



The Miocene/Pliocene boundary and the Early Pliocene micropalaeontological record: new data from the Tertiary Piedmont Basin (Moncucco quarry, Torino Hill, Northwestern Italy)

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KEY WORDS - Miocene/Pliocene boundary, Foraminifers, Ostracods, Calcareous nannofossils, Tertiary Piedmont Basin.

ABSTRACT - This paper reports new integrated biostratigraphic and palaeoecological data from the upper Messinian to Zanclean succession exposed in the Moncucco quarry (Torino Hill, Tertiary Piedmont Basin, Northwestern Italy). The foraminifer, ostracod, and calcareous nannofossil assemblages have been studied in detail. In the Moncucco quarry the Vena del Gesso Formation is followed by post-evaporitic chaotic deposits (Valle Versa Chaotic Complex) and by continental and brackish water sediments, correlatable to the Lago-Mare deposits of the Mediterranean area. The latter are in turn followed by marine sediments of the Argille Azzurre Fm. (Zanclean) through an irregular surface that is overlaid by a 10-50 cm thick black arenitic layer very rich in organic matter. At the top of the bed an omission surface, evidenced by a network of firm ground burrows filled by the Zanclean sediments, has been observed. The ostracod assemblages recognised in the sediments just below the black layer are referable to the *Loxocorniculina djafarovi* biozone (upper Messinian post-evaporitic interval). They indicate oligo-mesohaline shallow-water conditions and show the influx of Paratethyan faunas. Foraminifers and calcareous nannofossils in this interval are reworked. Microfaunas and calcareous nannofossils found in the sediments just above the black layer testify the MPI1 foraminifer biozone and the MNN12 calcareous nannofossil biozone. However, the absence of the first sinistral coiling shift of *Neoglobobulimina acostaensis* and of *Trifarina angulosa* in the lowermost Pliocene samples suggests a short hiatus, further confirmed by the presence of the omission surface at the top of the black layer. The recognition of biostratigraphic markers along the section allows to identify the MPI2, MPI3, and MPI4a foraminifer biozones and MNN13 and MNN14-15 calcareous nannofossil biozones, even if partially documented by the sedimentary record. The occurrence of *Agrenocythere pliocenica* within the MPI2 biozone, confirms the biostratigraphic importance of this taxon at the Mediterranean scale. Foraminifer and ostracod palaeoecological data suggest an upper epibathyal depositional palaeoenvironment in the MPI1 biozone, a further deepening in the MPI2 biozone and a progressive reduction of the water depth in the MPI3 and MPI4a biozones. On the whole, these data suggest that also in the Tertiary Piedmont Basin the termination of the Messinian salinity crisis was abrupt, followed by the deep-sea Zanclean flooding event.

RIASSUNTO - [Dati micropaleontologici relativi al limite Miocene/Pliocene ed al Pliocene inferiore: nuovi dati dal Bacino Terziario Piemontese (cava di Moncucco, Collina di Torino, Italia nord-occidentale)] - In questo lavoro vengono riportati nuovi dati integrati biostratigrafici e paleoecologici relativi alla successione del Messiniano-Zancleano (Pliocene inferiore) affiorante nella cava di gesso di Moncucco T.se (Collina di Torino, Bacino Terziario Piemontese). Sono state studiate in dettaglio le associazioni a foraminiferi, ostracodi e nannofossili calcarei e i dati acquisiti evidenziano eventi già registrati nelle successioni del bacino Mediterraneo. Nella cava di Moncucco la Formazione della Vena del Gesso è seguita da depositi caotici post-evaporitici (Complesso Caotico della Valle Versa) e da sedimenti continentali tipici di acque salmastre, correlabili ai depositi di Lago-Mare (Messiniano superiore) dell'area mediterranea. La successione termina con i sedimenti francamente marini della Formazione delle Argille Azzurre (Zancleano). Il limite tra i sedimenti di Lago-Mare e le Argille Azzurre è caratterizzato da una superficie erosionale sigillata da un livello arenitico nero, ricco in materia organica e potente da 10 a 50 cm. Il tetto di questo livello corrisponde ad una superficie di omissione, caratterizzata da un reticolato di gallerie da firm-ground, riempite dai sedimenti soprastanti. L'associazione ad ostracodi riconosciuta nei sedimenti sottostanti il livello nero è riferibile alla biozona a *Loxocorniculina djafarovi* (intervallo post-evaporitico 2 del Messiniano superiore). Questa associazione indica condizioni di acque basse oligo-mesosaline e risulta caratterizzata dalla presenza di faune tipiche della Paratetide. I foraminiferi ed i nannofossili calcarei rinvenuti in questo intervallo sono invece da considerarsi rimaneggiati. Le microfaune e i nannofossili calcarei riconosciuti nei sedimenti sovrastanti il livello nero sono riferibili alla biozona a foraminiferi MPI1 e alla biozona MNN12 a nannofossili calcarei. L'assenza del primo picco di *Neoglobobulimina acostaensis* ad avvolgimento sinistrorso e l'assenza di *Trifarina angulosa* nei primi campioni di età pliocenica della successione indicano un breve hiatus, confermato dalla presenza di una superficie di omissione al tetto del livello nero. Il riconoscimento dei marker zonali dello Zancleano ha inoltre permesso l'identificazione delle biozone MPI2, MPI3 and MPI4a a foraminiferi planctonici e delle biozone MNN13 e MNN14-15 a nannofossili calcarei. Queste biozone, rappresentate da spessori ridotti di sedimenti, sembrano tuttavia solo parzialmente documentate. La presenza di *Agrenocythere pliocenica* nella parte bassa della biozona MPI2 conferma l'importanza biostratigrafica di questo taxon alla scala del bacino Mediterraneo. I dati paleoecologici relativi alle associazioni a foraminiferi ed ostracodi riconosciute nei sedimenti della biozona MPI1 indicano un ambiente di deposizione epibatiale superiore. Con il passaggio alla biozona MPI2 si assiste ad un ulteriore approfondimento, a cui segue una progressiva riduzione della profondità, testimoniata dalle associazioni riferibili alle biozone MPI3 e MPI4a. Complessivamente i dati ricavati indicano che, anche nel bacino Terziario Piemontese, la rapida trasgressione marina che ha seguito la crisi di salinità messiniana è avvenuta nello Zancleano basale.

INTRODUCTION

The Miocene/Pliocene boundary in the Mediterranean region is a long debated topic, involving many multidisciplinary research groups (e.g. Hsü et al., 1973; Cita, 1975a; Cita et al., 1978; Suc et al., 1997; Iaccarino et al., 1999a, b; Bassetti et al., 2006; Pierre et al., 2006; Cosentino et al., 2007; Popescu et al., 2007; Rouchy et al., 2007; Carnevale et al., 2008).

In the last thirty years the knowledge on this boundary has improved, thanks to a wealth of bio- and lithostratigraphic data on both marine and land sections that show the abrupt refilling of the Mediterranean basin by marine waters in the Early Zanclean, after the end of the Messinian salinity crisis.

In the Tertiary Piedmont Basin (TPB, Fig. 1), the Miocene/Pliocene boundary has been briefly described in the Narzole core (Sturani, 1976), but detailed microbiostratigraphic data are still lacking. Recent works devoted to the study of the Messinian sediments in the TPB (Dela Pierre et al., 2002, 2003, 2007; Irace, 2004; Irace et al., 2005) allowed the first recognition of the boundary in the Moncucco quarry, located in the southern flank of the Torino Hill.

In this paper new integrated biostratigraphic and palaeoecological data from the upper Messinian to Zanclean succession exposed in the Moncucco quarry are reported. The foraminifer, ostracod and calcareous

nannofossil assemblages have been studied in detail and biostratigraphic events have been recognized, allowing the comparison with previously studied Mediterranean successions (Ciampo, 1992; Di Stefano et al., 1996; Sgarrella et al., 1997; Barra et al., 1998; Iaccarino et al., 1999b, among others) and the Zanclean micropalaeontological record is discussed.

REGIONAL GEOLOGICAL SETTING

The Torino Hill, located in the northern part of the TPB (Fig. 1), corresponds to a SW-NE striking anticline fold separated by the adjoining Monferrato domain by the Rio Freddo deformation zone, a regional NW-SE transpressional fault zone interpreted as the surface expression of a deep-seated steep shear zone (Piana & Polino, 1995; Piana, 2000). Both the Monferrato and the Torino Hill are overthrust to the north onto the Po Plain foredeep, along the late Neogene to Quaternary Padane thrust fronts, presently buried below the Quaternary Po Plain deposits (Dalla et al., 1992; Castellarin, 1994; Falletti et al., 1995).

The stratigraphic succession of the Torino Hill unconformably overlies a metamorphic basement buried at a depth of 2-3 km (Biella et al., 1997), interpreted recently as the South Alpine basement (Mosca, 2006). It consists of Upper Eocene to Tortonian deep-water

