



Micropalaeontological analyses of the Narzole core: biostratigraphy and palaeoenvironment of the late Messinian and early Zanclean of Piedmont (Northwestern Italy)

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ABSTRACT - Integrated biostratigraphic and palaeoenvironmental analyses of foraminiferal, ostracod and calcareous nannofossil assemblages are here presented for the late Messinian/early Zanclean succession of the Narzole borehole (Albese area, Piedmont, Northwestern Italy). The Narzole core is made out of about 20 m of marine sediments and is stored in the collections of the Torino University, deposited at the Torino Regional Museum of Natural Sciences and until now represents the only documentation of the Messinian/Zanclean boundary (M/Z) in the Albese subsurface. The uppermost Messinian "Lago-Mare" deposits yield reworked marine microfossils and a brackish ostracod assemblage representative of the *Loxocorniculina djafarovi* Zone, indicating their deposition in oligo-mesohaline shallow waters and the influx of Paratethyan faunas. The boundary between the post-evaporitic Messinian sediments and the overlying early Zanclean Argille Azzurre Fm. (AA) is marked by a 0.50 m thick barren arenitic layer, dark brown to black in its middle part, well correlatable to the black level recognized at the M/Z boundary in the nearby Moncucco quarry outcrop (Torino Hill). The Early Zanclean succession yields abundant microfossils, which document the MP11 (*Sphaeroidinellopsis acme*) and the MP12 foraminiferal zones, and the MNN12 calcareous nannofossil zone. Many bioevents recognized at Moncucco and at the Mediterranean scale are recorded in the studied succession: one sinistral coiling shift of *Neoglobobulimina acostaensis*, the *Globorotalia scitula* common occurrence (CO), the re-immigration of *Siphonina reticulata*, the *Globorotalia margaritae* first common occurrence (FCO), the first influx of North Atlantic Deep Water (NADW) forms as *Cibicides robertsonianus*, *Henryhowella asperima* and *Oblitacythereis mediterranea* firstly occurred in the MP11 zone, like in the Moncucco section, while in southern Italy and Mediterranean Pliocene sections they occurred at the base of MP12 biozone. Foraminiferal and ostracod assemblages document an epibathyal basin just from the early Zanclean. Fluctuations in water temperature and productivity are suggested by quantitative changes of warm water, oligotrophic surficial taxa (*Globigerinoides*) versus intermediate water, eutrophic and phytoplankton grazers (*N. acostaensis*). A deepening of the basin during the MP11 is suggested by the increasing diversity of benthic foraminifers and of deep bathyal ostracods. All palaeobiological data suggest open marine circulation patterns in this sector of the Northwestern Italy during the MP11-MP12 Early Pliocene zones. This palaeoenvironmental interpretation is corroborated by the very high P/(P+B) ratio, the presence of mesopelagic planktonic foraminifers as *Sphaeroidinellopsis* spp., common to frequent deep cosmopolitan benthic foraminifers (*Cibicides pseudoungerianus*, *Sphaeroidina bulloides*, *Uvigerina peregrina* etc.), common bathyal ostracods (*Argilloecia acuminata*, *A. kissamovensis*, *O. mediterranea*, *Paijenborchella iocosa*, *P. dimorpha*, *Xestoleberis prognata* etc.), the rare discoasterids and ceratoliths (*Ceratholithus acutus*, *Amaurolithus primus*, *A. delicatus*), typical tropical open marine taxa, usually very rare in the Mediterranean Zanclean.

RIASSUNTO - [Analisi micropaleontologiche del sondaggio di Narzole: interpretazione biostratigrafica e paleoambientale del Messiniano superiore e Zancleano inferiore del Piemonte (Italia nord-occidentale)] - Il presente lavoro espone i risultati dello studio micropaleontologico integrato (foraminiferi, ostracodi e nannofossili calcarei) condotto sui medesimi campioni della carota prelevata presso Narzole (Alba, Piemonte, Italia Nord-occidentale) nel 1975, nella quale Sturani ha descritto e illustrato il livello arenitico nero al limite Messiniano/Zancleano e in cui sono conservati circa 20 m di sedimenti marini. Il materiale di Narzole è catalogato nelle collezioni dell'Università di Torino, depositate presso il Museo Regionale di Scienze Naturali di Torino e rappresenta tuttora l'unica documentazione del limite Messiniano/Zancleano (M/Z) nel sottosuolo dell'Albese. I sedimenti messiniani della facies di "Lago-Mare" contengono microfossili marini rimaneggiati e ostracodi salmastri indicativi della zona a *Loxocorniculina djafarovi*, che documentano condizioni di acque basse oligo-mesohaline e l'influsso di faune della Paratetide. Il limite tra i depositi post-evaporitici messiniani e le sovrastanti Argille Azzurre (AA) dello Zancleano inferiore è evidenziato da un livello arenitico da scuro a nero di 0.50 m di spessore, simile a quello presente al limite M/Z a Moncucco. Le associazioni a microfossili delle AA documentano le zone MP11 (*Sphaeroidinellopsis acme*) e MP12 a foraminiferi planctonici e la zona MNN12 a nannofossili calcarei. Molti bioeventi noti in area Mediterranea e segnalati a Moncucco sono stati riconosciuti anche nella successione di Narzole: un cambiamento della direzione di avvolgimento di *Neoglobobulimina acostaensis*, i successivi influssi/re-immigrazione di *Globorotalia scitula* e di *Siphonina reticulata*, la First Common Occurrence (FCO) di *Globorotalia margaritae*, i primi influssi di forme profonde, tipiche delle "North Atlantic Deep Water" (NADW), quali *Cibicides robertsonianus*, *Henryhowella asperima* e *Oblitacythereis mediterranea* compaiono per la prima volta durante la zona MP11, come a Moncucco, mentre in Italia meridionale e in Mediterraneo la loro comparsa è segnalata alla base della zona MP12. I dati micropaleontologici documentano fondali epibatiali già a partire dalla base dello Zancleano. Fluttuazioni climatiche e della produttività sono suggerite dalle variazioni quantitative dei taxa planctonici di acque superficiali, calde e oligotrofiche (*Globigerinoides*) e delle forme di acque intermedie eutrofiche (*N. acostaensis*). L'aumento della diversità specifica dei foraminiferi bentonici e degli ostracodi suggerisce un ulteriore approfondimento del bacino e buone comunicazioni con il Mediterraneo durante le zone MP11 e MP12. Questa interpretazione è basata sull'elevato rapporto P/(P+B), sulla presenza di foraminiferi planctonici mesopelagici (*Sphaeroidinellopsis* spp.), sull'associazione a foraminiferi bentonici formata da taxa profondi cosmopoliti (*Cibicides pseudoungerianus*, *Sphaeroidina bulloides*, *Uvigerina peregrina* ecc.), sui comuni ostracodi batiali (*Argilloecia acuminata*, *A. kissamovensis*, *O. mediterranea*, *Paijenborchella iocosa*, *Xestoleberis prognata* ecc.) e sulla presenza di rari discoasteridi e ceratolitidi (*Ceratholithus acutus*, *Amaurolithus primus*, *A. delicatus*), tipiche forme tropicali di mare aperto, generalmente molto rari nello Zancleano dell'area Mediterranea.



Fig. 1 - Structural sketch of Northwestern Italy (Modified from Bigi et al., 1990).

INTRODUCTION

In the Messinian Symposium, yield at Erice (Sicily) in September 1975, Carlo Sturani, a researcher of the Torino University and a young emerging Italian palaeontologist, presented an original and detailed analysis of the Piedmont (Northwestern Italy) Messinian succession. Sturani described and figured a very abrupt contact at the Messinian/Zanclean boundary, documented in a borehole drilled near Narzole, in the Albese area (Piedmont, Northwestern Italy) (Figs. 1-2). Above the lacustrine clays of the Messinian *Congerina* facies, about one meter of coarse sands, dark brown to black in their middle 50 cm, was recorded underneath Early Pliocene marls, interpreted as open marine, outer neritic deposits on the basis of preliminary micropalaeontological analyses carried out by Mario Sampò. After the tragic death of Carlo Sturani in the gypsum quarry of Scaparoni in December 20, 1975, his communication at the Erice Seminar was published thanks to a record of his talk, edited by his wife and colleagues (Sturani, 1978). Studies of the core stopped and no micropalaeontological data were published.

The Narzole core was initially laid in the storage of the Institute of Geology, Palaeontology and Physical Geography of the Torino University, soon after it was relocated in the nearby University Museum of Geology and Palaeontology and then apparently it was lost. In 1980, thanks to a convention between the Piedmont Region and the Torino University, the rearrangement of the rich geological and palaeontological collections was undertaken by researchers and technicians of the Torino Regional Museum of Natural Sciences (TRMNS). After the move of the TRMNS to the present address, the collections reordering continued and the Narzole core was found in a temporary storage. After a careful rearrangement of the material (L.M. Gallo), the core is now definitely placed in Storage D9, drawers 12.5 to 12.10 of the TRMNS collections and represents the

sediment interval between 6-26.80 m below the ground level (Fig. 3). On the basis of the procedures followed in the inventory of the TRMNS collections, the core was numbered as GEO.2459 and described in the “*Catalogo delle collezioni geologiche e litologiche del Museo di Geologia e Paleontologia dell’Università di Torino*” (p. 90) under the name “Collection 21 - Narzole core of Messinian sediments” (Gallo, 2004).

Up to now the Narzole core represents the only documentation of the Messinian/Zanclean boundary (M/Z) in the subsurface of the Albese region, where both the Messinian pre-evaporitic to post-evaporitic succession and the Zanclean marls and silts are well exposed (Sturani & Sampò, 1973), but the boundary is generally covered. Only recently it was detected in outcrops exposed along the Tanaro river (Pollenzo section, Clari et al., 2008), where studies are in progress.

