Palaeogeography, Palaeoclimatology, Palaeoecology 499 (2018) 131–137

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Sr isotope variations in the Upper Triassic succession at Pizzo Mondello, Sicily: Constraints on the timing of the Cimmerian Orogeny

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ARTICLE INFO

Keywords:
Carnian
Norian
Limestone
Tethys
Climate change
Cimmerian Mountains

ABSTRACT

The Late Triassic Cimmerian Orogeny was a result of the final closure of the Palaeotethys Ocean and the accretion of Gondwana-derived (Cimmerian) continents to southern Eurasia. Determining the timing of the Cimmerian Orogeny is crucial to our understanding of the large-scale climate changes driven by the uplift of the Cimmerian Mountains. Here we present stratigraphic variations in $^{87}Sr/^{86}Sr$ values of Upper Triassic pelagic limestone from the Pizzo Mondello section, Sicily, Italy, that constrain the timing of uplift of the Cimmerian Mountains. The $^{87}Sr/^{86}Sr$ values remain relatively constant in the lower part of the section, decreasing slightly in the Tuvalian (upper Carnian) and Lacian (lower Norian). However, $^{87}Sr/^{86}Sr$ ratios rise sharply at the Lacian–Alaunian (lower–middle Norian) boundary and continue to rise through to the Sevatian (upper Norian). This observation indicates an increased input of radiogenic strontium derived from continental weathering, which resulted from the rapid uplift and erosion of the Cimmerian Mountains at this time. The climatic and environmental changes following the uplift of the Cimmerian Mountains provide an explanation for (1) an intense sea-surface-temperature warming event in the western Tethys Ocean, and (2) a rapid increase in precipitation on the northern coast of the Tethys during the Alaunian–Sevatian.

1. Introduction

The Late Triassic (201.5–237 Ma) is an important Phanerozoic epoch for which there is no evidence of any glacial activity (Boucot et al. 2013). During this time, the interior of the Pangea supercontinent was largely arid at low to mid latitudes and had an equatorial humid climate, while the higher latitudes from about 30°N were dominated by a humid climate (Muttoni et al. 2013; Kent et al. 2017). This period is generally considered to have had a stable climate, based on sedimentological evidence from the western Tethys (Preto et al. 2010). However, some studies have shown that the long arid to semi-arid periods in the Late Triassic were interrupted by two humid events recorded in the Tethys during the late Carnian (the Carnian Pluvial Event; Simms and Ruffell 1989; Rigo et al. 2007; Preto et al. 2010) and the late Norian (Berra et al. 2010; Fijałkowska-Mader 2015; Haas et al. 2017).

There are several lines of evidence for the Carnian Pluvial Event: one of the most distinctive being the observation of a sudden input of coarse siliciclastic material to most of the shallow-water Carnian successions in Europe (Simms and Ruffell 1989). This event was characterized by a temporary shutdown of carbonate systems across the western Tethyan realm (Rigo et al. 2007) and high extinction rates in several groups, such as ammonoids, crinoids, bryozoa, and conodonts (Simms and Ruffell 1989; Rigo et al. 2007). It has been suggested that the Carnian Pluvial Event was caused by major flood-basalt volcanism, specifically the eruption of the Wrangellia large igneous province in the Panthalassa Ocean (Furin et al. 2006; Preto et al. 2010).

The Norian climate was relatively stable, interrupted by only one episode of humid conditions in the Sevatian (late Norian). This climatic change shows a close correlation with the timing of evolution of modern fauna and flora, and with episodes of biotic crises in the western Tethys. For example, the Sevatian is characterized by the mobilization and infaunalization of shallow marine benthos (Tackett and Bottjer 2012), a floral change to more hygrophytic forms (Fijałkowska-Mader 2015), the evolution and diversification of calcareous nanoplankton (Gardin et al. 2012; Preto et al. 2013), and large perturbations in the organic carbon-isotope record (Zaffani et al. 2017). As a first

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https://doi.org/10.1016/j.palaeo.2018.03.025
Received 26 January 2018; Received in revised form 22 March 2018; Accepted 22 March 2018
Available online 26 March 2018

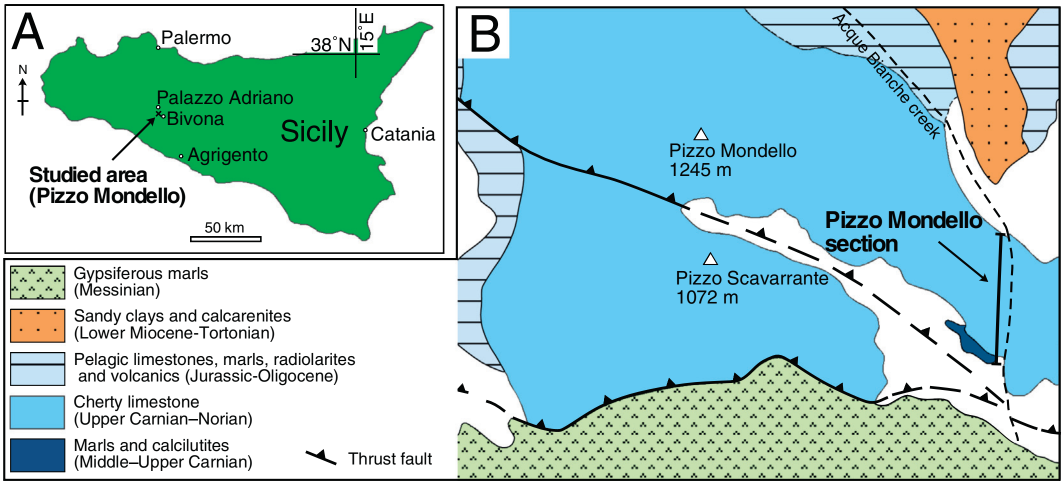

Fig. 1. Location (A) and geological map (B) of the Pizzo Mondello section in the Sicani Mountains, Sicily (modified after Muttoni et al. 2004).

approximation, it is reasonable to assume that this pattern in the evolution of marine and terrestrial organisms was related to environmental changes that occurred during the Norian humid interval. Although some studies have suggested that volcanic events, and global cooling or warming episodes, played a role (Berra 2012; Trotter et al. 2015; Zaffani et al. 2017), it is unclear how these processes would have triggered the environmental and biotic changes described above.

