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CALCAREOUS PLANKTON BIOSTRATIGRAPHY AND AGE OF THE MIDDLE MIOCENE DEPOSITS OF LONGANO FORMATION (EASTERN MATESE MOUNTAINS, SOUTHERN APENNINES)

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Abstract. The integrated calcareous plankton biostratigraphy (planktonic foraminifera and calcareous nannofossils) and an accurate fieldwork, allowed us the reconstruction of the sedimentary evolution of the Longano Formation (*Orbulina Marls*). In particular the correlation between the bioevents recognised in the *Orbulina Marls* sequence and those recorded in astronomically calibrated Middle Miocene sections, offered the possibility to date the passage from the shallow-water Cusano Formation to the deep-water deposits of the Longano Formation at about 13.21 Ma and the successive onset of terrigenous deposits of the Pietraroia Formation at 10.54 Ma. In addition, an high resolution study of the terrigenous sequence, showed that this sedimentary event is not abrupt but it is characterised by a progressive increase, bed by bed, of the siliciclastic fraction up to the deposition of the sandstones. The recognition in all the studied sections of the base of the first Acme (AB1) of *Paragloborotalia siakensis* dated at 13.21 Ma, just above the phosphate-rich interval (this interval marks the transition between Cusano and Longano Formations), proved that the transgression which led to the deposition of the *Orbulina Marls* was synchronous in all the south-eastern Matese Mountains.

Riassunto. Allo scopo di datare sia l'inizio della deposizione delle marne pelagiche della Formazione Longano che l'inizio della sedimentazione terrigena della Formazione di Pietraroia, sono state studiate otto sezioni affioranti nel Matese sud-orientale (Appennino meridionale). Lo studio stratigrafico integrato (foraminiferi planctonici e nannofossili calcarei) con il supporto di una accurata analisi di campagna ha permesso di stabilire l'inizio della sedimentazione delle marne emipelagiche della Formazione Longano (*Marne ad Orbulina*) a circa 13.21 Ma e l'inizio della sedimentazione terrigena della Formazione di Pietraroia a 10.54 Ma. Inoltre il ritrovamento del primo acme (AB1) di *Paragloborotalia siakenis*, appena sopra il livello fosfatico, che marca la transizione tra i depositi di acqua bassa della Formazione Cusano e quelli di acqua profonda della Formazione Longano, indica che la trasgressione che porta alla deposizione delle *Marne ad Orbulina* è sincrona in tutto il settore sud-orientale del Matese.

Introduction

Dating the onset of the terrigenous deposition in the Cenozoic successions of the central-southern Apennines is important for establishing the time of migration of the nappes.

In this area, flysch deposition age is related to the building phases of the thrust and fold complex of Late Miocene. Flysch unit commonly overlies hemipelagic carbonate deposits following a major transgressive event.

The hemipelagic deposits, which in the Matese area are referred to the Longano Formation (Selli 1957), are commonly known in literature as *Orbulina Marls*. Several authors used this informal name to identify the Miocene hemipelagic carbonate and marly sediments overlying the shallow-water deposits. However, they span different time intervals and belong to different paleoceanographic domains from the Matese to the Maiella massif (Amore et al. 1988; Pampaloni et al. 1994; Cosentino et al. 1997; Mutti et al. 1999; Cascella et al. 2001).

At present, no first order calibration of the Longano Fm. is yet available. The only stratigraphic data known so far from the Matese area were proposed by Ciampo et al. (1987) who dated the uppermost part of the *Orbulina Marls* to the early Late Miocene (*Neoglo-*

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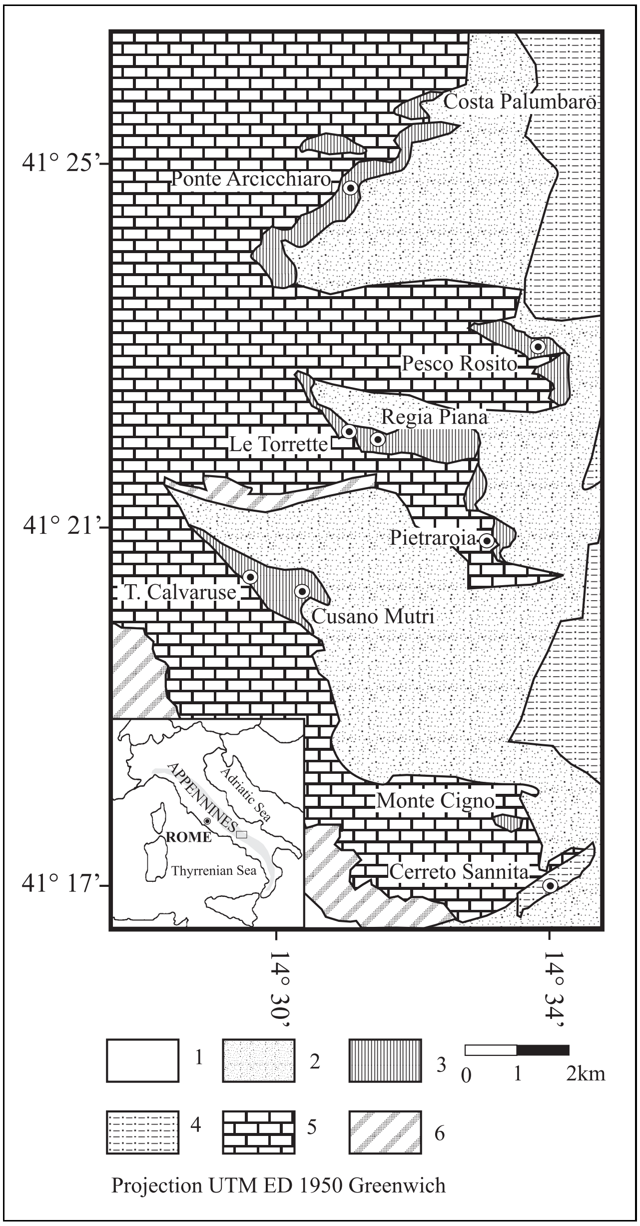

Fig. 1 - Location map of the studied sections. Geology modified after Foglio n°173 (Benevento) and 162 (Campobasso), 1:100.000, Carta Geologica d'Italia, 1975; 1) Quaternary deposits; 2) Flysch deposits; 3) Miocene carbonate deposits: BBL Bryozoan and Lithotaminion Limestones & OM Orbulina Marls; 4) Upper Cretaceous -Paleogene carbonate/clastic sequences; 5) Cretaceous Limestones; 6) Upper Jurassic Limestones.

boquadrina continuosa Subzone of Colalongo et al. 1979 or *Neogloboquadrina acostaensis* Zone of Foresi et al. 1998), on the basis of the presence of *Neogloboquadrina continuosa* in the absence of *Globigerinoides obliquus extremus*. The same age was assigned to the lower part of the siliciclastic turbiditic deposits of the overlying Pietraroia Formation (Ciampo et al. 1987), while no precise age was provided for the lowermost part of the Longano Fm.

The aim of this study was to provide integrated biostratigraphic data (planktonic foraminifera and calcareous nannofossils) of the Longano Fm., in order to determine the timing of drowning of the Lower Miocene open-shelf domain, which coincided with the beginning of the *Orbulina Marls* deposition, and the onset of the siliciclastic sedimentation in the south-eastern Matese area.

Geological setting

The Matese Mountains represent part of the thrust and fold complex of the southern Apennines (Fig. 1), and are commonly believed to have been deformed since the Late Miocene (D'Argenio et al. 1973). The south-eastern part of the Matese mountains, which comprises the studied area, consists of a few thousand metres-thick carbonate succession spanning from the uppermost Triassic?-Lower Jurassic to lower Middle Miocene (Catenacci et al. 1963; D'Argenio et al. 1973). The carbonate succession is overlaid by a flysch sequences (Pietraroia Fm.) that represent the first phase of clastic sedimentation in the area dated to Tortonian-Messinian (Ciampo et al. 1983).

The Mesozoic carbonate succession includes Lower Jurassic – Aptian platform limestones passing upwards into marginal sequences of Albian to Late Cretaceous in age. Carannante et al. (2001) suggested an Early Cretaceous structuring phase that down-faulted the Jurassic-Lower Cretaceous platform domains and led to the development of a narrow, eastward-facing, channelised carbonate margin. According to these authors, periodical re-activations of the main tectonic lines allowed the establishment of marginal environmental conditions in the area during the Late Cretaceous and Burdigalian-Serravallian time intervals.

Since the Burdigalian the south-eastern Matese area was flooded by a multi-phase transgression. Temperate-type carbonate factories developed in the outer-shelf areas, probably favoured by cold, nutrient-rich, upwelling waters (Carannante 1982b), while relatively warmer water conditions characterised the inner shelf areas (Simone & Carannante 1985). This led to deposition of coarse foramol-rhodalgal type carbonate deposits (Carannante et al. 1988), known in literature as Bryozoan and Lithotamnion limestones and referred to the Cusano Formation (dated to the Miocene).

According to Carannante & Vigorito (2001), the eastern edge of the studied area was a channelised carbonate margin which extended N-S for about 15 km and was up to 6 km wide. This margin was characterised by a complex paleophysiography which shows alternating E-W highs and lows.

Starting from Serravallian time the whole area was drowned. A progressive but generalised deepening led to the gradual demise of the carbonate factories while

