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Marine productivity changes during the end-Permian crisis and Early Triassic recovery

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ABSTRACT

The latest Permian mass extinction (LPME) coincided with major changes in the composition of marine plankton communities, yet little is known about concurrent changes in primary productivity. Earlier studies have inferred both decreased and increased productivity in marine ecosystems immediately following the end-Permian crisis. Here, we assess secular and regional patterns of productivity variation during the crisis through an analysis of the burial fluxes of three elemental proxies: total organic carbon (TOC), phosphorus (P), and biogenic barium (Ba_{bio}). Primary productivity rates appear to have increased from the pre-crisis Late Permian through the Early Triassic in many parts of the world, although the South China Craton is unusual in exhibiting a pronounced decline at that time. Most of the 14 Permian–Triassic study sections show concurrent increases in sediment bulk accumulation rates, suggesting two possible influences linked to subaerial weathering rate changes: (1) intensified chemical weathering, resulting in an increased riverine flux of nutrients that stimulated marine productivity, and (2) intensified physical weathering, leading to higher fluxes of particulate detrital sediment to continental shelves, thus enhancing the preservation of organic matter in marine sediments. An additional factor, especially in the South China region, may have been the intensified recycling of bacterioplankton-derived organic matter in the ocean-surface layer, reducing the export flux rather than primary productivity *per se*. The ecosystem stresses imposed by elevated fluxes of nutrients and particulate sediment, as well as by locally reduced export fluxes of organic matter, may have been important factors in the ~2- to 5-million-year-long delay in the recovery of Early Triassic marine ecosystems.

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1. Introduction

1.1. Marine productivity changes during the Permian–Triassic crisis

The latest Permian mass extinction (LPME) was the largest biotic crisis of the Phanerozoic, resulting in an ~90% loss of species-level biodiversity among marine invertebrates (Erwin et al., 2002; Yin et al., 2012; Clapham, 2013). This event was accompanied by major changes in the composition of marine phytoplankton (Xie et al., 2005; Knoll et al., 2007; Payne and van de Schootbrugge, 2007; Lei et al., 2012; Shen et al., 2013a) and zooplankton communities (Feng and Algeo, 2014), suggesting a far-reaching restructuring of the marine trophic system. The end-Permian crisis was followed by an extended, ~2 to 5-Myr-long interval of delayed recovery in marine ecosystems (Payne et al., 2004; Chen and Benton, 2012) that may have been related to repeated major environmental perturbations (Algeo et al., 2011a; Retallack et al., 2011) and/or sustained elevated Earth-surface temperatures (Sun et al., 2012; Romano et al., 2013). These biotic developments played out against a backdrop of widespread marine anoxia (Wignall and Twitchett, 1996; Isozaki, 1997; Bond and Wignall, 2010) and unsettled conditions in the marine C and S cycles (Payne et al., 2004; Bottrell and Newton, 2006; Richoz et al., 2012; Song et al., 2014).

Changes in marine productivity rates during the Permian–Triassic transition have been the subject of much speculation without development of a consensus to date. Arguments for reduced primary productivity in the aftermath of the LPME have been based on drastically diminished fossil abundance (Twitchett, 2001; Payne, 2005; Twitchett, 2007), reductions in body size (the “Lilliput effect”) in many clades including molluscs (Twitchett, 2007), conodonts (Luo et al., 2008), sponges (Liu et al., 2013), and brachiopods (He et al., 2007, 2010), and negative excursions in marine carbonate $\delta^{13}C$ profiles (Rampino and Caldeira, 2005). On the other hand, arguments for increased primary productivity have been based on an increased frequency of organic-rich mudstones (Kakuwa, 1996; Suzuki et al., 1998), positive excursions in marine carbonate $\delta^{13}C$ profiles (Suzuki et al., 1998; Horacek et al., 2007), and enhanced carbon-isotope depth gradients in Lower Triassic limestones (Meyer et al., 2011). The lack of agreement among these diverse records may indicate that many, and perhaps all, of them are not primarily related to variations in marine productivity.

A more quantitative approach to evaluation of marine productivity changes based on the fluxes of productivity-related sedimentary components has been developed in recent studies. Algeo et al. (2010) calculated organic carbon burial fluxes for Japanese deep-sea sections, showing significant increase just prior to and, possibly, following the end-Permian extinction event. These changes were accompanied by a major decline in radiolarian (zooplankton) productivity, probably due to upward expansion of the oceanic oxygen-minimum zone (Feng and Algeo, 2014). Algeo et al. (2013) undertook a more comprehensive analysis of 40 Permian–Triassic boundary (PTB) sections with a near-global distribution, back-calculating the organic carbon sinking flux to the sediment–water interface based on transfer functions accounting for diagenetic losses of organic matter due to aerobic and anaerobic respiration. They determined that sections in the South China region almost uniformly recorded a >50% decline in organic carbon burial during the end-Permian crisis, but that sections elsewhere showed variable changes with an average increase of ~400% that they attributed to a comparable increase in average bulk sediment accumulation rates.

Various proxies have been used to estimate paleomarine productivity, including carbon isotopes, biomineral fluxes, and elemental concentrations or fluxes (Zonneveld et al., 2010). The concentrations or fluxes of productivity-related elements have been widely used in this capacity owing to their ease of measurement and inferred relationship to primary productivity, especially organic carbon (Pedersen and Calvert, 1990; Canfield, 1994; Tyson, 2005), phosphorus (Filippelli and Delaney, 1996; Schenau and De Lange, 2001; Schenau et al., 2005), and biogenic barium (Dehairs et al., 1980, 1987; Dymond et al., 1992; see also reviews by Tribovillard et al. (2006); Calvert and Pedersen (2007). Schoepfer et al. (2015–in this volume) examined the correlation of sedimentary fluxes of these three proxies to primary productivity in modern marine systems, establishing relationships that we apply in