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Editorial

The Paleozoic-Mesozoic transition in South China: Oceanic environments and life from Late Permian to Late Triassic

1. Introduction

The Triassic was a critical period for the evolution of life on Earth. It witnessed the greatest biocrisis of the Phanerozoic (the Permian-Triassic (P-Tr) mass extinction) at its beginning, a limited and fitful recovery from this biocrisis during the Early Triassic, and a more sustained recovery and re-radiation of life during the Middle Triassic. The Middle Triassic recovery featured not only a biotic radiation but also significantly altered ecosystem structures, facilitating the emergence of calcareous nanofossils in the ocean and early dinosaurs on land. During the early Late Triassic, a long-lasting climate extreme (the mid-Carnian Pluvial Event, or CPE) had global effects. South China harbors some of the most accessible and continuous Triassic marine successions in the world, providing opportunities for geologists to probe these biotic and environmental events and their possible causes. The theme of this special issue of *Palaeogeography Palaeoclimatology Palaeoecology* is the transition from Paleozoic to Mesozoic systems as recorded in latest Permian and Triassic strata of South China. This issue includes biostratigraphic, paleoecologic, sedimentologic, and geochemical studies focused on marine environmental and climatic variation and the biotic and biosedimentary responses to it during the latest Permian and P-Tr transition (4 papers), the Early Triassic (6 papers), and the Late Triassic (2 papers). These contributions advance our understanding of Triassic global events, with a special emphasis on organism-environment interactions during this critical period of Earth history.

2. The Paleozoic-Mesozoic transition in South China

2.1. Latest Permian and Permian-Triassic boundary

Oceanic redox changes, specifically a major expansion of anoxic regions, are thought to have played an important role in the latest Permian mass extinction (LPME) (Wignall and Twitchett, 1996; Meyer et al., 2008). Recent studies have provided evidence that sustained anoxia developed in oxygen minimum zones (OMZs) of the oceanic thermocline (~200-1000 m water depth) during the latest Permian (Algeo et al., 2011a; Winguth and Winguth, 2012; Feng and Algeo, 2014), probably by ~50-100 kyr prior to the LPME (Algeo et al., 2012; Huang et al., 2017). Oceanic OMZs represented long-term reservoirs of euxinic waters that set the stage for episodic, brief incursions of H_2S into the ocean-surface layer (Kump et al., 2005; Algeo et al., 2007, 2008) that may have had a decimating effect on shallow-marine biotas (Bottjer et al., 2008; Chen and Benton, 2012), except in areas protected from such incursions (e.g., Beatty et al., 2008).

Two studies in this volume provide new evidence that euxinic watermasses developed during the Late Permian prior to the LPME. Lei et al. (2017) generate a high-resolution redox history from the latest Wuchiapingian (early Late Permian) through the earliest Induan based on Fe-S-C-Mo geochemical study of a carbonate-ramp section at Ganxi, western Hubei Province. They demonstrate the development of intensely anoxic conditions during three intervals: (1) in the latest Wuchiapingian, (2) in the early to mid-Changhsingian, and (3) during the latest Changhsingian (following the LPME). Whereas the end-Permian euxinic episode is well-established, the earlier episodes do not appear to have global significance (cf. Elrick et al., 2017), and their underlying causes remain unknown. The latest Wuchiapingian and latest Changhsingian episodes are characterized by ferruginous conditions (versus euxinic for the early to mid-Changhsingian episode), suggesting that seawater sulfate was intermittently drawn down to low concentrations during the Late Permian.

The study of Li Y. et al. (2017b) in this volume examines the rare earth element (REE) and trace-element content of conodont apatite from a shallow carbonate platform at Yangou in Jiangxi Province. Because the geochemical composition of conodonts can be easily altered by diagenetic uptake of REEs and trace elements released to sediment porewaters from clay minerals (Chen et al., 2015; Zhang et al., 2016), use of conodonts for analysis of paleo-seawater chemistry requires that the host sediments be nearly clay-free. Pre-LPME Upper Permian strata at Yangou meet this condition, and their Ce/Ce* ratios and U concentrations document mostly oxic conditions on the shallow Yangou carbonate platform punctuated by episodes of suboxic to anoxic conditions possibly produced through shoaling of the oceanic chemocline. Conodonts in post-LPME uppermost Permian and lowermost Triassic strata at Yangou contain substantial amounts of clay-derived REEs that overprinted any original hydrogenous signal, reflecting a general increase in the siliciclastic content of marine sediments following the LPME as a result of intensified pedogenic clay-mineral production (cf. Algeo and Twitchett, 2010; Algeo et al., 2011b).