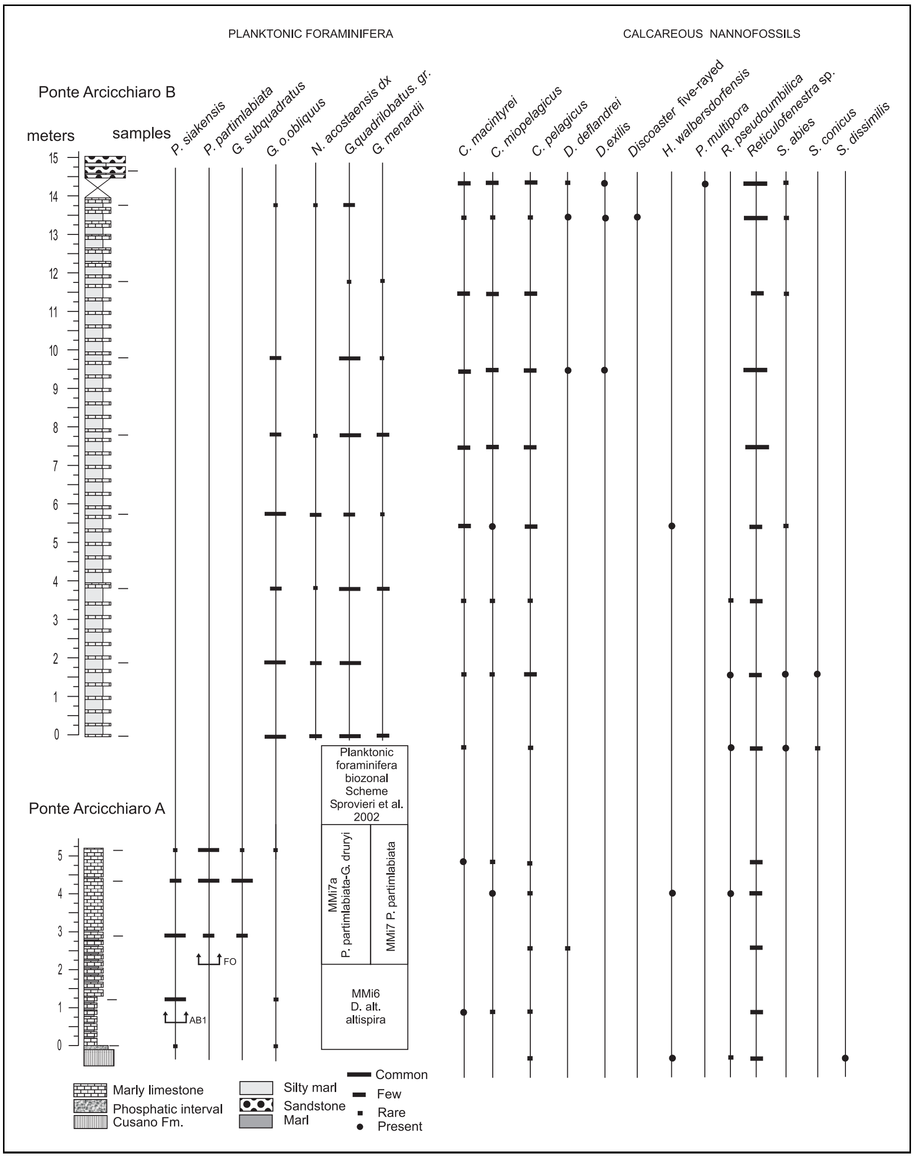

Fig. 2 - Lithologic logs of Ponte Arcicchiaro A and B sections plotted versus the range charts of selected planktonic foraminifera and calcareous nannofossils with their estimated abundance. The position of planktonic foraminiferal bioevents are indicated by the following acronyms: FO (First Occurrence) and AB1 (Acme Base 1).

the loose rhodalgal sediments covering the sea floor became relict and underwent to severe phosphatization. According to Carannante (1982b) and Simone & Carannante (1985), the transgression was associated to upwelling of cold, nutrients-rich waters which in turn would have promoted phosphatization.

The relict sediments rich in phosphatic grains show a progressive upward increase in planktonic foraminifera and pass upwards, either gradually or abruptly, to the hemipelagic *Orbulina Marls* (Selli 1957) that mark the complete drowning of the shelf. In the eastern part of the Matese area, the transition from the *Orbulina Marls* to the overlying flysch deposits, which, according to Ciampo et al. (1987), started in the early Late Miocene, is commonly gradual and marked by a progressive increase of clastic components within the uppermost portion of the *Orbulina Marls* sequence.

The *Orbulina Marls*

The *Orbulina Marls* (*OM*) consist of bluish to reddish dark grey limestones and marly limestones dated as the Helvetian (Serravallian) by Selli (1957), Serravallian – Lower Tortonian by Ciampo et al. (1987), and Serravallian – middle Late Tortonian by Sgrosso (1998). These deposits widely crop out in wide sectors of the Central and Southern Apennines and are attributed, depending on the localities, to the Longano Fm. (Selli 1957) or Montagnella Fm. (Selli 1957), or to a member of the Bolognano Fm. (Crescenti et al. 1969). The *OM* are well stratified, with bed thickness less than 0.2 m, passing upwards to thinner (0.01 to 0.04 m) clayey marls; they yield a rich planktonic foraminiferal assemblage with minor amounts of detrital fragments of rhodalgal-type sediments in the lowermost part, and by a steadily increasing amount of carbonate mud and clay in the uppermost part. The *OM* strata show clear evi-

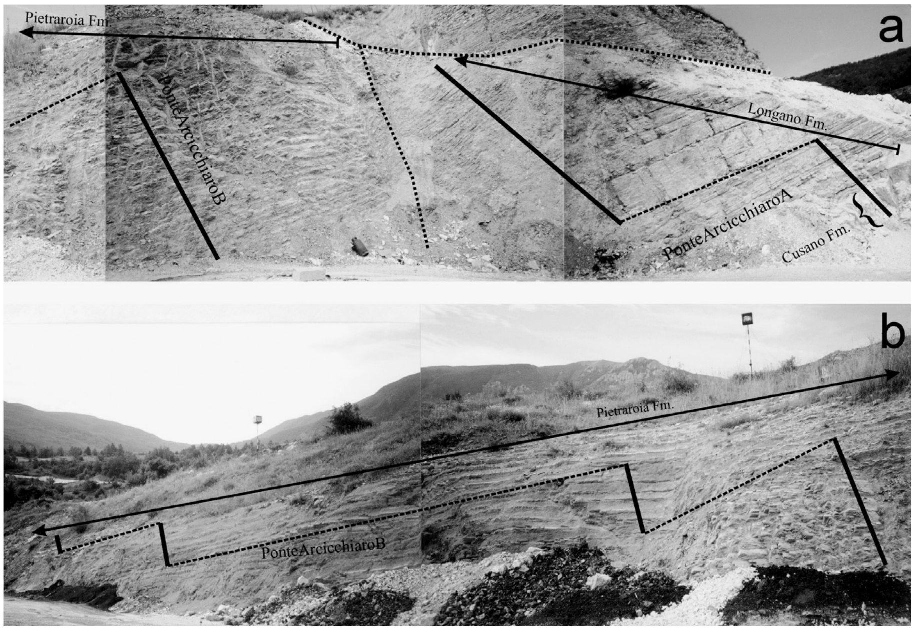

Fig. 3 - a: Ponte Arcicchiaro A section (5 m-thick): position (dotted line) of the main tectonic crushing and sampling trajectory (thicker line); b: Sampling trajectory of the Ponte Arcicchiaro B section (15 m-thick).

dence of intense bioturbation (*Chondrites* or *Planolites* dominating assemblage) that locally led to the complete homogenisation and destruction of all sedimentary structures. Abundance of phosphate and glauconite grains occur in the lower part of the succession and rapidly decrease upwards. Phosphate grains occur as peloids and less frequently as phosphatised planktonic tests, and locally brownish phosphatised micrite rim burrows. Glauconite also occurs as infilling of planktonic foraminiferal tests (autochthonous glauconite) or as sub-polygonal-shaped grains (allochthonous glauconite).

The *Orbulina Marls* are thought to indicate deep, open marine conditions. In south-eastern Matese area, on the basis of sedimentological features (e.g.: normal/ reverse gradation; Ta, Ta-b, Ta-c Bouma intervals, cross micro-lamination) and internal geometry (e.g. tabular to concave-up bedding, large to small scale cross stratification, slumped intervals), these deposits were interpreted, depending on local peculiarities, as hemipelagites or biogenic turbidites.

The studied sections

The sections investigated (Ponte Arcicchiaro, Le Torrette A and B, Regia Piana, Pesco Rosito, Torrente Calvaruse and Pietraroia) are located in the eastern-Matese massif (Fig.1) and comprise thinly bedded hemipelagic sediments of the Longano Fm. overlying the shallow-water bioclastic deposits of the Cusano Fm.

All the sections have been sampled and logged along different trajectories because of small faults and slumping which rendered very difficult the record of a continuous sedimentary sequence. The eight sections surveyed all together span more or less the entire investigated sequence. Sedimentary cyclicity is not equally distinct and visible in the different sections due to lateral changes, different sedimentary facies, weathering and bad exposure.

Correlation between the studied sections was established both on the basis of calcareous plankton bioevents (planktonic foraminifera and calcareous nannofossils) and of a distinct phosphate-rich interval which marks the transition between the Cusano and Longano formations. This phosphate rich interval has variable thickness (between 10-15 cm and 2 m) and is characterised by phosphate cement, crusts and grains, often associated with glauconite. Bioturbation is common and well diversified throughout the overall studied sections.

Ponte Arcicchiaro section

The Ponte Arcicchiaro section (E14°31'17"; N41°24'47"), cropping out along the right side of the dam on the Quirino river (Fig. 1), consists of two distict subsections (A and B) of 5 and 15 m-thick, respectively (Figs 2, 3), separated by an important tectonic line. In particular, subsection A (Fig. 3) belongs to the Longano Fm., subsection B (Fig. 3) to the Pietraroia Fm.

The subsection A shows, at the base, a very short interval of 50 cm characterised by high abundance of phosphatic grains, marking the transition from Cusano to Longano Fms. Above this interval the sedimentary sequence consists of a rhythmic alternation of light-brownish marly limestones, which become progressively thicker upward (Fig. 2), and thin light-brownish marly beds.

Subsection B, belonging to the Pietraroia Formation, consists of a coarsening-upward sedimentary sequence, which displays a progressive increase in siliciclastic fraction (Fig. 2). This subsection shows a quasi-regular rhythmic alternation of brownish limestones and greenish-grey marly silty beds. In some stratigraphic portions of this subsection, the sedimentary cycles are expressed by triplets marked by the intercalation of an additional dark-grey, organic-rich marly bed within the greenish-grey marly silty layers. Upwards, this well-stratified interval of the Pietraroia Fm. displays the occurrence of sandstones and green shales (Fig. 2), but the presence of a tectonic line between these two deposits, prevents to recognise the sedimentary evolution from limestones to sandstones intervals.

Regia Piana section

The Regia Piana section (E14°31'53"; N41° 21'55"), cropping out along the road to Bocca di Selva (Fig. 1), is 26.45 m-thick (Fig. 4). A medium-grained bioclastic calcarenite interval without phosphatic grains, separates the Cusano and Longano Fms. This bioclastic interval, 5 m-thick (probably related to the Cusano Fm) contains abundant phosphatic grains which usually mark the transition between the two formations only in the uppermost 1.2 m.

Upward, the sedimentary sequence of the Regia Piana section (Fig. 4), 20 m-thick, shows a rhythmic alternation of greyish marly limestones and grey marly beds. Horizons of dark organic-rich marls are present within the sequence. In the uppermost part of the section the cycles are progressively thinner and less evident than in the underlying part. In addition, the clayey fraction progressively increases in the uppermost 10 meters where also micro-slumpings are present.

