Chemostратigraphy indicates a relatively complete Late Permian to Early Triassic sequence in the western United States

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ABSTRACT

Although the latest Permian mass extinction and associated δ13C excursion are well documented from the Tethys Ocean, carbonate rocks preserving these events in the eastern Panthalassic Ocean (western Pangea) are unknown. We present rocks preserving these events in the eastern Panthalassic Ocean. Although middle Panthalassa is preserved (Musashi et al., 2001) and siliciclastic environments of eastern Panthalassa (western Pangea) are known (Sperling and Ingle, 2006; Grasby and Beauchamp, 2008), latest Permian carbonate shelf deposits of western Pangea have long been thought to be absent at an unconformity (Collinson et al., 1976). However, this conclusion has been questioned due to a lack of diagnostic fossils (Alvarez and O’Connor, 2002).

We examined δ13C and δ87Sr/δ18Sr trends across the Gerster and Thaynes Formations in the western United States to address whether age refinement of these carbonate shelf deposits was possible using chemostratigraphy. An integrated C-Sr isotope study was necessary because δ13C excursions alone cannot identify the latest Permian due to multiple maxima and minima through the Middle Permian to Early Triassic (Payne et al., 2004; Bond et al., 2010). Seawater δ87Sr/δ18Sr rises continuously through this time (Korte et al., 2003) and therefore may constrain hypotheses of δ13C correlations. Here we report a negative δ13C excursion across the Gerster-Thaynes transition in the Confusion Range (Utah) and assess its likely age.

BIOSTRATIGRAPHY AND LITHOSTRATIGRAPHY OF GERSTER AND THAYNES FORMATIONS

The youngest conodont fauna from the Gerster Formation contains Neogondolella biteri and Neospathodus divergens (Wardlaw and Collinson, 1978, 1986), and could be as old as the Wordian stage (Guadalupian) or as young as Wuchiapingian (Lopingian) (Henderson, 1997). In the Confusion Range of Utah, which contains the thickest section in the region, the uppermost ~80 m of the Gerster above this N. biteri–N. divergens fauna contain no index fossils, and a minimum age is uncertain (Wardlaw and Collinson, 1978). Near the top of this ~80 m interval, a succession with several meters of red sandstone followed by limestone with unusually large chert nodules is unique to the Confusion Range.

These unusual uppermost Gerster beds are overlain by an ~8-m-thick interval containing a succession of carbonate lithologies that is also unique to the Confusion Range, including a lower 2 m of laminated, fenestral limestone with coated grains, and 6 m of microgastropod-rich wackestone. Collinson et al. (1976) assigned these beds to the basal “Thaynes” but noted that the contact with the underlying Gerster was difficult to discern and lacked relief. The age of the laminated, fenestral, and microgastropod-rich beds is controversial. Collinson et al. (1976) and Carr (1981) reported the Triassic (Smithian) conodont Parachirognathus ethingtoni from these beds in the Confusion Range. However, Wardlaw and Collinson (1986) later assigned these same basal “Thaynes” beds to the uppermost “Gerster,” consistent with conodonts they identify as the Permian genus Merrillina in the microgastropod-rich wackestone facies (B. Wardlaw, 2012, personal commun.). Because Merrillina is likely ancestral to Parachirognathus (Orchard, 2007), taxonomic uncertainty regarding the timing and morphological definition of this transition can explain the discrepancy in age assignments of these key beds. Above the microgastropod-rich beds, the lower Thaynes Formation consists of silstone, mudstone, and interbedded brownish-gray limestone beds typical of the region and containing abundant Meekoceras ammonites of Smithian age (Carr, 1981; Collinson et al., 1976; Lucas and Orchard, 2007).

METHODS

We sampled the Gerster and lowermost Thaynes Formations in the Confusion Range, Utah. Due to structural complications, the remainder of the Thaynes was sampled at Spruce Mountain, Nevada (see Field Sampling Methods and Figure DR1 in the GSA Data Repository). Micritic limestone was preferentially drilled for analysis using a Kiel-III device coupled to the dual inlet of a Finnigan MAT 253 mass spectrometer. Analytical precision based on analyses of reference material NBS19 was ±0.04‰. A δ13C–δ18O crossplot is inconsistent with major resetting of δ13C (see Table DR1 and Fig. DR2).