Aim of the micropalaeontological analysis of the Narzole core is to complete the brief information given by Sturani (1978) and to compare these data with those of the recently studied coeval succession of Moncucco

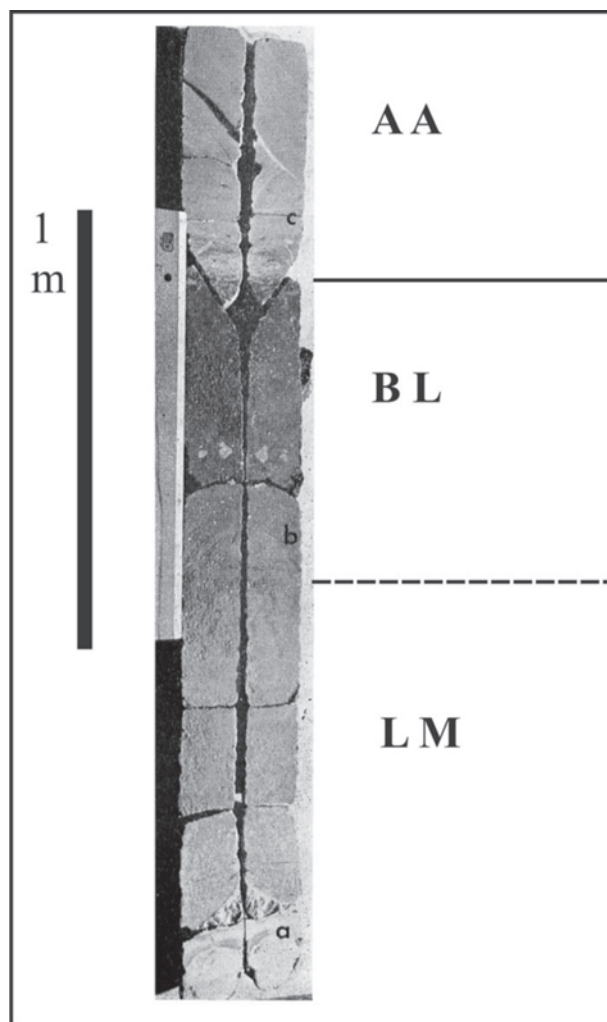


Fig. 2 - The Messinian/Zanclean boundary in the Narzole core, as figured in Fig. 7 of Sturani (1978); LM: “*Congerina* beds” = *Lago-Mare* sediments; BL: coarse sands with pebbles, dark brown to black in colour = Black Layer; AA: bioturbated, Lower Pliocene marls with forams and mollusks = Argille Azzurre Formation.



Fig. 3 - A detail of the Pliocene blue-grey bioturbated clayey marls, referable to the Argille Azzurre Formation (AA) drilled in the Narzole bore-hole and stored in the Torino Regional Museum of Natural Sciences.

Torinese (Bicchi et al., 2002; Trenkwalder et al., 2008; Violanti et al., in press), in order to investigate the palaeoenvironmental evolution of the central Piedmont region at the Messinian/Zanclean boundary and in the early Zanclean. Moreover, this study wants to be a tribute to the late Torino University palaeontologists Carlo Sturani and Mario Sampò.

MATERIAL AND METHODS

As reported on the CNR technical report (courtesy F. Da Roit), the drill-hole was aimed to core the Messinian/Zanclean boundary (M/Z) and was drilled on a river terrace on the left side of the Tanaro river, near Cascina Torre, Narzole (Cuneo, Piedmont, Northwestern Italy) during January 1975, by the CNR technicians Walter Boltri and Francesco Da Roit, under the supervision of Carlo Sturani (Fig. 4). The core penetrated 0.50 m of anthropic soil, 5.20 m of alluvial coarse deposits, 18.40 m of Pliocene blue-grey bioturbated clayey marls, referable to the Argille Azzurre Formation (AA) (from 5.70 to 24.10 m below the ground level), a 0.50 m thick layer of arenitic sediments with small pebbles, dark brown to black in its middle, interpreted in the report as a palaeosoil (from 24.10 to 24.60 m) and finally 2.20 m of sands and clays referred to the Messinian (*Congeria* beds of Sturani, 1978, i.e. *Lago-Mare* facies). The drilling stopped at 26.80 m below the ground level. No erosional surfaces between the different lithologies were evidenced.

Twenty-six samples were analyzed from the Messinian/Zanclean succession at intervals ranging from 0.30 to 1.5 m and numbered with their depth below the ground level (m b.g.l.). Washing residues for foraminifer and ostracod analyses were prepared gently boiling the dry sediment with a small quantity of sodium carbonate to disaggregate the sediment, then washing the disaggregated material on the sieves set. Three fractions (>250 μ m, 250-125 μ m, and 125-63 μ m) were obtained for each sample. Residues were dried at 50°C and weighted.



Fig. 4 - The drilling of the Narzole bore-hole, near Cascina Torre, Narzole (Cuneo, Piedmont, Northwestern Italy) during January 1975, by the CNR technicians Walter Boltri and Francesco Da Roit, under the supervision of Carlo Sturani (courtesy of W. Boltri).

Foraminiferal taxonomy is according to Kennett & Srinivasan (1983) and Hemleben et al. (1989) for planktonic species, Agip (1982) and Van Morkhoven et al. (1986) for benthic species. The biostratigraphic scheme adopted here is that of Cita (1975a), emended by Sprovieri (1993).

Quantitative analyses of foraminiferal assemblages (D. Violanti) were carried out on total residues >125 μ m of the Pliocene succession, split into aliquots of at least 300 well-preserved tests, in order to allow comparison with recent studies in the area (Violanti, 2005; Trenkwalder et al., 2008). The number of foraminiferal specimens per gram of dry sediment (FN/g) and the P/(P+B) ratio were calculated. Two indexes of specific diversity were measured separately for planktonic and benthic taxa: 1) species richness (S) as the total number of taxa for each sample; 2) Fisher's diversity index (α) which is a measure of diversity taking into account the number of taxa as well as the number of specimens for each sample. These indices were calculated using the PAST ver. 1.77 Program (Hammer et al., 2008). A Planktonic Faunal curve was constructed by the algebraic sum of the percentages of warm-water oligotrophic indicators (positive values) (*Globigerinoides* spp., *Globoturborotalita apertura* group, including also *G. decoraperta* and rarer *G. woodi*, and *Orbulina* spp.) and of cold-water eutrophic indicators (negative values) (*Globigerina bulloides* group, including *G. falconensis*, Neoglobobadrinids (*Neoglobobadrina acostaensis* dextral, scarce *N. humerosa*), *Globorotalia scitula* and *Turborotalita quinqueloba*).

All the ostracod valves present in residues >125 μ m of each sample were picked and then identified (S. Trenkwalder); their taxonomy is according mainly to Bonaduce et al. (1976), Abate et al. (1993) and Aiello et al. (1996). Species were counted following the Normalized Method (Mana & Trenkwalder, 2007): all the grown-up valves were counted and the number of minimum certain individuals was calculated as the sum

of complete carapaces plus the highest number of valves (left or right). For each sample, the number of species and the number of minimum certain individuals were calculated; the presence of juvenile forms was just pointed out.

Calcareous nannofossil analyses (F. Lozar) were performed on smear slides prepared according to standard methods and studied on light microscope under polarized light (transmitted light and crossed nicols) at 1250X magnification. Abundance data of nannofossil taxa were collected counting five hundreds specimens per sample; helicoliths were counted among 50 specimens of the group; discoasters and ceratoliths on 2-4 mm² of area as already established in previous works (Backman & Shackleton, 1983; Rio et al., 1990). Taxonomy is according to Perch-Nielsen (1985), Rio et al. (1990), Young (1998) and Raffi et al. (2003). The biostratigraphic scheme here adopted is that of Rio et al. (1990) for the Mediterranean region.

RESULTS

Grain size and composition

Percentages of the total >63 µm fraction are very high in the *Lago-Mare* samples and reach their maximum at 24.4 m b.g.l., in the black layer. Samples collected from the AA showed very low grain size percentages, only in the upper sample at 7 m b.g.l. the total >63 µm fraction

was greater than 3% (Fig. 5). Terrigenous components (quartz grains, green schist debris, micas, pyrite aggregates) are dominant in the *Lago-Mare* sediments. The black layer is composed of a terrigenous fraction (quartz and lithic fragments of metamorphic rocks) with subordinate intrabasinal grains (glaucony and phosphates). It is totally homogenised, devoid of fossils and very rich in organic carbon. The terrigenous content is very scarce in most of the AA, it is common only in the lowermost and uppermost samples of the Pliocene succession.

Foraminiferal specimens are frequently diagenized in the *Lago-Mare* samples, whereas tests are very well preserved in most of the AA assemblages. Foraminifers and calcareous nannofossils are abundant in the AA succession, ostracods, echinoids, mollusk fragments, and vegetal debris are rare to common. Fish debris (otoliths, teeth, and bones) are rare.