Torrente Calvaruse section

The Torrente Calvaruse section (E14°29'35"; N41°20'36"), cropping out along the right side of Cal-

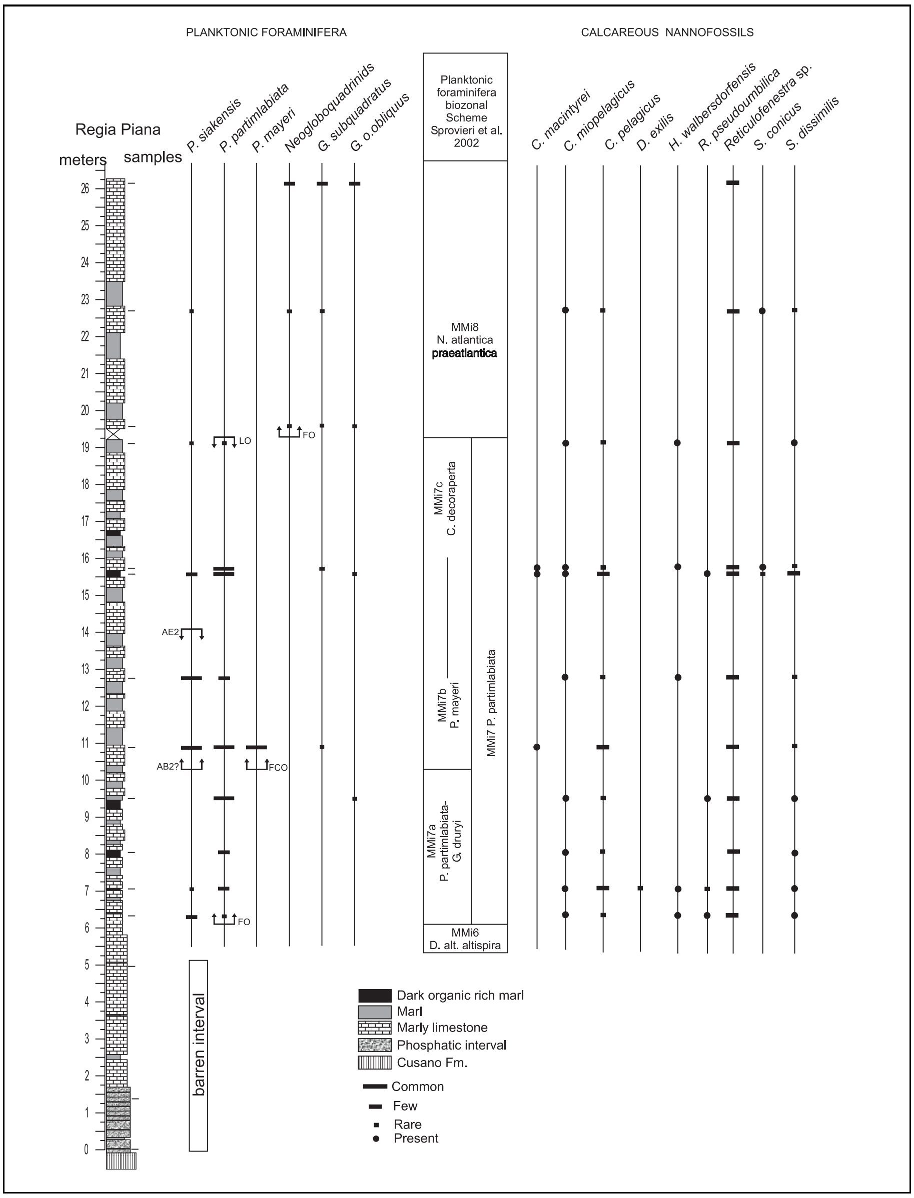

Fig. 4 - Lithologic log of Regia Piana section plotted versus the range charts of selected planktonic foraminifera and calcareous nannofossils with their estimated abundance. The position of planktonic foraminiferal bioevents are indicated by the following acronyms: FO (First Occurrence); FCO (First Common Occurrence); LO (Last Occurrence); AB2 (Acme Base 1); AE2 (Acme End 2).

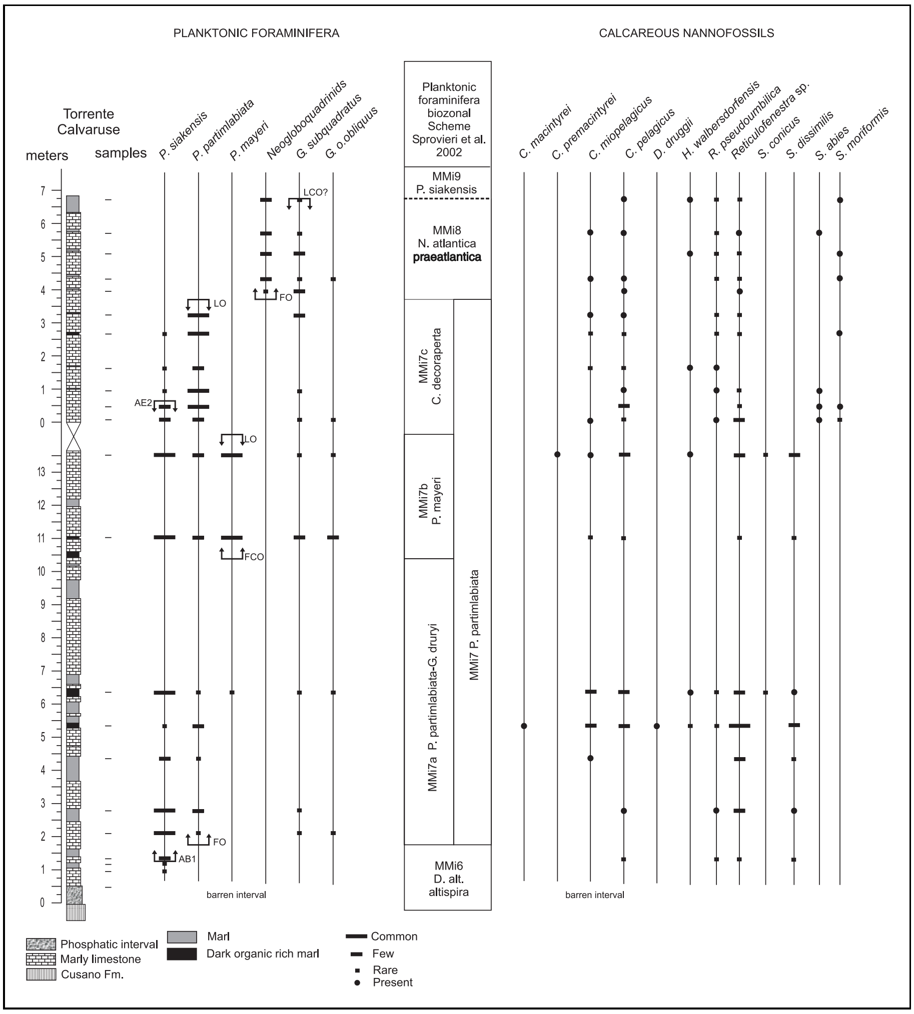

Fig. 5 - Lithologic log of Torrente Calvaruse section plotted versus the range charts of selected planktonic foraminifera and calcareous nannofossils with their estimated abundance. The position of planktonic foraminiferal bioevents are indicated by the following acronyms: FO (First Occurrence); FCO (First Common Occurrence); LO (Last Occurrence); AB1 (Acme Base 1); AE2 (Acme End 2); FCO (First Common Occurrence).

varuse river (Fig.1), is 20.05 m-thick (Fig. 5). At the base of the section, the phosphate interval, 50 cm-thick, rich in pellets and phosphatic grains, occurs. The sedimentary cycles are thicker and less evident than in the other sections (Figs 5, 6), even though the cyclic patterns are similar consisting of an alternation of greyish marly limestones and grey marly beds. From 12 meters up to the top of the section the sedimentary cyclicity becomes unclear, bioturbation and nodular structures are continuously present. In addition, four distinct dark, organic-rich marls in the middle and one in the uppermost part of the section are recorded (Fig. 5).

Le Torrette section

In this area two sections have been sampled and logged (Figs 1, 7, 8). The first, the Le Torrette A (E14°31'13"; N41°22'11"), cropping out very close to the main road to Bocca di Selva, is 11.15 m thick (Fig. 7). The sedimentary cycles are not clearly recognisable because the bioturbation and nodular structures deleted the original bed patterns. A thick, phosphate-rich interval (2 m) has been recorded at the base of the section above several high-density turbiditic layers, marking the top of the shallow-water deposits of the underlying Cusano Fm.

The Le Torrette B section (E14°31'07"; N41°22'03"), 35 m-thick (Figs 8, 9), cropping out close to Fontana Sparago, consists of two intervals (Fig. 8). The lowest interval, 1.5 m-thick, belonging to the Longano Fm., is characterised by a rhythmic alternation of beige marly limestones and greenish-grey marly beds (Fig. 8). The upper interval, from 2 m up to the top, characterised by a progressive increase of siliciclastic fraction and clay content, has been referred to the lower part of the Pietraroia Fm. This interval shows in the first 3 meters a quasi-regular alternation of beige limestones and greenish-grey marly silty beds. From 5 up to 12.50 meters the cyclic pattern consists of a more or less rhythmic alternation of brownish silty limestones and greenish-grey marly silty beds (Fig. 8).

As in Ponte Arcicchiaro section, the sedimentary cycles of the Pietraroia Fm. show triplets expressed by the intercalation of additional dark-grey, organic-rich marly bed within the greenish-grey marly silty layers.

From 12.50 up to 22 m the siliciclastic sediments are characterised by thick fine-grained sandstones interlayered to a rhythmic alternation of thin fine-grained

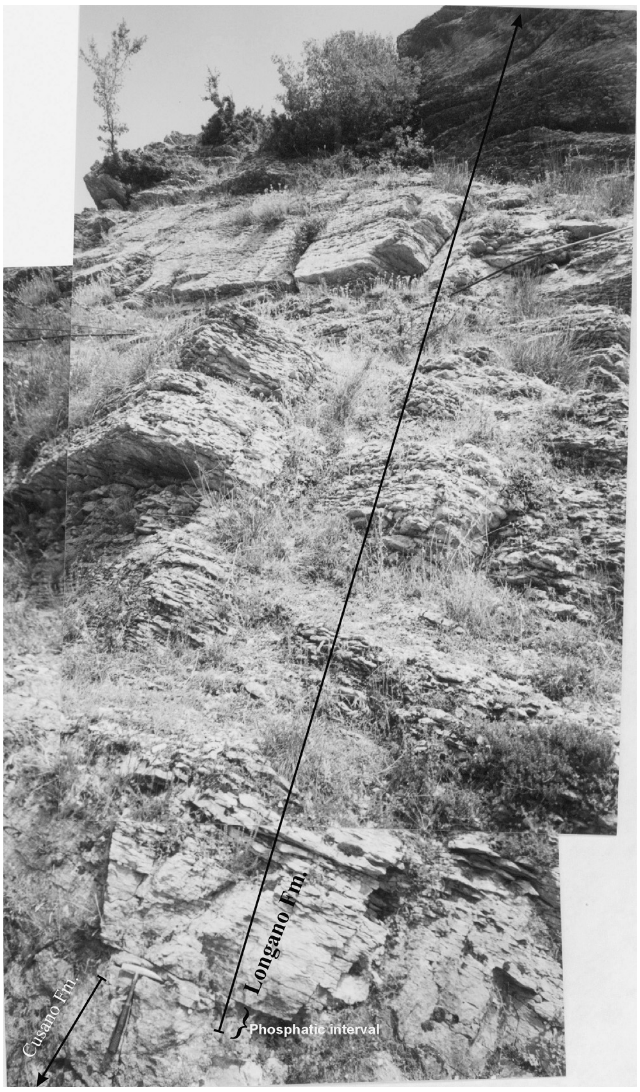

Fig. 6 - Sampling trajectory of the Torrente Calvaruse section (lower part, 13 m-thick). Hammer for the scale.