Another form of environmental stress during the P-Tr transition in the South China region was frequent volcanic ash fall events. Some P-Tr

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boundary sections contain dozens of K-bentonites (altered ash layers; e.g., Shen et al., 2012), some of which may be traceable for > 1000 km across the South China Craton (Yang et al., 1991). These eruptive events were responsible, at least in part, for the P-Tr biocrisis in the South China region (Gao et al., 2013). In this volume, Hong et al. (2017) examine the composition, alteration history, and potential sources of these volcanic ashes based on the clay mineralogy, elemental chemistry, and Sr and Nd isotopic compositions of the Pengda and Xinmin sections in Guizhou Province, representing shallow-marine and deep-marine settings, respectively. The deep-water section (Xinmin) exhibits notably higher $^{87}Sr/^{86}Sr$ ratios and higher K_2O content, which is attributed to more intense chemical weathering and greater incorporation of K^+ into clay minerals at low porewater pH during early diagenesis. These differences are consonant with generally lower pH in deep-water sections due to sinking and decay of organic carbon via the biological pump, although the intensity of these processes may have increased during the P-Tr transition (cf. Song et al., 2013).

In response to environmental stresses, some marine invertebrates reduced their body sizes during the P-Tr transition, a pattern known as the 'Lilliput Effect' (Twitchett, 2007; Song et al., 2011). However, controls on body size are complex, as shown by the study of He et al. (2017) in this volume. They investigated influences on the sizes of two chonetid brachiopod species in South China during the Changhsingian, demonstrating a strong correlation with water depth, which correlates with a number of direct controls such as nutrient availability, redox conditions, habitat temperature, and substrate type. With respect to Late Permian chonetid brachiopods, food restriction, low-oxygen conditions, and high bottom water temperatures are inferred to have been important factors limiting body size. These findings may provide insights into the nature of the environmental stresses that triggered the Lilliput Effect among many marine invertebrates during the P-Tr transition.

2.2. Early Triassic

Early Triassic oceans were characterized by volatile conditions, as reflected in large $\delta^{13}C_{carb}$ excursions (to > 10 ‰; Payne et al., 2004; Tong et al., 2007; Korte and Kozur, 2010), large but fluctuating vertical $\delta^{13}C$ gradients of dissolved inorganic carbon (DIC) (Meyer et al., 2011; Song et al., 2013), and large sulfur cycle perturbations (Song et al., 2014). The significance of all of these perturbations remains under debate. The large fluctuations in $\delta^{13}C_{carb}$ may have been driven by volcanic/volcanogenic inputs of ^{13}C-depleted carbon (Payne and Kump, 2007), by fluctuations in marine productivity and organic carbon burial (Schoepfer et al., 2012, 2013; Song et al., 2014), or a combination of processes (Algeo et al., 2011b). Increases in vertical $\delta^{13}C$ gradients of DIC may have been driven by marine productivity increases (Meyer et al., 2011) or intensified water-column stratification (Song et al., 2013). Evidence from the marine sulfur cycle may be important in constraining viable options in that strong coupling of $\delta^{34}S_{CAS}$ and $\delta^{13}C_{carb}$ during the Early Triassic requires a mechanism consonant with coburial of reduced carbon and sulfur (Song et al., 2014).

In this volume, Schobben et al. (2017) investigate marine sulfur cycling during the P-Tr transition (late Changhsingian to mid-Griesbachian) at Balvany, Hungary and Kuh-e-Ali Bashi and Zal, Iran based on paired sulfur isotopic analyses of chromium-reducible sulfur (CRS) and carbonate-associated sulfate (CAS). They document nearly invariant $\Delta^{34}S_{CAS\text{-}CRS}$ values of 15–16‰ at all three sections, indicating low but relatively uniform latest Permian to Early Triassic seawater sulfate concentrations of 1.7 ± 1.1 mM (calculated based on the MSR-trend method of Algeo et al., 2015; cf. < 4 mM estimate of Luo et al., 2010). A secular trend toward heavier $\delta^{34}S_{CAS}$ and $\delta^{34}S_{CRS}$during the earliest Triassic may have been due to more rapid overturn of the marine sulfur cycle and a concurrent change in terrestrial sulfur sources, possibly related to inputs of ^{34}S-enriched sulfur from Cambrian evaporite deposits mobilized by Siberian Traps magmatism. The high turnover rate of marine sulfate may have left the ocean system vulnerable to development of widespread euxinic conditions during the Early Triassic.