Micropalaeontological data

LAGO-MARE ASSEMBLAGES. Samples from 26.8 to 25.7 m b.g.l. contain frequent but poorly preserved planktonic foraminifers, mainly represented by Miocene to Pliocene taxa (*Globigerina bulloides*, *Globigerinella obesa*, *Globigerinoides obliquus*, *Globorotalia* gr. *scitula*, *Orbulina universa*, *Neogloboquadrina acostaensis* (dominantly sinistral) and *Turborotalita quinqueloba*). Benthic foraminifers are extremely rare. Some Tortonian to Messinian species, as *Globorotalia suterae*, are also present. The same samples contain few valves of the

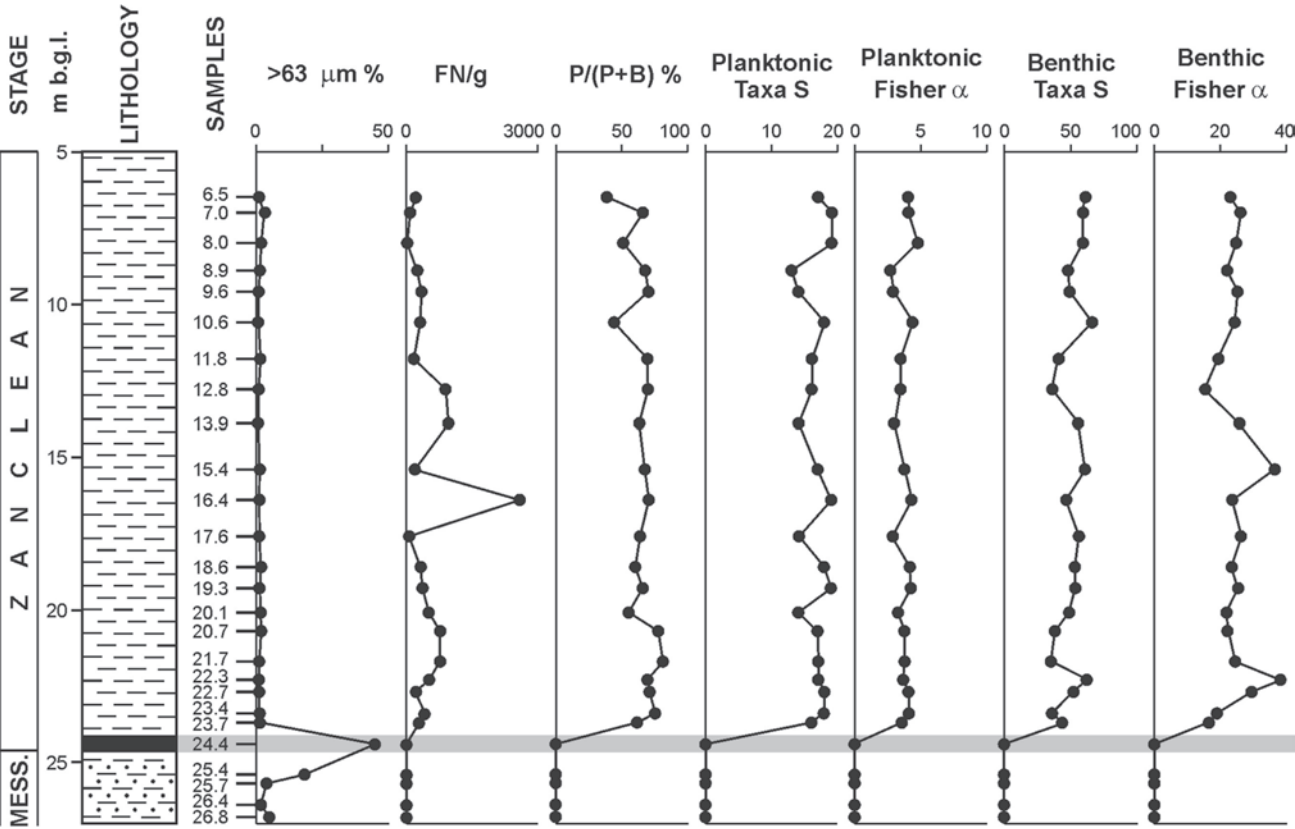


Fig. 5 - Stage, lithological column, sample depths, indicated as meters below ground level (m b.g.l.), percentage variations of the grain size >63 µm fraction, FN/g (number of foraminiferal tests per gram of dry sediment), P/(P+B) ratio percentages, planktonic foraminifers richness (S, number of species) and Fisher's α index, benthic foraminifers richness (S, number of species) and Fisher's α index in the Narzole core late Messinian/early Zanclean succession.

ostracod *Cyprideis agrigentina*. Calcareous nannofossil (CN) assemblages are quite abundant, but consist mainly of reworked and poorly preserved Upper Cretaceous, Oligocene and Lower and Middle Miocene taxa (*Watznaueria barnesae*, *Eiffellithus turriseiffelii*, *Micula decussata*, *Zygrhablithus bijugatus*, *Dictyococcites bisectus*, *Helicosphaera euphratis*, *H. walbersdorfensis*, *Sphenolithus heteromorphus*, *Coccolithus miopelagicus* among others). No typical Messinian CN is present. Sample at 25.4 m b.g.l., just below the black layer, is barren of foraminifers and ostracods and contains only very rare CN specimens, consisting mainly of dwarf placoliths (*Helicosphaera carteri*, *Coccolithus pelagicus*, *Sphenolithus abies*, *Reticulofenestra* sp.).

ARGILLE AZZURRE FORMATION ASSEMBLAGES. Microfossil preservation in the blue-grey clayey marls (AA) was generally good, only at 7.0 m b.g.l. the preservation is moderate and biogenic fragments are frequent.

The FN/g (number of foraminiferal tests per 1 gram of dry sediment) (Fig. 5) displays low values, below 500 tests/g in the lowermost samples, shows an increase between 22.3-20.1 m b.g.l., then a strong abundance peak at 16.4 m b.g.l. (maximum 2572.39 FN/g) and

approximated 1000 FN/g at 13.9 and 12.8 m b.g.l. Decreasing values are registered in the upper interval.

The P/(P+B) ratio shows very high percentages (70-80%) within the lowermost samples up to 21.7 m b.g.l. (Fig. 5). Values become slightly lower upwards, ranging between 60-70% up to 11.8 m b.g.l. and then display some stronger variations, decreasing to about 40% at 13.9 and 12.8 m b.g.l.

Planktonic foraminiferal diversity indices are expressed as the species richness (S) and the Fisher's α index and display low variations throughout the succession. The species richness (S) (=species number) ranges between 13-19, while the Fisher's α index is lower than 5 (Fig. 5).

Benthic diversity indices register wide variations. The benthic species richness (S) is comprised between 40-60 just from the lowermost samples, the benthic Fisher's α index is low in the basal samples, increases upwards (Fig. 5), and shows two peaks at 22.3 and 15.4 m b.g.l.

Planktonic foraminifera

Sphaeroidinellopsis spp. are recognized in the interval from 22.7 to 20.7 m b.g.l. and at 8.0 m b.g.l., some large specimens are present. *Sphaeroidinellopsis* spp. reach percentages >1% only at 22.3 m b.g.l. (Fig. 6).

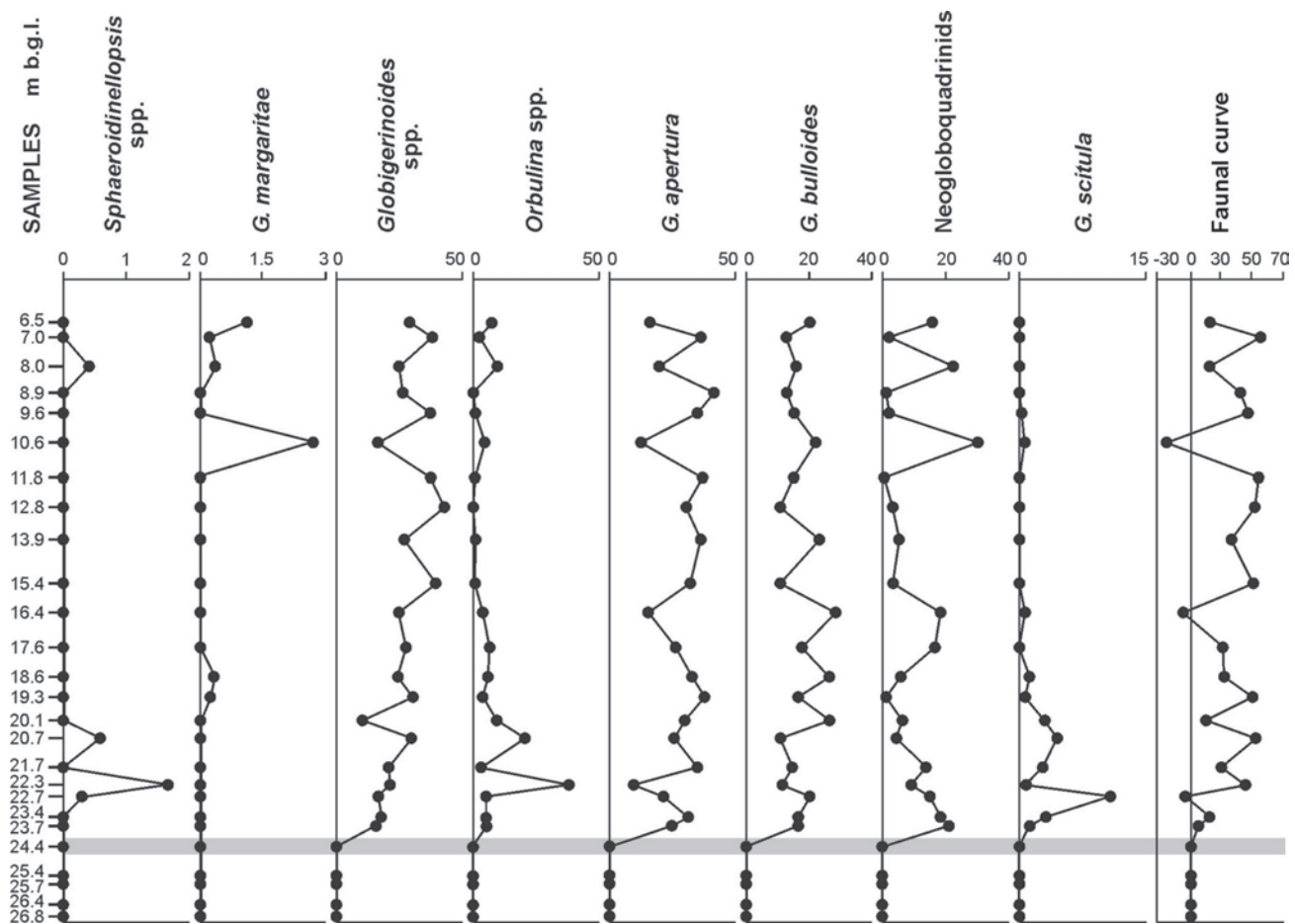


Fig. 6 - Percentage variations of planktonic foraminiferal taxa (*Sphaeroidinellopsis* spp., *Globorotalia margaritae*, *Globigerinoides* spp., *Orbulina* spp., *Globorotalia apertura* group, *Globigerina bulloides* group, Neogloboquadrinids (mainly *Neogloboquadrina acostaensis*), *Globorotalia scitula* and Planktonic faunal curve (warm oligotrophic taxa percentages minus cold eutrophic taxa percentages) in the Narzole core late Messinian/early Zanclean succession.