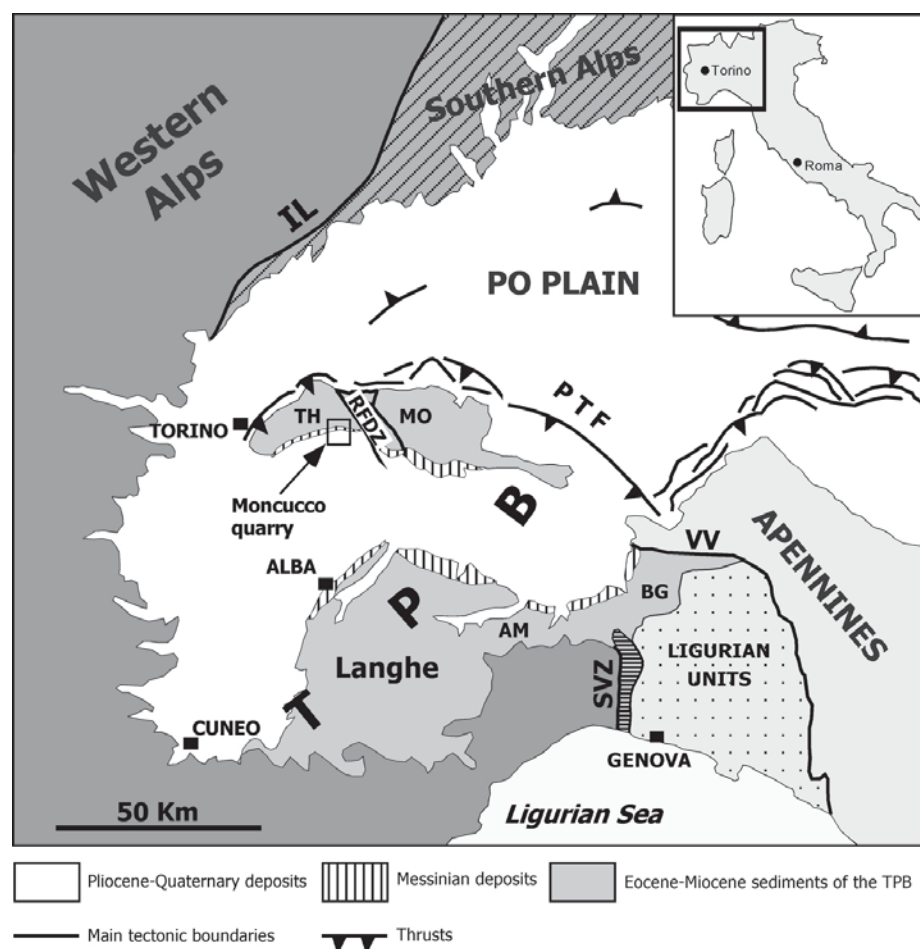


Fig.1 - Structural sketch of North-Western Italy (Modified from Bigi et al., 1990). IL = Insubric Line; TH = Turin Hill; RFDZ = Rio Freddo Deformation Zone; MO = Monferrato; PTF = Padane Thrust Fronts; TPB = Tertiary Piedmont Basin; AM = Alto Monferrato; BG = Borbera Grue Zone; SVZ = Sestri-Voltaggio Zone; VVL = Villalvernia-Varzi Line.

deposits, composed of alternating hemipelagic marls and arenaceous to conglomeratic resedimented beds (Dela Pierre et al., 2003).

The Messinian interval is composed of deep-water alternating planktonic foraminifer-rich hemipelagic marls and finely laminated organic rich mudstones (Marne di Sant'Agata Fossili, Lower Messinian), overlaid by remnants of shallow water primary evaporites, consisting of an alternation of decimetre-thick black mudstone beds and selenitic gypsum tabular bodies 10-30 m thick. Following the recommendations of APAT (Agenzia per la Protezione dell'Ambiente e per Servizi Tecnici), this evaporitic succession has been mapped as Vena del Gesso Formation (*sensu* Roveri & Manzi, 2007) in the new "Torino Est" sheet of the Geological Map of Italy at the scale 1:50,000. In the Moncucco quarry, the Vena del Gesso Formation is followed by post-evaporitic chaotic deposits (Valle Versa Chaotic Complex) and by continental and brackish-water sediments (Marne a Congeria, Irace, 2004; Dela Pierre et al., 2007), correlatable to the *Lago-Mare* deposits of the Mediterranean area (Fig. 2). The succession of the Torino Hill ends with the deep- to shallow-water marine sediments of the Argille Azzurre Fm. and Sabbie di Asti Fm. (Zanclean, Lower Pliocene), which are in turn followed by "Villafranchian" transitional to continental deposits of Middle Pliocene-Pleistocene age.

THE MIOCENE/PLIOCENE BOUNDARY IN THE MONCUCCO QUARRY

In this quarry, most of the Messinian sediments are characterized by a chaotic setting resulting from the interaction of tectonic, sedimentary and diapiric processes. They make up a composite chaotic unit that is unconformably overlaid by post-chaotic sediments (Dela Pierre et al., 2007).

The post-chaotic sediments, object of this paper, consist of upper Messinian post-evaporitic deposits and Zanclean deep-water marine sediments (Argille Azzurre Fm.). Here, the Miocene/Pliocene boundary has been observed (Figs. 2-3).

The upper Messinian *Lago-Mare* sediments reach a thickness of 6.5 m, and consist of beige clayey marls (about 5 m thick) with rare intercalations of brown mudstone beds interpreted as palaeosoils (Irace, 2004). These sediments grade upwards into green to blue marls (maximum thickness: 1.5 m) with scattered root traces and, in the uppermost part, firm ground burrows filled with the overlying black arenitic deposits. The *Lago-Mare* sediments contain rare brackish-water molluscs (*Dreissena* sp., *Limnocardium* sp., *Melanopsis* sp., and *Melanoides* sp.).

The boundary between the Messinian *Lago-Mare* and the Zanclean Argille Azzurre Fm. is marked by an

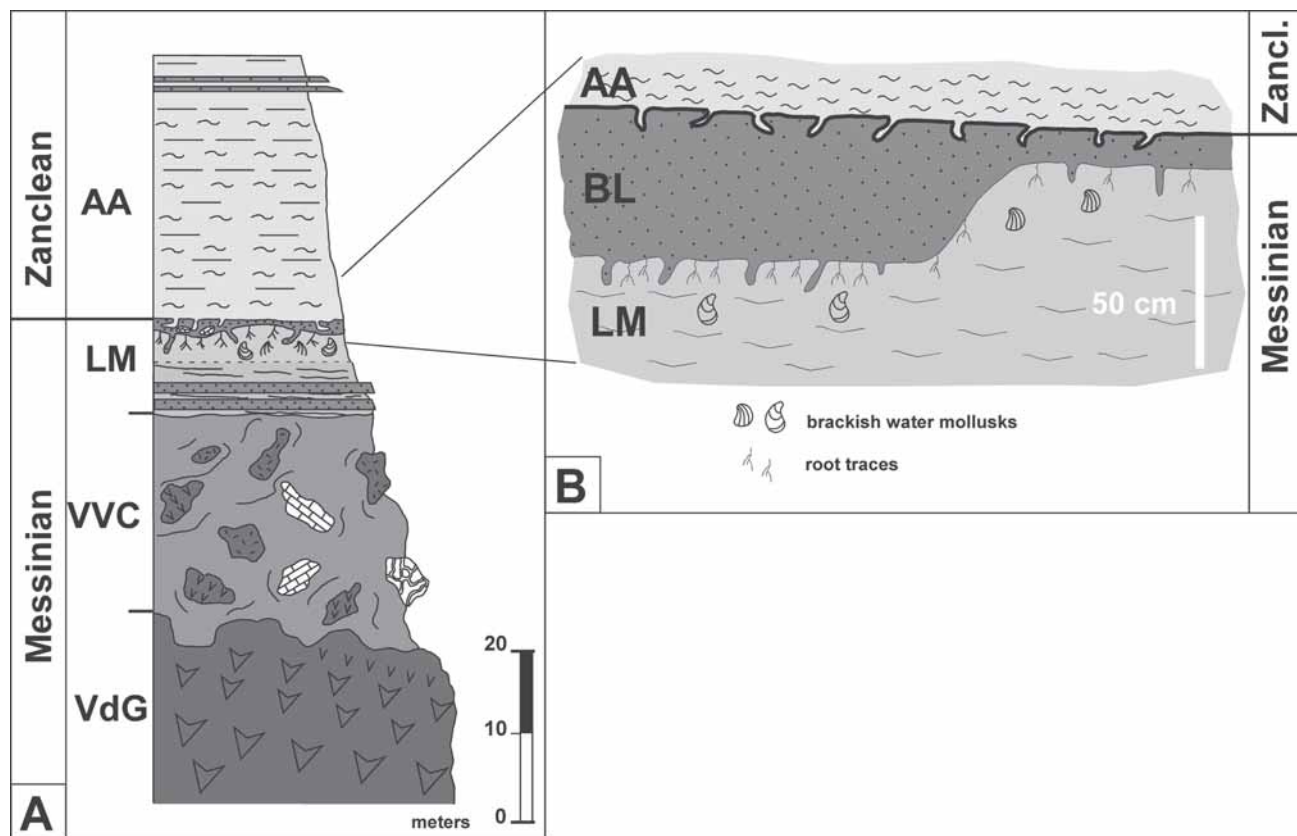


Fig. 2 - A) Stratigraphic section of the Moncucco quarry; B) Detail of the Miocene/Pliocene boundary. VdG = Vena del Gesso Formation; VVC = Valle Versa Chaotic Complex; LM = *Lago Mare* deposits (Marne a Congeria); BL = black arenitic layer; AA = Argille Azzurre Formation (modified from Irace, 2004).

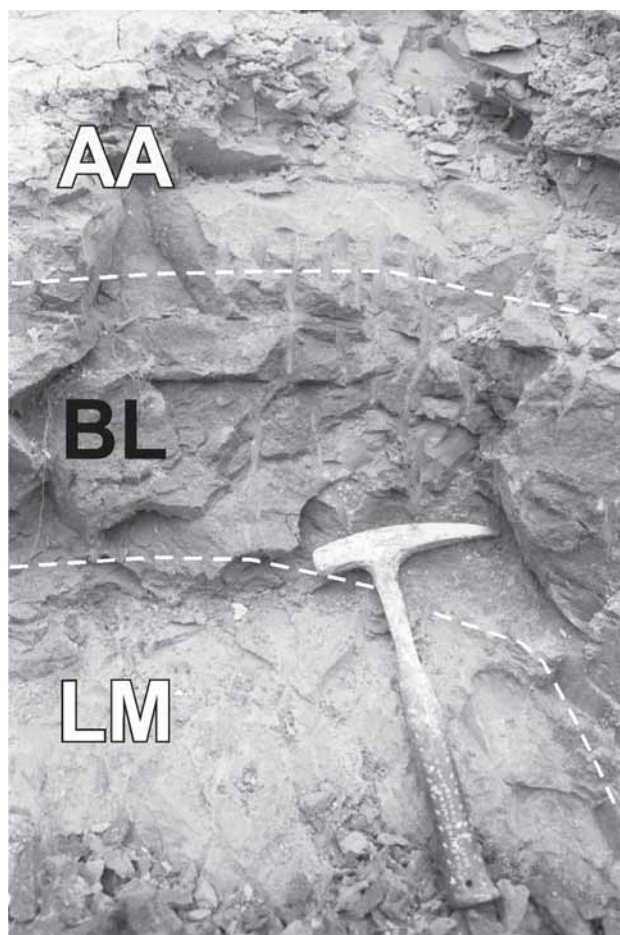


Fig. 3 - The Miocene-Pliocene boundary in the Moncucco quarry. LM = *Lago Mare* deposits (Marne a *Congerina*); BL = black arenitic layer; AA = Argille Azzurre Formation (modified from Irace, 2004).

irregular (erosional) surface that is overlain by a 10-50 cm-thick black arenitic layer very rich in organic matter (Figs. 2-3). This layer is mainly composed of terrigenous grains (quartz, mica flakes, fragments of metamorphic rocks), subordinated intrabasinal grains (glaucony and phosphates) and disarticulated valves of both brackish-water and continental bivalves; this black layer is barren of microfossils. The top of the bed corresponds to an omission surface (*sensu* Bromley, 1990), evidenced by a network of firm-ground burrows filled by the sediments of the overlying Argille Azzurre Fm. This unit consists of a monotonous succession, about 26 m thick, of grey- to light-coloured planktonic foraminifer-rich marly clays; in the upper part biocalcarene layers 0.50 m thick are interbedded.

