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Benthic foraminiferal assemblages from Messinian deposits (western Sardinia, Italy): preliminary report

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ABSTRACT - Micropalaeontological analyses of benthic foraminiferal assemblages were carried out on stratigraphic sections from the Late Miocene of Sinis Peninsula (Capo San Marco, western Sardinia, Mediterranean Sea). Biotic index values and the relative abundance of the most abundant foraminiferal species have been used for a palaeoenvironmental reconstruction. The palaeoenvironmental significance of foraminiferal assemblages indicates a shallower trend from an upper bathyal-circalittoral environment to coastal lagoon facies that are characterized by variable salinity and some fluvial run-off episodes during the pre-Messinian Salinity Crisis stage. After a subaerial exposure, a siliciclastic carbonate platform developed at the start of the Messinian Salinity Crisis. The re-establishment of marine conditions during the Upper Messinian is marked by fossiliferous marly limestone and sandy marls (cfr. Terminal Carbonate Complex) bearing microfaunas (benthic foraminifera, ostracods, rare planktonic taxa) and macrofauna intercalated in siliciclastic fluvial deposits. During the Messinian stages, the paleoecological conditions in the Sinis Basin were intermittently suitable for sustaining marine biotas, indicating that this basin was not uninterruptedly desiccated.

Keywords: Benthic foraminifera; diversity quantitative analysis; palaeoecology.

1. INTRODUCTION

In the Messinian (Late Miocene), the Mediterranean Sea subjected to environmental changes when it became isolated from the Atlantic and the resulting severe evaporation caused a salinity crisis (Messinian Salinity Crisis - MSC) which had worldwide implications (Selli, 1960; Hsü et al., 1973 a,b). The MSC was an ecological crisis, induced by a combination of geodynamic and climatic drivers, which had a great impact on the marine biota and on the salinity of the global oceans. As reported by Roveri et al. (2014), the MSC developed in three main stages characterized by different palaeoenvironmental conditions: in the first stage, evaporites precipitated in shallow sub-basins; during the second stage, the MSC reached the acme; and the third stage was characterized by large-scale environmental fluctuations that led to the transformation of the Mediterranean in a brackish water lake.

Numerous recent studies on the Mediterranean area before, during and after the Messinian Salinity Crisis have been carried out using a multidisciplinary approach (e.g., Krijgsman et al., 1999; Kouwenhoven et al., 1999, 2003; Goubert et al., 2001; Rouchy and Caruso, 2006; Bache et al., 2012; Roveri et al., 2014).

In Sardinia, the palaeontological interest in the upper Miocene succession outcropping in Capo San Marco (southern Sinis Peninsula, Sardinia; Fig. 1) is documented by a number of historical studies (Lovisato, 1885; Mariani and Parona, 1888). The Capo San Marco cliff has been attributed to the Messinian by Pecorini (1972) and Cherchi (1974) on the basis of malacofaunas and planktonic foraminifera, respectively. Successive biostratigraphical and palaeoecological studies have been performed by Cherchi et al. (1978, 1985), Cherchi and Martini (1981) and, more recently Moisette et al. (2002), André et al. (2004) and Saint Martin (2010).

The aim of this preliminary study is to analyze benthic foraminiferal assemblages as indicators of environmental change during the Messinian stages. This paleoecological approach uses the available data on recent foraminiferal assemblages from the Mediterranean (see Murray, 1991). In fact, benthic foraminiferal assemblages are especially useful as indicators for the characterization of the environmental conditions of the ecosystems providing information on sea-level fluctuations, substrate interfaces, bottom water oxygenation and organic fluxes to the sea floor. Examining changes in benthic foraminiferal assemblages (e.g., patterns of species diversity) is a reliable method that has also been used to identify past environments (Murray, 2006).

