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A shallow water record of the onset of the Messinian salinity crisis in the Adriatic foredeep (Legnagnone section, Northern Apennines)

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ABSTRACT

The Legnagnone section (North-eastern Apennines) represents one of the few shallow water records of the onset of the Messinian salinity crisis. Here we present a detailed description of a ~200 kyr time interval encompassing the pre-/syn-evaporitic transition based on a multidisciplinary approach, integrating sedimentological, bio-magnetostratigraphical, palaeontological and stable isotope data. Such a shallow water setting is potentially more sensitive to the palaeoenvironmental change leading to the MSC than the more often studied deeper Mediterranean basin. The aquatic palaeoenvironmental reconstruction proposed here is based on the study of foraminifer, ostracod and mollusc assemblages. It depicts a change from infralittoral (20–50 m) to inner circalittoral environment (60–100 m) that, since 6.12 Ma, was progressively affected by a reduction of oxygen at the sea floor punctuated by short-lived anoxic events. At least three cooling events have been recognized on the basis of relative abundance data in mid to high altitude pollen, which, before 6.03 Ma, are in phase with abundance peaks of *Turborotalia* spp., a taxon indicating eutrophic and cool surface waters. The absence of stress-tolerant benthic foraminifers during these peaks points to strong ventilation episodes triggered by a generally cooler climate. The proximity of a deltaic system and the consequent riverine input probably caused a salinity decrease of the surface waters, hindering the proliferation of planktonic foraminifers in the water column, which prevalently occur in short influxes and disappear at ca. 6 Ma. Our results suggest that the onset of the crisis occurred during a phase of relative sea level high stand, whereas no evidences of sea level drop can be envisaged. The palaeoclimatic reconstruction based on palynological data indicates the dominance of a "subtropical humid forest" vegetation type, where fresh water swamps are well represented. From 6.03 Ma onward, the transition to the salinity crisis is marked by more pronounced cyclical expansions of the temperate broad-leaved deciduous forest, along with herbaceous taxa. The establishment of the strongly evaporative condition at the crisis onset is not associated with major vegetational changes towards drier conditions, but linked to a sudden increase of $\delta^{18}O$ and the disappearance of benthic foraminifers just prior to the deposition of the 1st laminated carbonate, which represents the base of the Primary Lower Gypsum unit.

1. Introduction

A better appreciation of causal processes leading to the onset of the Messinian salinity crisis (MSC) necessarily requires a thorough understanding of the palaeoenvironmental evolution responsible of this event. The broadly accepted CIESM (2008) scenario describes a synchronous onset of the MSC in all the geological settings of the Mediterranean at 5.96 Ma (Krijgsman et al., 1999) and indicates that the Primary Lower Gypsum unit (PLG; Roveri et al., 2008) was deposited in shallower oxygenated marginal settings. At the same time, deeper settings experienced the deposition of organic-rich anoxic deposits, starting to receive clastic evaporite deposits only later, derived from the dismantlement and the

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en-masse resedimentation of the PLG to form the Resedimented Lower Gypsum (RLG; Roveri et al., 2008). The Messinian pre-evaporitic timing, palaeoceanographic and palaeoenvironmental history are relatively well known regarding its distal, slope to basin settings (Greece, Krijgsman et al., 2004; Cyprus, Kouwenhoven et al., 2006; Sicily, Hilgen and Krijgsman, 1999; Bellanca et al., 2001 and Blanc-Valleron et al., 2002; Northern Apennines, Roveri et al., 2006; Manzi et al., 2007). Usually four main palaeoenvironmental steps are envisaged from the base of the Messinian to the onset of the MSC, describing the progressive establishment of stressing condition both at the sea floor and in the water column (Kouwenhoven et al., 2006). Unfortunately, these studies generally refer to successions older than 6.5–6.3 Ma and/or that were deposited in basins lacking the PLG unit and characterized by the presence of limestone or diatomite, usually alternated with organic-rich clay devoid of calcareous microfossils, thus making the definition of the salinity crisis onset more problematic (Gennari et al., 2009; Lugli et al., 2010; Manzi et al., 2011).

On the contrary, pre-evaporitic shallow water marine settings are less documented (Los Yesos; Goubert et al., 2001) in spite of their relevance as monitors of the changes in surface water masses, coastal habitats and sea level changes.

Here we discuss the Legnagnone section, a rare record of the pre-/syn-evaporitic transition in a coastal setting, through a comprehensive approach integrating sedimentological, bio-magnetostratigraphical, palaeontological and geochemical data.

2. Geological setting

The Legnagnone section sits on the allochtonous "Val Marecchia" Ligurian nappe, a portion of the Apennines accretionary prism, which migrated since the early Oligocene on top of the deformed autochthonous Umbro-Marchean-Romagna unit (Fig. 1a, b).

Up to the Messinian times, the Val Marecchia terrains were still located in a more inner position, closer to the Apennines divide. Consequently, the Messinian succession of the Val Marecchia was deposited in a coastal shallow environment.

The situation therefore differs from the well-known Vena del Gesso basin, where the Messinian Evaporites were deposited on top of an open-marine succession laying on the autochthonous Umbro-Marchean-Romagna unit (Vai, 1997; Roveri et al., 2003).