Rare, small tests of *Globorotalia margaritae* occur from 19.3 m b.g.l., but large specimens of *G. margaritae evoluta* (Cita, 1973, 1975b) become more common at 10.6 m b.g.l. (2.68%) and are present in the uppermost samples.

The warm-water, oligotrophic genus *Globigerinoides* (Hemleben et al., 1989) is represented by frequent *G. extremus* and *G. obliquus*, common to rare *G. gomitulus*, *G. ruber*, *G. sacculifer*, and *G. trilobus*. *Globigerinoides* spp. display values lower than 20% in the lowermost sample (minimum 10%, 20.1 m b.g.l.) (Fig. 6) and become dominant in most of the following planktonic assemblages, attaining more than 40% of the planktonic assemblage at 12.8 m b.g.l. A strong decrease is recorded at 10.6 m b.g.l. (18%).

Warm-water oligotrophic taxa include also *Orbulina universa* (Hemleben et al., 1989) and the *Globoturborotalita apertura* group (*Gt. apertura*, *Gt. decoraperta*, *Gt. woodi*) (Serrano et al., 1999) (Fig. 6). *Orbulina universa* is in general scarce (5-10%), its specimens are large and frequent only in few lower samples, with its frequency maximum at 22.3 m b.g.l. (37.74%). The *Globoturborotalita apertura* group is frequent to abundant, ranging between 25-40% in most assemblages but shows few strong variations, decreasing to about 10% at 22.3 and 10.6 m b.g.l.

The cold-water, eutrophic taxa are mainly given by the *Globigerina bulloides* group (*G. bulloides*, *G. falconensis*) and by Neogloboquadrinids (dextral coiling *Neogloboquadrina acostaensis*, rare *N. humerosa*) (Pujol & Vergnaud Grazzini, 1995; Serrano et al., 1999). Percentages of the two taxa are always lower than 30% (Fig. 6). The *Globigerina bulloides* group reaches its maximum in the middle part of the succession, whereas the phytoplankton grazers Neogloboquadrinids (Hemleben et al., 1989; Serrano et al., 1999) are common in the lowermost samples and show some frequency peaks upwards, with a maximum of 10.6 m b.g.l. (29.89%). Sinistrally coiled *N. acostaensis* tests are fairly common in the lowermost sample (23.7 m b.g.l., 3.09%), rare at 23.4 and 8.0 m b.g.l. (1.18% and 1.54%, respectively) and absent in all other samples. *Globorotalia scitula* is present in the lower samples and shows a frequency peak at 22.7 m b.g.l. (10.80%), it is rare to absent from 19.3 m b.g.l. upwards (Fig. 6).

A minor component of the planktonic assemblages is *Globigerina nepenthes*, found randomly in all the counted assemblages. Its values reach 1-2% only between 21.7-19.3 m b.g.l. *Turborotalita quinqueloba*, very frequent to dominant in the finer fractions (qualitatively analyzed), becomes common in the >125 µm residues of the upper succession.

The Planktonic Faunal curve, obtained by the algebraic sum of percentages of warm-water, oligotrophic indicators (positive values) (*Globigerinoides* spp., *Globoturborotalita apertura* gr., and *Orbulina universa*) and of cold-water eutrophic indicators (negative values) (*Globigerina bulloides* gr., Neogloboquadrinids, *Globorotalia scitula*, and *Turborotalita quinqueloba*), displays a positive trend in most of the succession (Fig. 6). Values are rather low in the two lowermost samples and fastly increased after a slightly negative fluctuation at 22.7 m b.g.l. A moderate negative value is measured at

16.4 m b.g.l. and a rather more negative peak at 10.6 m b.g.l.

Benthic foraminifera

Also frequencies of benthic foraminiferal taxa show repeated fluctuations. The most common benthic species (10-30%) (Fig. 7) are *Cibicidoides pseudoungerianus*, frequent at the very base of the succession and *Uvigerina peregrina*, showing increasing percentages in the middle-upper assemblages, followed by *Bulimina minima*. Also *Sphaeroidina bulloides* and *Planulina ariminensis* are present in most samples, with maximum frequencies between 5-8%. *Globocassidulina subglobosa* is common in the lower part of the Zanclean succession, whereas the genus *Bolivina* (mainly *B. gladiiformis* and *B. usensis*, followed by *B. leonardii*, *B. lucidopunctata*, *B. pseudoplicata*, *B. punctata*, rare *B. apenninica*) displays its higher values (10-15%) in the middle succession (Fig. 7). Among the less common taxa recognized from the lowermost samples are *Oridorsalis umbonatus* (which attains its higher frequencies (about 4%) at the very base of the succession), *Sigmoilopsis schlumbergeri*, and *Gyroidinoides neosoldanii*, more common in the upper samples. *Siphonina reticulata* is absent in the lower samples, firstly occurs at 20.1 m b.g.l., is common (8-9%) up to 13.9 m b.g.l. and decreases in the uppermost samples. Other less frequent taxa, absent at the succession base, appear in the following order: *Anomalinoides helacinus* and *Uvigerina longistriata* from 23.4 m b.g.l., *Karreriella gaudryinoides* from 22.7 m b.g.l., *K. bradyi* from 22.3 m b.g.l., *Cibicidoides robertsonianus* from 19.3 m b.g.l., *C. kullenbergi* from 18.6 m b.g.l. (Fig. 7), *Cylindroclavulina rudis* from 17.6 m b.g.l., *Anomalinoides granosus* from 8.9 m b.g.l., *A. ornatus* is recognized in the counted assemblage only in the uppermost sample. Nodosariidae are generally common, abundant at 22.3 m b.g.l. (about 25%) (Fig. 7) and represented by many species of *Dentalina* (*D. communis*, *D. leguminiformis*, *D. mucronata*), *Lenticulina* (*L. cultrata*, *L. echinata*, *L. rotulata*, *L. vitrea*, etc.), *Marginulina* (*M. crebricosta*, *M. spinulosa*, etc.), *Nodosaria* (*N. longiscata*, *N. raphanus*, etc.), by *Chrysalogonion obliquatum*, *Dimorphina tuberosa*, *Mucronina gemina*, *Planularia auris*, *Saracenaria italica*, *Vaginulina legumen*, and *Vaginulinopsis carinata*. Many other outer neritic to epibathyal taxa, as *Amphicoryna* spp., *Bigenerina nodosaria*, *Eggerella bradyi*, *Gyroidinoides laevigatus*, *Heterolepa bellincionii*, *H. dertonensis*, *Martinottiella communis*, *M. perparva*, *Melonis padanum*, *M. soldanii*, *Oridorsalis stellatus*, *Uvigerina pygmaea*, and *U. rutila* are recognized in most samples. *Brizalina* spp. (*B. dilatata*, *B. spathulata*) and shallow water taxa (*Cibicides lobatulus*, *Elphidium* spp., *Neoconorbina terquemi*, and *Rosalina* spp.) are very rare or absent in most samples.

Ostracods

A total of 35 ostracod species belonging to 21 genera has been identified in the counted assemblages of the Pliocene A.A. The number of species throughout the succession (Fig. 8) is relatively low (less or equal than 22 per sample); the curve representing the number of minimum certain individuals (Fig. 8) shows almost the

