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Plankton and productivity during the Permian–Triassic boundary crisis: An analysis of organic carbon fluxes

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ABSTRACT

Changes in marine primary productivity following the latest Permian mass extinction (LPME) have been debated at length, with little resolution to date owing to a paucity of quantitative data. Herein, we report total organic carbon (TOC) concentrations and organic carbon accumulation rates (OCAR) for 40 Permian–Triassic boundary (PTB) sections with a near-global distribution and consider their implications for changes in marine productivity during the boundary crisis. Many sections in South China exhibit abrupt declines in TOC and OCAR from the Changhsingian (latest Permian) to the Griesbachian (earliest Triassic), a pattern not observed for sections in other regions. This pattern cannot be explained through secular changes in sedimentation rates, sedimentary facies, or redox conditions, all of which would have favored higher (rather than lower) TOCs and OCARs during the Griesbachian. Further, back-calculation of OC fluxes demonstrate that this pattern cannot be attributed to diagenetic loss of OC in the sediment or, possibly, to OC remineralization in the water column. The most likely explanation is a collapse of marine primary productivity across the South China region concurrently with the LPME and continuing for an extended interval into the Early Triassic. The productivity crash as well as the coeval decimation of benthic marine fauna coincided with deposition of the "boundary clay" at Meishan D, suggesting that both events were related to a large explosive volcanic eruption of uncertain provenance. In other PTB sections having a wide geographic distribution, OCARs increased on average by a factor of ~4× across the LPME, largely owing to a concurrent increase in bulk accumulation rates (BARs). Radiometric dating uncertainties can account at most for only a fraction of the secular change in BARs, which are likely to reflect an increase in subaerial weathering rates and elevated fluxes of detrital material to Early Triassic marine systems. Intensification of chemical weathering relative to physical weathering may have increased the flux of nutrients to the Early Triassic ocean, enhancing marine productivity and contributing to the widespread development of marine dysoxia–anoxia.

1. Introduction

The latest Permian mass extinction (LPME), just prior to the ~252-million-year-old Permian–Triassic boundary (PTB), represents the largest mass extinction in the Phanerozoic record, during which ~90% of marine invertebrate and ~80% of terrestrial vertebrate species disappeared (Erwin et al., 2002; Irmis and Whiteside, 2011). While the ultimate causes of this event remain under discussion (Wignall, 2007), recent work has demonstrated unambiguously that the effects of this event extended to the base of the trophic web in marine ecosystems (Fig. 1). The end-Permian crisis coincided with an abrupt decline in eukaryotic marine phytoplankton (Knoll et al., 2007; Luo et al., this volume), proliferation of prasinophyte and acritarch "disaster taxa" (Payne and van de Schootbrugge, 2007), and a general increase in the abundance of green sulfur and N-fixing cyanobacteria (Grice et al., 2005; Xie et al., 2005, 2007; Hays et al., 2007; Cao et al., 2009; Luo et al., 2011). Cyanobacterial autotrophs may have flourished in the aftermath of the crisis owing to their greater resistance to harsh environmental conditions and a competitive advantage over eukaryotic phytoplankton in anoxic waters rich in ammonium (Knoll et al., 2007). Further, changes in phytoplanktic community (Fig. 1) may have been detrimental to organisms at higher trophic levels in that cyanobacteria generate harmful toxins and do not synthesize the sterols needed by marine invertebrates, as do eukaryotic phytoplankton (Knoll et al., 2007).

Changes in taxonomic diversity and community structure, however, do not necessarily equate with changes in primary productivity rates, which might have been sustained at pre-crisis levels or even have increased following the LPME. At present, no consensus exists concerning changes in nutrient inventories and energy flows in marine ecosystems

