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A Middle–Late Triassic (Ladinian–Rhaetian) carbon and oxygen isotope record from the Tethyan Ocean

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ABSTRACT

We obtained bulk-sediment $\delta^{18}O$ and $\delta^{13}C$ data from biostratigraphically-constrained Tethyan marine sections at Aghia Marina (Greece), Guri Zi (Albania), and Brumano and Italcementi Quarry (Italy), and revised the published chemostratigraphy of the Pizzo Mondello section (Italy). We migrated these records from the depth to the time domain using available chronostratigraphic tie points, generating Ladinian–Rhaetian $\delta^{13}C$ and $\delta^{18}O$ records spanning from ~242 to ~201 Ma. The $\delta^{18}O$ record seems to be affected by diagenesis, whereas the $\delta^{13}C$ record appears to preserve a primary signal and shows values increasing by ~1‰ in the Ladinian followed by an ~0.6‰ decrease across the Ladinian–Carnian boundary, followed by relatively constant (but oscillatory) Carnian values punctuated by a negative excursion at ~233 Ma in the early Carnian, a second negative excursion at ~229.5 Ma across the early–late Carnian boundary, and a positive excursion at ~227 Ma across the Carnian–Norian boundary. The Norian record is characterized by a long-term decreasing trend and a negative excursion at ~216 Ma. Rapid increases and decreases in $\delta^{13}C$ have been observed in the Rhaetian, but these may be at least in part due to mixing of different sources of carbonate carbon with different $\delta^{13}C$ values. Our Triassic $\delta^{13}C$ record has been compared to data from the literature, and a composite $\delta^{13}C$ record spanning the last ~242 Myr of Earth's history has been generated. This composite record shows a sequence of dated $\delta^{13}C$ trends and events that can be used for stratigraphic correlation as well as for a better understanding of the global carbon cycle in the Mesozoic–Cenozoic.

1. Introduction

Our goal in this paper is to construct a continuous oxygen and carbon isotope profile anchored to Middle–Late Triassic (Ladinian–Rhaetian) biostratigraphy and magnetostratigraphy to augment the definition of the Triassic time scale. We present new biostratigraphic (conodonts), chemostratigraphic (oxygen and carbon isotopes), and paleomagnetic data from the Middle–Late Triassic (Ladinian–Norian) Aghia Marina section, which is a well exposed and continuous marine section comprised of Tethyan pelagic limestones located on the island of Hydra in Greece (Angiolini et al., 1992). Because the Aghia Marina section is remagnetized, its bio-chemostratigraphic results cannot be directly tied to magnetic polarity reversals; nonetheless, the section remains a useful ancillary section for the definition of the Late Triassic time scale. We also present new chemostratigraphic data and a revised conodont biostratigraphy from the Late Triassic (Carnian–Norian) Guri Zi section from Albania (Muttoni et al., 2005), as well as new chemostratigraphic data from the Late Triassic (Rhaetian) Brumano and Italecmenti Quarry sections from northern Italy (Muttoni et al., 2010). Moreover, we summarize the published chemostratigraphy, magnetostratigraphy, and conodont biostratigraphy of the Carnian–Norian Pizzo Mondello section (Muttoni et al., 2004; Mazza et al., 2012a). We place these chemostratigraphic records in the numerical time domain by applying age models of sedimentation obtained by means of magnetostratigraphic correlations with the Newark Astrochronological Polarity Time Scale (APTS) (Kent and Olsen, 1999; Olsen and Kent, 1999) anchored to a Triassic–Jurassic (Rhaetian–Hettangian) boundary at ~201.5 Ma after recent numerical age estimates for the base of Central Atlantic Magmatic Province (=~age of end-Triassic Extinction; Blackburn et al., 2013). The resulting stable isotope profiles spanning ~40 Myr of the Triassic represent a significant step forward for the development of an important chemostratigraphic correlation tool in sections with insufficient magnetobiostratigraphy to determine higher-resolution age models. Finally, we integrated our Triassic $\delta^{13}C$ record with data from the literature in order to generate – and discuss – a composite record of the global carbon cycle spanning the last ~242 Myr of Earth's history.

