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Estuarine Lago Mare fauna from the Tertiary Piedmont Basin indicates episodic Atlantic/Mediterranean exchange during the final stage of the Mediterranean Salinity Crisis

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ABSTRACT

The geochemical signature of fossils from Lago Mare deposits at Moncucco Torinese (NW Italy) indicates a temporary marine ingression into the Tertiary Piedmont Basin just before the Miocene/Pliocene boundary. Isotope ($\delta^{18}O$, $\delta^{13}C$, $^{87}Sr/^{86}Sr$) and trace element (Sr/Ca, Ba/Ca) data from mollusk shells of multiple species and croaker otoliths indicate an upper estuarine environment with considerable seasonal variability in evaporation and freshwater input. Reconstructed salinities < 10 psu and low $^{87}Sr/^{86}Sr$ values indicate the close proximity of a watershed draining off of Mesozoic ophiolites and carbonates of the Alps and/or Apennines. Communication with an open marine environment is supported by otoliths of fully marine fishes such as lanternfishes, codlets, and slimeheads found in the same assemblage that carry a euhaline signature close to open ocean values. A thorough taphonomic evaluation renders reworking of the otoliths from pre-evaporitic deposits unlikely; instead we explain their presence in the Lago Mare assemblage as related to large predatory marine fish that periodically migrated into marginal marine and estuarine environments.

The presence of a paralic paleobiotope with thalassogenic water in the Tertiary Piedmont Basin contradicts ideas of the Mediterranean as a brackish lake fed by the Paratethys during the latest stage of the Mediterranean Salinity Crisis. Instead, our data support previous notions of temporary Atlantic/Mediterranean exchange during sea-level highstands preceding the permanent re-connection at the Miocene/Pliocene transition. The establishment of short-lived and disjunct estuarine and lagoonal environments such as in the Tertiary Piedmont Basin during marine ingressions also puts highly variable $^{87}Sr/^{86}Sr$ values and occurrences of shallow water benthic foraminifera in Lago Mare deposits of other Mediterranean basins into a new perspective.

1. Introduction

Tectonic and climatic forcing increasingly isolated the Mediterranean Sea from the open ocean during the early Messinian. Exchange with the Atlantic was finally severed at ~5.97 Ma, marking the onset of the Messinian Salinity Crisis (MSC), and a permanent connection was only re-established by the early Pliocene (Manzi et al., 2013; Hernández-Molina et al., 2014; Roveri et al., 2014a; Van der Schee et al., in press). Isolation resulted in a succession of hyper- and hyposaline conditions in the Mediterranean: widespread deposition of thick evaporitic deposits, progressing stepwise from marginal to deep basins and culminating at 5.6–5.55 Ma, was followed by mostly brackish deposits until 5.33 Ma (Roveri et al., 2014a). The fossil record suggests that these stressful and volatile conditions had a devastating impact on Mediterranean ecosystems and strongly favored opportunistic species. The peculiar and prevalent late MSC "Lago Mare" fauna, mainly consisting of euryhaline ostracods and mollusks, is often cited as a prime example. Based on its species content and low strontium isotope values the existence of a late MSC brackish lake, probably sourced by Paratethys waters, was inferred (Orszag-Sperber, 2006; Rouchy and Caruso, 2006; Roveri et al., 2014b). However, this interpretation has been challenged by frequent occurrences of foraminifera and marine fish in Lago Mare deposits, and episodic exchange with the Atlantic during the late MSC has been proposed as an alternative hypothesis (see e.g., Butler et al., 1999; Carnevale et al., 2006b, 2008b; Bache et al., 2012; Mezger, 2012; Zecchin et al., 2013; Roveri et al., 2014a and

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references therein). In addition, the taxonomic revision of a Lago Mare mollusk fauna from northern Italy has cast doubt on biogeographic relations to Paratethyan faunas (Harzhauser et al., 2015; Neubauer et al., 2015).

In this study, we apply geochemical proxy methods to co-occurring brackish mollusks and marine otoliths from Lago Mare deposits in the Tertiary Piedmont Basin (NW Italy) to unravel their taphonomy and habitats. The paleoenvironmental reconstruction will offer new perspectives on Atlantic/Mediterranean exchange during the late MSC.

2. Study area

The Tertiary Piedmont Basin (TPB) in NW Italy is a wedge-top basin within the arc of the Southwestern and Ligurian Alps that developed in response to the collision of the European and Adriatic plates (Fig. 1; Bertotti and Mosca, 2009; Rossi et al., 2009; Maino et al., 2013). The TPB infill consists of Eocene to Pliocene sediments which are in turn covered by Pliocene to Holocene deposits of the Savigliano and Alessandria piggy-back basins (see e.g., Bertotti and Mosca, 2009; Rossi et al., 2009; Irace et al., 2010 for details). The Messinian deposits of the TPB show a fourfold development characteristic of marginal Mediterranean basins. Hemipelagic marls and laminated mudstones of the upper Tortonian to lower Messinian Marne di Sant'Agata Formation are unconformably overlain by selenitic gypsum of the Vena de Gesso Formation (corresponding to the Primary Lower Gypsum, 5.97–5.6 Ma; Roveri et al., 2014a). The top of the evaporites is bound by an erosional surface, followed by re-deposited evaporites of the “Valle Versa Chaotic Complex” (Dela Pierre et al., 2011). The uppermost Messinian is marked by intercalation of brackish and continental deposits of the “facies à *Congeria*” with the Conglomerati di Cassano Spinola Formation (Irace et al., 2010). Marine shales and marls of the Argille Azzurre Formation document the re-establishment of normal marine conditions at the base of the Pliocene (Violanti et al., 2011). At present, Messinian sediments are exposed in two areas along the northern (Torino Hill, Monferrato) and southern (Langhe, Alto Monferrato, Borbera Grue domains) margins of the TPB (Fig. 1).