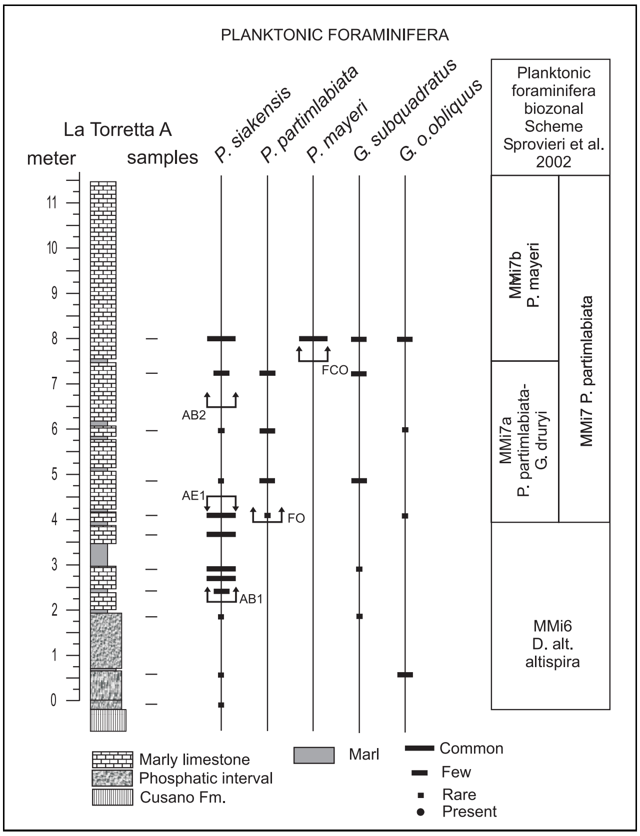

Fig. 7 - Lithologic log of Le Torrette A section plotted versus the range charts of selected planktonic foraminifera with their estimated abundance. The position of planktonic foraminiferal bioevents are indicated by the following acronyms: FO (First Occurrence); FCO (First Common Occurrence); AB1 (Acme Base 1); AE1 (Acme End 1); AB2 (Acme Base 2).

sandstones and marly silty beds. From 22 m up to the top of the section a thick and homogeneous clayey marly silty interval is present.

Pesco Rosito section

The Pesco Rosito section (E14°34'11"; N41° 23'05"), cropping out east of the Monte Palumbaro (Fig. 1), is 7.97 m-thick and consists of a quasi-regular rhythmic alternation of greyish marly limestones and grey marly beds. In the upper part of the section a progressive increase in clayey fraction is recorded and the sediments appear like paper shales. A very thin phosphate-rich interval at the base of the studied section is recorded (Figs 10, 11).

Pietraroia section

The Pietraroia section (E14°33'17"; N41°20'55"), cropping out at Pietraroia village, is 40 cm-thick and comprises a very thin phosphate-rich interval at the base of the section (Figs 12, 13). This very short section is characterised in the lowest part by a couplet of light brownish marly limestone and light brownish marly beds. The latter, is replaced at the top by dark-brown coloured marly beds.

Material and methods

Planktonic foraminiferal analyses were carried out on a total number of 100 samples collected at variable interval of 30-40 cm to 1-2 m, from all the sections (Ponte Arcicchiaro, Regia Piana, Pesco Rosito, Torrente Calvaruse, Le Torrette A and B and Pietraroia). Samples for foraminiferal analyses have been treated with the new method "cold acetolise" proposed by Lirer (2000). Samples were first broken in small fragments of 5 mm size, subsequently disaggregated in acetic acid for 20 hours and washed with a 63 μm sieve. Only the samples from the phosphate-rich intervals have been disaggregated in acetic acid for 30-35 hours to remove all the incrustation and obtaining clean washed residue. A semi-quantitative analysis based on survey of the >125 μm fraction, was performed. The distribution of selected taxa and their estimated abundance, for all the investigated sequences are reported in Figs. 2, 4, 5, 7, 8, 10, 12.

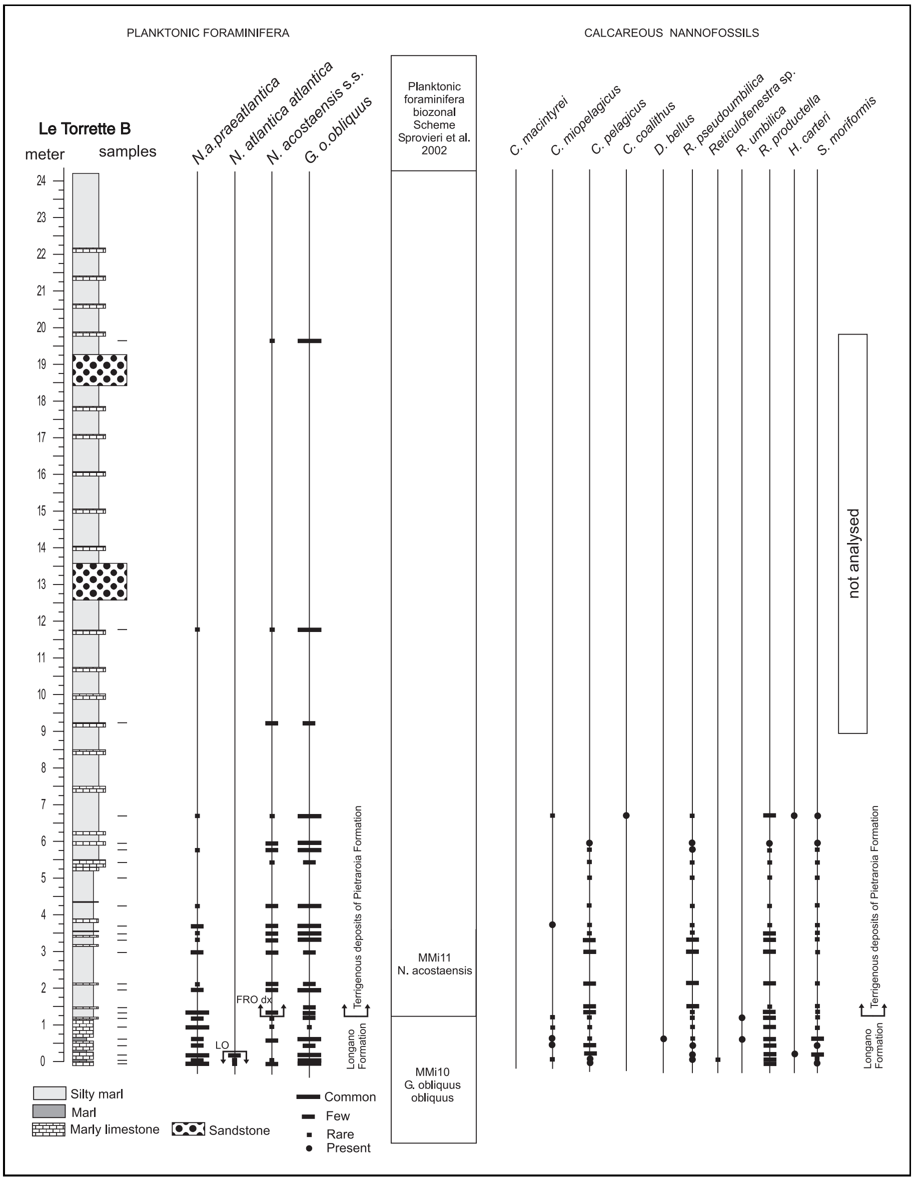

Fig. 8 - Lithologic log of Le Torrette B section plotted versus the range charts of selected planktonic foraminifera and calcareous nannofossils with their estimated abundance. The position of planktonic foraminiferal bioevents are indicated by the following acronyms: LO (Last Occurrence) and FRO (First Regular Occurrence).

Calcareous nannofossil study is based on quantitative analysis of 60 samples from the Ponte Arcicchiaro A and B, Regia Piana, Pesco Rosito, Torrente Calvaruse, Pietraroia and Le Torrette B sections.

Smear slides were prepared from unprocessed sediments following the standard techniques (Backman & Shackleton 1983; Rio et al. 1990). To obtain the distribution pattern of selected calcareous nannofossil taxa, light microscope analyses were performed (transmitted light and crossed nicols) at about 1000X magnification. Abundance data were collected using the methodology described by Backman & Shackleton (1983), Rio et al. (1990) and extensively used in Mediterranean and extra-Mediterranean quantitative biostratigraphic studies of Neogene marine records (Raffi & Flores 1995; Raffi et al. 1995; Fornaciari et al. 1996; Backman & Raffi 1997; Di Stefano 1998; Hilgen et al. 2000).

From counting the number of specimens of an index species or genus in a prefixed area of the slide (4.52 mm^2) the distribution of selected calcareous nannofossil taxa was calculated and their estimated abundance are reported in Figs 2, 4, 5, 8, 10, 12.

Biostratigraphy

Several biostratigraphic schemes, based on calcareous nannofossils (Fornaciari et al. 1996) and planktonic foraminifera (Iaccarino 1985; Foresi et al. 1998), have been in the last years proposed for the Mediterranean Middle Miocene. More recently Sprovieri et al. (2002) emended the biostratigraphic zonal scheme of Foresi et al. (1998) (Fig. 14). Such a zonal scheme provides the abundance fluctuation of different marker species, their absence (paracme) and abundance (acme) intervals, their last common and regular occurrence (LCO, LRO), and their first common and regular occurrence (FCO, FRO) and their astronomical calibration. Following the abun-

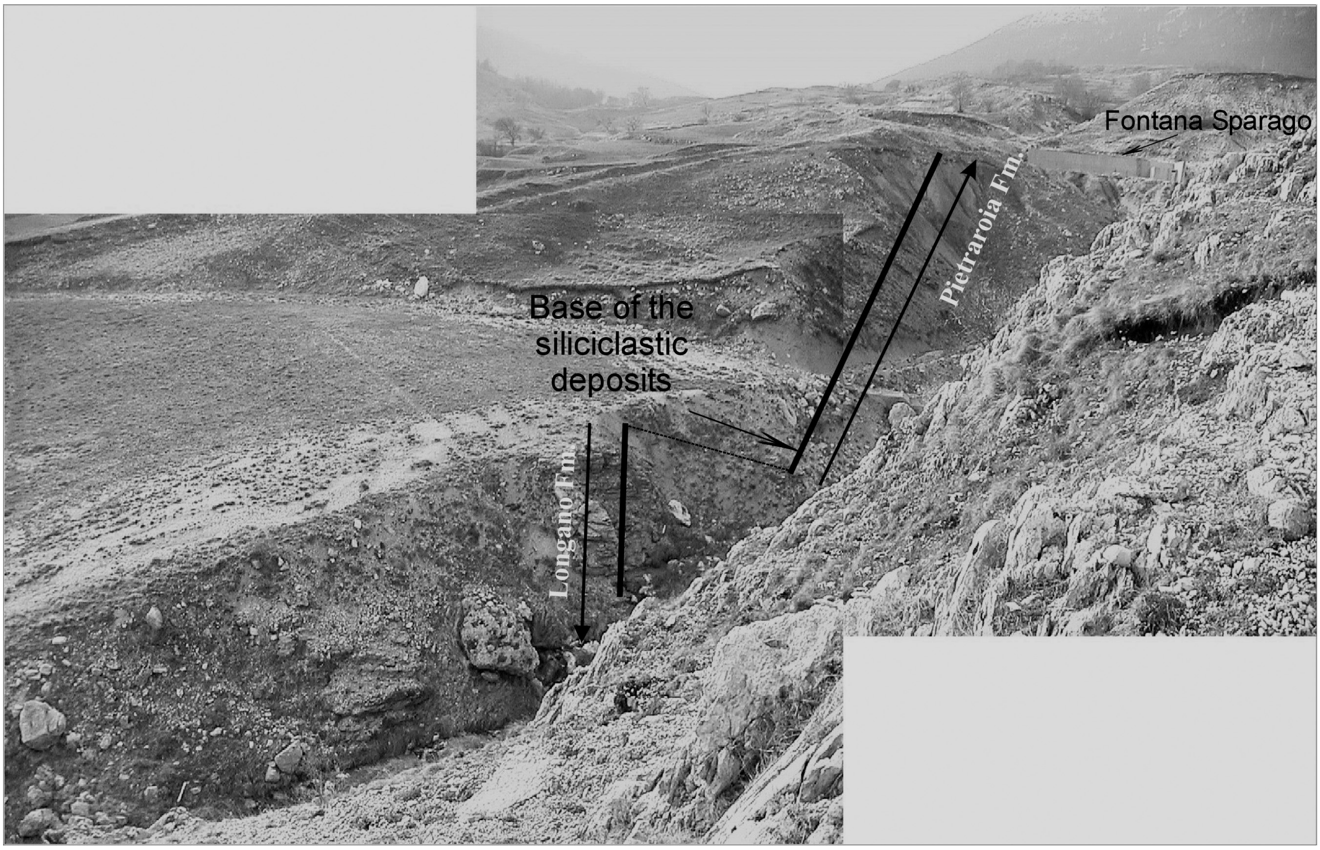

Fig. 9 - Sampling trajectory of the Le Torrette B section (24 m-thick). The arrow shows the position of the boundary between Longano and Pietraroia Formations.