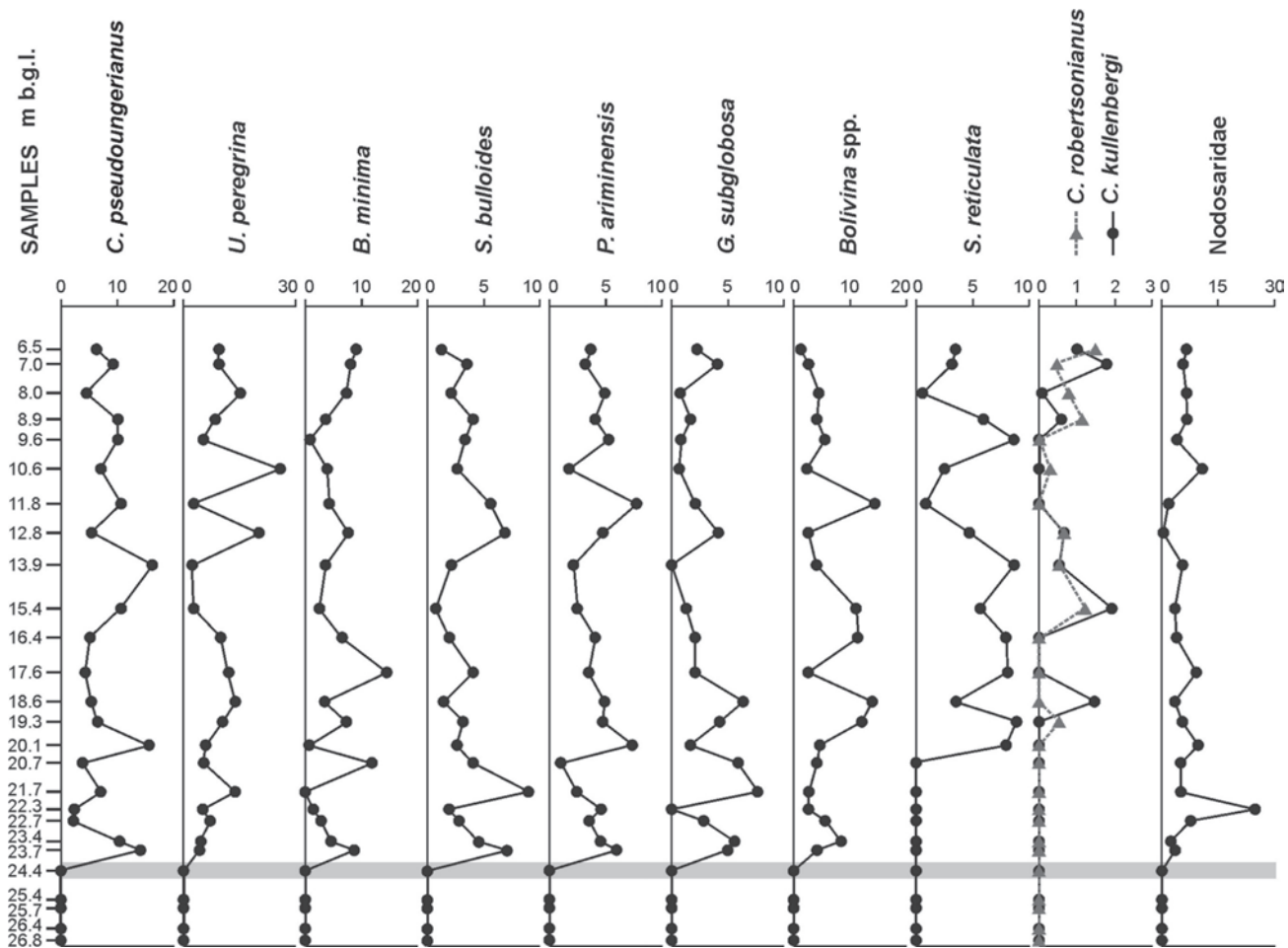


Fig. 7 - Percentage variations of benthic foraminiferal taxa (*Cibicidoides pseudoungerianus*, *Uvigerina peregrina*, *Bulimina minima*, *Sphaeroidina bulloides*, *Planulina ariminensis*, *Globocassidulina subglobosa*, *Bolivina* spp., *Siphonina reticulata*, *Cibicidoides robertsonianus*, *C. kullenbergi*, and *Nodosariidae*) in the Narzole core late Messinian/early Zanclean succession.

same trend as that of the number of species and reaches its maximum in the interval between 22.7–19.3 m b.g.l., where the diagram shows values >100 for sample. The main taxa identified in Pliocene sediments are: *Argilloecia acuminata*, *A. kissamovens*, *Bythocypris bosquetiana*, *B. obtusata producta*, *Cytherella gibba*, *C. russoi*, *C. vulgatella*, *Henryhowella asperima*, *Krithe compressa*, *K. iniqua*, *Oblitacythereis mediterranea*, *Paijenborchella iocosa*, and *Parakrithe dimorpha*.

Moreover, *Argilloecia acuminata*, *A. kissamovens*, *B. obtusata producta*, *Henryhowella asperima*, *Krithe compressa*, *K. iniqua*, *Oblitacythereis mediterranea*, *Paijenborchella iocosa*, and *Xylocythere producta* occur from 23.7 m b.g.l., *Bythocypris bosquetiana* and *Parakrithe dimorpha* from 23.4 m b.g.l., *Cytherella gibba*, *C. russoi*, *C. vulgatella*, and *Xestoleberis prognata* from 22.7 m b.g.l. (Fig. 8).

Calcareous Nannofossils

Within the AA samples, calcareous nannofossil reworking is very low (Fig. 9); rare specimens of *Ceratholithus acutus* have been recorded, whereas specimens of *Triquetrorhabdulus rugosus*, usually present at the very base of the Zanclean (Di Stefano, 1998,

Castradori, 1998), do not occur. Upwards in the section, calcareous nannofossil assemblages are very diversified and dominated by reticulofenestrids, together with helicoliths (the only species being *Helicosphaera carteri*); minor components of the assemblage are discoasterids and ceratholiths (*C. acutus*, *Amaurolithus primus*, *A. delicatus*), typical tropical open marine taxa, usually very rare in the Mediterranean Pliocene. *Helicosphaera sellii* with pores larger than 1.5 μm (Raffi et al., 2003) has not been recorded in this material. Directly above the black layer, a species of *Reticulofenestra* with a circular outline (*Reticulofenestra pseudoumbilicus* - circular outline - in Castradori, 1998; *Reticulofenestra zancleana*, according to A. Di Stefano, pers. comm.) occurs. This taxon ranges from 6 to 8 μm in diameter, has an open squared central area and is common in the assemblage up to 19.3 m b.g.l., upward in the core this taxon becomes rare or absent (Fig. 9). Moreover, the lowermost Pliocene samples are characterized by high but discontinuous abundances of *R. minuta* up to 19.3 m b.g.l. Abundance peaks of *S. abies* are recorded at 19.3, 15.4 and 11.8 m b.g.l. *Braarudosphaera bigelowi*, usually very rare or absent, is locally present in low abundances in discrete layers (18.6, 15.4, and 11.8 m b.g.l., Fig. 9).

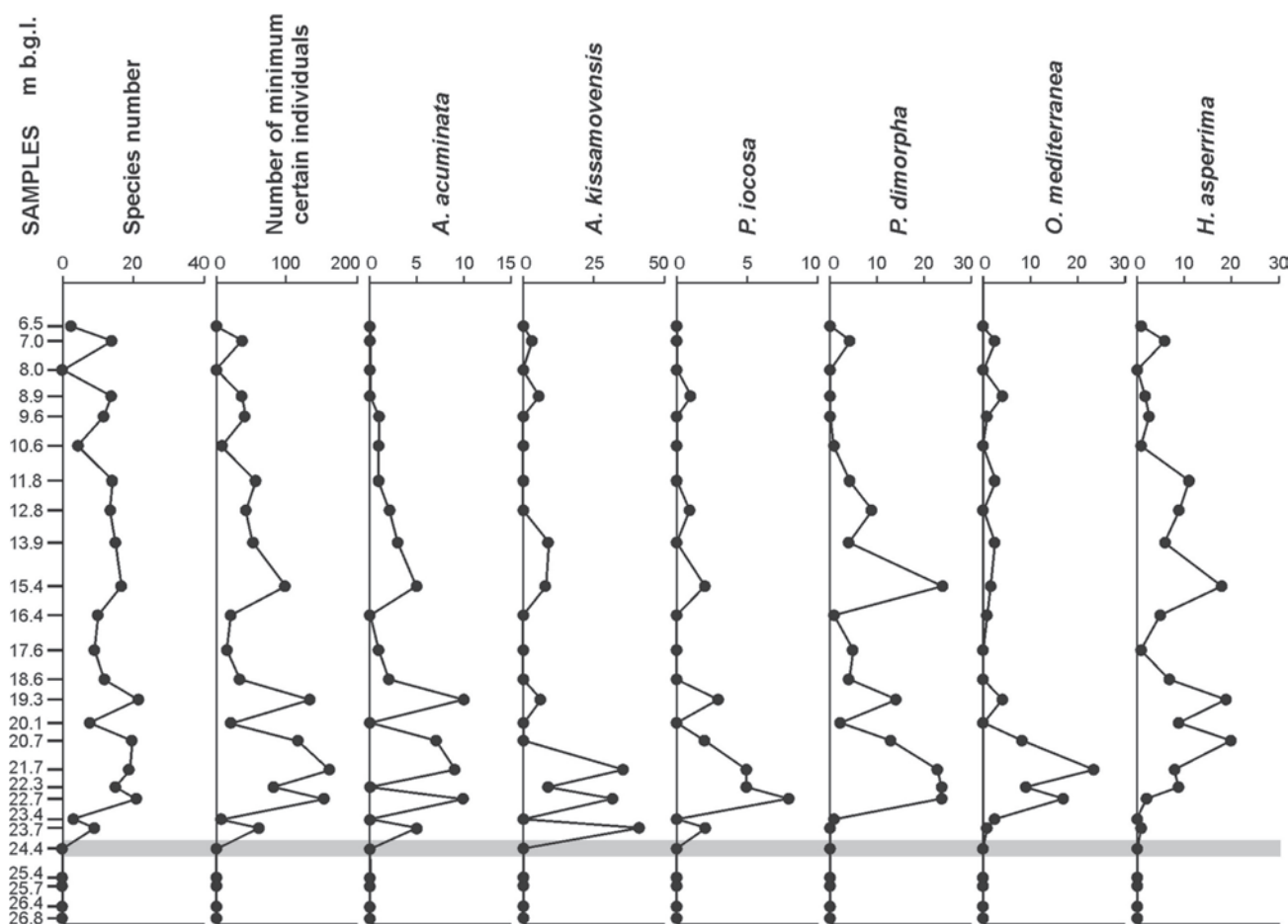


Fig. 8 - Number of ostracod species, number of minimum certain ostracod adult individuals and number of minimum certain ostracod adult taxa (*Argilloecia acuminata*, *A. kissamovens*, *Paijenborchella iocosa*, *Parakrithe dimorpha*, *Oblitacyptheris mediterranea*, and *Henryhowella asperrima*) in the Narzole core late Messinian/early Zanclean succession.