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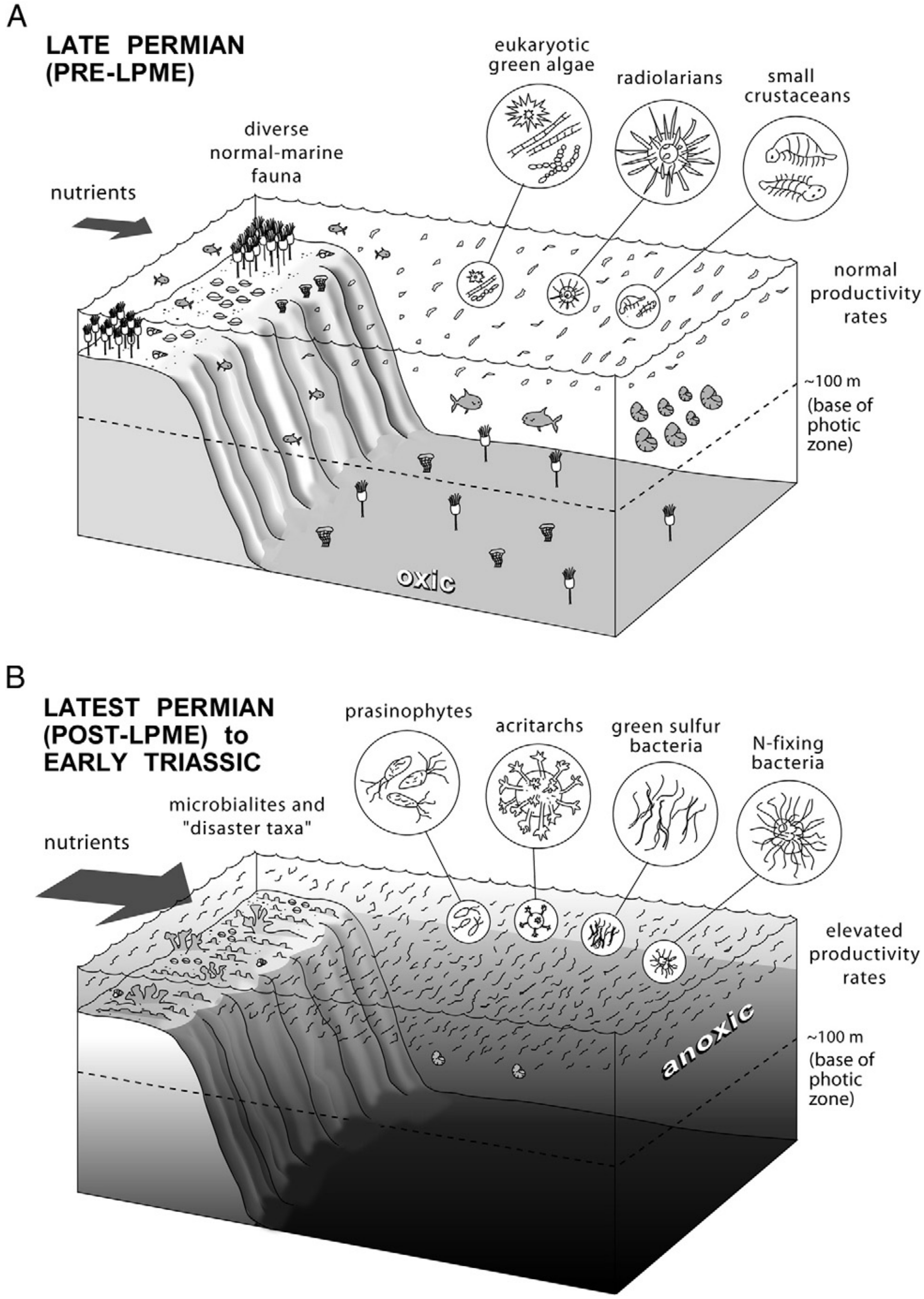

Fig. 1. Interpretative changes in planktic community composition, nutrient fluxes, and primary productivity rates in conjunction with the latest Permian mass extinction (LPME): (A) Changhsingian (i.e., pre-LPME Late Permian only), and (B) Griesbachian (i.e., including the post-LPME latest Permian). Note that this study evaluates changes in OC fluxes across the LPME rather than the PTB.

as a result of the LPME. Martin (1996) claimed that nutrient-poor conditions led to a general collapse of marine primary productivity during the Early Triassic, a view seconded by Rampino and Caldeira (2005) on the basis of the ubiquitous ~3‰ decline in $\delta^{13}C_{carb}$ at the LPME. However, this C-isotopic shift has multiple potential causes (Berner, 2002; Payne and Kump, 2007), and other considerations do not favor Martin's hypothesis. First, global starvation during the Early Triassic is hard to reconcile with the observation that taxa with high rates of basal and exercise metabolism, e.g., many mollusks, disproportionately survived the crisis relative to those with lesser oxygen demands (Rhodes and Thayer, 1991; Knoll et al., 2007). Second, the widespread dysoxia and anoxia in Early Triassic oceans (subsequently "anoxia" for brevity) (Fig. 1; Isozaki, 1997; Meyer et al., 2008; Brennecka et al., 2011) may have been caused in part by higher sinking fluxes of organic matter (Meyer et al., 2011; Winguth and Winguth, 2012). While these considerations argue against strongly diminished rates of marine primary productivity following the LPME, quantitative data bearing on this issue have been lacking to date. The goal of the present study is to assess changes in organic carbon fluxes in conjunction with the LPME, in order to determine the relationship of the end-Permian crisis to changes in marine primary productivity.

Qualitative changes in primary production are commonly inferred in paleoceanographic studies (e.g., Caplan and Bustin, 1999; Cramer and Saltzman, 2005). In contrast, quantitative estimation of primary production in paleomarine systems is inherently difficult owing to large losses of organic carbon (OC) within both the water and sediment columns prior to final preservation. In one early attempt of this type, Bralower and Thierstein (1984) estimated primary production assuming a fixed preservation factor of 2% for organic matter in Cretaceous