2. MATERIALS AND METHODS

Two sections (A- Capo San Marco, and B- Monte Palla quarry; Fig. 1) have been sampled for the purposes of

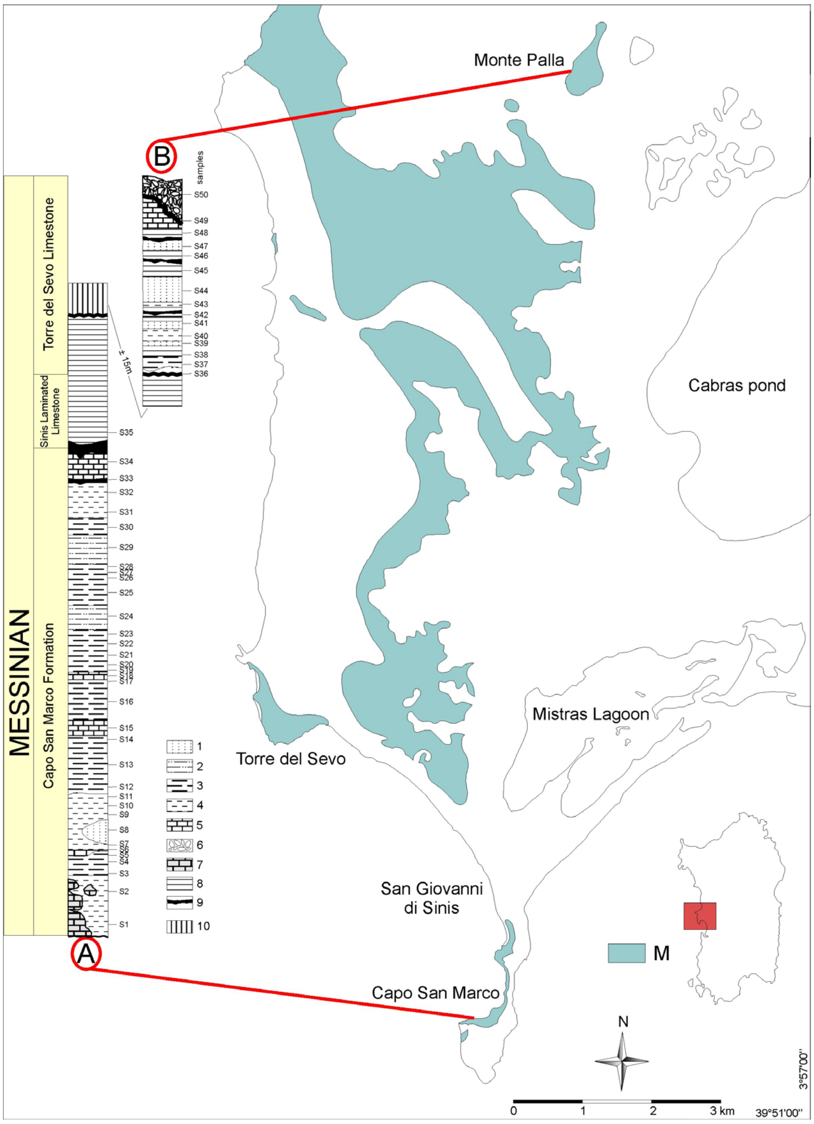

Fig. 1 - Geographic location of the Messinian outcrops in the Sinis Peninsula showing the studied synthetic stratigraphic sections: the Capo San Marco (A) and Monte Palla (B). Lithology: (1) sandstones; (2) muddy siltstones; (3) mudstones; (4) marls; (5) marly and bioclastic limestones; (6) brecciated limestones and dolostones; (7) microbial mounds; (8) laminated limestones; (9) paleosoils; (10) basalt. M: Messinian outcrops.

quantitative analyses of benthic foraminifera.

Three lithostratigraphic units have been recognized in the Messinian succession from Capo San Marco (Section A) and M. Palla (Section B): (a) the Capo San Marco Formation (CSMF), consisting prevalently of fossiliferous sandy marls and marly limestones, including microbial mounds and microbialithic crusts; (b) the azoic Sinis Laminated Limestone Formation (SLLF), which is composed of micritic limestones; and (c) the Torre del Sevo Formation (TSF) (Cherchi et al., 1978; André et al., 2004; Cornée et al., 2008).

Fifty samples were collected from a total thickness of about 41 m. In the laboratory, the samples were washed with water through a 63 μm sieve. At least 300 specimens were selected from each sample and identified following the generic classifications of Loeblich and Tappan (1987) and other taxonomic works (Cimerman and Langer, 1991; Hottinger et al., 1993; Sgarrella and Moncharmont Zei, 1993). Foraminiferal species diversity was quantified by Species Richness (S, the number of species in a sample), evenness (E), dominance (D), the Fisher-α index (Fα; Fisher et al., 1943; Murray, 1973), and the Shannon-Weaver index or information function (H) (Shannon and Weaver, 1963). Calculations were carried out using the PAST statistical software (Hammer et al., 2001).