DISCUSSION

Upper Messinian Lago-Mare assemblages

Marine assemblages of *Lago-Mare* sediments contain long-ranging and Tortonian to Messinian foraminiferal taxa such as *Globorotalia suterae*, Cretaceous to Miocene calcareous nannofossils, which are interpreted as reworked from older pre-evaporitic sediments. Ostracods are characterized by the presence of *Cyprideis agrigentina*, a taxon restricted to the Messinian (Decima, 1964; Colalongo, 1968), common in the *Lago-Mare* sediments of many Sicilian sections (Decima & Sprovieri, 1973; Bonaduce & Sgarrella, 1999). *C. agrigentina* was a taxon characteristic of brackish waters (Rouchy et al., 2007), which inhabited waters probably not deeper than 50 m (Van Harten, 1990) and indicates a shallow-oligohaline palaeoenvironment (Grossi et al., 2008) for the uppermost Messinian deposits of the Narzole core. This taxon, according to Cipollari et al. (1999a) and to Gliozzi (1999) is typical of the *Loxoconcha djafarovi* Zone, a biozone originally defined by Sissingh (1972) and re-described by Carbonnel (1978), which approximates the Miocene/Pliocene boundary. According to Gliozzi et al. (2006) the *Loxocorniculina djafarovi* biozone includes the *Lago-Mare* Biofacies 2 of Bonaduce & Sgarrella (1999) and the Paratethys

Assemblage (*Loxoconcha djafarovi* assemblage) of Iaccarino & Bossio (1999). *Cyprideis agrigentina* represented an Italian *Lago-Mare* species with Paratethyan affinity (Cipollari et al., 1999b; Orszag-Sperber, 2006; Gliozzi et al., 2007; Ligios & Gliozzi, 2008) that indicates a post-evaporitic Messinian age.

These assemblages are well comparable to those of the *Lago-Mare* deposits of the Moncucco quarry succession, in which also characteristic lower Messinian species such as *Globorotalia conomiozea* (LO 6.52 My, Gradstein et al., 2004) and *G. nicolae* (LO 6.72 My, Hilgen et al., 1995) were recovered (Trenkwalder et al., 2008; Violanti et al., in press). Reworking of marine microfossils is widely documented in late Messinian brackish *Lago-Mare* sediments (Ryan et al., 1973; Cita et al., 1978; Spezzaferri et al., 1998; Iaccarino et al., 1999; Irace et al., 2005; Pierre et al., 2006; Rouchy et al., 2007; Grossi et al., 2008). No *in-situ* open marine forms, that could suggest normal marine episodes or influxes, have been detected in the uppermost Messinian sediments.

Early Zanclean Argille Azzurre Fm. Assemblages

The Pliocene succession cored at Narzole could be dated to an interval encompassing the Zanclean MP11 and MP12 zones on the basis of the occurrence of *Sphaeroidinellopsis* spp. and *Globorotalia margaritae*.

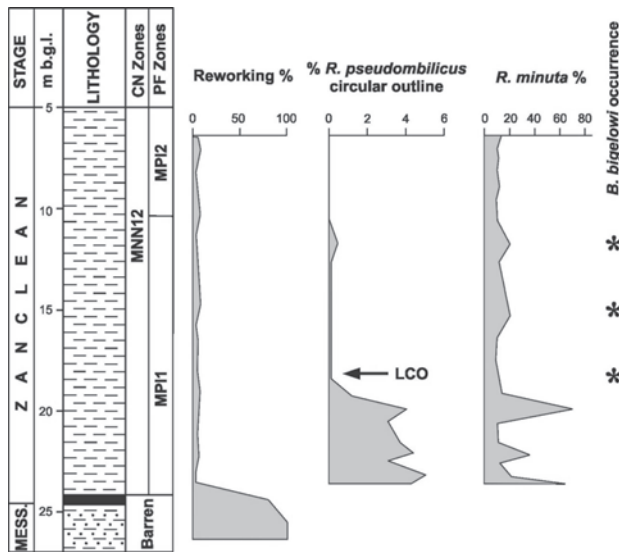


Fig. 9 - Foraminiferal and calcareous nannofossils biozones, percentage distribution of significant calcareous nannofossil species (*Reticulofenestra pseudumbilicus* - circular outline -, and *R. minuta*) in the Narzole core late Messinian/early Zanclean succession.

The absence of *Helicosphaera sellii* with pores larger than 1.5 μm (Raffi et al., 2003) testifies that the entire core pertains to the MNN12 zone. The *Sphaeroidinellopsis* acme interval (5.29-5.20 My, Iaccarino et al., 1999), which extends from cycles 2 to 6 (Di Stefano et al., 1996), was recognized between 22.7 m b.g.l. (1.4 m above the BL) and 20.7 m b.g.l. (3.4 m BL). The FCO (First Common Occurrence) of *G. margaritae* (5.08 My, Gradstein et al., 2004), marker of the lower boundary of the MPI2 Zone (Cita, 1975a, b; Rio et al., 1984) and correlated to cycle 10 (Di Stefano et al., 1996) was tentatively recognized at 10.6 m b.g.l. (13.5 m above BL).

The presence of *Braarudosphaera bigelowi*, a typical nearshore/low salinity taxon, is recorded only in few layers; this taxon was already recorded in the Moncucco quarry section (Trenkwalder et al., 2008), where it correlates with increasing coarseness of the sediment, suggesting shallowing of the water column. Its presence here could be related to the same factors as well as a change in salinity in the upper part of the water column, as also suggested by the presence of discrete peak abundances of *Sphenolithus abies*.

Other useful bioecostatigraphic events include:

a) the occurrence of sinistral specimens of *Neogloboquadrina acostaensis*, rather common at 23.7 m b.g.l. (0.4 m above the BL) (3.09%), rarer in the following sample at 23.4 m b.g.l. (0.7 m BL) (1.18%). Only dextral specimens occur upwards, with the exception of sample at 8.0 m b.g.l. Two sinistral shifts of *N. acostaensis* were identified below the *Sphaeroidinellopsis* spp. acme in the Rocella Ionica-Capo Spartivento section (Southern Italy) (Di Stefano et al., 1996), where the basal Zanclean succession is completely preserved: the first and older between lithological cycles 1-2, the second and younger between cycles 2-3, near the base of the *Sphaeroidinellopsis* spp. acme, which encompasses cycles 2 to 6. In the Narzole

core, as in the Moncucco quarry (Trenkwalder et al., 2008), *N. acostaensis* is essentially right-coiled. Left coiling specimens, even if occurring as a minor component, are present only in the first few decimeters above the BL. Their occurrence could approximate one of the coiling shifts detected by Di Stefano et al. (1996). Also the occurrence of *Ceratholithus acutus* just above the black layer and the absence of *Triquetrorhabdulus rugosus* suggest that the very basal Zanclean could be missing in the section.

b) the abundance peak of *Globorotalia scitula* dextral, found at 22.7 m b.g.l. The CO (Common Occurrence) of *Globorotalia scitula* dextral, reported as a “delayed invasion event” in the basal Zanclean of the Western Mediterranean was correlated to cycle 6 (Iaccarino et al., 1999).

c) the occurrence of *Oblitacythereis mediterranea* among Pliocene ostracods is of stratigraphic importance, because the taxon had its first appearance only in the Zanclean (Early Pliocene) and extended to the Middle Pliocene of the entire Mediterranean area (Ilani et al., 2008). Moreover, at Narzole, *Henryhowella asperrima* and *Oblitacythereis mediterranea* firstly occurred in the MPI1 biozone since the basal sample (Fig. 8), like in the Moncucco section (Trenkwalder et al., 2008), while in Pliocene sections of the Ionian Calabria (Ciampo, 1992), in Eraclea Minoa in Sicily (Barra et al., 1998) and in Site 654A, ODP Leg 107, drilled in the Tyrrhenian Sea (Colalongo et al., 1990) they occurred later, at the base of MPI2 biozone.

d) the occurrence of a medium size circular *Reticulofenestra* species, already observed in deep-sea sediments of the Eastern Mediterranean (*Reticulofenestra pseudumbilicus* circular outline, Castradori, 1998; *R. zancleana*, A. Di Stefano, pers. comm., 2008) within the lower part of the core (from 23.7 to 19.3 m b.g.l.). Its biostratigraphic value has recently been proposed and tested in other basal Zanclean sediments of both Eastern and Western Mediterranean DSDP and ODP Sites (Di Stefano & Sturiale, 2008), where its LCO (Last Common Occurrence) is located just below the MPI1/MPI2 boundary (A. Di Stefano, pers. comm., 2008).

Sedimentological characteristics, microfossil (foraminifers, ostracods, and calcareous nannofossils) assemblages composition and fluctuations suggest various changes in the palaeoenvironmental parameters during the deposition of the AA. Four intervals can be evidenced in the Pliocene succession of Narzole, from the bottom to the top and sedimentation rates for three of them, well defined by the biostratigraphic data, were calculated with the aim to compare with sedimentation rates of other coeval Mediterranean successions. Zanclean sedimentation rates from the Messinian/Zanclean boundary, 5.33 My (Van Couvering et al., 2000), to the *G. margaritae* LO (Last Occurrence), 3.9 My (Cita et al., 1999), were low in the entire Mediterranean deep-sea records, ranging from 1 cm/1000 y to 11 cm/1000 y (Cita et al., 1999). The abrupt sea-level rise at the Pliocene transgression strongly modified the equilibrium between erosion and deposition and only after the *G. margaritae* LO the terrestrial input increased, leading to higher sedimentation rates. In the Moncucco T. quarry,

Trenkwalder et al. (2008) calculated a mean sedimentation rate of 4.6 cm/1000 y for the MP11 time interval, documented in the outcrop by about 11.5 m of AA and very similar to the values calculated from drillsites in the Alboran Sea and the Balearic Basin (Cita et al., 1999). A lower value of 1.66 cm/1000 y was obtained at Moncucco T. for the entire time interval from 5.33 My to 3.9 My, but it was probably biased by non-detectable sedimentary hiatuses in the MPI2 and MPI3 zones.

1) - From 5.33 to 5.29 My (M/Z boundary, 24.1 m b.g.l. - base of the *Sphaeroidinellopsis* acme 22.7 m b.g.l.).