MATERIALS AND METHODS

An about 28 m-thick stratigraphic section, comprising the uppermost 1.5 m of the *Lago-Mare* sediments, the black layer and the Argille Azzurre Fm., has been measured and sampled at a mean distance of 50 cm (Fig. 4). A total of 56 samples have been collected after an accurate cleaning of the outcrop weathered surface. Three

samples (sample 1 to 3) have been collected from the uppermost 1.5 m of the *Lago-Mare* deposits, one sample (sample 0) was taken from the black layer and 52 samples, numbered from sample 4 to sample 54, with an additional sample 50a just below the lower calcarenitic layer, have been collected in the Argille Azzurre Fm.

For foraminifer and ostracod analyses 100-150 g of sediment were dried in an oven at 50°C, disaggregated and gently washed on a set of 250 µm, 125 µm, and 63 µm sieves. Residues >250 µm, 125-250 µm, and 125-63 µm were dried at 50°C and weighed. Foraminifer species were identified on the three grain size fractions to describe the assemblage composition and to identify the biostratigraphic markers (Kennett & Srinivasan, 1983; Iaccarino, 1985; Hemleben et al., 1989 for the identification of planktonic species; Agip, 1982; Van Morkhoven et al., 1986 for benthic species). The biostratigraphic scheme here adopted is that of Cita (1975a), emended by Sprovieri (1992).

Foraminifer quantitative analyses were carried out on total residues >125 µm of the Pliocene succession. Residues were split into aliquots containing at least 300 well-preserved specimens. The P/(P+B) ratio, proposed by Wright (1978) as a useful index of palaeodepth, was calculated.

The picking of ostracods contained in all the washed residue of each sample has been carried out in the size fractions >125 µm; the species have been identified and counted following the Normalized Method (Mana & Trenkwaller, 2007); all valves have been counted, and then the number of minimum certain individuals has been calculated as the sum of complete carapaces plus the highest number of valves (left or right); juvenile forms have not been counted but their presence has been pointed out. Qualitative analyses of the 63-125 µm fraction are in progress in order to find particularly useful small species (Bonaduce et al., 1994). For each sample the number of species and the number of minimum certain individuals have been calculated.

Calcareous nannofossil analyses were based on light microscope observation of smear slides prepared according to standard methods and studied under polarized light (transmitted light and crossed nicols) at 1250x magnification. Abundance data of nannofossil taxa are based on counting of five hundreds specimens per sample; helicoliths were counted among 50 specimens of the group; discoasterids 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 Rio et al. (1990) and Raffi et al. (2003). The biostratigraphic scheme here adopted is that of Rio et al. (1990) for the Mediterranean region.

RESULTS

Residues grain size and composition

Percentages of the three grain size fractions (>250 µm, 125-250 µm, and 125-63 µm) are rather high in the lowermost samples 1-4, in particular the coarse fraction (>250 µm) is abundant within the samples 3 (*Lago Mare* sediments) and 0 (black layer). Upwards, total residues >63 µm reach very low percentages, except in sample 40

and in the top samples (52-54), in which the $>250\ \mu\text{m}$ fraction is again abundant (Fig. 4). The coarse grain size fraction is common also in samples 11-14, whereas the mean and fine fractions constitute most of the other residues.

Samples 1 and 2, respectively 1.5 e 1 m below the black layer, are rich in biogenic content, mainly given by planktonic foraminifers. On the contrary, terrigenous content (quartz grains, green rock debris) is dominant within sample 3 (0.3 m below the black layer) that yields few mollusc fragments, but is barren of microfossils. Terrigenous components, as well as macrofossil and vegetal debris, are scarce within most of the overlying residues up to sample 39 and increase in abundance upwards. Glaucony is common in sample 40 and is present also in most of the samples above sample 49.

Foraminifers

Lago-Mare assemblages

Samples 1 and 2 contain abundant but poorly-preserved planktonic specimens, mainly represented by Miocene to Pliocene taxa (*Globigerina bulloides*, *Globigerinella obesa*, *Globigerinoides trilobus*, *G. obliquus*, *Globorotalia* gr. *scitula*, *Orbulina universa*, dominantly sinistral *Neogloboquadrina acostaensis*, and

Turborotalita quinqueloba). Some Messinian species, as *Globorotalia nicolae*, *G. praemargaritae*, and *G. suterae* and the benthic *Bolivina tectiformis* are also present. Sample 3 (0.3 m below the black layer) and sample 0 (black layer) are barren of foraminifers.

Argille Azzurre Fm. assemblages

Assemblages of the overlying Argille Azzurre Fm. (samples 4-54) are rich and generally well preserved, with the exception of two calcarenitic beds near the top of the section (samples 51 and 53), in which the quantitative study is hampered by the poor tests preservation.

The P/(P+B) ratio displays very high values, uniformly about 80%, within the lowermost samples 4-8 (Fig. 4). Upwards, through some short and small oscillations, planktonic specimens remain dominant in the foraminiferal assemblages up to sample 40. Stronger changes and a general decrease of the P/(P+B) ratio characterize the upper part of the succession.

A total of 226 benthic species has been recovered in the counted assemblages. In most of the succession, common to frequent taxa are *Cibicidoides pseudoungerianus*, *Sphaeroidina bulloides*, *Uvigerina peregrina*, *Bulimina* spp. (mainly *B. minima*), *Bolivina* spp., followed by *Globocassidulina subglobosa*, *Gyroidinoides* spp., *Planulina ariminensis*, *Siphonina*

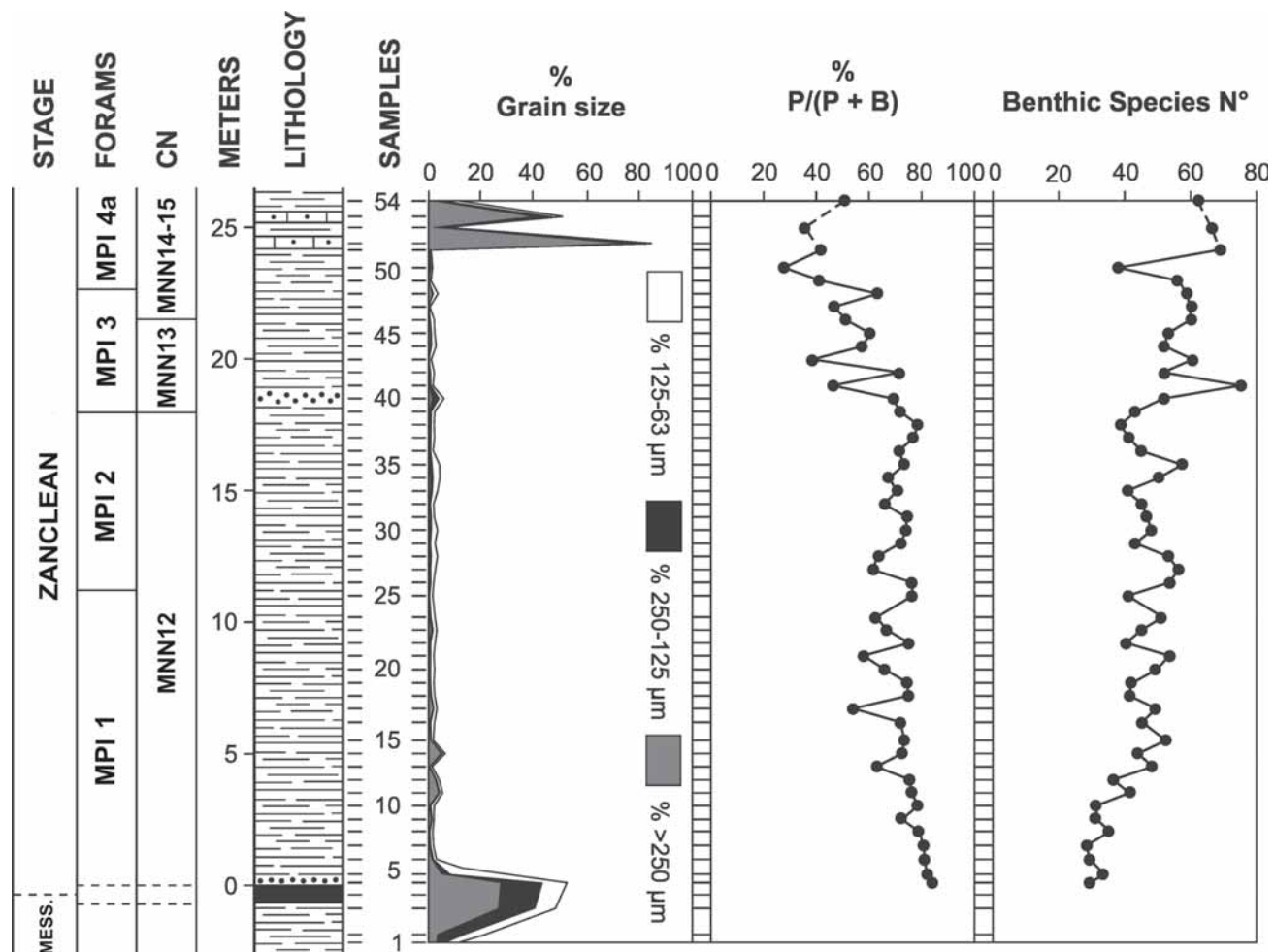


Fig. 4 - Foraminifers (FORAMS) and calcareous nannofossils (CN) biozones, percentage variations of the grain size fractions and of the P/(P+B) ratio, number of foraminiferal benthic species in the Moncucco upper Messinian/Zanclean succession.

reticulata and *Uvigerina rutila*. Benthic diversity, expressed as the species number, is low within the samples 4-10 (30-35 species), but progressively increases from sample 11 upwards (Fig. 4), reaching its maximum (75 species) in sample 41.

