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Assessing Early Triassic paleoceanographic conditions via unusual sedimentary fabrics and features

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ABSTRACT

Analysis of the Lower Triassic sedimentary rock record has revealed a variety of unusual sedimentary fabrics and features, many of which were more common in the Proterozoic than the Phanerozoic. These so-called "anachronistic facies" developed across Lower Triassic carbonate platforms from shallow subtidal environments to deep, basinal environments and include features associated with the enhanced precipitation of calcium carbonate (e.g., synsedimentary seafloor cements), microbialites, and fabrics that formed due to a reduction in the intensity and depth of bioturbation (e.g., vermicular limestones). Three interacting factors controlled the development of anachronistic facies during the Early Triassic including: 1) environmental conditions (i.e., the unusual chemistry of Early Triassic oceans); 2) biotic factors (e.g., bioturbation and grazing pressures); and, 3) actualistic sedimentologic processes (e.g., waves and currents, sedimentation). Because these three factors typically acted in concert with each other, it is important to consider the role of each when using anachronistic facies to reconstruct Early Triassic paleoceanographic conditions. Overall, anachronistic facies are indicative of enhanced calcium carbonate precipitation during the Early Triassic, but do not necessarily indicate the former presence of anoxic or suboxic conditions where they were deposited. The influence of seawater chemistry on the deposition of anachronistic facies was most pronounced in deeper water environments, where anomalous paleoceanographic conditions heightened calcium carbonate precipitation and caused a decrease in bioturbation and grazing pressures via the upwelling of anoxic, alkaline waters. The degree of environmental influence lessened shorewards, where biotic factors and actualistic processes were more important, and slight modification of seawater by microbial activity, shallow burial, or CO_2-degassing was necessary for calcium carbonate precipitation to occur. Anachronistic facies are a useful tool for reconstructing paleoceanographic conditions and examining shifts in the distribution of environmental stress during the recovery from the Permian–Triassic mass extinction, but only when the biologic, sedimentologic, and geochemical factors that led to their growth are carefully considered.

1. Introduction

The Permian–Triassic mass extinction was one of the most critical and influential events of the Phanerozoic. The extinction represents the largest disturbance to the macrofauna in the history of the Earth (e.g., Raup, 1979; Sepkoski, 1981; Erwin, 2006; Alroy et al., 2008), and the aftermath was complex and uneven with many regions exhibiting dampened recovery across much (e.g., Galfetti et al., 2008), if not all, of the Early Triassic (e.g., Schubert and Bottjer, 1995; Payne et al., 2006a; Lehrmann et al., 2007; Chen et al., 2011). Recovery was rapid in the absence of environmental stress (e.g., Krystyn et al., 2003; Twitchett et al., 2004; Chen et al., 2007; Hofmann et al., 2011; Song et al., 2011), however, nascent recoveries were often interrupted and reset when environmental conditions worsened (e.g., Twitchett et al., 2004; Alms and Woods, 2008; Galfetti et al., 2008; Song et al., 2011). A variety of stresses have been proposed for or documented from the Early Triassic, with periodic flooding of the shallow continental shelves with deep anoxic, and possibly euxinic, waters being the best supported by the Lower Triassic marine record (Abdullah, 1999; Wignall and Twitchett, 2002a; Thomas et al., 2004; Algeo et al., 2007; Son et al., 2007; Galfetti et al., 2008; Grasby and Beauchamp, 2009; Bond and Wignall, 2010; Liao et al., 2010; Varol et al., 2011). Therefore, the area of the seafloor where recovery could begin (i.e., the "habitable zone" of Beatty et al., 2008) was squeezed between a periodically upward-expanding redoxocline and shallow, wave-stressed environments where benthic colonization has been limited throughout Earth history (Beatty et al., 2008; Zonneveld et al., 2010a, 2010b). Closely associated with the extinction and subsequent environmental stresses are a plethora of unusual sedimentary facies and fabrics that are often associated more closely with Proterozoic sedimentary rocks than Phanerozoic sedimentary rocks, and are referred to as "anachronistic facies" (e.g., Wignall and Twitchett, 1999; Pruss et al., 2005a). Anachronistic facies include a wide range of microbialites (e.g., stromatolites, thrombolites, wrinkle structures, oncoids) and other features that are indicative of environmental stress and enhanced precipitation

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of calcium carbonate during the period (e.g., sea-floor precipitates, flat pebble conglomerates, vermicular limestone) (e.g., Wignall and Twitchett, 1999; Pruss et al., 2005a; Zhao et al., 2008; Woods, 2009). Anachronistic facies, therefore, provide a means to document and track temporal and spatial shifts in seawater chemistry and deleterious environmental conditions during the Early Triassic.