This time interval of 0.04 My is documented by about 1.4 m of AA (Fig. 5) and a sedimentation rate of 3.5 cm/1000 y was calculated, excluding the still undated BL, marking the Messinian/Zanclean boundary. If the BL was included, the sedimentation rate would increase to 4.75 cm/1000 y. Terrigenous debris (quartz grains, micas, rock fragments) are rather common, suggesting a continental input. Foraminiferal number per 1 gram of dry sediment (FN/g, Fig. 5) was low, whereas the P/(P+B) percentages were very high, ranging between 70-80%. Planktonic diversity indices are uniformly rather high from the Zanclean base (16-18 species and Fisher's α about 4). On the contrary, the benthic diversity was low in the lowermost sample and fastly increased.

Percentages of tropical to subtropical oligotrophic planktonic taxa, inhabiting waters of the summer mixed layer above the thermocline, such as *Globigerinoides* spp. (Hemleben et al., 1989; Pujol & Vergnaud Grazzini, 1995) or that thrived near the thermocline as the extinct *Globoturbotalita apertura* (Serrano et al., 1999) (Fig. 5) are quite similar to those of cool to cold-water eutrophic forms, thriving in intermediate waters characterized by upwelling or vigorous vertical mixing, such as the *G. bulloides* group (Bé & Tolderlund, 1971; Pujol & Vergnaud Grazzini, 1995), and close to- or below the thermocline, such as the phytoplankton grazers Neogloboquadrinids (Fairbanks & Wiebe, 1980; Kennett et al., 1985). *Turbotalita quinqueloba*, inhabiting surficial cool eutrophic waters (Hemleben et al., 1989) is here scarce. The Planktonic Faunal curve (Fig. 6) shows very low positive values. This pattern suggests temperate to warm-temperate waters and rather high primary productivity. Also the high abundance of *R. minuta* in the sediments overlaying the black layer suggests high nutrient levels in the upper water column, as already hypothesized for the pre-evaporitic Messinian (Negri & Villa, 2000; Lozar et al., in press).

The rather poorly diversified lowermost benthic foraminiferal assemblages yield common to frequent outer neritic to bathyal taxa (*Cibicidoides pseudoungerianus*, *Bulimina minima*, *Planulina ariminensis*, *Sphaeroidina bulloides*, *Uvigerina peregrina*, etc.) (Boltovskoy & Wright, 1976; Murray, 2006). They were dominated by the cosmopolitan *Cibicidoides pseudoungerianus* (Van Morkhoven et al., 1986), usually considered to be epifaunal (Jorissen, 1987), doubtfully oxyphilic (Kouwenhoven, 2000) and preferential of well-oxygenated bottoms under high organic carbon fluxes (Woodruff, 1985; Jones, 1996; Murgese & De Deckker, 2005). Also spinose buliminids

(mainly *Bulimina minima*), considered to be infaunal, adapted to low oxygen and/or high organic matter content (Corliss 1985; Murray, 2006) are frequent. Both the shallow infaunal *Sphaeroidina bulloides* (Corliss, 1985; Fontanier et al., 2006), frequent in high productivity slope areas influenced by seasonal input or coastal upwelling (Licari & Mackensen, 2005), and *Planulina ariminensis*, epifaunal, characteristic of well-oxygenated conditions (Kouwenhoven & Van der Zwaan, 2006), widespread on deep outer neritic to epibathyal bottoms (Wright, 1978; Van Morkhoven et al., 1986) are common. The shallow infaunal *Uvigerina peregrina*, preferential of high productivity (Jorissen, 2000; Loubere & Fariduddin, 2002) and *U. pygmaea*, followed by *U. longistriata*, and *U. rutila*, represent only less than 5% of the lowermost benthic assemblages. *Oridorsalis umbonatus*, an epifaunal taxon, preferential of low organic carbon fluxes (Mackensen et al., 1985), frequent in the lowermost Zanclean successions of the central Mediterranean area (Barra et al., 1998; Iaccarino et al., 1999) is rather common (about 4%) only in this interval. *Gavelinopsis praegeri* and *Eponides tumidulus*, recorded from the bathyal Mediterranean (Parker, 1958) and from bottoms influenced by high seasonal input of phytodetritus (Altenbach et al., 2003) are present in the finest fraction with lower frequencies than registered in the basal Zanclean of Moncucco (Trenkwalder et al., 2008). Benthic assemblages dominated by *S. bulloides* and *Gavelinopsis translucens* (very close to *G. praegeri*) have been inferred to represent the fauna associated with the Oxygen Minimum Water in the Gulf of Mexico Late Pleistocene, in a depth range of about 450-670 m (Denne & Sen Gupta, 2003).

Ostracods are represented by low number of species and of individuals (Fig. 8). The oldest Zanclean ostracod assemblages are characterized by the presence, among others, of: *Argilloecia acuminata* (found in the Mediterranean down to 2600 m, Bonaduce et al., 1983), *Bythocypris bosquetiana* (described in the sediments of the Atlantic-Mediterranean area from 150 m to 3381 m, Aiello et al., 2000), *Bythocypris obtusata producta* (a taxon with a bathyal distribution, Bertini et al., 2008), *Krithe compressa* (living in the South China Sea at depth of 900 m, Whatley & Quanhong, 1993), *Paijenborchella iocosa* (living in the South China Sea at depth greater than 500 m, Keij, 1966), *Parakrithe dimorpha* (described in Italy in epibathyal Pliocene sediments (Aiello et al., 2000; Aiello & Barra, 2001). Also the presence of *Oblitacythereis mediterranea* (considered an inhabitant of the transitional facies between psychrospheric and shelf assemblages, Benson, 1978 and Ilani et al., 2008, upper bathyal thermospheric ostracod found in the Mediterranean between 300 and 1000 m depth, with an optimum between 400 and 600 m at bottom temperatures $>10^{\circ}\text{C}$, Benson, 1977) suggests a deep palaeo-environment.

At the base of the Zanclean succession, both foraminiferal and ostracod assemblages suggest open-marine conditions and upper epibathyal bottoms, probably not deeper than 500-700 m, for the rareness of deep bathyal taxa. Planktonic foraminiferal assemblages, in which warm oligotrophic and cool eutrophic planktonic taxa are nearly equally represented, suggest a temperate

or warm-temperate climate. A rather high seasonal productivity could be inferred based upon the frequencies of *Neogloboquadrina acostaensis*, *Globigerina bulloides* and is corroborated by the common presence of *Sphaeroidina bulloides*, *Bulimina minima*, *Gavelinopsis praegeri*, and *Eponides pusillus* in the benthic assemblage. Well-oxygenated or only moderately disaerobic bottom seem to be documented by the common epibenthic taxa (*Cibicidoides pseudoungerianus*, *Planulina ariminensis*) and by the low percentages of stress-tolerant taxa as *Uvigerina peregrina* and *B. minima*, species adapted to high organic content and low oxygen level (Schönfeld & Altenbach, 2005), as in the Moncucco section (Trenkwalder et al., 2008). The strong bottom disaerobic conditions registered in the early Zanclean of Capo Rossello (Barra et al., 1998; Sgarrella et al., 1999) would have not affected the northern Piedmont basin. A good bottom oxygenation has been documented in other sites of the Mediterranean area (Orszag-Sperber & Rouchy, 1979; Spezzaferri et al., 1998; Pierre et al., 2006), and different sedimentary situations, influenced by local palaeomorphologies, developed during the deep-sea flooding, rapidly extending to the entire Mediterranean basin.

2) - From 5.29 My to 5.20 My (base to top of the *Sphaeroidinellopsis acme*).

About 2 meters of AA, from 22.7 to 20.7 m b.g.l., represent the time interval of 0.09 My and a mean sedimentation rate of 2.22 cm/1000 y was calculated. Residues are almost totally biogenic. Foraminiferal assemblages are characterized by increasing FN/g, very high P/(P+B) ratio, a peak of benthic Fisher's α index (Fig. 5), the maximum abundance of *Sphaeroidinellopsis* spp. and a frequency peak of *Globorotalia scitula* (Fig. 6). Warm water oligotrophic taxa such as *Globigerinoides* spp. and the *Globoturborotalita apertura* group show higher values than in the lowermost samples and *Orbulina* spp. attain here their maximum. A concurrent decrease occurs in the cold water, eutrophic taxa. The Planktonic Faunal curve evidences the fluctuation toward warmer, oligotrophic conditions in the water column (Fig. 6). More temperate or eutrophic conditions were registered in the same interval at Moncucco (Violanti et al., in press), where Neogloboquadrinids and *G. scitula* reached higher percentages. At Narzole, a lower productivity in the water column and/or a deeper thermocline in the photic zone could be inferred in comparison with Moncucco. The quantitative importance of deeper-dwelling taxa, occurring within and below the thermocline in association with the chlorophyll maximum was reduced, whilst the shallower-dwelling forms such as *Globigerinoides* spp. became quantitatively more important (Thunell et al., 1983). Benthic foraminiferal assemblages display lower frequencies of *Cibicidoides pseudoungerianus* and *Planulina ariminensis*, whereas percentages of *Uvigerina peregrina* increase to about 10-15%. Some bathyal taxa such as *Karreriella bradyi*, *Anomalinoides helcinus*, and *K. gaudryinoides* firstly occur. The Nodosariidae reach their highest abundance in this interval (Fig. 7). Also the ostracod diversity and abundances increase, the number of individual here attains its maximum, *Argilloecia kissamovensis*, *A. acuminata*, *Cytherella*

spp., *Paijenborchella iocosa*, *P. dimorpha*, and *Oblitacythereis mediterranea* are frequent and *Xestoleberis prognata* (a taxon living in bathyal environments, whose evaluated minimum palaeodepth corresponds to 600-800 m according to Abate et al., 1994) firstly occurs. All these data document the increasing assemblages palaeobathymetry and faunal diversity related to the progressive repopulation of the Mediterranean basin by deep bathyal Atlantic taxa (Spezzaferri et al., 1998).

3) From 5.20 My to 5.08 My (top *Sphaeroidinellopsis acme*-*G. margaritae* FCO).