Planktonic assemblages of the lowermost Pliocene samples (4 and 5) yield common specimens of *Globoturbotalita apertura*, *Gt. decoraperta*, *Globigerina bulloides*, *G. falconensis*, *Globigerinella obesa*, *Globigerinita glutinata*, *Globigerinoides extremus*, *G. obliquus*, dominantly dextral *Neogloboquadrina acostaensis*, *Orbulina suturalis*, *O. universa*, and *Turbotalita quinqueloba*. The latter species is strongly dominant in the sample 4 finer fraction (qualitatively analyzed); *Turbotalita quinqueloba* is abundant also in the following residues, where small and juvenile tests of *Globigerina* spp., *Globigerinita glutinata*, *Globigerinoides* spp. and *Globorotalia scitula* become progressively well represented.

Among the less common but biostratigraphically diagnostic taxa, *Sphaeroidinellopsis* spp. have been recognized in sample 6 (1 m above the black layer). Their tests are more common in samples 7 and 8 and are present up to sample 11; above this sample the taxon disappears (Fig. 5). Specimens are small and their specific attribution (*S. seminulina*, *S. subdehiscens*) could be misleading. Rare specimens of *Globorotalia margaritae* randomly occur from sample 14 upwards (Fig. 5). The taxon becomes more common from sample 24 (1.24%), reaching its highest abundance from sample 26 (2.93%) to 35 (1.49%) and occurs up to sample 48. *Globorotalia*

puncticulata has been recovered from sample 40 and becomes common to frequent upwards.

Globigerinoides spp. (dominant *G. extremus* and *G. obliquus*, common to rare *G. gomitulus*, *G. ruber*, *G. sacculifer*, and *G. trilobus*) is the dominant taxon in most of the succession and shows strong frequency changes (Fig. 5). It is common in the lowermost samples (4-7, about 20%), shows a decrease in abundance in samples 8-11, is very frequent and has strong percentage variations up to sample 24 (maximum in sample 19: 45.07%). It is abundant within samples 25-33 (about 30-35%) and fastly decreases to values ranging between 10 and 20% within most of the uppermost samples.

Neogloboquadrina acostaensis is almost totally dextral coiling; rather common sinistral-coiled specimens have been detected only in sample 4. The taxon is common to frequent within the lowermost assemblages, strongly decreases in abundance between samples 10 and 12 and shows two frequency peaks in samples 13 (26.84%) and 15 (26.43%) (Fig. 5). Upwards, it is scarce or rare in samples 18-30, displays strong frequency variations in the upper succession and remains common also in the uppermost samples.

Globorotalia scitula is very rare in the lowermost samples and becomes common in samples 8-15 (Fig. 5). It is rare in most of the following succession, reaching percentages ranging from 2% to about 7% only in the interval of samples 30-40.

Globigerina nepenthes is very rare and has been detected in the counted assemblages up to sample 32 (Fig. 5). Its frequency peak occurs within the lowermost

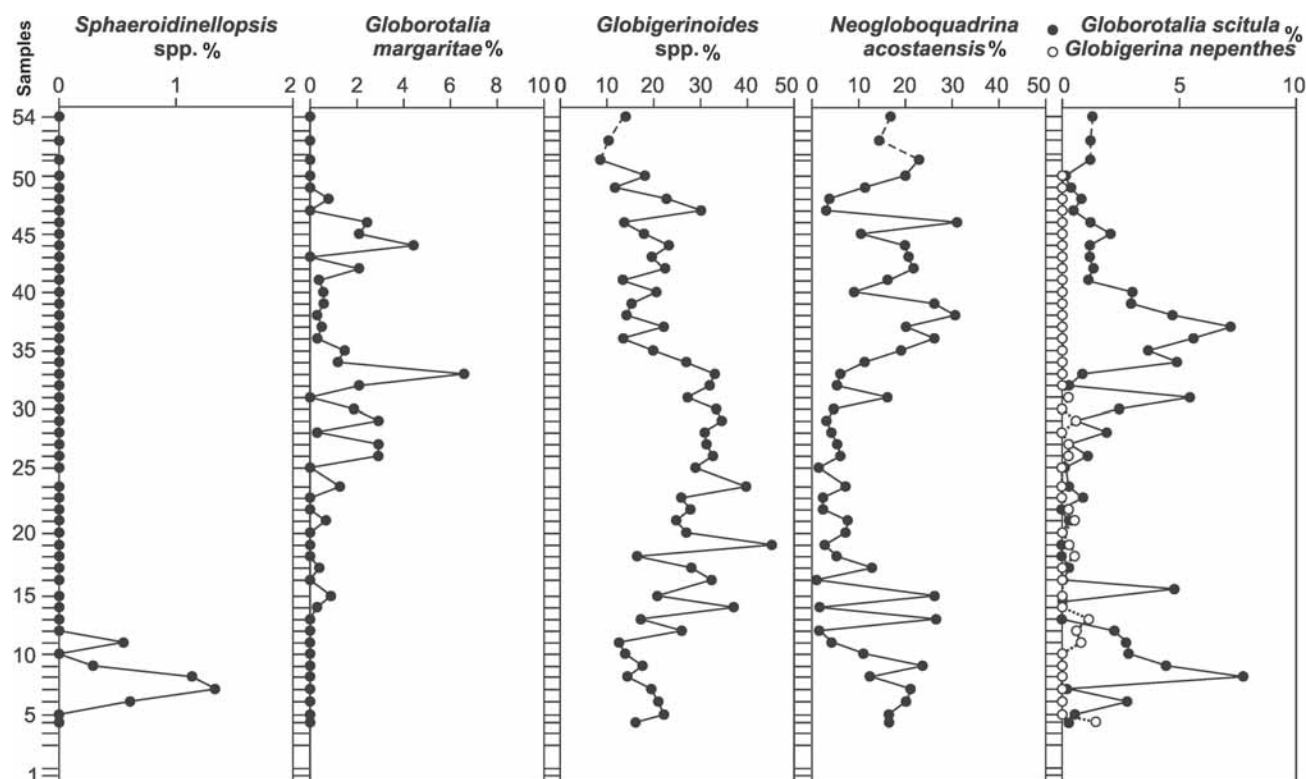


Fig. 5 - Percentage variations of planktonic foraminiferal taxa (*Sphaeroidinellopsis* spp., *Globorotalia margaritae*, *Globigerinoides* spp., *Neogloboquadrina acostaensis*, *Globorotalia scitula*, and *Globigerina nepenthes*) in the Moncucco upper Messinian/Zanclean succession.

sample 4 (1.46%); the species is still rather well represented in the interval between samples 12-14.

Benthic foraminiferal assemblages of the lowermost samples differ from the following ones for the composition and the lower abundances and diversity. In particular, sample 4 yields abundant *Hoeglundina elegans* (21.74%) and *Sphaeroidina bulloides* (16.30%) specimens (Fig. 6). *Amphicoryna semicostata*, *Bulimina minima*, *Cibicidoides pseudoungerianus*, *Gyroidinoides neosoldanii*, *Sigmoilopsis schlumbergeri*, each of them accounting for 4-5% of the benthic assemblage and *Uvigerina peregrina* (2%) (Fig. 6), *Bolivina leonardii* and *Gavelinopsis praegeri* are also common. Benthic taxa of the finer fraction 63-125 µm (qualitative analysis) are almost totally represented by *Eponides pusillus*, *E. tumidulus*, *Gavelinopsis praegeri*, and small bolivinids.

In the overlying levels *Bolivina* spp., *Bulimina minima*, *Cibicidoides pseudoungerianus*, *Planulina ariminensis*, and *Uvigerina peregrina* become more common or frequent and many other species occur in the benthic assemblage: *Anomalinoides helcinus*, *Bolivina usensis*, *Globocassidulina subglobosa*, *Heterolepa dertonensis*, *Martinottiella perparva*, *Melonis padanum*, *Pullenia bulloides*, and *Uvigerina pygmaea* have been detected from sample 5 upwards. *Cassidulina carinata*, *Uvigerina rutila* (from sample 6 upwards), *Bulimina aculeata*, *Oridorsalis umbonatus*, *Eggerella bradyi*, *Cibicidoides kullenbergi*, *Uvigerina longistriata*, *Bigenerina nodosaria*, *Cylindroclavulina rudis*, *Siphonina reticulata* (from sample 11 upwards) (Fig. 6), *C. robertsonianus* (from sample 12 upwards)

(Fig. 6) progressively occur. On the contrary, some species, dominant to common in the lowermost part of the Pliocene succession, nearly disappear (*Hoeglundina elegans*) or strongly decrease (*Amphicoryna semicostata*, *Gavelinopsis praegeri*, *Sigmoilopsis schlumbergeri*, and *Sphaeroidina bulloides*). *Uvigerina peregrina* is the most common taxon in many samples of the interval between samples 17-41 and is dominant in sample 47. Assemblages become more diversified also in the finer residues, matching the composition of >125 µm residues.

In the uppermost part of the succession, most of the previous species decrease in abundance (*B. minima*, *C. pseudoungerianus*, *Planulina ariminensis*, and *U. peregrina*) or disappear (*C. robertsonianus*, *Cibicidoides kullenbergi*, *Martinottiella perparva*, *Siphonina reticulata*, *Uvigerina longistriata*, and *Uvigerina rutila*). Instead, *Brizalina* spp. (mainly *B. spatulata*) and shallow water taxa (*Ammonia beccarii*, *Cibicides lobatulus*, *Elphidium* spp., *Neoconorbina terquemi*, *Rosalina* spp. etc.) increase in abundance from sample 49 upwards and reach their maxima in the uppermost samples.

Ostracods

A total of 95 ostracod species belonging to 56 genera has been identified in the counted assemblages.