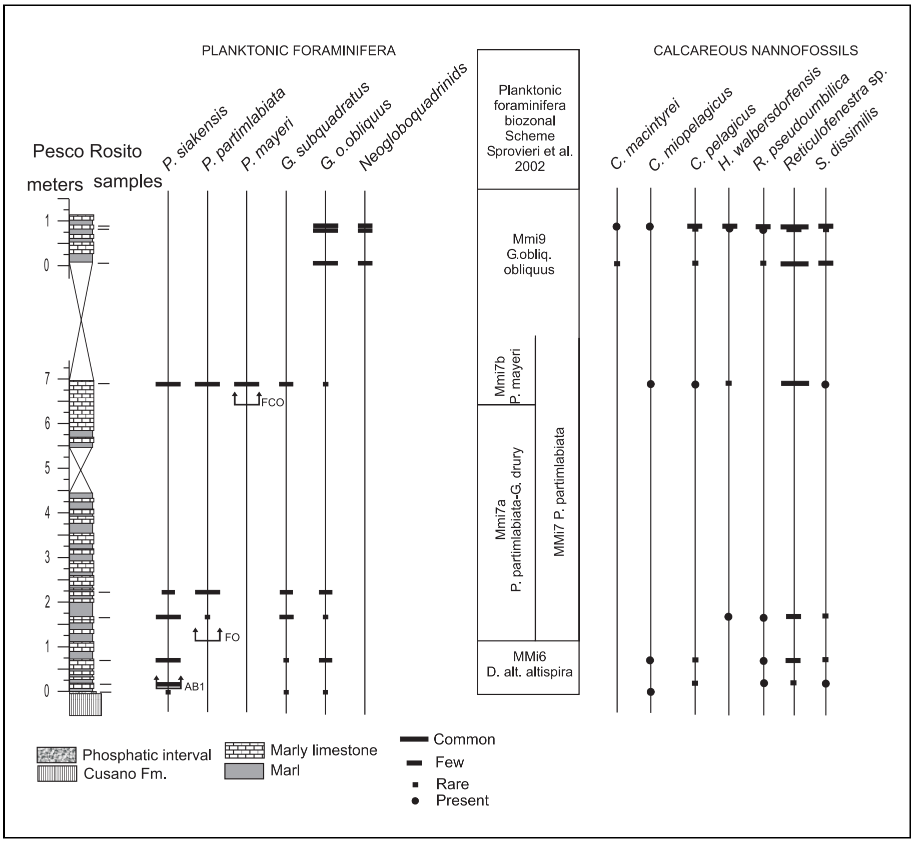

Fig. 10 - Lithologic log of Pesco Rosito section plotted versus the range charts of selected planktonic foraminifera and calcareous nannofossils with their estimated abundance. The position of planktonic foraminiferal bioevents are indicated by the following acronyms: FO (First Occurrence); FCO (First Common Occurrence); AB1 (Acme Base 1).

Fig. 11 - Sampling trajectory of the Pesco Rosito section (11.5 m-thick).

dance pattern of the taxa and their chronology, proposed by Sprovieri et al. (2002) and Iaccarino et al. (2004), it was possible to date the various sections at different degrees of precision.

Planktonic foraminifera

Planktonic foraminifera are more abundant, well preserved, and well diversified in the marly deposits of the Longano Fm. than in the flysch deposits of the Pietraroia Fm.. Only the dark grey organic-rich, marls of the Longano Fm. are characterised by high abundance in oligo-typic benthic foraminifera (*Uvigerina rutila* and *U. peregrina* and *Lenticulina* spp., Guasti 2001 pers. com.) and low diversified planktonic foraminifera. Generally, high values of *Globigerinoides* spp. are recorded. Reworking is absent in the studied sections.

The taxa *Dentogloboquadrina altispira* gr., *Globigerina bulloides* gr., *G. druryi-nepenthes*, *Globigerinita glutinata*, *Globigerinoides quadrilobatus* gr., *Globoquadrina dehiscens dehiscens*, *Globorotalia scitula*, *Orbulina* spp. and *Turborotalita quinqueloba* gr. are continuously present and show abundance fluctuations throughout the studied sections. Among the species having a discontinuous distribution, *Globigerinoides subquadratus*, *G. obliquus obliquus*, *Globorotalia obesa* gr., and *Globorotalia praemenardii- menardii* gr., occasionally, reach significant percentages.

In this paragraph we consider only the appearance/disappearance of marker species, which are used as biohorizons. The results are reported in Figures (2, 4, 5, 7, 8, 10, 12) together with the adopted biozonal scheme.

Despite the low sampling resolution, it has been easily possible to recognise the abundance pattern of

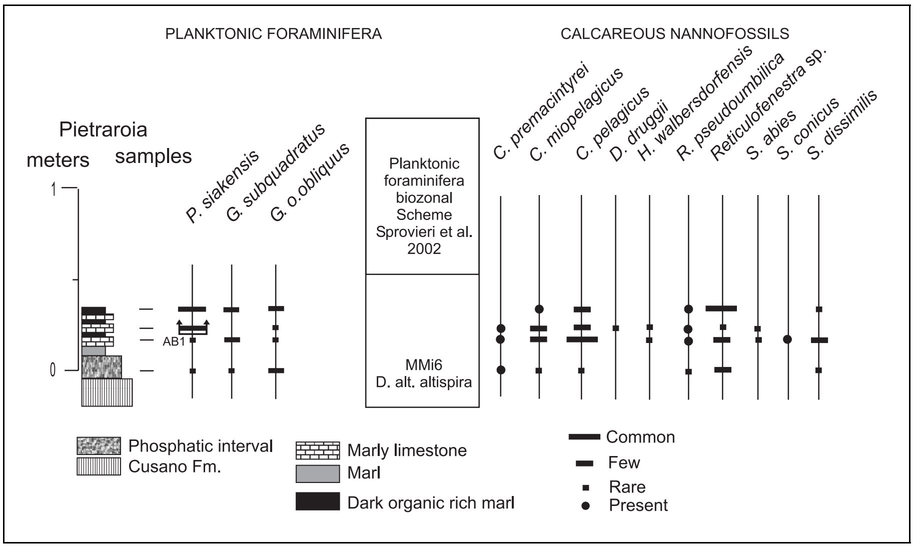

Fig. 12 - Lithologic log of Pietraroia section plotted versus the range charts of selected planktonic foraminifera and calcareous nannofossils with their estimated abundance. The position of planktonic foraminiferal bioevent is indicated by the following acronyms: AB1 (Acme Base 1).

Fig. 13 - Sampling trajectory of the Pietraroia section (40 cm-thick). Hand pack for the scale.

Paragloborotalia siakensis (4, 5, 7, 10, 12), which provides a good tool for biostratigraphic reconstruction of Middle Miocene Mediterranean stratigraphy (Foresi et al. 2002a; Foresi et al. 2002b; Sprovieri et al. 2002).

The age of the lower part of the sections is very close to the AcmeBase 1(AB1) of *P. siakensis,* astronomically dated at 13.21 Ma (Sprovieri et al. 2002; Iaccarino et al. 2004). This bioevent is recognised just above the phosphate-rich interval in different sections (Figs. 5, 7, 8, 10, 12). Unfortunately, this datum was not recognised in the Regia Piana section because the basal interval is completely barren.

The First Occurrence (FO) of *P. partimlabiata*, which defines the base of the MMi7 zone of Sprovieri et al. (2002) has been recognised in the Torrente Calvaruse, Le Torrette A, Pesco Rosito, Ponte Arcicchiaro A sections (Figs 4, 5, 7, 10).

The total range of *P. mayeri* is recorded within the range interval of *P. partimlabiata*. This biostratigraphic unit was entirely recorded at the Torrente Calvaruse section, and only partially in the other sections. After its appearance, the species is present, more or less frequently, in all the samples up to its extinction level, astronomically dated at 12.14 Ma (Lirer et al. 2002; Foresi et al. 2002a), (Fig. 5). The FCO and the LO of this species which define the base and the top of homonymous subzone (MMi7b) (Sprovieri et al. 2002) are also recorded in this section.

The exit of *P. partimlabiata*, recorded only in Regia Piana and Torrente Calvaruse sections (Figs 4, 5), coincides with the entry of the genus *Neogloboquadrina* (Foresi et al. 1998; Hilgen et al. 2000; Foresi et al. 2002a; Sprovieri et al. 2002; Di Stefano et al. 2002). The arrival of the Neogloboquadrinids (astronomically dated at 11.8 Ma, Lirer et al. 2002; Hilgen et al. 2000; Foresi et al. 2002a; Iaccarino et al. 2004) is caracterised by the FO of two species: *Neogloboquadrina acostaensis* and *N. atlantica praeatlantica* (Foresi et al. 2002c), which are two events easily detectable in the Mediterranean area (Hilgen et al. 2000; Foresi et al. 2002a; Foresi et al. 1998; Di Stefano et al. 2002; Iaccarino et al. 2004), defining the base of *N. atlantica praeatlantica* Zone (MMi8) (Sprovieri et al. 2002). At the beginning of their distribution range the coiling direction of the Neogloboquadrinids is random, *N. acostaensis* s.s. is rare and not typical, *N. atlantica praeatlantica* is dominant.

Another easily recognisable event in the Mediterranean is the Last Common Occurrence (LCO) of *G. subquadratus* which defines the top of *N. atlantica praeatlantica* Zone. In this paper, we tentatively placed this event only in Torrente Calvaruse section (Fig. 5).

The exit from the Mediterranean of *P. siakensis*, which defines the top of the homonymous zone (MMi9), is missing in all the studied sections.

In addition the LO of *N. atlantica atlantica*, astronomically dated at 10.9 Ma (Hilgen et al. 2000; Di Stefano et al. 2002; Iaccarino et al. 2004) and the FRO of *N. acostaensis* s.s. dx., which defines the base of the *Neogloboquadrina acostaensis* Zone (MMi11) (Sprovieri et al. 2002), astronomically dated at 10.54 Ma by Hilgen et al. (2000) and Di Stefano et al. (2002), have been recorded in the lower part of the Le Torrette B section (Fig. 8).

