia, North China, with a focus on the detailed macroscopic characteristics and petrography of the Gzhelian (Late Pennsylvania)–Sakmarian (Early Permian) carbonate mud-mounds. Special attention is paid to the origin of lime mud, depositional setting and formation mechanism of carbonate mud-mounds. Carbonate mud-mounds represent four types of mud-mound so far unknown for North China, and expand the spectrum of the Gzhelian (Late Pennsylvania)–Sakmarian (Early Permian) carbonate mud-mounds on a global scale.

2. Geological and stratigraphic setting

The Shangdan section is located 40 km east of Uliji Town, Alxa Left Banner County, Inner Mongolia Autonomous Region (Fig. 1). Tectonically, it is part of the Shalazhashan Zone, which is located between the Badan Jaran Faultzone and the Engeerwusu Faultzone, at the northern margin of the Alxa Block (Wu and He, 1993; Fig. 1). During the early and middle Paleozoic, the area was located in the interior of an active continental margin (Zheng and Zhu, 1986) that subsequently evolved to a mature island arc and back-arc basin during the Carboniferous–Permian, which was closed after the Permian (Wu and He, 1992, 1993).

The Carboniferous–Permian marine deposits in the study area consist of, from oldest to youngest, the Amushan, Wuhaxibi, Maihanhada, and Aqide formations (Zheng and Zhu, 1986). The Amushan Formation consists of three members. The first member is composed of thin- and medium-bedded sandy limestone with grayish green, thin-bedded tuff and grayish green andesite interbeds. The second member is dominated by marine carbonates. The third member consists of marine–terrigenous clastic rocks, mainly conglomerate, sandstone, and siltstone, with interbeds of pyroclastic deposits (Zheng and Zhu, 1986). Compared with the first and third members, carbonate deposition in the second member suggests a relatively stable tectonic environment (Zhao et al., 2010) in a mature island arc and back-arc basin setting.

The second member of the Amushan Formation, composed of massive wackestone, thin- to medium-bedded wackestone, massive lime mudstone, thin-bedded lime mudstone, skeletal or ooidal packstone, grainstone, boundstone and pebble limestone, is well exposed at the Shangdan section (Fig. 2). This member is divided into seven units based on the lithological features (Fig. 2). Carbonate mud-mounds occur in Units II–V (Fig. 2).

Three fusulinida biozones have been identified at the Shangdan section: the *Triticites* Zone, *Pseudoschwagerina* Zone, and *Pseudofusulina* Zone. Based on these biozones, the age of the second member of the Amushan Formation is assigned to the Gzhelian (Late Pennsylvania) to Sakmarian (Early Permian) (Jin et al., 1999; Fig. 3).

3. Methods

Individual carbonate mud-mounds at the Shangdan section, Inner Mongolia, were examined in detail in the field and laboratory. In the field, the lithofacies, scale and sedimentary characteristic of carbonate mud-mounds, as well as the relationship between carbonate mud-mounds and intra-mounds, were investigated. About 80 samples of carbonate mud-mounds and intra-mounds were collected, and cut perpendicular to bedding. Polished slabs and oriented thin-sections were analyzed for microfacies.

4. Results

4.1. Macroscopic sedimentary characteristics of carbonate mud-mounds

Carbonate mud-mounds are massive, and exhibit depositional relief (Fig. 4). From the base to the carbonate mud-mound, the variation from medium-bed to massiveness is obvious (Fig. 4B). The scale of the mud-mounds is 3–25 m in vertical thickness and more than 100 m in maximum lateral extent. High-relief carbonate mud-mounds are generally superimposed on each other (Fig. 4A) whereas low-relief ones are commonly isolated (Fig. 4C). High-relief carbonate mud-mounds always have steep margins without obvious slump structures. Bioturbation structures, subaerial exposures, and stromatactis cavities are absent.

4.2. Description of sedimentary lithofacies

Using the classification scheme of Dunham (1962), ten lithofacies were distinguished in the Shangdan section (Table 1), based on bedding thickness, petrography and sedimentary structures. These lithofacies fall into two categories according to their distribution in carbonate mud-mounds and intra-mounds (Table 1). Carbonate mud-mounds are characterized by massive wackestone, massive lime mudstone and boundstone. Intra-mounds consisit of grainstone, packstone, thin- to medium-bedded wackestone, thin-bedded lime mudstone, pebble limestone and conglomerate-sandstone alternation.

4.3. Interpretations of depositional environments in intra-mounds

Based on the sedimentary characteristics, environmental interpretations (Table 1) and associated relationships of the lithofacies in intra-mounds, the second member of the Amushan Formation is assigned to shallow and deep subtidal lithofacies associations, where sediments were deposited: shallow and deep subtidal zones on a ramp, respectively.

Shallow subtidal lithofacies association is distributed in Unit I, and is typically composed of grainstone, packstone (Subfacies F and G) and conglomerate with graded bedding-sandstone with cross-bedding alternation, as well as a small number layers of