Lago-Mare assemblages

Sample 1 yields a typical fresh-brackish water ostracod assemblage, mostly represented by *Amnicythère costata*, *A. subcaspia*, *A. propinqua*, *A. sp. A*,

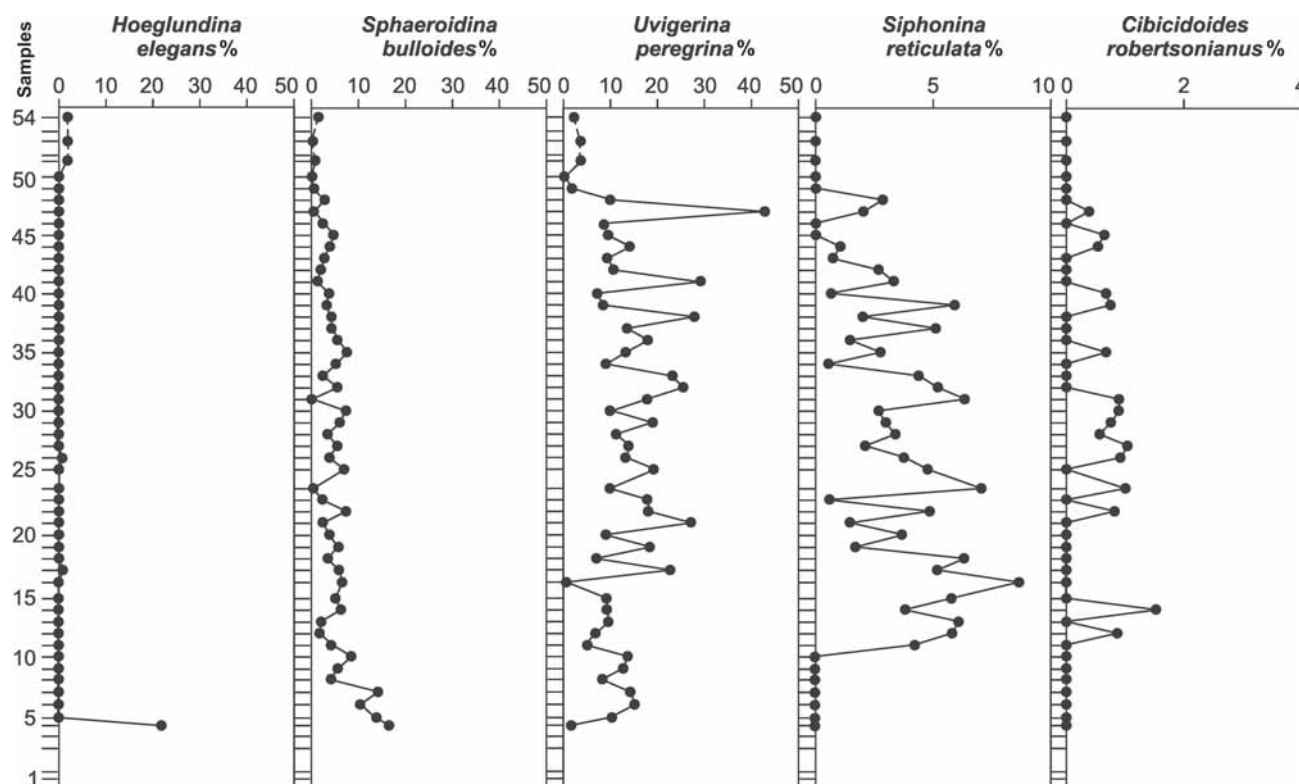


Fig. 6 - Percentage variations of benthic foraminiferal species (*Hoeglundina elegans*, *Sphaeroidina bulloides*, *Uvigerina peregrina*, *Siphonina reticulata*, and *Cibicidoides robertsonianus*) in the Moncucco upper Messinian/Zanclean succession.

Camptocypria sp. 1, *Cyprideis agrigentina*, *C. anlavauxensis*, *Loxocauda limata*, *Loxoconcha eichwaldi*, *L. muelleri*, *Loxocorniculina djafari*, and *Tyrrenocythere ruggierii*. Sample 2 contains only one valve of *Cyprideis agrigentina*, while sample 3 is barren of ostracods.

Argille Azzurre Fm. assemblages

Assemblages of the overlying succession (samples 4-54) are rich and generally well preserved, with the exception of two biocalcarene layers near the top of the section (samples 51 and 53), in which the poor preservation of the tests prevents the quantitative study.

The main taxa identified in Pliocene sediments are: *Argilloecia acuminata*, *A. kissamovens*, *Cytherella gibba*, *C. russoi*, *C. vulgatella*, *Henryhowella asperima*, *Krithe compressa*, *K. iniqua*, *K. pernoides*, *Paijenborchella iocosa*, *P. malaiensis cymbula*, *Parakrithe dimorpha*, and *P. rotundata*.

The number of species throughout the succession (Fig. 7) is relatively low (less or equal than 16 per sample), except for samples 16, 35, and 40 (in which 18 to 26 species per sample have been found) and samples 52 and 54 (that record an anomalous peak, with 38 and 49 species per sample). The diagram representing the number of minimum certain individuals (Fig. 7) shows almost the same trend as that of the number of species, with the exception of sample 5, where the number of minimum certain individuals and the number of species are in opposition. Samples 52 and 54 show a similar, but amplified trend, with peaks of 246 and 443 specimens

per sample. The first appearance of the most important species in the section is represented in Fig. 8. In particular, *Kunihirella eracleaensis* firstly occurs in sample 4, *Henryhowella asperima* from sample 8, *Oblitacythereis mediterranea* from sample 16 and *Agrenocythere pliocenica* from sample 28 (Fig. 8).

Calcareous nannofossils

Preservation and abundance of the assemblage is generally good, except for the lowermost samples (1-3).

Lago-Mare assemblages

In the samples from the topmost *Lago-Mare* deposits, calcareous nannofossil (CN) assemblage consists mainly of reworked and poorly preserved Oligocene and Lower and Middle Miocene taxa (*Dictyococcites bisectus*, *Helicosphaera euphratis*, *H. walbersdorfensis*, *Sphenolithus heteromorphus*, *Coccolithus miopelagicus* among others). Sample 3, just below the black layer, contain rare CN specimens, consisting mainly of dwarf placoliths (*Helicosphaera carteri*, *Coccolithus pelagicus*, *Dictyococcites* sp.).

Argille Azzurre Fm. assemblages

Above the black layer, in sample 4, rare specimens of *Ceratholithus acutus* have been recorded, whereas no specimens of *Triquetrorhabdulus rugosus*, usually recorded at the very base of the Zanclean (Di Stefano, 1998; Castradori, 1998), have been found. Upwards in the section, the CN assemblage is very diversified and dominated by reticulofenestrids, together with helicoliths (mainly *Helicosphaera carteri*). Minor components of

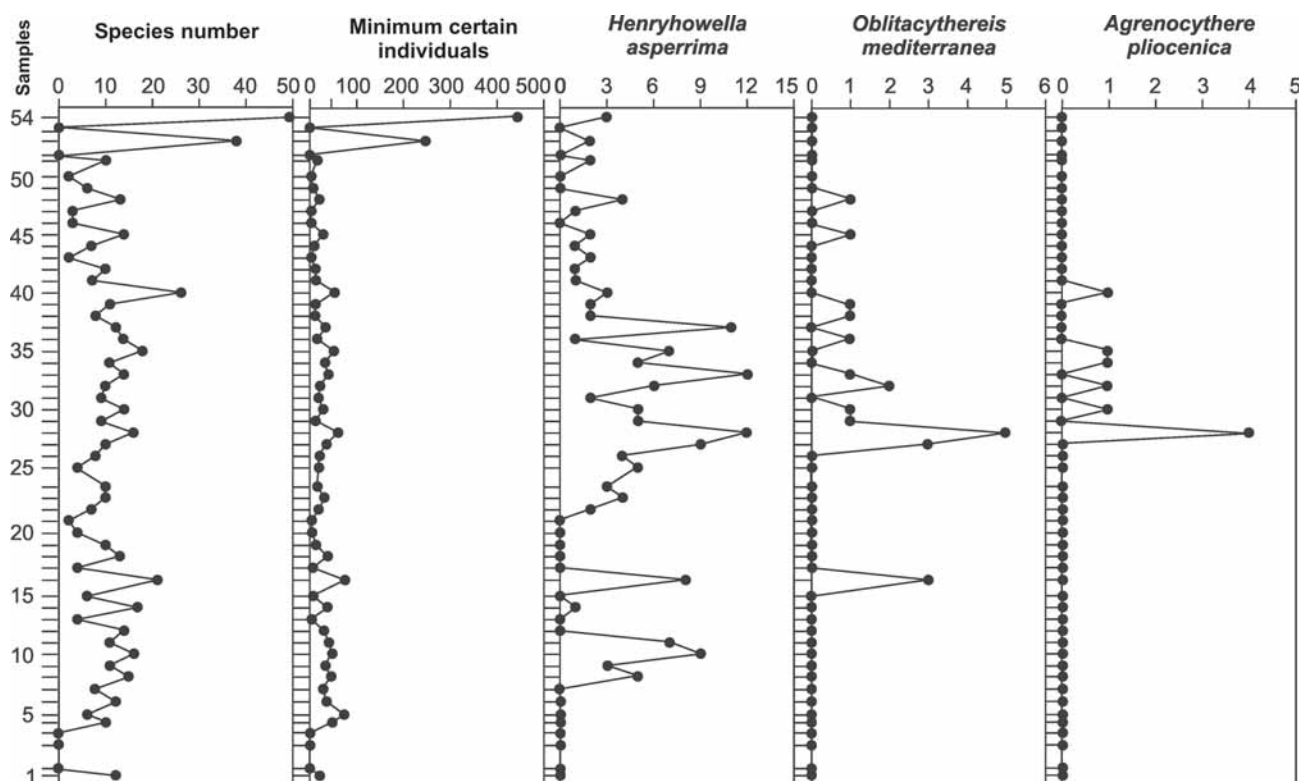


Fig. 7 - Number of ostracod species, number of minimum certain ostracod adult individuals and number of minimum certain ostracod adult taxa (*Henryhowella asperima*, *Oblitacythereis mediterranea*, and *Agrenocythere pliocenica*) in the Moncucco upper Messinian/Zanclean succession.

Species	First Finding samples
<i>Acantocythereis histrix</i>	29
<i>Agrenocythere pliocenica</i>	28
<i>Paijenborchella malaiensis cymbula</i>	24
<i>Oblitacythereis mediterranea</i>	16
<i>Parakrithe rotundata</i>	12
<i>Parakrithe arimensis</i>	11
<i>Krithe pernoides</i>	11
<i>Henryhowella asperrima</i>	8
<i>Cytherella vulgatella</i>	8
<i>Cytherella gibba</i>	8
<i>Parakrithe dimorpha</i>	6
<i>Occultocythereis culter</i>	6
<i>Cytherella russoi</i>	6
<i>Paijenborchella iocosa</i>	4
<i>Kunihirella eracleaensis</i>	4
<i>Krithe iniqua</i>	4
<i>Krithe compressa</i>	4
<i>Argilloecia kissamovens</i>	4
<i>Argilloecia acuminata</i>	4

Fig. 8 - First findings of the most important ostracod species in the Moncucco upper Messinian/Zanclean succession.

the assemblage are discoasterids, usually very rare in Mediterranean Pliocene samples, together with ceratoliths (*Amaurolithus primus*, *A. delicatus*). *Braarudosphaera bigelowi*, usually very rare or absent, is locally common in discrete layers. *Helicosphaera sellii* has been firstly recorded in sample 39 and *Discoaster asymmetricus* has been detected from sample 46 upwards. Moreover, *Amaurolithus* spp. and *Discoaster tamalis* have been recorded respectively from sample 47 and 49 upwards.