2. Anachronistic facies

The term "anachronistic facies" was first used by Sepkoski et al. (1991) to refer to a variety of sedimentary facies and fabrics that are common in Cambrian and Lower Ordovician-aged rocks, but are rare afterwards. Sepkoski et al. (1991) considered flat pebble conglomerates to be an example of anachronistic facies, and proposed that they are indicative of the presence of environmental stress that limited the pervasive bioturbation that typically destroys the primary fabric of sediments deposited after the Early Ordovician. Flat pebble conglomerates were first noted from Lower Triassic rocks from south China and northern Italy by Wignall and Twitchett (1999), and they were recognized as being anachronistic in nature. Additional examples of anachronistic facies have since been documented from Lower Triassic sedimentary rocks deposited across a broad spectrum of depositional environments, and include a wide array of sedimentary features and fabrics, as discussed below.

2.1. Types of anachronistic facies

Lower Triassic anachronistic facies typically fall into three main groups: 1) microbialites; 2) features associated with the enhanced precipitation of carbonate cement, either on the seafloor or just below the surface, as well as within microbialites; and, 3) fabrics that form due to limited biologic activity related to persistent environmental stress and/or the severity of the extinction (e.g., vermicular limestone). These groups are not exclusive of each other, and a substantial amount of overlap may exist between them.

2.1.1. Microbialites

Microbialites are the best-documented example of Lower Triassic anachronistic facies. Stromatolites from the Virgin Limestone of southwestern Nevada (U.S.A.) were the first described Lower Triassic (Spathian) subtidal microbialites, and were proposed to be an example of disaster taxa by Schubert and Bottjer (1992). Disaster taxa are generalists that are typically relegated to stressed, marginal environments during much of Earth history, but expand into normal marine environments during biotic crises (Fischer and Arthur, 1977). More recent research, however, has downplayed the role of microbialites as disaster taxa (Kershaw et al., 2009), and stresses the role of the unusual chemistry of Early Triassic oceans in their formation (e.g., Pruss et al., 2005a; Woods et al., 2007; Woods, 2009; Kershaw et al., 2011).

2.1.1.1. Permian–Triassic boundary microbialites. Microbialites are commonly found in sedimentary sequences deposited immediately following the Permian–Triassic mass extinction event (Kershaw et al., 2007, 2012), and are referred to by Kershaw et al. (2012) as Permian–Triassic boundary microbialites (PTBMs). These microbialites are thin (5 cm to 15 m; Kershaw et al., 2012) and mostly limited to the Tethyan realm, with documented examples including northern south China (eastern Sichuan and Hubei provinces and the Chongqing area) (Kershaw et al., 1999, 2002; Ezaki et al., 2003; Adachi et al., 2004; Yang et al., 2006; Lehrmann et al., 2007; Ezaki et al., 2008; Galfetti et al., 2008; Yang et al., 2011), the Taurus Mountains of southern Turkey (Marcoux and Baud, 1986; Baud et al., 1997; Richoz, 2004; Groves et al., 2005; Kershaw et al., 2011), the Alborz Mountains (Gaetani et al., 2009) and Zagros Mountains (Wang et al., 2007) of Iran, and the Bükk Mountains of northern Hungary (Hips and Haas, 2006). While less common, examples of PTBMs from western Panthalassa include examples from the Nanpanjiang Basin of southern South China (Lehrmann, 1999; Lehrmann et al., 2003; Krull et al., 2004) and the Chichibu Terrane in southwest Japan (Sano and Nakashima, 1997; Horacek et al., 2009). PTBMs commonly rest on older Permian reef, oolitic, or shallow subtidal facies that are often highly fossiliferous, resulting in a stark contrast across the Permian–Triassic boundary (e.g., Baud et al., 1997; Gaetani et al., 2009; Wang et al., 2009). Shelly faunas are often associated with micrite lenses or layers found within the PTBMs, and include crinoids, bivalves, ostracodes, foraminifera and microgastropods (Kershaw et al., 2012); foraminifera (*Earlandia*) and microgastropods are occasionally found entombed in PTBMs (Yang et al., 2011). PTBMs may be overlain by oolitic limestones (e.g., Baud et al., 2005; Yang et al., 2006; Gaetani et al., 2009), but are not interbedded with them (Kershaw et al., 2012). Boundary microbialites are commonly found within shallow marine settings (Kershaw et al., 2007, 2012), but have also been documented from deeper-water facies, including examples from the Bükk Mountains of northern Hungary (Hips and Haas, 2009), and the southern Caucasus Mountains of Armenia (Baud et al., 1997). PTBMs are usually stromatolites or thrombolites (Pruss et al., 2006); dendrolites are uncommon, but have been documented from localities in south China, although recrystallization has made conclusive identification of dendrolites difficult (Kershaw et al., 2007; Yang et al., 2011; Kershaw et al., 2012).