2. The Ladinian–Norian Aghia Marina section

2.1. Geological setting and lithostratigraphy

The Aghia Marina section is located on the island of Hydra in Greece (Fig. 1). Hydra is characterized by a Permian to Jurassic sedimentary

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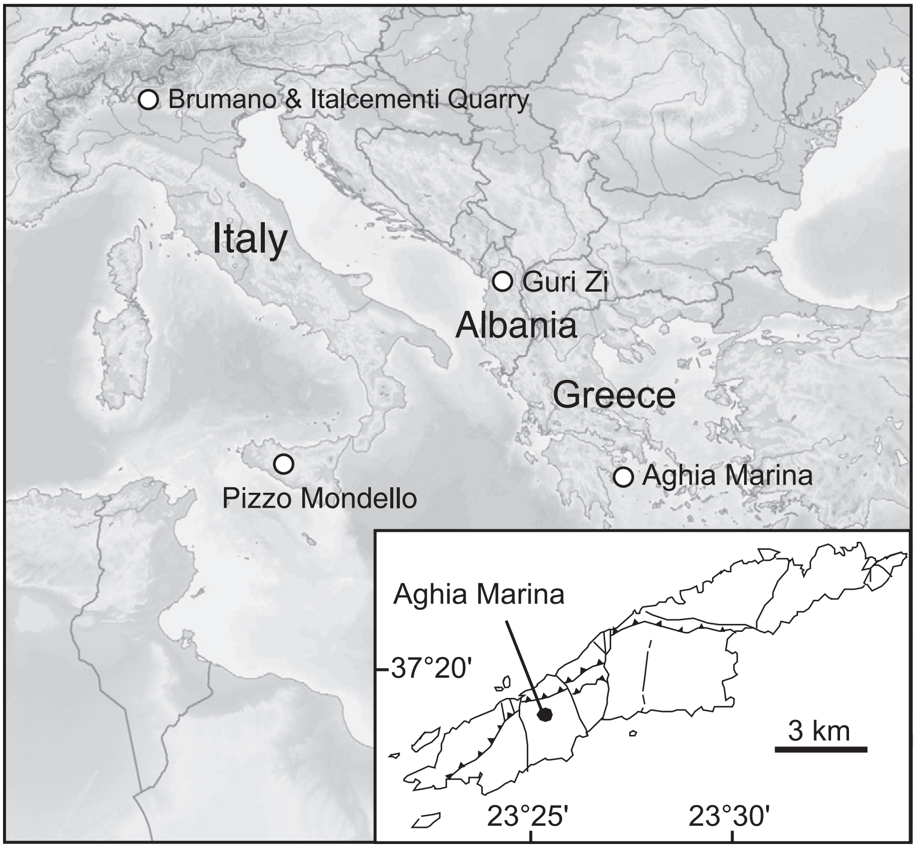

Fig. 1. Location map of the stratigraphic sections discussed in the text: Aghia Marina (Greece), Pizzo Mondello (Italy), Guri Zi (Albania), and Brumano and Italcementi Quarry (Italy). The inset shows the tectonic map of Hydra, Greece (Angiolini et al., 1992) with location of the Aghia Marina section.

succession (Renz, 1931; Angiolini et al., 1992; Balini, 1994; Muttoni et al., 1994, 1997) arranged in four major thrust sheets dissected by north–south trending faults as the result of deformation during the Late Jurassic and Cenozoic (Baumgartner, 1985; Angiolini et al., 1992). The Middle–Late Triassic (Ladinian–Norian) Aghia Marina section, first described by Angiolini et al. (1992, Section A), is located near the Aghia Marina chapel (37°19′14.07″N; 23°25′15.60″E) in the southern thrust sheet (Fig. 1; see also Angiolini et al., 1992). The section starts with an ~5 m-thick interval of thinly bedded cherts and continues with ~157 m of cm to dm-thick planar beds of gray limestones with chert nodules with occasional thin levels of red clays and meter-scale levels of calcarenites, altogether pertaining to the Adhami Limestone, overlain by ~12 m of pink and gray nodular limestones of the Rosso Ammonitico (Fig. 2).