The studied samples are characterized by reworking of older specimens; the reworking is easily distinguished and increases towards the top of the section, particularly from sample 49. Among the reworked specimens marker species as old as Early Cretaceous have been found (*Cruciellipsis cuvillieri*, *Nannoconus steinmannii*).

DISCUSSION

The biostratigraphic events and changes in the assemblage composition recognized in the Moncucco section are well correlatable with those described in many Mediterranean sites where the Miocene/Pliocene boundary is preserved as the Capo Rossello area and bore-hole (Sprovieri, 1978, 1993; Di Stefano et al., 1996; Sgarrella et al., 1997, 1999; Barra et al., 1998), the Mediterranean Sea (Cita, 1973, 1975a, b; Sprovieri & Hasegawa, 1990; Hasegawa et al., 1990; Spezzaferri et al., 1998; Iaccarino et al., 1999b) and its margins (Pierre et al., 2006; Rouchy et al., 2007).

Biostratigraphy and ecobiostratigraphy

Sediments underlying the black layer, referred to the *Lago-Mare* deposits (Bicchi et al., 2002; Irace, 2004),

yield foraminiferal assemblages that can be unambiguously interpreted as reworked from Messinian pre-evaporitic deposits, based on the presence of rather common specimens of *Globorotalia nicolae*, whose stratigraphic distribution ranges between 6.82-6.72 My (Hilgen et al., 1995). Moreover, benthic Miocene taxa (*Bolivina tectiformis*) are present and no typical Pliocene species has been recovered. These data and interpretation are in agreement with those of many other authors (Ryan et al., 1973; Cita et al., 1978; Spezzaferri et al., 1998; Iaccarino et al., 1999a, b; Pierre et al., 2006; Rouchy et al., 2007; Grossi et al., 2008).

In the same deposits, the ostracod assemblage is dominated by taxa that are common in upper Messinian deposits of several Mediterranean sections (Cita et al., 1980; Bonaduce & Sgarrella, 1999; Cipollari et al., 1999; Gliozzi, 1999; Iaccarino & Bossio, 1999; Cosentino et al., 2006; Bassetti et al., 2006, among others). The recovering of *Loxocorniculina djafarovi* and the presence of Paratethyan species that entered the Mediterranean during the late Messinian "*Lago-Mare*" event, such as *Amnicythere costata* and *A. subcaspia*, allow to refer this sample to the *Loxocorniculina djafarovi* biozone (upper post-evaporitic, late Messinian interval) as defined by Carbonnel (1978), that 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).

In the Argille Azzurre Fm., the acme of *Sphaeroidinellopsis* spp. extends between sample 6 and 11 (base of the *Sphaeroidinellopsis* acme, 5.29 My, Di Stefano et al., 1996; Iaccarino et al., 1999b), above which the taxon never occurs (top *Sphaeroidinellopsis* acme, 5.17 My, Di Stefano et al., 1996; 5.20 My, Iaccarino et al., 1999a, b). The absence of the biozonal marker in the lowermost part of early Pliocene sediments is a common feature, frequently observed in the Mediterranean basins and margins (Cita, 1973, 1975b; Ryan et al., 1973; Di Stefano et al., 1996; Iaccarino et al., 1999b; Pierre et al., 2006; Rouchy et al., 2007 among others).

The interval above the black layer up to sample 26, where the FCO of *Globorotalia margaritae* (5.07 My, Iaccarino et al., 1999b; 5.08 My, Gradstein et al., 2004) has been recorded, is about 11.50 m thick and has been ascribed to the MP11 biozone (Fig. 4), previously recognized by Bicchi et al. (2002). *G. margaritae* randomly occurs from sample 14, but reaches percentages higher than 1% in sample 24 and more uniform values greater than 2% from sample 26.

The basal sample of the Pliocene succession (sample 4) is characterized by an abundance peak of *Globigerina nepenthes*, as reported also in the Western Mediterranean basins (Iaccarino et al., 1999b) as well as in Southern Italy (Zachariasse & Spaak, 1983). Moreover, very abundant small planktonic foraminifers occur within the 63-125 µm fraction (out of countings), almost totally represented by *Turborotalita quinqueloba*. A similar assemblage, with large- and dwarf-sized specimens, has been described in the lowermost Zanclean of the Eastern Mediterranean basin (Spezzaferri et al., 1998). Also the

presence in sample 4 of *Kunihirella eracleaensis*, described from the lowermost Pliocene Trubi Formation of Eraclea Minoa (Bonaduce et al., 1994; Sgarrella et al., 1997; Barra et al., 1998) supports the correlation to the MP11 foraminiferal biozone. At Moncucco *Henryhowella asperrima* and *Oblitacythereis mediterranea* firstly occur in the MP11 biozone (samples 8 and 16 respectively, Figs. 7-8), while in Pliocene sections of the Ionian Calabria (Ciampo, 1992), in Eraclea Minoa in Sicily (Barra et al., 1998) and in the site 654A of the ODP Leg 107 drilled in the Tyrrhenian Sea (Colalongo et al., 1990) they occur later, at the base of MP12 biozone.

Another useful bioevent is the *Globorotalia scitula* occurrence: the dextral coiling taxon is rare at the bottom of the Pliocene succession, sporadic in the first 1.50 m and commonly occurs only from sample 8, correlatable with its CO (Common Occurrence), to sample 12. The CO of *Globorotalia scitula* dextral has been reported as a "delayed invasion event" in the basal Early Pliocene of Sites 974B and 975B of the Western Mediterranean (Iaccarino et al., 1999b).

Lithological cycles and faunal fluctuations have been described and correlated in MP11 and MP12 biozones of the reference section of Roccella Ionica/Capo Spartivento (Channell et al., 1988; Hilgen & Langereis, 1993; Di Stefano et al., 1996) as well as in the Capo Rossello bore-hole (Sgarrella et al., 1997), in Western Mediterranean basin (Iaccarino et al., 1999b) and in outcrops from Spain to Greece (Pierre et al., 2006). Where the basal Pliocene succession is complete, as in the Roccella Ionica/Capo Spartivento, Capo Rossello sections (Di Stefano et al., 1996) and Western Mediterranean sites (Iaccarino et al., 1999b), two sinistral shifts of *Neogloboquadrina acostaensis* have been described below the *Sphaeroidinellopsis* spp. acme, 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 (Di Stefano et al., 1996).

In the Moncucco lowermost Pliocene samples, *Neogloboquadrina acostaensis* is common and almost totally dextral; common sinistral specimens have been recovered only in the basal sample 4. Sample spacing is larger in the present study than in the reference sections (10-50 cm at Moncucco, 5-20 cm at Roccella Ionica/Capo Spartivento section and Capo Rossello bore-hole, Di Stefano et al., 1996; Barra et al., 1998) and makes difficult to clearly demonstrate the completeness of the stratigraphic record (i.e. if part of the basal Pliocene is missing). The *G. nepenthes* peak, the following *G. scitula* CO, the benthic foraminiferal assemblage, that will be discussed in the following paragraph, as well as the presence of *Kunihirella eracleaensis* suggest that the basal Pliocene at Moncucco might be nearly complete and that only a short hiatus, encompassing cycles 1-2, could be envisaged. This hiatus is also suggested by the absence of *Triquetrorhabdulus rugosus*, usually recorded in the lowermost Zanclean (Di Stefano, 1998; Castradori, 1998).

Globorotalia margaritae has been recovered up to sample 48, which can be inferred to correspond to its LCO (*G. margaritae* LCO 3.98 My, Gradstein et al.,

2004). *Globorotalia puncticulata* has been firstly identified in sample 40 and is present within all the overlying succession. The FO of *Helicosphaera sellii* has been recovered in sample 39: this event marks the MNN12/MNN13 boundary (Rio et al., 1990) and is coeval with the Mediterranean FO of *Globorotalia puncticulata* (4.52 My, Hilgen, 1991). Therefore, the interval between sample 26 (*Globorotalia margaritae* FCO) and sample 39 (*Helicosphaera sellii* FO), has been referred to the MP12 foraminifer biozone and to the MNN12 calcareous nannofossil biozone. *Agrenocythere pliocenica* occurs within the lower part of the MP12 biozone (sample 28, Figs. 7-8) as in other Mediterranean sections (Colalongo et al., 1990; Ciampo, 1992; Barra et al., 1998). This finding stresses its biostratigraphic importance at the scale of the Mediterranean basin and testifies the entrance of the Atlantic psychrosphere into the Mediterranean, which caused the initiation of an active circulation (Barra et al., 1998).

The interval between samples 39 and 48 (*G. margaritae* LCO) has been ascribed to the MP13 zone. The uppermost part of the Pliocene succession, from sample 48 to sample 54, is representative of the lower MP14a biozone, which was not recognized in the preliminary study of Bicchi et al. (2002). Moreover, the FO of *Discoaster asymmetricus* in sample 46 marks the MNN13/MNN14-15 boundary (Rio et al., 1990) (Fig.4).

On the basis of the biostratigraphic events and biozones recognized in the studied succession, a striking difference in the sediment thickness characterizes the deposits correlated to the MP11, MP12 and MP13 biozones. About 11.5 m of Argille Azzurre Fm. marly clays document the MP11 biozone and about 0.25 My (from 5.33 My, base of Pliocene, to 5.08 My, *G. margaritae* FCO, Gradstein et al., 2004) and a mean sedimentation rate of 4.6 cm/1000 y can be calculated for this time interval. Instead, only 6.5 m of sediments represent the 0.56 My of the MP12 biozone (from 5.08 My, *G. margaritae* FCO, to 4.52 My, *G. puncticulata* Mediterranean FO, Gradstein et al., 2004) and 4.5 m document the 0.54 My of the MP13 biozone (from 4.52 My, *G. puncticulata* Mediterranean FO, to 3.98 My, *G. margaritae* LO, Gradstein et al., 2004), given the extremely low mean sedimentation rates of 1.16 cm/1000 y for the MP12 interval and of 0.83 cm/1000 y for the MP13 interval. Episodes of down-slope transport or of reduced sedimentation, suggested also by the locally common glaucony in the uppermost layers, may be inferred in the upper part of the studied succession.