For δ87Sr/δ18Sr, we used the same rock samples studied for δ13C. Pre-treatment of all samples with ammonium acetate buffered to a pH of 8 was followed by dissolution in 4% acetic acid to minimize leaching of Sr from noncarbonate phases (Montañez et al., 1996) (see Analytical Methods in the Data Repository). δ87Sr/δ18Sr was measured using dynamic multicollection with a Finnigan MAT 261A thermal ionization mass spectrometer at the Ohio State Radiogenic Isotope Laboratory (Columbus, Ohio). The value for the SRM 987 standard was 0.710242 ± 0.000010 (1σ external reproducibility) during the study.

RESULTS

δ13C is steady near +3.0‰ through most of the Gerster Formation (Fig. 1). Near the top of the Gerster, at a distinct red sandstone bed, δ13C values decline to −0.3‰ at the highest chert bed (Fig. 2). δ13C continues to decline in overlying fenestral, laminated, and microgastropod-rich limestone beds to −2‰. In succeeding brownish-gray, ammonite-bearing limestone beds of the typical lower Thaynes Formation (containing Smithian fossils), δ13C is shifted to values as light as −4‰. Above a thick covered

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ammonites published Middle Permian to Early Triassic. Permian (late Guadalupian) or as young as Early Triassic (Smithian). Published Middle Permian to Early Triassic δ13C curves for the Tethys (e.g., Carr, 1981).

87Sr/86Sr increases from 0.7072 in the upper Gerster to 0.7080 in the lower Thaynes (Fig. 3). We take a conservative approach and assume that all of our 87Sr/86Sr values have been shifted to more radiogenic (higher) values to some degree by diagenesis (indicated by low Sr concentrations; see Table DR2 and Fig. DR7), and therefore report here only the least radiogenic values to estimate minimum relative ages (e.g., Veizer, 1989). This method of relative age dating using 87Sr/86Sr is particularly useful for this time period because of the large monotonic rise in the global seawater curve from ~0.7069 at the Middle Permian–Late Permian boundary to 0.7082 at the end of the Early Triassic (Martin and Macdougall, 1995; Korte et al., 2003, 2004; Twitchett, 2007). For example, because the Permian-Triassic (P-T) boundary is at ~0.7072 on the seawater curve, we assume that a sample with an 87Sr/86Sr of 0.7072 could date to any part of the Late Permian (with an earliest Lopingian age requiring alteration by ~+0.0003) but is unlikely to be younger than the P-T boundary. A post-P-T boundary age would require the original seawater value to have been altered to lower 87Sr/86Sr, which, while possible in the presence of nonradiogenic Sr sources such as volcanic ash from the McCloud Arc (Miller, 1987), is not supported by a lack of bentonites in the area.

DISCUSSION

δ13C declines from +2.0 in the uppermost cherty beds of the Gerster Formation to ~−2.0‰ in the overlying fenestral limestone sequence with no major discontinuities or offsets (Figs. 1 and 2). Although we interpret a steady δ13C decline as a reflection of relatively continuous sedimentation, coarse biostratigraphic control and uncertainty in ranges of conodonts Merriilla and Pararhachitodus allow for the excursion to be as old as Middle Permian (late Guadalupian) or as young as Early Triassic (Smithian). Published Middle Permian to Early Triassic δ13C curves for the Tethys (e.g., Xie et al., 2007; Korte et al., 2004; Payne et al., 2004; Horacek et al., 2007; Yin et al., 2007; Bond et al., 2010; Tong and Zhao, 2011; Huang et al., 2012) indicate significant negative excursions at the end-Guadalupian, latest Permian, or middle Olenekian (Smithian) that can all potentially correlate to the Confusion Range (see Figs. DR4–DR7). Here we examine age constraints on δ13C based on our new 87Sr/86Sr, and then consider possible ages in the context of sequence stratigraphy and facies analysis.