The FRO of *N. acostaensis* s.s. dx (astronomically dated at 10.54 Ma by Hilgen et al. 2000; Di Stefano et al. 2002) coincides with the beginning of the siliciclastic deposits of Pietraroia Formation (Fig. 8). Above this event the planktonic foraminiferal assemblage is mainly dominated by *G. obliquus obliquus* and *N. acostaensis* s.s. dx, but the preservation is very poor and sometime the tests are deformed.

Calcareous nannofossils

Calcareous nannofossils are generally rare to very rare and poorly preserved in all the studied sections, both in the Longano and Pietraroia Fms.. Reworking is very rare in the Longano Fm., while is continuously

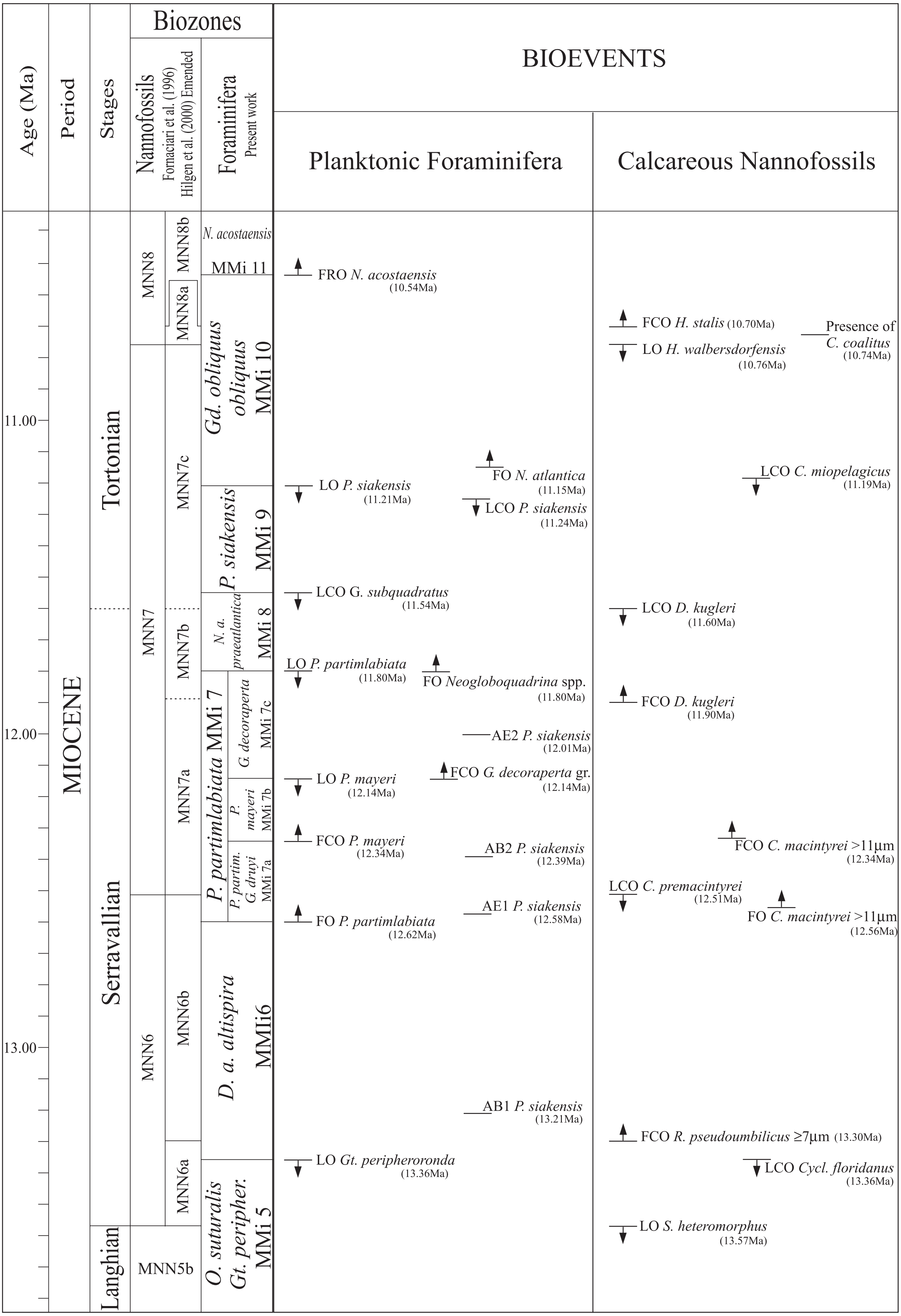

Fig. 14 - Integrated calcareous plankton biostratigraphy scheme of Sprovieri et al. (2002).

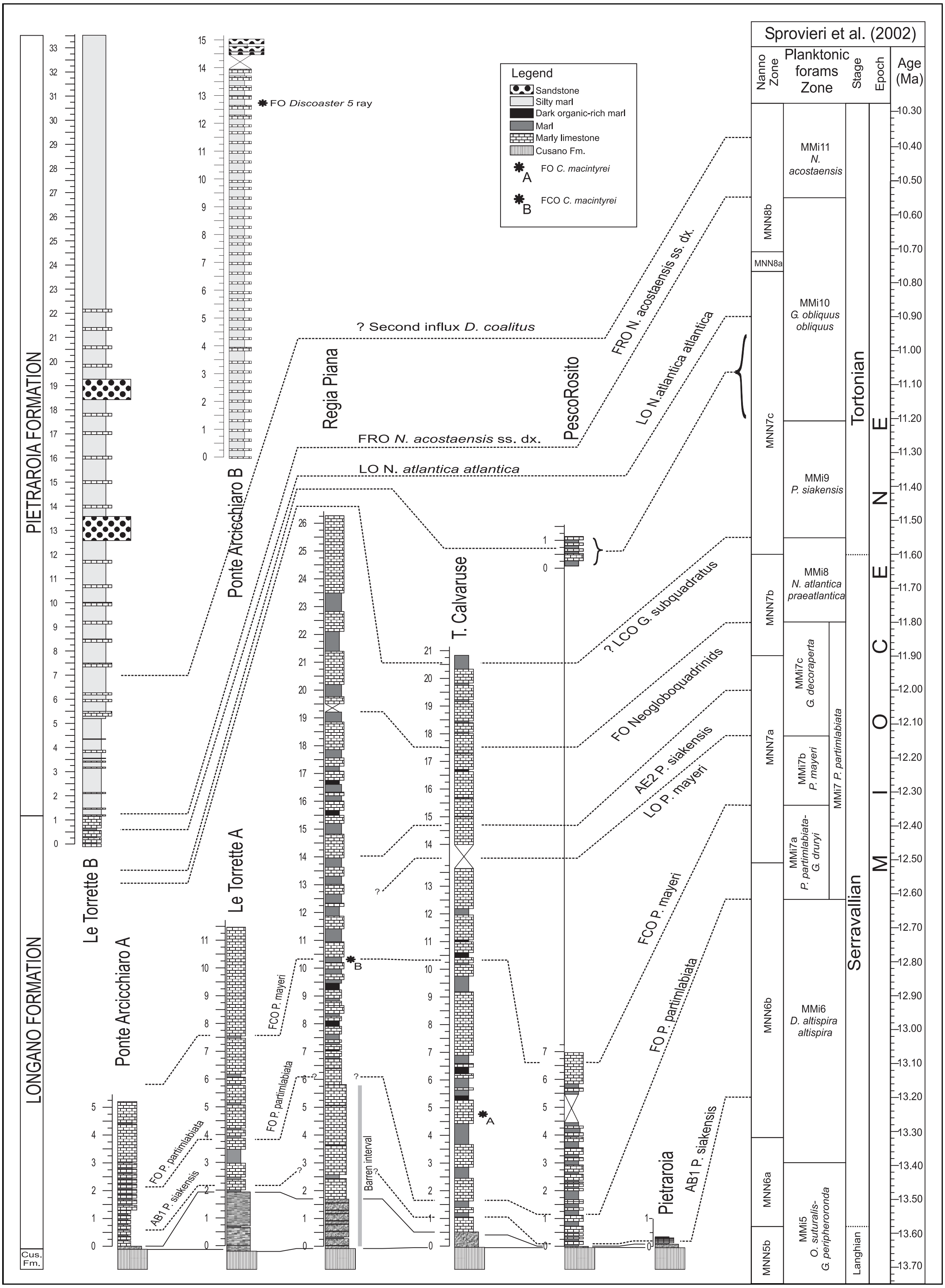

Fig. 15 - Biostratigraphic correlation of the studied sections. The position of bioevents are indicated by the following acronyms: FO (First Occurrence); LO (Last Occurrence); FCO (First Common Occurrence); LCO (Last Common Occurrence); FRO (First Regular Occurrence); AB1 (Acme Base 1); AE1 (Acme End 1); AB2 (Acme Base 2); AE2 (Acme End 2).

present and mainly consisting of Paleogene and Cretaceous taxa in the Pietraroia Fm..

Poor preservation and low abundance of the marker species prevent any biozonal attribution, therefore we could tentatively place against the planktonic foraminiferal zonation only the position of the FO and FCO of *Calcidiscus macintyrei* in the Torrente Calvaruse and Regia Piana sections, respectively (Figs 4, 5). In addition integrating calcareous plankton data, the second influx of *Catinaster coalitus*, dated at 10.379 Ma by Hilgen et al. (2000), is possibly present (Fig. 8), just above the base of the terrigenous deposits of the Pietraroia Fm. in the Le Torrette B section.

Moreover, the presence of five-rayed *Discoaster* is recorded in the uppermost part of the Ponte Arcicchiaro B section; these *Discoaster* can be referred to the late Miocene *Discoaster* five-rayed species (*D. bellus* group, *D. quinqueramus/berggrenii* and *D. hamatus,* sensu Rio, in Fornaciari, et al. (1990)) (Fig. 2 and Pl. 2). For more detail about discoasterids see Flores & Raffi (1995). This occurrence is very important because it allows to refer this subsection to the Tortonian and document the sedimentary hiatus between Ponte Arcicchiaro A and B sections (Fig. 2).

Conclusions

The integrated biostratigraphic data (planktonic foraminifera and calcareous nannofossils) from several sections belonging to the Longano Fm. along with a detailed fieldwork, allowed us to characterise and date the beginning of the deposition, of both the marly foraminifer-rich limestones and the successive siliciclastic deposits in the eastern part of Matese mountains.

The Miocene sedimentary succession of Longano Fm., although disturbed by many fractures, faults, and microslumpings, is almost complete from the lower Serravallian to the lowermost Tortonian.

In particular, in the lowest part of the studied sections, just above the transition from Cusato to Longano Fms., the AB1 of *P. siakensis* has been recorded (Fig. 15). This event astronomically dated at 13.21 Ma (Sprovieri et al. 2002 and Iaccarino et al. 2004) allowed us to date the beginning of marly limestone sediments of Longano Fm. (Fig. 15).