2.1.1.2. Later Early Triassic microbialites. In addition to the Permian–Triassic boundary microbialites discussed above, microbialites have also been documented from facies deposited later in the Early Triassic. Pruss et al. (2006) and Baud et al. (2007) examined the distribution of Lower Triassic microbialites, and proposed that they were particularly common in 3 additional intervals: 1) from the late Griesbachian to the Dienerian; 2) during the Smithian; and, 3) from the Spathian to the early Anisian. Most examples are limited to the Tethyan realm (e.g., Lehrmann, 1999; Thomas et al., 2004; Enos et al., 2006; Ezaki et al., 2012), however, microbialites have also been documented from Griesbachian-age strata from eastern Greenland, along the Boreal Sea (Wignall and Twitchett, 2002b), along the eastern margin of Panthalassa from the Smithian to the earliest Anisian (Schubert and Bottjer, 1992; Pruss and Bottjer, 2004b; Mary and Woods, 2008; McCoy and Woods, 2010; Brayard et al., 2011), and in lower-middle Anisian rocks from Yunnan, southwest China (second Member of the Guanling Formation; Z. Q, Chen, pers. comm., 2012). Microbialites from western North America appear to be more ecologically more complex than PTBMs, with sponges, *Tubiphytes*, and serpulids associated with many of the microbialite build-ups (Griffin et al., 2010; Brayard et al., 2011; Marenco et al., 2012).

2.1.1.3. Oncoids, peloids, and microspheres. Oncoids have been noted from Lower Triassic sedimentary deposits from around the world (e.g., Baud et al., 1997; Sano and Nakashima, 1997; Kershaw et al., 1999; Thomas et al., 2004; Nützel and Schulbert, 2005; Enos et al., 2006; Baud et al., 2007; Horacek et al., 2009), and some are quite large, with those from the Abadeh region of Iran reaching diameters of up to 5 cm (Baud et al., 2007). Large micritic spheroids that are proposed to have formed from microbial activity have been documented from Spathian-aged rocks (Virgin Limestone) from southern Nevada; the spheroids are of a similar size to typical oncoids (3–12 mm in diameter; Flügel, 2010), but lack a nucleus and a laminated cortex (Pruss and Payne, 2009). Baud et al. (2007) consider Lower Triassic oncoids to be indicative of unusual oceanic conditions; however, Woods (2009) recommends caution when attributing an allochem that is relatively common in Phanerozoic rocks to be the result of atypical oceanic conditions. Unusually large oncoids like those documented by Baud et al. (2007) from the Abadeh region of Iran are, however, less ambiguously anomalous, as are oncoids found in subtidal depositional environments (e.g., Baud et al., 1997; Kershaw et al., 1999).

Peloidal limestones that are thought to be microbial in origin have also been documented from multiple Lower Triassic sedimentary sequences (Ezaki et al., 2003; Adachi et al., 2004; Hips and Haas, 2006;