In the Val Marecchia, the Tortonian–Messinian succession rests unconformably and relatively undeformed on the Miocene calcarenites of the "San Marino Fm". This succession (Fig. 2) consists from the base of fluvio-deltaic conglomerates and sandstones of the "Aquaviva Fm." abruptly fining-upward and grading in the marly unit of the "Casa i Gessi Fm." (see Ruggieri, 1958, 1970 for further information). This unit is capped in turn by the Gessoso-Solfifera Fm.

During the Early Pliocene the "Val Marecchia nappe" translated to its present location in the Adriatic foredeep. Thank to this mechanism, an almost unique shallow water record of the marginal setting of Northern Apennines has been preserved to date.

3. The Legnagnone section

The Legnagnone section (recorded as Ca' Seriola section in Carloni et al., 1974) is located at 43°55′10″ N–12°21′08″ E. The section is a 55 m-thick monotonous unit, extending from the uppermost sandy layer of the Acquaviva Formation, up to the first gypsum bed of the Gessoso-solfifera Group (Roveri and Manzi, 2006), mainly consisting of marly and clay deposits with minor intercalation of sandstone and indurated limestone bed related to differentiated cementation (Fig. 3). The transition with the overlying Gessoso-solfifera Gr. is recorded by two couplets of laminated limestone and organic-rich shale (overall thickness 1.2 m). These limestone layers consist of a partly clotted micrite matrix crossed by contractional cracks and including intraclasts and silt-size quartz and muscovite flakes. Both layer contain minor amounts of dolomite and appear very similar to the carbonate beds associated to the PLG deposits in the Piedmont Basin (Dela Pierre et al., 2011).

Based on facies and stacking pattern characteristics of Gessoso-solfifera Gr. in the Val Marecchia area, Lugli et al. (2010) showed that these limestone/shale couplets are actually a lateral equivalent of the two lowermost gypsum cycles of the Primary Lower Gypsum unit (Roveri et al., 2008); accordingly, the first gypsum bed of the Legnagnone section correlates with 3rd cycle of the PLG unit and the transition between pre- and syn-evaporitic stages of the MSC lies below the two carbonate-shale couplets.

4. Material and methods

4.1. Stable isotope geochemistry

Bulk samples were collected from 9 levels in the uppermost 1.50 m of the section (LW samples, Fig. 3B), just below the lowermost gypsum bed. The analyses were performed at the Laboratory of Isotope Geochemistry of the Earth Sciences Department of Parma. The isotopic composition of bulk carbonates was measured on CO_2 developed after reaction of the powdered solid with 100% H_3PO_4 *in vacuo* at 25 °C. A selective acid extraction method has been used to measure the stable isotopic composition of samples containing both, calcite and dolomite. The samples were (~40 mg) reacted in three steps: 1) with >100% H_3PO_4 at 25 °C for 2 h in vacuum to extract CO_2 from the calcite fraction, 2) continuously with >100% H_3PO_4 at 25 °C for 4 h in vacuum to extract CO_2 from the calcite–dolomite mixture (CO_2 obtained in second step was pumping out from the system) 3) the remaining material was reacted at 25 °C for more than 72 h to obtain CO_2 from the dolomite.

The isotopic composition of CO_2 was measured on a Finnigan Delta S mass spectrometer vs. an internal laboratory CO_2 standard gas obtained by the reaction at 25 °C of extra pure Carrara marble powder with 100% phosphoric acid. The standard deviation of these measurements was systematically equal to or lower than ±0.15‰ (1σ). The CO_2 standard is periodically calibrated against NBS-19 revealing an isotopic composition of −2.43‰ ($\delta^{18}O$ vs. VPDB) and +2.45‰ ($\delta^{13}C$ vs. VPDB) respectively.

4.2. Palynology

For palynological studies (pollen, dinocysts and palynofacies) 55 subsamples (about 12 g) were processed at the "ENI-E&P Division" laboratory of Milan, using a standard methodology that involves the removal of carbonate with hydrochloric acid (HCl) and the silicate fraction with hydrofluoric acid (HF). Pollen concentration, ranging from 259 to 42,278 grains/g, was calculated using marker grains (Matthews, 1969). Pollen counts, ranging from 100 to 1073 grains, were expressed as percentages in a summary palynological diagram; the calculation sum included pollen of all the vascular plants. The main components of sedimentary organic matter were organized in five main groups and expressed as percentages: 1) Amorphous Organic Matter (AOM) and among the Structured Organic Matter (SOM): 2) Black debris (black elongate woody fragments essentially of fusinite); 3) Brown woody fragments; 4) Cuticles (leaf-epidermal tissue; cutinite tissues, etc.); 5) Terrestrial (pollen and spores) and marine (essentially dinoflagellate cysts and other marine phytoplankton) palynomorphs. Detailed data on pollen, dinocysts and palynofacies are archived and available on request.

4.3. Foraminifers

A total of 93 samples were washed on a 60 μm mesh sieve and only the fraction greater than 125 μm was studied. The quantity of