In this study we examine the stratigraphic variations in $^{87}Sr/^{86}Sr$ in the Upper Triassic limestone succession of Sicily, to understand environmental changes in the western Tethys Ocean during the Norian. As seawater $^{87}Sr/^{86}Sr$ ratios are controlled principally by continental riverine flux and by the hydrothermal flux at mid-oceanic ridges, the record of Sr isotope ratios in carbonate rocks is a useful proxy for the intensity of continental weathering, and an indicator of orogenesis and changes in global climate (Koepnick et al. 1990; Korte et al. 2003). Using these data, we discuss the relationship between the marine Sr isotope record, and climatic and tectonic processes in the Norian.

2. Geological setting

Pizzo Mondello is located in the Sicani Mountains, central Sicily (Fig. 1). The Sicani Mountains belong to the eastern part of the Maghrebian fold-and-thrust belt. The mountains comprise a pile of south-verging thrust sheets, known as the Sicanian structural units, which were formed by the contraction of the Sicanian basin during the Neogene (Catalano et al. 1995).

The Sicanian Basin was filled with Permian–Cenozoic deep-water sediments deposited along the southern margin of the Ionian Tethys (Muttoni et al. 2004). Of this sequence, the Pizzo Monello succession consists of ca. 1500 m of Upper Triassic to Eocene deep-water sediments, the majority of which are micrite limestones intercalated with Middle Jurassic radiolarites and pillow lava (Nicora et al. 2007). The lower part of the Pizzo Mondello succession is Late Triassic in age and comprises Carnian marly limestones that show a transition to dark gray marls of the Mufara Formation. This transition represents a climatic change to more humid conditions (Rigo et al. 2012; Trotter et al. 2015), known as the Carnial Pluvial Event (Simms and Ruffell 1989). The Sicanian Basin sediments record the return of carbonate sedimentation following this humid period, with the deposition of the Scillato Formation during the late Carnian to early Rhaetian. This formation contains micritic limestones rich in conodonts and pelagic bivalves (e.g., *Halobia*) with cherty nodules and thin beds, and is comparable to other Upper Triassic carbonate successions throughout SE Europe; e.g., the Calcari con Selce in the Southern Appennines (Italy), the Adhami Limestone in Greece, and cherty limestones in Albania (e.g., Muttoni et al. 2014).

The Pizzo Mondello section is a monotonous 400-m-thick succession of bedded and nodular cherty calcilutites that is well exposed on the southern and eastern slopes of Pizzo Mondello mountain (Muttoni et al. 2004; Nicora et al. 2007). The lower part of the section is exposed in an abandoned quarry ("La Cava") and is the candidate section for the Norian Global Stratotype Section and Point (Nicora et al. 2007; Mazza et al. 2012; Rigo et al. 2017). Above this, the cherty limestones show a sharp transition to a ca. 20 m thick section of white marly calcilutite, the Rhaetian–Pliensbachian Portella Gebbia Limestone, which is rich in condonts, radiolarians, calcispheres, and calcareous nannofossils (Gullo 1996; Preto et al. 2012, 2013).

3. Methods

3.1. Sample preparation and screening

Acid-leached micrite provides a reliable primary $^{87}Sr/^{86}Sr$ signature, as demonstrated by the good agreement between $^{87}Sr/^{86}Sr$ values of coeval conodonts, brachiopods, and limestones obtained in previous studies of Triassic to Jurassic limestone units (Koepnick et al. 1990; Korte et al. 2003). To approximate the primary $^{87}Sr/^{86}Sr$ signature, we selected samples of fine-grained limestone from two microfacies of lime-mudstone and wackestone, identified through microfacies analysis (Table S1). The micrites in both microfacies samples are composed mainly of lime mud derived from calcareous nanofossils (Preto et al. 2012, 2013).

We collected samples for whole-rock geochemical analysis from 104 limestone beds in the Pizzo Mondello section. We avoided veins and strongly recrystallized and weathered parts of the limestone beds to minimize the effects of diagenetic overprinting on sediment geochemistry. Samples were treated with 0.1 N HCl, rinsed with ultrapure water, and then dried and crushed. Crushed fragments were carefully handpicked (discarding any altered or weathered material) and pulverized in an agate mortar prior to Sr isotope analyses.

The presence of detrital material influences the Sr isotopic composition of limestone because detrital materials contain radiogenic Sr. In particular, the presence of clay minerals and feldspar derived from continental crust results in increased $^{87}Sr/^{86}Sr$ ratios, as these materials generally have higher Rb/Sr ratios than $CaCO_3$. To minimize this effect, we dissolved the samples in weak acetic acid (10%) using a short reaction time (30 min) at room temperature, as described in the section below. We then checked the enrichment factor of Al and K (normalized by the composition of the average upper continental crust; Table S1) and Rb/Sr ratios to estimate the influence of the detrital component, as