The studied material derives from post-evaporitic upper Messinian deposits in the gypsum quarry at Moncucco Torinese, situated along the southern slope of the Torino Hills (Figs. 1, 2; Trenkwalder et al., 2008; Angelone et al., 2010; Alba et al., 2014; Colombero et al., 2014, 2015). The brackish and continental “facies à *Congeria*” overlies the “Valle Versa Chaotic Complex” and comprises up to 6.5 m of beige to green-blue clayey marls with occasional, locally constrained calcareous paleosol interbeds. Several depositional units have been distinguished within the “facies à *Congeria*” that vary laterally in thickness and fossil content (Angelone et al., 2010). The basal unit consists of sandy clays and contains ostracods and rare brackish mollusks representing the Lago Mare biofacies (M1 in Angelone et al., 2010). Conglomerates mark an erosional surface at the top of the basal layer. Overlying units M2–8 consist of sandy clays with occasional, locally constrained conglomerates and paleosols. Fossil assemblages consist of mixed terrestrial and reworked brackish fossils; the latter are shells of dreissenid and limnocardiid bivalves along with melanopsid and hydrobiid gastropods (Harzhauser et al., 2015). Ostracods and mammals allow a correlation with upper Messinian mammal zone MN 13 and the *Loxocorniculina djafarovi* Zone (5.40 to 5.33 Ma; Trenkwalder et al., 2008; Angelone et al., 2010; Colombero et al., 2014).

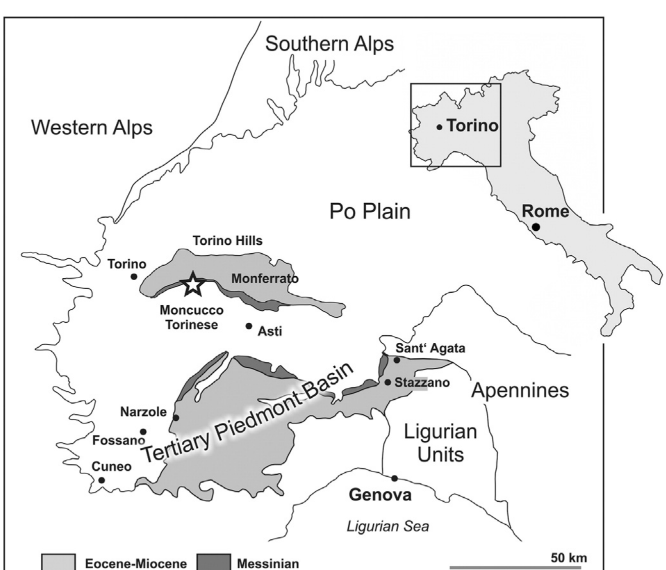

Fig. 1. Geographic and geological setting of the Tertiary Piedmont Basin and the Po Plain, showing the position of the Moncucco Torinese section. Sediment distribution in grey; black lines indicate boundaries between major tectonic units (adopted from Harzhauser et al., 2015).

3. Material and methods

A variety of terrestrial and aquatic mollusk taxa has been selected for analyses from beds M3 and M4 (Table 1; Fig. 2). Whenever possible, portions of the same shell fragment have been used for geochemical analyses and SEM documentation. A variety of marine and estuarine otolith taxa have been recovered from the “facies à *Congeria*”, of which 5 taxa from units M3-M5 have been selected for isotope analyses (Tables 2, 3).

3.1. Stable isotopes ($\delta^{18}O$, $\delta^{13}C$)

With the exception of *Limax*, mollusk shells have not been drilled due to their small size, but small pieces have been broken off close to the aperture. For some larger specimens, measurements have been performed on several fragments to observe internal variability. Shell fragments and otoliths have been ultrasonically cleaned with H_2O_{dest} and Methanol for several minutes to remove clay. Isotopic analyses have been performed using an automatic Kiel II preparation line and a Finnigan MAT Delta Plus mass spectrometer at the Institute of Earth Sciences, University of Graz. Samples were reacted with 100% phosphoric acid at 70 °C. Analytical precision, based on replicate analysis of international standards NBS-19 and NBS-18 and an internal laboratory standard is <0.04‰ for $\delta^{13}C$ and <0.08‰ for $\delta^{18}O$. Results are reported in conventional δ-notation relative to the Vienna Pee Dee Belemnite standard (VPDB) in ‰ units.

3.2. Trace metals

Shell fragments (weight: 170–450 μg) of thirteen terrestrial and aquatic gastropods have been analyzed for Sr/Ca and Ba/Ca. Adherent clays were removed by repeated wash with distilled, deionized (dd) H_2O and Methanol. Organic matter was removed with an oxidative reagent (200 μL H_2O_2 + 20 mL dd H_2O + 10 mL NH_4OH). Finally, a dilute acid rinse with 250 μL of 0.001 N HNO_3 was applied. Following cleaning, the samples were dissolved in 100–150 μL of 0.065 N HNO_3. After 10 min of centrifugation, 90 μL of the dissolved sample were added to 300 μL of 0.5 N HNO_3.

Trace metal analysis was performed at the Department of Marine and Coastal Sciences, Rutgers University, on a Thermo Scientific Element 2 inductively coupled plasma mass spectrometer (ICP-MS). Repeated analyses of standard solutions with constant element ratios (El/Ca) but changing Ca concentrations ([Ca] = 1.5 mM–8 mM) were used to quantify and correct for matrix changes. Precision is <0.5% for Sr/Ca and <1% for Ba/Ca (RSD).