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Peritidal carbonate cycles induced by carbonate productivity variations: A conceptual model for an isolated Early Triassic greenhouse platform in South China

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Abstract Eustasy has commonly been invoked to explain peritidal carbonate cyclicity, but is difficult to explain cycles formed in a greenhouse climate when eustasy is minimal. We propose that peritidal cycles on an Early Triassic isolated carbonate platform in Guizhou, South China, were formed by hierarchical carbonate productivity variations. Most of the 149 shallowing-upward cycles are typically terminated by flooding over intertidal facies and contain rare supratidal facies and no prolonged subaerial exposure. Low-diversity benthos in the platform interior during the post-end-Permian biotic recovery were sensitive to environmental perturbations, which caused variations in benthic sediment productivity in the subtidal carbonate factory. The perturbations may be driven by changes in salinity and degree of eutrophication, or repeated platform mini-drowning by anoxic and/or CO_2-charged deep water upwelled onto the banktop. They were modulated by Milankovitch orbitally-driven climatic and oceanographic factors as suggested by the hierarchical stacking pattern and spectral signals of these cycles. A one-dimensional conceptual model shows that hierarchical productivity variations alone may generate hierarchical peritidal carbonate cycles under conditions of constant subsidence and no sea-level fluctuation.

Key words carbonate, peritidal, cycle, productivity, climate, Triassic, South China

1 Introduction

Shallowing-upward peritidal carbonate cycles result from interplay of allogenic and autogenic processes controlling accommodation space and sediment accumulation (*e.g.*, Goldhammer *et al.*, 1990, among many others). The former is controlled by eustasy and subsidence (*e.g.*, Read and Goldhammer, 1988), the latter by factors affecting carbonate productivity and sediment redistribution, such as water depth, biota, salinity, oxygenation, nutrient, and current energy (cf. Tucker *et al.*, 1990; Schlager, 2005). Three mechanisms, all assuming constant subsidence and sedimentation, are commonly suggested for peritidal cycle formation: composite eustasy (*e.g.*, Goldhammer *et al.*, 1990), tidal flat sediment accumulation and progradation (*e.g.*, Ginsburg, 1971; Pratt and James, 1986), and random processes (*e.g.*, Spencer and Demicco, 1989; Drummond and Wilkinson, 1993a; Wilkinson *et al.*, 1999; Burgess, 2001, 2008), among which only Milankovitch-related composite eustasy can generate multi-order hierarchical cycles. In this study, we explore the link between carbonate productivity and cyclicity on the basis of sedimentary and quantitative evidence of peritidal cycles in South China.

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2 Characteristics of peritidal carbonate cycles

The peritidal carbonate cycles described here are suitable to explore the role of carbonate productivity variations on peritidal cyclicity, because they developed during the Early Triassic (Induan) greenhouse period when eustasy was minimal (Frakes *et al.*, 1992; Scotese *et al.*, 1999) and the benthic biota recovering from the end-Permian mass extinction was highly sensitive to varying oceanic conditions. They were deposited on an isolated flat-topped carbonate bank, which covers 10×70 km^2 in the eastern Paleo-Tethys (Figure 1A, 1B; Lehrmann *et al.*, 1998). It was named as the Great Bank of Guizhou by Lehrmann (1993) and as the Luodian Carbonate Platform by Feng *et al.* (1997). The bank has a low-relief profile with oolite shoals at the margin, shallow-subtidal and peritidal deposits in the interior, and pelagics, debris-flow deposits and turbidites on gentle basin-margin slopes (Figure 1C). Interior strata are 265 m thick beginning in the lowermost Triassic with *Renalcis* biostromes, followed by lime mudstone, oolite, and cyclic peritidal carbonate.

The cyclic carbonate is Olenekian in age. Two sections, Dajiang (DJ) on the windward side and Dawen (DW) toward the leeward side, are 140 m and 162 m thick, respectively (Figure 1C). They contain a total of 149 cycles that range from 0.2 to 7.4 m thick and are 2 m thick on average (Figures 1C, 2A, 2B). A typical cycle consists of four facies (Figure 2C; Lehrmann *et al.*, 1998, 2001): subtidal skeletal packstone or oolitic grainstone in the lower part, calcimicrobial *Renalcis* mound or biostrome facies in the middle, and intertidal flaser-bedded ribbon-rock facies in the upper part, all of which are pyritiferous. The skeletal packstone and reef mounds contain a low-diversity biota of cyanobacteria, echinoderms, bivalves, gastropods, lingulid brachiopods, spirorbids, and ostracodes. Ribbon rocks contain alternating lime mud and fine peloidal packstone and grainstone laminae, scour surfaces, ripple cross-lamination, lime-mud drapes, and minor prism cracks. Rarely, cycles are capped by supratidal microbial laminite facies, which account for only 2% of the section thickness. Overall, the facies were deposited in a dominantly low-energy, restricted- to normal-marine peritidal environment. The facies stacking suggests a shallowing-upward trend of depositional environments within each cycle, upward from high-energy shallow subtidal, relatively deep low-energy subtidal, to intertidal and, rarely, supratidal (see Lehrmann *et al.*, 1998, 2001 for thorough descriptions and interpretations).

Furthermore, cycle (parasequence) stacking patterns show gradual increase and decrease of cycle thickness, defining a third-order sequence boundary and several fourth-order cycle sets that correlate between DJ and DW sections (Figures 2, 3A; Lehrmann *et al.*, 2001). Lehrmann *et al.* (2001) stated that the cycle stacking patterns are similar to those of lower Paleozoic green-house sequences and different from those of ice-house sequences. They concluded that facies similarities such as *Renalcis* mound and flaser-bedded intertidal ribbon rock reflect anomalous oceanic conditions resulting in low biodiversity and low intensity of bioturbation after the end-Permian extinction. Similarities in cycle stacking patterns reflect low-amplitude, high-frequency sea-level fluctuations resulting from greenhouse conditions common to the Early Paleozoic and Early Triassic.

The three-order hierarchical stratigraphic relationship as suggested by Lehrmann *et al.* (2001) was quantitatively tested by Yang and Lehrmann (2003) through time series and spectral analysis of cycle thickness and facies data of DJ and DW sections (Figure 4). Milankovitch climatic signals of prominent short-eccentricity (94.9−131.2 kyr), short-obliquity (35.8 kyr), and long precessional index (21.2 kyr), and minor long-eccentricity (412.9 kyr), long-obliquity (45.3 kyr), short precessional index (17.7 kyr), and a constructional-tone (9.7 kyr) were detected. The estimated stratigraphic completeness is much greater than that of icehouse stratigraphic records. The results suggest that Milankovitch climatic forcing had greatly influenced sedimentation. Yang and Lehrmann (2003) speculated that variations in carbonate productivity and environmental conditions driven by Milankovitch climatic forcing, combined with low-amplitude sea-level fluctuations, were likely major controls on cyclic sedimentation. Furthermore, evolutive spectra of the two sections show that dominant Milankovitch climatic forcings varied from short eccentricity, obliquity, to long-precessional index during the course of sedimentation, suggesting variations in the type and magnitude of oceanic and climatic processes and their mechanisms during the course of cyclic sedimentation of DJ and DW sections. Finally, the DW and DJ cycles accumulated during the Early Triassic aftermath of end-Permian mass extinction. This period is characterized by extremely low biodiversity, a mollusk-dominated skeletal biota, low skeletal abundance, extremely small and lightly calcified fauna (*e.g.*, Payne *et al.*, 2006), and microbial and cement precipitates (*e.g.*, Woods *et al.*, 1999; Lehrmann *et al.*, 2003; Payne *et al.*,