Cita et al. (1999) calculated the sedimentation rates of three stratigraphic intervals, from 5.33 My to time zero, in 46 Mediterranean drillsites. In the Zanclean, from 5.33 to 3.9 My, the authors documented low sedimentation rates, both on highs and lows, ranging from about 1 to 11 cm/1000 y. Starved basin conditions persisted during this time interval in all the Mediterranean, due to the rapid sea-level rise of the Pliocene transgression that abruptly modified the equilibrium between erosion and deposition.

In the Moncucco section, a mean sedimentation rate of 1.66 cm/1000 y can be calculated for the time interval from 5.33 to 3.9 My. Nevertheless, taking into account that the MP12 and MP13 biozones could be only partially

documented, the comparison could be more reliable for the MP11 interval, where the calculated sedimentation rate of 4.6 cm/1000 y results to be very similar to the values reported by Cita et al. (1999) from the drillsites of the Alboran Sea and the Balearic Basin.

Palaeoenvironmental interpretations

Low salinity and very shallow depth of the uppermost Messinian deposits are indicated by *Tyrrenocythere*, *Cyprideis*, and *Loxoconcha* that suggest salinity values lower than 10‰ and water depth up to 30 m (Cipollari et al., 1999). In particular, *Tyrrenocythere* tolerates shallow waters (maximum depth 30 m) with salinity of 1–13.5‰ (Yassini & Gharheman, 1976; Boomer et al., 1996, among others), *Cyprideis* inhabits very shallow waters (optimum less than 10 m depth) and is strongly euryhaline (Neale, 1988). Moreover, *Amnocythere propinqua* represents a typical taxon of shallow (10–12 m) and oligo-mesohaline (4–13.25‰) waters (Gliozzi & Grossi, 2004).

Foraminifers of sediments immediately overlying the black layer are poorly diversified, as reported at the Pliocene base in all the Mediterranean area (Cita, 1973; Sprovieri, 1978; Di Stefano et al., 1996; Sgarrella et al., 1997; Sprovieri & Hasegawa, 1990; Hasegawa et al., 1990; Spezzaferri et al., 1998; Iaccarino et al., 1999a, b; Pierre et al., 2006; Rouchy et al., 2007). Planktonic assemblages contain nearly similar percentages both of warm-water oligotrophic species, predatory, thriving in shallow (*Globigerinoides* spp.) to intermediate waters (*Orbulina universa*) and of cold-water eutrophic taxa, proliferating in the surficial water column (*Turborotalita quinqueloba*) or at intermediate depth (*Globigerina bulloides*, *Neogloboquadrina* spp.) of modern high-productivity or upwelling-influenced areas (Bé & Tolderlund 1971; Hemleben et al., 1989; Pujol & Vergnaud Grazzini, 1995; Machain-Castillo et al., 2008). Also benthic foraminifers are poorly diversified and partially differ from coeval more southern assemblages (Eraclea Minoa and Capo Rossello bore-hole, Sgarrella et al., 1997, 1999) for the abundance of *Hoeglundina elegans* and *Sphaeroidina bulloides* within the basal sample 4, as well for the lower percentages of *Uvigerina peregrina*, a shallow infaunal form (Van der Zwaan et al., 1986; Murray, 1991, 2006), adapted to high organic content and low oxygen level (Kaiho, 1999; Schönfeld & Altenbach, 2005).

Both *Hoeglundina elegans* and *Sphaeroidina bulloides* are shallow infaunal (Corliss, 1985; Fontanier et al., 2006), mesotrophic to eutrophic and oxic/suboxic form (Kaiho, 1994, 1999), with a wide depth range from outer shelf to bathyal bottoms (Parker, 1958; Chierici et al., 1962; Sgarrella & Moncharmont Zei, 1993; Eberwein & Mackensen, 2006), common in high productivity slope areas influenced by seasonal input or coastal upwelling (Altenbach et al., 2003; Licari & Mackensen, 2005). *Hoeglundina elegans* is also reported as epifaunal (Jorissen et al., 1998) and has been related to warm deep water in the Eastern Atlantic Quaternary (Lutze, 1979). *Sphaeroidina bulloides* is probably more tolerant of slightly suboxic condition (Kouwenhoven, 2000) and is common in Early Pliocene disoxic assemblages (Violanti, 1994). Assemblages dominated by *Gavelinopsis translucidus* and *Sphaeroidina bulloides* have been

reported along the Morocco Atlantic coasts at intermediate water depth (500–700 m), and in areas more influenced by seasonal variation in food supply (Eberwein & Mackensen, 2006).

In the basal samples of the Pliocene Moncucco succession, *Gavelinopsis praegeri*, *Eponides tumidulus*, and *E. pusillus*, common in bathyal Mediterranean bottom (Parker, 1958; Parisi, 1981), also recorded from bottoms influenced by high seasonal phytodetritus input (Gooday, 1993; Altenbach et al., 2003) are frequent. Moreover, the other few common species are represented by the infaunal, stress-tolerant *Bulimina minima* or the dubiously epifaunal, oxyphilic *Cibicidoides pseudoungerianus*, often correlated to high organic carbon fluxes (Van der Zwaan, 1983; Murgese & De Deckker, 2005). Nevertheless, many taxa as *Brizalina* spp., *Bolivina* spp., and *Uvigerina peregrina*, known as the most opportunistic taxa, thriving in disaerobic bottoms with abundant organic matter (De Rijk et al., 2000) as well in upwelling areas (Sen Gupta et al., 1981; Licari & Mackensen, 2005) are absent or scarce.

On the whole, the lowermost foraminiferal assemblage suggests rather high seasonal productivity, allowing the diffusion of both herbivorous planktonics as *N. acostaensis*, related to upwelling or high seasonal productivity (Serrano et al., 1999), and opportunistic phytodetritus feeder benthics as *Eponides pusillus* (Gooday, 1993). Labile organic matter with a high nutritious value, requested by the most opportunistic taxa living in the Mediterranean as *Uvigerina peregrina* (De Rijk et al., 2000), could have been limited to some period of the year when slightly disaerobic conditions could have affected the bottoms.

Ostracod assemblages referable to the lower MP11 biozone are characterized by the presence, among others, of: *Argilloecia acuminata* (found in the Mediterranean down to 2600 m, Bonaduce et al., 1983), *Krithe compressa* (living in the South China Sea at depth of 900 m, Whatley & Quanhong, 1993), *Kunihirella eracleaensis* (suggesting bathyal environment with low oxygen conditions, Barra et al., 1998), *Paijenborchella iocosa* (living in the South China Sea at depth greater than 500 m, Keiji, 1966), *Typhloeocytherura calabra* (described in the Eastern Atlantic at depth up to 700 m, Coles et al., 1996).

Taking into account the palaeoecological indications given by foraminifer and ostracod assemblages, a palaeodepth in the upper epibathyal zone, probably not deeper than 500 m, due to the absence of mesopelagic and deep bathyal taxa, could be inferred during the lower part of the MP11 biozone.

Palaeoenvironmental conditions appear to change fastly during the MP11 biozone, both in the water column and at the bottom. Mesopelagic foraminifers become more common (*G. scitula*) or firstly occur (*Sphaeroidinellopsis* spp., sample 6, 1 m above the black layer) as well as shallow and intermediate infaunal detritivorous taxa (*Uvigerina*, *Bulimina*) and the benthic foraminiferal diversity increases. These data suggest a basin deepening, probably to about 800 m depth. The abundance increase of shallow-water dwelling, oligotrophic *Globigerinoides* spp. from sample 12 to 34, and the concomitant decrease of the eutrophic *N.*

acostaensis suggest oligotrophic conditions in most of the upper MP11 biozone and the following MP12 biozone. Fluctuations in abundance of *Globigerinoides* spp. are correlated to astronomical precessional record (Sprovieri, 1993; Di Stefano et al., 1996; Sgarrella et al., 1997) and to lithological cycles (Hilgen, 1991; Sgarrella et al., 1999) in the Southern Italy Zanclean successions. *Globigerinoides* spp. fluctuations in the Moncucco samples are opposite to those of *N. acostaensis*. Similar opposite fluctuations of *Globigerinoides* spp. and *N. acostaensis* have been reported in the same time interval in the sapropels or sapropelitic layers of the Roccella Ionica-Capo Spartivento section (Di Stefano et al., 1996) and of the Metochia section (Schenau et al., 1999). The increasing frequencies and similar values of *Globigerinoides* spp. from the lower MP11 biozone to the MP12 biozone allow also the comparison with the Eastern Mediterranean (Spezzaferri et al., 1998) and the Western Mediterranean (Iaccarino et al., 1999b) deep bore-holes.

Also the benthic fauna testifies a deeper and more complex palaeoenvironment, with an increasing number of taxa common in the Zanclean assemblages of Southern Italy (Brolsma, 1978; Sprovieri, 1978; Sgarrella et al., 1999) and Northern Italy (Barbieri, 1967; Rio et al., 1988 among others). The ostracod diversity is higher and deep taxa as *Oblitacythereis mediterranea* (representing a typical inhabitant of the lower thermosphere, found in the Mediterranean between 300 and 1000 m depth, with an optimum between 400 and 600 m and bottom temperatures >10 °C, Benson, 1977) and *Paijenborchella malaiensis cymbula* (a deep water taxon, Benson, 1975), add to the assemblages during the MP11 biozone. It is noteworthy the progressive occurrence of many bathyal "Lazarus species" (*Anomalinoides helycinus*, *Cibicidoides kullenbergi*, *C. robertsonianus*, *Siphonina reticulata*), widespread in the Mediterranean region during the Tortonian and early Messinian (Kouwenhoven, 2000). In particular, *C. robertsonianus* is a typical NADW (North Atlantic Deep Water) form and is frequently reported from the Mediterranean Early Pliocene, where its diffusion has been related to a deep oceanic-type circulation (Sprovieri & Hasegawa, 1990; Spezzaferri et al., 1998; Iaccarino et al., 1999b; Pierre et al., 2006). In the Moncucco assemblages, the percentages of *C. robertsonianus* and other bathyal species (*C. kullenbergi*, *C. italicus*, *Planulina ariminensis* etc.) are lower than those reported from the Mediterranean basin and Sicily deposits (Hasegawa et al., 1990; Sgarrella et al., 1997). This pattern suggests a slightly shallower bottom in the studied section than in the Sicily deposits, probably about 1000 m below the sea level.