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87Sr/86Sr Stratigraphy

Making the assumption that secondary alteration typically results in increases in 87Sr/86Sr to ratios more radiogenic than the initial primary seawater value (due largely to contamination by radiogenic strontium from silicilastic components; Veizer, 1989), we utilize least radiogenic values in our section to provide minimum age estimates on the timing of the δ13C excursion. In the Confusion Range, the least radiogenic 87Sr/86Sr near the onset of the negative δ13C excursion is 0.70730 (position b in Fig. 2). Because 0.70730 falls between best estimates of seawater Sr for the base...
3) is less than the 0.70774 from the latest Induan GEOLOGY age estimates, it is difficult to confidently place a maximum age on the Twitchett, 2007), this suggests that the onset of the negative Triassic (0.7071–0.7072) and middle Induan (~0.7074) (Korte et al., 2004; 87Sr/86Sr agreement with our 87Sr/86Sr (0.70797 for point h in Figs. 2 and 3). Conodont zones: ction with a negative δ13C excursion in the Early Triassic (Smithian) of the Tethys (see Figs. DR4–DR7). Last, the large positive δ13C shift to +7.5‰ in the Spathian part of the Thaynes Formation at Spruce Mountain confirms the significance of this particular event (Hauser et al., 2001; Tong and Zhao, 2011; Huang et al., 2012) (see Fig. DR6) and more generally the global large Early Triassic carbon cycle perturbations (Payne et al., 2004).

Sequence Stratigraphy and Facies Analysis

Both the end- Guadalupian and latest Permian negative δ13C excursions occur near prominent sequence boundaries (Yin et al., 2007; Bond et al., 2010). However, while the end-Guadalupian sequence boundary postdates the δ13C minimum in the Jinggondolella presuxuanhanensis–J. xuanhanensis conodont zones (Bond et al., 2010), the latest Permian sequence boundary predates the δ13C minimum in the Hindeodus praeparvus zone (e.g., Wignall et al., 2009). In the Confusion Range, a prominent lowstand in sea level is known from the upper Gerster Formation (Fig. 2) (Warland and Collinson, 1978). This lowstand is represented by several meters of red-colored, high-angle cross-bedded, fine-grained sandstone recognized by previous workers as a persistent marker bed above the thick (~200 m) open-marine, cherty limestone of the Gerster (Collinson et al., 1976) (Figs. 1 and 2). Because the lowstand predates the δ13C minimum in the Confusion Range, this is consistent with a latest Permian but not an end-Guadalupian age. Although not age-diagnostic, the facies succession associated with the δ13C minimum in the Confusion Range shares similarities with those described from Tethyan sections that span the latest Permian δ13C excursion and mass extinction. For example, the latest Permian extinction in many parts of the world is marked by disappearance of chert (Henderson, 1997; Isozaki, 1997; Wignall and Newton, 2003; Sperling and Ingle, 2006) and in the Tethys by appearance of unique biofacies or lithofacies including inorganically precipitated carbonate (Pruss et al., 2006; Groves et al., 2007; Kershaw et al., 2007; Algeo et al., 2007). In the Confusion Range, the last beds of cherty limestone of the Gerster Formation are overlain by strata that record the δ13C minimum within a succession of dominantly fenestral, laminated stromatolitic, and oolitic facies (Figs. 2 and 3) (although thin sections so far do not confirm microbiolites such as those recorded in postextinction strata in the equatorial Tethys; S. Kershaw, 2012, personal commun.). In addition, the lack of larger gastropod species in beds of the δ13C minimum (Fig. 2) is consistent with a latest Permian age, but less consistent with Guadalupian, which is dominated by larger gastropods in the western United States (Fraiser and Bottjer, 2004).

IMPLICATIONS

The evidence presented here taken as a whole suggests that the negative δ13C excursion in the Confusion Range is latest Permian, which would represent the first documentation of carbonates of this age in western Pangea assumed to be missing at an unconformity (Fig. DR3). Continuity of deposition across the latest Permian extinction interval in the western United States is consistent with global transgression (Yin et al., 2007). The magnitude of the δ13C excursion in the Confusion Range (reaching values as light as ~2‰) is greater than most equatorial Tethyan sections but similar to higher-latitude, outer-shelf sections in the Neotethys (Korte and Kozer, 2010) (Fig. DR4). This relatively light δ13Cmin in eastern Panthalassa may reflect proximity of 13C-enriched, deep anoxic water masses (e.g., Isozaki, 1997; Wignall and Newton, 2003). Although 87Sr/86Sr stratigraphy is useful in providing minimum age estimates, it is difficult to confidently place a maximum age on the
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