The boundary between the marly sequence of Longano Fm. and the beginning of siliciclastic deposits of Pietraroia Fm. is well exposed in the Le Torrette B section. As documented by Sgrosso (1998) and P. Scandone (pers. com.) the onset of the flysch deposition occurs through the increasing bed by bed influx of the siliciclastic fraction. In fact, in the lowest part of Le Torrette B section the occurrence of greenish marly silty beds at 1.50 m shows the end of carbonate sedimentation and the migration of the nappes from inner to external domains (Figs 8 and 9).

Our data are almost in good agreement with those recorded by Ciampo et al. (1987) for the beginning of terrigenous deposits of Pietraroia Fm. The FRO of *N. acostaensis* s.s. dx., astronomically dated at 10.54 Ma (Hilgen et al. 2000; Di Stefano et al., 2002; Iaccarino et. al. 2004) occurs in the first silty layer of the Le Torrette B section close to the Longano/Pietraroia Fm. boundary (Figs 2, 14, 15) identifying the base of *N. acostaensis* Zone (MMi 11) (Sprovieri et al. 2002). This zone corresponds to the *N. continuosa* subzone of Colalongo et al. (1979) identified by Ciampo et al. (1987) at the transition between the Longano and Pietraroia Fms..

Finally, our study proves that the trangression that led to the deposition of the *Orbulina Marls* was synchronous in all the south-eastern Matese Mountains and can be dated at 13.21 Ma, and the onset of terrigenous sedimentation in the investigated area started at 10.54 Ma. These data suggest about 2.66 My for the deposition of the Longano Fm.

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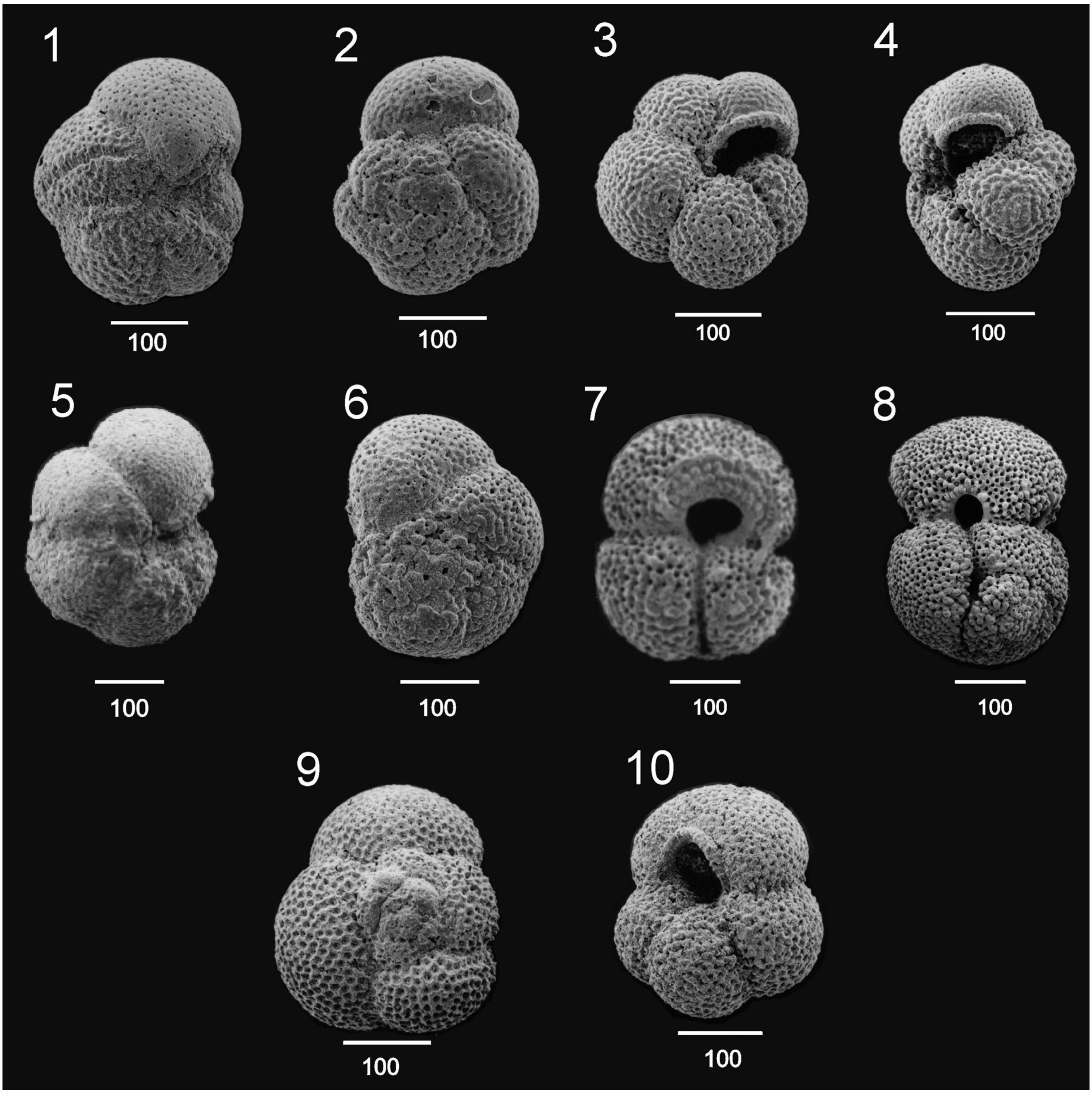

PLATE 1

Fig. 1 - *Paragloborotalia partimlabiata* ventral view, Sample CM10;
Fig. 2 - *Paragloborotalia partimlabiata* spiral view, Sample CM10;
Fig. 3 - *Paragloborotalia siakensis* ventral view, Sample CM10;
Fig. 4 - *Paragloborotalia siakensis* axial view, Sample CM10;
Fig. 5 - *Paragloborotalia mayeri* ventral view, Samples RP8;
Fig. 6 - *Paragloborotalia mayeri* spiral view, Samples RP8;
Fig. 7 - *Globigerinoides subquadratus* ventral view, Sample PR18;
Fig. 8 - *Globigerinoides subquadratus* axial view, Sample PR18;
Fig. 9 - *Neogloboquadrina atlantica praeatlantica* spiral view, Sample PR18;
Fig. 10 - *Neogloboquadrina atlantica praeatlantica* ventral view, Sample PR18. The bars=100 microns

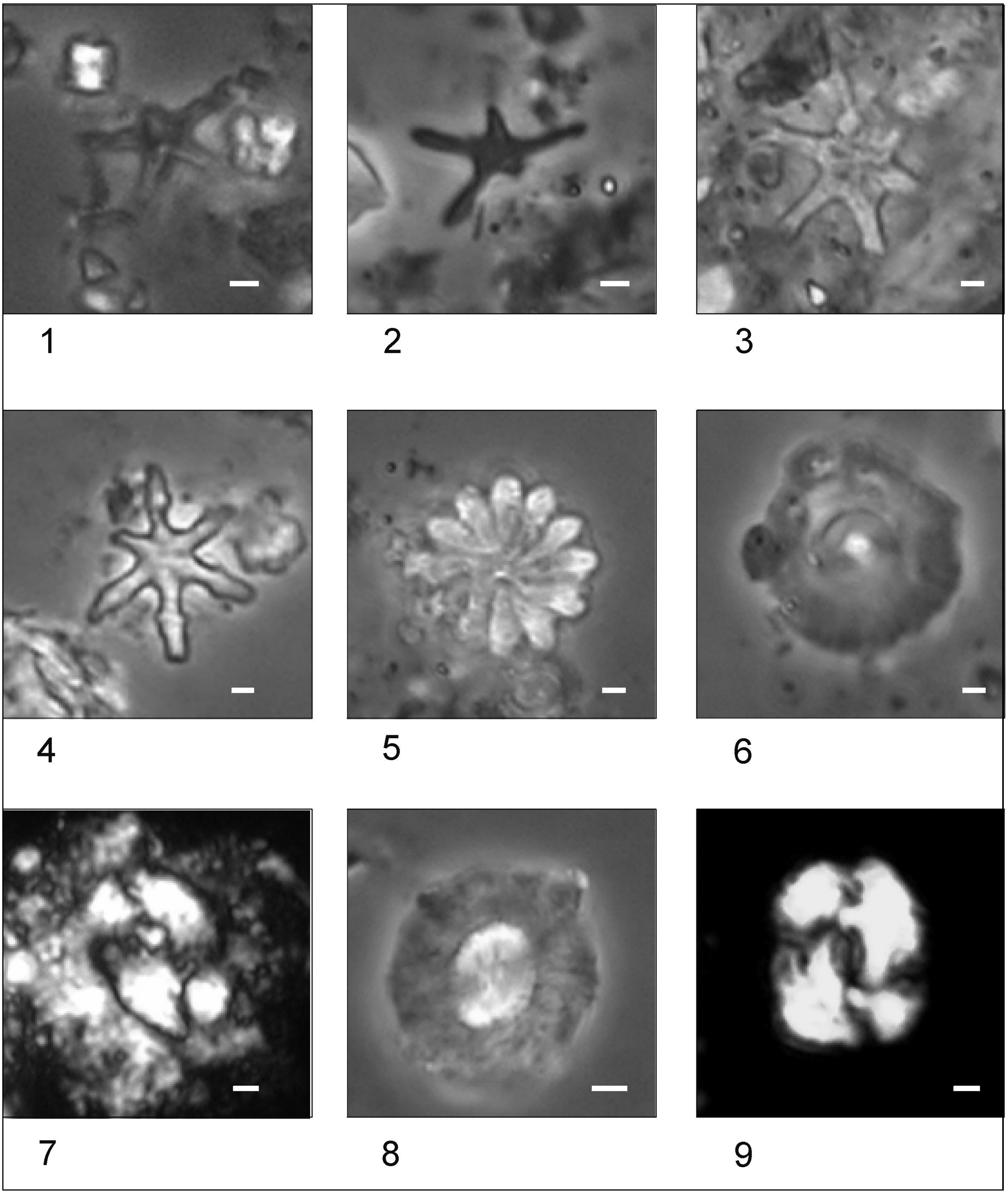

PLATE 2

Fig. 1 - *Discoaster* cf. *berggreeni* (5 ray), MO, phase contrast. Sample PA13;
Fig. 2 - *Discoaster* spp. (5 ray), MO, phase contrast. Sample PA13;
Fig. 3 - *Discoaster variabilis*, MO, phase contrast. Sample RP5;
Fig. 4 - *Discoaster tani nodifer* MO, phase contrast. Sample PA13;
Fig. 5 - *Discoaster barbadiensis* MO, phase contrast. Sample PA13;
Fig. 6 - *Calcidiscus macintyrei* MO, phase contrast. Sample PR3;
Fig. 7 - *Coccolithus miopelagicus* MO, X nicols. Sample PJ4;
Fig. 8 - *Coccolithus pelagicus* MO, phase contrast. Sample RP10;
Fig. 9 - *Reticulofenestra pseudoumbilicus* MO, X nicols. Sample PA7. The bars=100 microns

REFERENCES

Amore O., Ciampo G., Ruggiero E., Santo A. & Sgrosso I. (1988) - La successione miocenica del Matese Nord-Occidentale: Nuovi dati biostratigrafici e conseguenti ipotesi paleoceanografiche. *Mem. Soc. Geol. It.*, 41: 311-319, Roma.