3. RESULTS

In total, 67 benthic foraminiferal species belonging to 41 genera were identified. The most common species were *Ammonia beccarii, A. tepida*, the *Bolivina* group *(Bolivina arta, B. dilatata), Bulimina echinata, Elphidium crispum, E. macellum, Lobatula lobatula, Melonis padanum, M. pompilioides* and *Massilina secans*.

Among the most frequent species, *Ammonia tepida* was relatively abundant in the middle-upper part of Section A (Capo San Marco), displaying peak occurrences of >80% between S25 and S31 (Fig. 2). *Ammonia beccarii* had a fluctuating pattern, particularly its relative abundance was low middle-upper parts of Section A (between S20 and S34), where it was replaced by *A. tepida*. In Section B (between S36 and S47; Fig. 2), *A. beccarii* was the most frequent species, ranging from 21% to 44%. The *Bolivina* group and *Bulimina echinata* only occurred in the lower part of Section A (between S1 and S25), and slowly disappeared (Fig. 2).

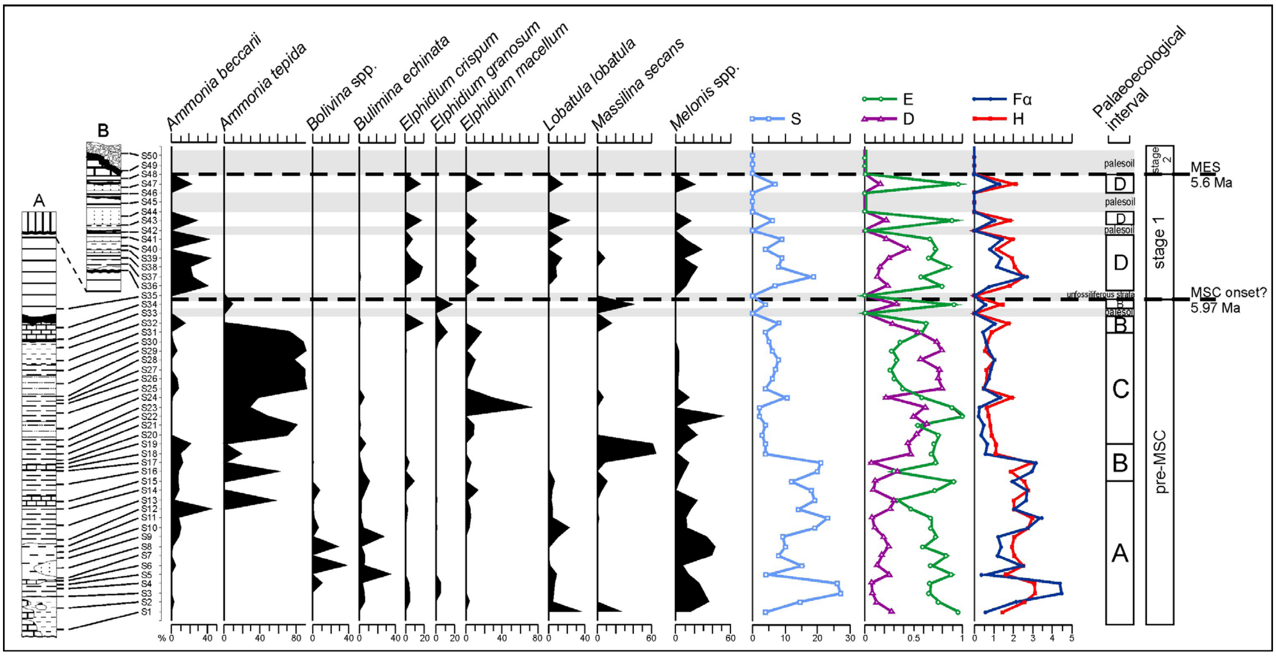

Fig. 2 - Summary diagram indicating: the relative abundance of selected benthic foraminiferal species; the quantitative distribution of selected biotic indices: Species Richness (S), evenness (E), Dominance (D), Fisher-α index (Fα) and Shannon-Weaver index (H); and the palaeoecological intervals.