Siphonina reticulata firstly occurs in sample 11 and is frequent during the MP11 and MP12 biozones, then decreasing in abundance to disappear in the MP14a assemblages. In the Mediterranean Miocene and Pliocene, the epifaunal *S. reticulata* was a common component of bathyal assemblages indicative of normal marine conditions and well-oxygenated bottoms (Van der Zwaan, 1983; Sgarrella & Moncharmont Zei, 1993), whereas it is seldom reported in recent oceanic assemblages (Van Morkhoven et al., 1986). Sgarrella et al. (1997) proposed *S. reticulata* as a Mediterranean

quasi-endemic form, indicative of Early Pliocene Mediterranean Intermediate Water (EPMIW). Moreover, its re-immigration in the Mediterranean appears to be a nearly synchronous event, correlated to the lithological cycle 6 within the Sicilian Trubi Fm. (Hilgen, 1991; Hilgen & Langereis, 1993; Di Stefano et al., 1996; Sgarrella et al., 1997) and recognized at considerable geographic distance (Spezzaferri et al., 1998; Iaccarino et al., 1999b; Pierre et al., 2006; Rouchy et al., 2007). Therefore, *S. reticulata* occurrence in the Moncucco sample 11 represents another significant element for the correlation of Northwestern Italy Zanclean deposits with the coeval ones of the Southern Mediterranean region. The MP12 biozone ostracod assemblages are characterized by the common occurrence of *Agrenocythere pliocenica*, which represents a typical upper psychrospheric taxon, indicative of temperature range of 4-8°C and is found between 500 and 2000 m (Benson, 1973, 1975). The co-occurrence of *Agrenocythere pliocenica* with *Argilloecia kissamovensis*, *Cytheropteron pinarense gillesi*, *Krithe compressa*, *K. iniqua*, *Parakrithe dimorpha*, and *Xestoleberis prognata*, supports the hypothesis of a palaeodepth up to 1000 m (Aiello & Barra, 2001). Moreover, the co-occurrence of *A. pliocenica* and *O. mediterranea* in the MP12 biozone may suggest the onset of a temporary upwelling regime (Barra et al., 1998).

In the upper part of the section, abundance fluctuations of *N. acostaensis*, *G. bulloides*, *T. quinqueloba* and *Globigerinita glutinata*, taxa of the "upwelling assemblage" (Schönfeld & Altenbach, 2005) suggest increasing eutrophic conditions during the time interval of the upper MP12 biozone and the following MP13 and MP14a biozones. Also benthic species typical of deep water, oxyc environment (*Siphonina reticulata*, *Cibicidoides kullenbergi*, *C. robertsonianus*) decrease in abundance to disappear, whereas shelf to epibathyal stress-tolerant, disoxic taxa (*Bolivina*, *Bulimina* and *Uvigerina*) become common to dominant, documenting increasing eutrophic conditions and a progressive shallowing, probably in the deep outer neritic or in the uppermost epibathyal zone. In the MP13 biozone allochthonous ostracod taxa typical of shallow waters (*Aurila* spp., *Callistocythere* spp., *Eucytherura* spp., *Loxoconcha* spp.) occur together with species representative of bathyal environments (*Agrenocythere pliocenica*, *Argilloecia* spp., *Cytherella* spp., *Henryhowella asperrima*, *Krithe* spp., *Oblitacythereis mediterranea*, *Paijenborchella* spp., *Parakrithe* spp., Benson, 1977, 1978).

At the top of the succession, referable to the MP14a biozone, epifaunal shallow water foraminifers (*Cibicides lobatulus*, *Elphidium* spp., and *Neoconorbina terquemi*), epiphytic or attached to sediment grains (Colom, 1974; Murray, 2006) and shallow-water ostracods (*Aurila* spp., *Callistocythere* spp., *Caudites calceolatus*, *Echinocythereis scabra*, *Loxoconcha* spp., *Urocythereis* sp. among others) become dominant. No evidence of reworking has been detected both in foraminiferal and ostracod assemblages. Therefore, the shallow-water forms have been interpreted as winnowed, testifying episodes of gravitative transport. The displaced shallow-water ostracod tests reach their maximum in sample 52

and 54, in which they are represented by almost 250 and 450 specimens, respectively. Moreover, the typical taxa of very deep palaeoenvironment (*Cibicidoides italicus*, *C. robertsonianus*, *Siphonina reticulata* and *Agrenocythere pliocenica*, *Argilloecia acuminata*, *Krithe compressa*, *Paijenborchella iocosa*, and *Parakrithe dimorpha*) are absent. The reduction of deep-water taxa and the increase of allochthonous inner shelf taxa suggest a decrease of the water depth.

CONCLUSIONS

The data collected at Moncucco have shown that in the TPB the Miocene/Pliocene boundary is marked by a decimetre-thick black level described in many other Mediterranean areas (Cita et al., 1978; Roveri et al., 2004).

The brackish ostracod assemblage found in the sediments just below the black layer is referable to the *Loxocorniculina djafarovi* biozone (Carbonnel, 1978; Gliozzi et al., 2006) of the upper Messinian post-evaporitic interval. This assemblage testifies the deposition in oligo-mesohaline, shallow water conditions and the influx of Paratethyan faunas, suggesting the breakdown of the ecologic barrier separating the Paratethys and the palaeo-Mediterranean at the end of the Messinian (Bonaduce & Sgarrella, 1999; Iaccarino & Bossio, 1999). No evidences of normal marine conditions have been found in these sediments, in contrast to recent proposals (Bassetti et al., 2006; Carnevale et al., 2008) suggesting that the marine refilling of the Mediterranean preceded the Miocene/Pliocene boundary. At Moncucco, the marine microfossils (planktonic foraminifers and calcareous nannofossils) found in the “Lago-Mare” sediments are clearly reworked.

Foraminifers and calcareous nannofossils recovered in the sediments just above the black layer allow, respectively, to recognize the MP11 and MNN12 biozones of the Zanclean. The drastic facies change across the boundary, with brackish water deposits of late Messinian age abruptly followed by deep marine (about 500 m depth) Zanclean sediments, documents a discontinuity surface and the occurrence of a short hiatus at the Miocene/Pliocene boundary. This is supported by the presence of an omission surface at the top of the black layer and is confirmed by the absence of the first sinistral coiling shift of *Neoglobobulimina acostaensis* and the absence of *Triquetrorhabdulus rugosus*, whose LO is reported at the very base of the Zanclean (Castradori, 1998).

During the MP11 biozone the *Sphaeroidinellopsis* acme, the occurrence and diffusion of planktonic (*G. nepenthes*, *G. scitula*) and benthic (*Cibicidoides robertsonianus*, *Siphonina reticulata*) foraminifers have been found, allowing a very good correlation with the successions known from the literature. At Moncucco the appearance of *Henryhowella asperrima* and *Oblitacythereis mediterranea* occurs in the MP11 biozone, while in other Mediterranean sections (Barra et al., 1998; Ciampo, 1992; Colalongo et al., 1990) it occurs later, at the base of MP12 biozone. Moreover, *Agrenocythere pliocenica* occurs at Moncucco within the MP12 biozone, as already reported in other Mediterranean sections; this datum attests the biostratigraphic

importance of this taxon at the scale of the Mediterranean. The recognition of biostratigraphic markers along the section allows to identify the MP12, MP13, and MP14a foraminifer biozones and the MNN13 and MNN14-15 calcareous nannofossil biozones. Nevertheless, the short thickness of the sediments correlatable to these biozones suggests their only partial documentation.

Palaeoecological data suggest an upper epibathyal depositional palaeoenvironment in the lower MP11 biozone, testified both by benthic foraminifers (*Cibicidoides pseudoungerianus*, *Hoeglundina elegans*, *Uvigerina peregrina*) and ostracods (*Argilloecia acuminata*, *Krithe compressa*, *Paijenborchella iocosa*) living at present in a water column up to 500 m depth. In the samples belonging to the upper MP11 and MP12 biozones, a progressive deepening of the palaeoenvironmental setting, to an inferred palaeodepth of about 1000 m, is suggested by the more common mesopelagic foraminifers, by the higher diversity of the benthic assemblages and by the occurrence of deep bathyal taxa (*C. robertsonianus*, *Paijenborchella malaiensis cymbula*). Upward in the section (MP13 and MP14a biozones), the reduction or absence of deep-water taxa and the abundance of allochthonous inner shelf species among foraminifer and ostracod assemblages suggest a water depth shallowing and winnowing. Moreover, in samples of the MP11 and MP12 biozones foraminifer assemblages and, particularly, the abundance of some taxa (*N. acostaensis*, *Bulimina* spp., *Cibicidoides robertsonianus*, *Planulina ariminensis*, *Uvigerina peregrina*) evidence some differences with coeval assemblages of southern Mediterranean sections and Mediterranean bore-holes (Legs 13, 160 and 161), suggesting stronger seasonal upwelling and a shallower bottom for the Moncucco deposits.

Palaeoecological indications deriving from foraminifer and ostracod assemblages suggest the sudden reassessment of deep-water conditions at the base of the Zanclean, confirming that also in the Tertiary Piedmont Basin the marine refilling occurred in this time-interval. The flooding event was contemporaneous at the Mediterranean scale, like recently suggested by multidisciplinary studies on Miocene/Pliocene boundary in the Mediterranean area (Pierre et al., 2006; Rouchy et al., 2007) and in contrast to Popescu et al. (2007), that attribute the entire post-evaporitic stratigraphic unit to the earliest Zanclean.

ACKNOWLEDGEMENTS

We thank Francesco Grossi (Università degli Studi Roma Tre) for helpful suggestions on the determination of upper Messinian ostracods and Magda Minoli for technical help. The authors sincerely thank Maria Bianca Cita and Elsa Gliozzi for their critical revisions of the manuscript.

This research was supported by MIUR ex 60%, Resp. D. Violanti and by CNR IGG Torino, Commessa TA PO1-006 Grants.

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Manuscript received 11 January 2008

Revised manuscript accepted 05 May 2008