Backman J., & Raffi I. (1997) - Calibration of Miocene nannofossil events to orbitally tuned cyclostratigraphies from Ceara Rise, In: Shackleton N.J., Curry W.B., et al. (eds.), *Proc. ODP, Sci. Res.*, 154: 83-99, College Station (TX).

Backman J. & Shackleton N.J. (1983) - Quantitative biochronology of Pliocene and early Pleistocene calcareous nannofossils from the Atlantic, Indian and Pacific oceans. *Mar. Micropaleont.*, 8: 141-170, Amsterdam.

Carannante G. (1982a) - La valle del canale (Civita di Pietraroia, Matese). Una incisione miocenica riesumata sul margine della piattaforma abruzzese-campana. *Geol. Romana*, 21: 511-521, Roma.

Carannante G. (1982b) - Modello deposizionale e diagenetico di un livello fosfatico del Miocene carbonatico dell'Appennino Campano. *Rend. Soc. Geol. It.*, 5; 15-20, Roma.

Carannante G., D'Argenio B. & Vigorito M. (2001) - I calcari Ittioliferi di Pietraroia: depositi di laguna o di riempimento di canale sottomarino? Nuove considerazioni deposizionali ed ambientali. In: *GeoSed 2001-Riunione Annuale del Gruppo Informale di Sedimentologia del CNR, 2-7 Ottobre, Potenza. – Atti e Guida alle Escursioni*. (Eds. Colella A., Longhitano S., Tropeano M.), 17-20.

Carannante G., Esteban M., Milliman J. D. & Simone L. (1988) - Carbonate lithofacies as paleolatitude indicators: problems and limitations. *Sedim. Geol.*, 60: 333-346, Amsterdam.

Carannante G., Severi C. & Simone L. (1996) - Off-shelf carbonate transport along foramol (temperate-type) open shelf margins: an example from the Miocene of the central-southern Apennines (Italy). *Mém. Soc. géol. France*, 169: 277-288, Paris.

Carannante G. & Vigorito M. (2001) - A channelized temperate-type carbonate margin: geometries and controlling factors. *Géologie méditerranéenne*, 28, 1-2: 41-44, Marseille.

Cascella A., Danese E., Merola D. & Sarti G. (2001) - Calcareous plankton biostratigraphy of the Fiume Orte section (Abruzzo, Central Apennines, Italy). *Geoitalia*, 3° *Forum FIST*: 234-236, Bellaria.

Catenacci E., De Castro P. & Sgrosso I. (1963) - Complessi-Guida del Mesozoico Calcareo-Dolomitico nella zona orientale del Massiccio del Matese. *Mem. Soc. Geol. It.*, 4: 1-20, Roma.

Ciampo G., Sgrosso I. & Ruggero Taddei E. (1983) - Età e modalità della messa in posto del massiccio del Matese nel bacino molisano. *Boll. Soc. Geol. It.*, 102: 573-580, Roma.

Ciampo G., Sgrosso I. & Ruggero Taddei E. (1987) - L'inizio della sedimentazione terrigena nel Matese nei Monti del Casertano e nei Monti di Suio. *Boll. Soc. Geol. It.*, 106: 323-330, Roma.

Cosentino D., Carboni M.G., Cipollari P., Di Bella L., Florindo F., Laurenzi M.A. & Sagnotti L. (1997) - Integrated stratigraphy of the Tortonian/Messinian boundary: The Pietrasecca composite section (Central Apennines, Italy). *Eclogae Geol. Helv.*, 90: 229-244, Basel.

Colalongo M.L., Di Grande A., D'Onofrio S., Giannelli L., Iaccarino S., Mazzei R., Romeo M. & Salvatorini G. (1979) - Stratigraphy of Late Miocene Italian section straddling the Tortonian/Messinian boundary. *Boll. Soc. Paleont. It.*, 18: 258-302, Modena.

Crescenti U., Costella A., Donzelli G. & Raffi G. (1969) - Stratigrafia della serie calcarea nella regione marchigiano-abruzzese (dal Lias al Miocene). Parte 2. *Mem. Soc. Geol. It.*, 8 (4): 343-420, Roma.

D'Argenio B., Pescatore T. & Scandone P. (1973) - Schema geologico dell'Appennino Meridionale (Campania, Lucania). *Acc. Naz. dei Lincei, Quaderno*, 183: 49-72, Roma.

Di Stefano E. (1998) - Calcareous nannofossils quantitative biostratigraphy of Holes 969E and 963B (Eastern Mediterranean), In: Robertson, A.H.F., Emeis, K.C., Ricther, C., and Camerlenghi, A., (eds.), *Proc. ODP, Sci. Res.*, 160: 99-112, College Station (TX).

Di Stefano E., Bonomo S., Caruso A., Dinarés-Turell J., Foresi L., Salvatorini G. & Sprovieri R. (2002) - Calcareous plankton bio-events in the Miocene Case Pelacani section (Southeastern Sicily, Italy), In: Iaccarino, S.M., (ed.), Integrated Stratigraphy and Paleoceanography of the Mediterranean Middle Miocene. *Riv. It. Paleont. Strat.*, 108 (2): 307-324, Milano.

Foresi L.M., Bonomo S., Caruso A., Di Stefano E., Salvatorini G. & Sprovieri R. (2002b) - Calcareous plankton high resolution biostratigraphy (foraminifera and nannofossils) of the uppermost Langhian - lower Serravallian Ras Il-Pellegrin section (Malta), In: Iaccarino, S.M., (ed.), Integrated Stratigraphy and Paleoceanography of the Mediterranean Middle Miocene. *Riv. It. Paleont. Strat.*, 108 (2): 195-210, Milano.

Foresi L.M., Bonomo S., Caruso A., Di Stefano A., Di Stefano E., Iaccarino S.M., Lirer F., Mazzei R., Salvatorini G. & Sprovieri R. (2002a) - High resolution calcareous plankton biostratigraphy of the Serravallian succession of the Tremiti Islands (Adriatic Sea, Italy), In: Iaccarino, S.M., (ed.), Integrated Stratigraphy and Paleoceanography of the Mediterranean Middle Miocene, *Riv. It. Paleont. Strat.*,108 (2): 257-274, Milano.

Foresi L.M., Iaccarino S., Mazzei R. & Salvatorini G. (1998) - New data on middle to late Miocene calcareous plankton biostratigraphy in the Mediterranean area. *Riv. Ital. Paleont. Strat.*, 104: 95-114, Milano.

Foresi L.M., Iaccarino S.M. & Salvatorini G. (2002c) - *Neogloboquadrina atlantica praeatlantica*, new subspecies from late Middle Miocene, In: Iaccarino, S.M., (ed.), Integrated Stratigraphy and Paleoceanography of the Mediterranean Middle Miocene, *Riv. It. Paleont. Strat.*, 108 (2): 325-336, Milano.

Fornaciari E., Di Stefano A., Rio D. & Negri A. (1996) - Middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. *Micropaleontology*, 42: 37-63, Amsterdam.

Hilgen F.J., Krijgsman W., Raffi I., Turco E. & Zachariasse W.J. (2000) - Integrated stratigraphy and astronomical calibration of the Serravallian/Tortonian boundary section at Monte Gibliscemi (Sicily, Italy). *Mar. Micropaleont.*, 38: 181-211, Amsterdam.

Iaccarino S. (1985) - Mediterranean Miocene and Pliocene planktic foraminifera. In: Bolli H.M. et al. - Plankton Stratigraphy, 1: 283-314, Cambridge Univ. Press.

Iaccarino S., Lirer F., Bonomo S., Caruso A., Di Stefano A., Di Stefano E., Foresi L.M., Mazzei R., Salvatorini G., Sprovieri M., Sprovieri R. & Turco E. (2004) -Astrochronology of Late Middle Mediterranean sections. In: Cyclostratigraphy: An Essay of Approaches and Case Histories *SEPM*, Special Publication, 81: 25-42, Boulder.

Lirer F. (2000) - A new technique for retrieving calcareous microfossils from lithified lime deposits. *Micropaleontology*, 46 (4): 365-369, New York.

Lirer F., Caruso A., Foresi L.M., Sprovieri M., Bonomo S., Di Stefano A., Di Stefano E., Iaccarino S.M., Salvatorini G., Sprovieri R. & Mazzola S. (2002) - Astrochronological calibration of the upper Serravallian/lower Tortonian sedimentary sequence at Tremiti Islands (Adriatic Sea, Southern Italy), In: Iaccarino S.M., (ed.), Integrated Stratigraphy and Paleoceanography of the Mediterranean Middle Miocene, *Riv. It. Paleont. Strat.*, 108 (2): 241-256, Milano.

Mutti M., Bernoulli D., Spezzaferri S. & Stille P. (1999) - Lower and Middle Miocene carbonate facies in the central Mediterranean: the impact of paleoceanography on sequence stratigraphy. *SEPM* (Spec. Vol.), 60: 371-384, Boulder.

Pampaloni M.L., Pichezzi R.M., Raffi I. & Rossi M. (1994) - Calcareous planktonic biostratigraphy of the marne a Orbulina unit (Miocene, central Italy). *Giorn. Geol.,* ser.3, 56(1): 138-153, Bologna.

Raffi I., Rio D., d'Atri A., Fornaciari E. & Rocchetti S. (1995) - Quantitative distribution patterns and biomagnetostratigraphy of middle and late Miocene calcareous nannofossils from equatorial Indian and Pacific oceans (Legs 115, 130 and 138), In: Pias, N.G., Mayer, L.A., et al., (eds.), *Proc. ODP Sci. Res.*, 138: 479-502, College Station (TX).

Raffi I. & Flores J.A. (1995) - Pleistocene through Miocene calcareous nannofossils from Eastern Equatorial Pacific Ocean (LEG 138), In: Pias, N.G., Mayer, L.A., et al., (eds.), *Proc. ODP, Sci. Res.*, 138: 233-286, College Station (TX).

Rio D., Raffi I., & Villa G. (1990) - Pliocene-Pleistocene calcareous nannofossil distribution patterns in the Western Mediterranean, *in* Kastens, K.A., Mascle, J. et al., eds., *Proc. ODP, Sci. Res.,*107: 513-533, College Station (TX).

Selli R. (1957) - Sulla trasgressione miocenica nell'Italia Meridionale. *Giornale Geologia*, 26: 1-54, Bologna.

Sgrosso I. (1998) - Possibile evoluzione cinematica nell'orogene Centro-Sud-Appenninico. *Boll. Soc. Geol. It.,* 117: 679-724, Roma.

Simone L. & Carannante G. (1985) - Evolution of a Miocene carbonate open shelf from inception to drowning: the case of the southern Apennines. *Rend. Acc. Sc. Fis. Mat.*, 52: 1-25, Napoli.

Sprovieri R., Bonomo S., Caruso A., Di Stefano A., Di Stefano E., Foresi L.M., Iaccarino S.M., Lirer F., Mazzei R. & Salvatorini G. (2002) - An integrated calcareous plankton biostratigraphic scheme and biochronology for the Mediterranean Middle Miocene, In: Iaccarino, S.M., (ed.), Integrated Stratigraphy and Paleoceanography of the Mediterranean Middle Miocene, *Riv. It. Paleont. Strat.*,108 (2): 337-353, Milano.