Elphidium macellum was absent from S1 to S9 (exception for S2), whereas it had its highest relative abundance in S23 (73%). *Lobatula lobatula, Melonis pompilioides* and *Elphidium crispum* disappeared approximately between S21 and S32 (Fig. 2) and were also found in Section B. *Massilina secans* was only found in a few samples of Section A (S1, S11, S14-S19, S24, S32, S34) and Section B (S39), with the highest relative abundance in S18 and S19 (62% and 65%, respectively). In general, the relative abundances of almost all the species showed a decline in the middle-upper part of Section A, in correspondence with the increasing relative abundance of *A. tepida*.

The biotic indices (S, H, E and Fα) highlighted a decline in biodiversity between S18 and S34. In contrast, D was high in the middle-upper interval (Section A) due to the greatest abundance of *A. tepida*. In the basal part of the Section A, the biotic indices had higher values than in the upper segment belonging to the Torre del Sevo Formation (Section B).

4. DISCUSSION AND CONCLUSIONS

Four main palaeoecological intervals (Fig. 2), have been highlighted on the basis of quantitative analyses performed on benthic foraminifera assemblages.

Interval 1 is interpreted as a marine environment (upper bathyal-circalittoral zone), locally hypoxic and rich in nutrients as highlighted by taxa with a large depth range from circalittoral to deep water like *Melonis* spp., bolivinids and buliminids. The biotic index values are high, as are the percentages of infaunal stress tolerant foraminiferal species (*Bolivina* spp. and *B. echinata*; e.g., Van der Zwaan, 1982; Jorissen et al., 1992; Violanti, 1996). The relative abundance of shallow-water species, mainly *A. beccarii*, *E. macellum* and *L. lobatula* suggests a progressively shallowing environment (infralittoral). Currently, these species are widespread Mediterranean taxa that live prevalently on infralittoral/circalittoral bottoms, well-oxygenated environment with a vegetation meadow present in areas nearby (Jorissen, 1987; Langer, 1993; Sgarrella and Moncharmont Zei, 1993; Buosi et al., 2012, 2013a).

Interval 2 is interpreted as a shallow sublittoral-infralittoral environment with high energy. The biotic indices show a small decline, whereas the abundance of infaunal species falls in correspondence with an increase of epifauna-shallow infauna taxa. A fluvial run-off, with a consequential reduction in the sea surface salinity, could be recognized by the occurrence of *Elphidium granosum* (Jorissen, 1988). A marine infralittoral condition is also suggested by the abundant presence of *Massilina secans* in association with *A. beccarii* and *Melonis soldanii* and in packstones layers. In particular, *M. secans* is known to live mainly in shallow water environments (littoral or sub-littoral sand flat) with water depths of only a few metres (Murray, 2006). Interval B can be interpreted as a period of rapid environmental changes induced by sea level fluctuations that precede the MSC onset.

Interval 3 is interpreted as a lagoon-brackish environment marked by the dominance of *A. tepida* an euryhaline cosmopolitan species that mainly lives in lagoons and shallow-normal and shallow-brackish marine and marginal environments characterized by lower salinity (e.g., Jorissen, 1988; Debenay et al., 1998; Buosi et al., 2013b; Salvi et al., 2015). The benthic foraminiferal data show a significant decrease in the biotic indices (S, H, E, FD and Fα) and an increase of D (Fig. 2). The benthic foraminiferal assemblage can be related to a high degree of confinement in a lagoonal environment, which leads to lowered salinity before the deposition of the TCC.

Interval 4 follows a monotone succession (±10 m) of thinly-stratified azoic laminated limestones made by a microporous, microsparite texture (Cherchi et al., 1978; André et al., 2004). This interval shows the restoration of marine conditions (sublittoral environment with high energy). The benthic foraminiferal assemblages were dominated by marine euryhaline species like *A. beccarii*, *E. crispum, L. lobatula, Melonis* spp. The increase in biotic index values and the abundance of epifaunal species document the re-establishment of marine conditions. During the deposition of the TSF (Fig. 1), the ecological conditions were intermittently favourable to the life of foraminiferal assemblages and macrofaunas.

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