Although there has been considerable debate about the extent and intensity of oceanic anoxia following the LPME, recent studies making use of the carbonate U-isotope global-ocean redox proxy have demonstrated substantial anoxia during the Early Triassic (Brennecka et al., 2011; Lau et al., 2016; Elrick et al., 2017). However, studies making use of local redox proxies have shown that oceanic redox changes were spatially and temporally complex (e.g., Bond and Wignall, 2010). In this volume, Liao et al. (2017) examine pyrite framboid size distributions at Dajiang, Guizhou Province, demonstrating a decrease in size in conjunction with the LPME. They note that the Dajiang section, which was located on the Panthalassic (paleo-eastern) margin of South China, exhibits smaller pyrite framboids as well as a more extreme negative $\delta^{13}C_{carb}$ shift at the LPME than sections from the craton's Paleo-Tethyan (paleo-western) margin. On the basis of this spatial variation, they infer that upwelling of reducing deep-ocean waters was relatively more intense on the Panthalassic margin of the South China Craton (cf. Algeo et al., 2007, 2008).

One consequence of the stressed environments and decimated marine ecosystems that followed the LPME was the widespread development of 'anachronistic' biosedimentary facies that more closely resembled those of the pre-metazoan Precambrian than the Phanerozoic (Baud et al., 2007; Kershaw et al., 2009; Woods, 2014). These facies include microbialites, oncoids, giant ooids, and vermicular limestones and are found in carbonate successions throughout the Lower Triassic of South China (Chen et al., 2014, 2017). These facies may provide insights into both the nature of seawater chemical changes during the P-Tr transition (e.g., transiently highly alkaline and carbonate saturated; Knoll et al., 1996; Woods et al., 1999; Heydari et al., 2003) and their relationship to microbial communities in the aftermath of the LPME (cf. Xie et al., 2005; Chen et al., 2011; Luo et al., 2013). Three studies in the present thematic issue examine various aspects of these anachronistic facies.

In this volume, Wu et al. (2017) document a new PTB microbialite deposit from the Xiushui area of Jiangxi Province, which was situated on the southeastern margin of the Yangtze Platform during the P-Tr transition. These microbialites have thrombolitic and dendritic growth forms, contain abundant calcified microbes (including columnar and clustered forms of *Gakhumella* and various microspheroids), and harbor an invertebrate community comprised mainly of ostracods with minor foraminifers, microgastropods, and microconchids. Both the ostracod assemblage and pyrite framboid size analyses indicate dysoxic tooxic conditions at the Xiushui site. In view of accumulating evidence of strong spatio-temporal variation in marine redox conditions (see above), this study provides further evidence of local habitats that were hospitable for metazoans in the immediate aftermath of the LPME. The variable redox conditions at Xiushui indicate that factors other than oxygen levels probably controlled microbialite growth, e.g., water temperatures (Sun et al., 2012) or carbonate saturation levels (Woods, 2014).

Another common type of anachronistic facies in the Lower Triassic of South China is giant ooids, which formed widely on shallow carbonate platforms during the Early Triassic (Lehrmann et al., 2012; Li et al., 2013; Tian et al., 2015). In this volume, Fang et al. (2017) report the discovery of a 30-m-thick giant-oolitic limestone of late Smithian age from the Lichuan area, western Hubei Province, South China. This oolitic unit contains an embedded 16-m-thick stromatolite that exhibits domal, stratified columnar, wavy laminated, cabbage-shaped, roll-up, and conical structures. Some interior layers within the ooids exhibit intense fluorescence, indicative of microbial organomineralization. Moreover, abundant nanometer-scale textures and particles in both stromatolites and ooids are attributed to abundant organic matter in seawater, resulting from microbial proliferation. This stromatolite-ooid complex represents the largest structure of this type reported globally from the Lower Triassic to date.

The role of microbial agents in the precipitation of coated carbonate grains has long been debated (Davies et al., 1978; Folk and Lynch, 2001; Duguid et al., 2010). In this volume, Li Y. et al. (2017a) investigate the genesis of Lower Triassic giant ooids from the Haicheng and Moyang sections,