About 10.10 meters of AA, from 20.7 to 10.6 m b.g.l., represent a time interval of 0.12 My and a mean sedimentation rate of 8.4 cm/1000 y was calculated. Residues are always biogenic. The FN/g showed wide fluctuations, between very low values in the lower part of the interval, a peak in its middle and again decreasing numbers in the upper samples. The P/(P+B) ratio slightly shallows to 60/70% and also the P and B diversity indexes display repeated fluctuations, often in negative correlation with the FN/g trend (Fig. 5). Planktonic foraminiferal assemblages are characterized by the very rare and sporadic occurrence of small specimens of *Globorotalia margaritae* and by a nearly progressive and cyclical increase of *Globigerinoides* spp. The cyclical astronomically forced frequency fluctuations of *Globigerinoides* spp. registered in Zanclean deep sea successions (Sprovieri, 1993) are also evident in this interval, even if the samples distance was rather large. The *Globigerina bulloides* trend is opposite to that of *Globigerinoides* spp., whereas a negative correlation is evident between the *Globoturborotalita apertura* gr. and Neogloboquadrinids curves (Fig. 6). The Planktonic Faunal curve suggests dominantly warm, oligotrophic water conditions, as documented in the same interval of the Moncucco section (Trenkwalder et al., 2008). Nevertheless, in the Narzole core short fluctuations of temperate or cooler, more eutrophic conditions are evidenced by the frequency increases of the upper intermediate dwellers tropical Neogloboquadrinids (Keller, 1985).

Frequency of *Uvigerina peregrina* and *Bulimina minima*, shallow and intermediate infaunal detritivorous taxa, adapted to high organic content and low oxygen level (Van der Zwaan et al., 1986; Schönfeld & Altenbach, 2005) increase and show opposite trends to the epifaunal and oxyphilic *Cibicidoides pseudoungerianus*, correlated to high organic carbon fluxes (Murgese & De Deckker, 2005). In this interval, *Siphonina reticulata* firstly occurs and becomes common. *S. reticulata* was inferred to be a Mediterranean quasi-endemic form (Sgarrella et al., 1997, 1999), indicative of Early Pliocene Mediterranean Intermediate Water (EPMIW) and its re-immigration in the Mediterranean appears to be a nearly synchronous event in the Mediterranean basin (Spezzaferri et al., 1998; Iaccarino et al., 1999; Pierre et al., 2006; Rouchy et al., 2007), correlated to the lithological cycle 6 (Di Stefano et al., 1996). The *S. reticulata* occurrence was also documented in the Moncucco section at a nearly similar level in the AA than in the Narzole core and could document the influx of

EPMIW into the Northwestern Italy as well as the connections with the Mediterranean basin during the early Zanclean. Other bathyal species (*Cibicidoides kullenbergi*, *C. robertsonianus*, *C. rudis*, and *Eggerella bradyi*) add to the benthic assemblages, supporting the previous hypothesis. In particular, *C. robertsonianus* is interpreted as a typical NADW (North Atlantic Deep Water) form, indicative of a deep oceanic-type circulation in the Mediterranean early Zanclean (Hasegawa et al., 1990; Pierre et al., 2006). Percentages of bathyal benthic foraminifers decrease in the upper part of this interval, as the ostracod numbers of species and of minimum certain individuals. *Argilloecia kissamovens*, *Krithe iniqua*, *Oblitacythereis mediterranea*, *Paijenborchella iocosa*, and *Parakrithe dimorpha* strongly decrease in abundance upwards. The concurrent frequency peaks of *Uvigerina peregrina*, *Bulimina minima*, and *Bolivina* spp. suggest episodes of higher organic carbon fluxes and/or an increasing availability of organic matter at the bottom.

4) From 5.08 My (*G. margaritae* FCO) to the top of AA.

About 4.10 m of AA, from 10.6 to 6.5 m b.g.l., represent the MPI2 foraminiferal zone and the upper MNN12 calcareous nannofossil zone. The markers of the upper limits of these zone are absent, excluding the presence of the MPI3 and MNN13/14 zones and there are not events that could indicate the extension of the interval. Nevertheless, the micropalaeontological composition and fluctuations of more common taxa are in positive correlation with assemblages of the 6.5 m thick MPI2 sediments of the Moncucco section (Trenkwalder et al., 2008) and could represent almost entirely the same interval. Foraminiferal assemblages show very low FN/g, fluctuations of the P/(P+B) ratio toward about 40% and rather constant benthic Fisher's α values. Warm water, oligotrophic planktonic taxa are often dominant, leading to a Planktonic Faunal curve with generally positive values. Nevertheless, abundance peaks of Neogloboquadrinids are registered in concomitance with the FCO of *Globorotalia margaritae* and in the upper samples and document brief fluctuations toward more eutrophic conditions and/or increased primary productivity. Only few bathyal taxa (*Anomalinoides granosus*, *A. ornatus*) add to the well-diversified benthic foraminiferal assemblages. *Bulimina minima* shows a slight progressive increase and *Siphonina reticulata* has strong abundance fluctuations (Fig. 7). The trend to a reduction in ostracod diversity, observed in the previous interval, becomes more evident (Fig. 8). The co-occurrence of *Argilloecia acuminata* with *A. kissamovens*, *Cytheropteron pinarense gillesi*, *Krithe compressa*, *K. iniqua*, *Parakrithe dimorpha*, and *Xestoleberis prognata*, documents a still deep basin and supports the hypothesis of a palaeodepth up to 1000 m (Aiello & Barra, 2001).

CONCLUSIONS

The about 20 meters of sediments cored at Narzole (Piedmont, Northwestern Italy), document an interval extended from the uppermost Messinian *Lago-Mare*

facies to the early Zanclean MPI2 foraminiferal zone and MNN12 calcareous nannofossil zone. The Messinian/Zanclean boundary was marked by a dark brown to black barren arenitic layer, as registered in the nearby outcrop of Moncucco, where about all the Zanclean is documented (MPI1 to MPI4 foraminiferal zones, MN12 to MNN13/14 calcareous nannofossil zones; Trenkwalder et al., 2008).

The present study confirms that the brackish ostracod assemblage of the uppermost *Lago-Mare* sediments is referable to the *Loxocorniculina djafarovi* biozone (Carbonnel, 1978; Gliozzi et al., 2006) of the upper Messinian post-evaporitic interval. At Narzole, the *Lago-Mare* biofacies is testified by monospecific associations of *Cyprideis agrigentina*, like in Sicily, at Pasquasia-Capodarso (Colalongo, 1968) and in the lowermost part of the Eraclea Minoa section (Bonaduce & Sgarrella, 1999). Moreover, this assemblage also indicates the influx of Paratethyan faunas (Orszag-Sperber, 2006; Trenkwalder et al., 2008).

Sedimentological and micropalaeontological (foraminifers, ostracods and calcareous nannofossils) content as well as fluctuations of planktonic and benthic taxa recorded in the Zanclean MPI1-MPI2/MNN12 zones interval of the Narzole and Moncucco successions are very similar and can be well correlated. Only minor differences within their faunal composition were registered, as the quantitative importance of eutrophic forms as Neogloboquadrinids, suggesting small differences in water productivity of the two areas.

In the basal Argille Azzurre Fm., immediately above the Messinian/Zanclean boundary, the occurrence of outer-neritic to bathyal benthic foraminifers and of deep marine ostracods testifies the sudden re-colonization of the Pliocene Mediterranean Basin after the extinction of the marine fauna during the Messinian Salinity Crisis. The composition of the identified assemblages, made of a typical Mediterranean-Atlantic stock, attests the restored connection between Atlantic and Mediterranean at the very beginning of the Pliocene.

Benthic foraminiferal assemblages show a specific composition very similar to those of early Zanclean deep marine succession of the Mediterranean area (Di Stefano et al., 1996; Sgarrella et al., 1997; Barra et al., 1998; Spezzaferri et al., 1998; Iaccarino et al., 1999; Pierre et al., 2006). Lower percentages of deep bathyal stress-tolerant taxa, associated to high organic fluxes and low oxygen content as *Uvigerina peregrina*, suggest rather well-oxygenated bottoms and seem to exclude or limit to seasonal fluctuations the strong disaerobic conditions registered at the very base of the Zanclean in southern Sicily (Sgarrella et al., 1997).

All palaeobiological data suggest open marine circulation patterns and epibathyal bottoms during the deposition of the AA Fm. This palaeoenvironmental interpretation is supported by the very high P/(P+B) ratio, the presence of mesopelagic planktonic foraminifers as *Sphaeroidinellopsis* spp., common to frequent deep cosmopolitan benthic foraminifers (*Cibicidoides pseudoungerianus*, *Sphaeroidina bulloides*, *Uvigerina peregrina*, etc.), common bathyal ostracods (*Argilloecia kissamovens*, *A. acuminata*, *Paijenborchella iocosa*, *Parakrithe dimorpha*, *Oblitacythereis mediterranea*,

Xestoleberis prognata, etc.), the rare discoasterids and ceratoliths (*Ceratholithus acutus*, *Amaurolithus primus*, *A. delicatus*), typical tropical open marine taxa, usually very rare in the Mediterranean Zanclean. Moreover, these data support the hypothesis of deep connections between the Northwestern Italy and the Mediterranean basin during the early Zanclean, allowing the apparently contemporary basin-wide diffusion of planktonic and benthic taxa.

Taking into account the palaeoecological indications given by benthic foraminifer and ostracod assemblages, a basin deepening to about 1000 m could be inferred during the MP11 biozone (ostracod increasing number and diversity, followed by the first influx of *S. reticulata* and of NADW taxa as *C. robertsonianus*). A similar palaeoenvironmental change was documented by Trenkwalder et al. (2008) and Violanti et al. (in press) in the nearby Moncucco outcrop, as well as in the Northern Apennines (Maccarone section; Cosentino et al., 2008).

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