2.2. Conodont biostratigraphy

We present a complete conodont biostratigraphic record of the Aghia Marina section (Figs. 2, 3; Supplementary Table 1) that takes into account previous results (Angiolini et al., 1992) and recent taxonomic revisions of Late Triassic conodonts (Kozur, 2003; Moix et al., 2007; Noyan and Kozur, 2007; Mazza et al., 2011, 2012a,b).

The section starts close to the Anisian–Ladinian boundary (Angiolini et al., 1992; Balini, 1994) and extends into the Ladinian, Carnian, and Norian (this study). In particular, in the interval between sample AM14 and sample AM37, the section is Ladinian (Longobardian) based on the occurrences of *Gladigondolella* sp., *Gladigondolella malayensis malayensis* Nogami, *Paragondolella inclinata* (Kovács), *Paragondolella foliata* Budurov and *Neocavitella tatrica* (Zawidzka). The Ladinian–Carnian boundary is placed at ~60 m in sample MA5 at the first occurrence of *Paragondolella polygnathiformis* (Budurov & Stefanov) (Fig. 3B), which is a proxy marker for the base of the Carnian (Mietto et al., 2012).

Above follows an early Carnian (Julian) association of *Paragondolella polygnathiformis*, *Paragondolella foliata*, *Paragondolella praelindae* Kozur (Fig. 3E), *Paragondolella tadpole* (Hayashi) (Fig. 3A, D), and *Carnepigondolella nodosa* (sensu Hayashi, 1968) (Fig. 3C). The interval from ~112 m in sample MA9 to ~135 m in sample AM55 is regarded as late Carnian (Tuvalian) based on the last occurrence in sample MA9 of *P. foliata* and the first occurrence in sample AM55 of *Carnepigondolella gulloae* Mazza and Rigo (Fig. 3F) [ex "*Metapolygnathus communisti* B" Krystyn, see Mazza et al. (2012a)], which is early Norian (Balini et al., 2010; Mazza et al., 2012a). The only species recovered in this Tuvalian interval are *P. polygnathiformis* and *C. nodosa*, which extend up to the early–middle Tuvalian (Martini et al., 1991; Moix et al., 2007; Balini et al., 2010; Mazza et al., 2012a).

The upper part of the section, from ~135 m in sample AM55 to ~172 m in sample AM65, dates to the early–middle Norian (Lacian–Alaunian) based on the first occurrence of *Carnepigondolella gulloae* in sample AM55 (super-adult growth stages; Fig. 3F), in association with juvenile stage specimens of *Epigondolella quadrata* Orchard (Fig. 3I, J). The interval comprised between sample AM61, located just below the base of the Rosso Ammonitico, and sample AM65 at the section top, yielded a middle Norian (Alaunian) association composed of *Norigondolella navicula* (Huckriede) (Fig. 3G), *Norigondolella steinbergensis* (Mosher) (Fig. 3H, L), *Norigondolella* sp. (Fig. 3M, N), and *Norigondolella kozuri* (Gedik) (Fig. 3K); the FO of *N. steinbergensis* in sample AM61 is here used as marker for the middle Norian. This conodont association indicates that the Ammonitico Rosso is Late Triassic in age and not Early Jurassic, as previously proposed (Angiolini et al., 1992).

The conodont color alteration index (CAI) ranges from 4 to 6.5 (Supplementary Table 1), suggesting that the succession has been subject to temperatures in excess of 300 °C (e.g., Epstein et al., 1977), which may