

Integrated calcareous nannofossil and foraminiferal biostratigraphy of Pliocene terrigenous deposits from the Southern Apennines (Lucania, Italy)

Patrizia MAIORANO

Dipartimento di Geologia e Geofisica
Università di Bari

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ABSTRACT – Pliocene terrigenous sediments cropping out at the transition between the Southern Apennines thrust belt and the Bradanic Foredeep (Southern Italy) were investigated by means of an integrated biostratigraphic study on calcareous nannofossil and planktonic foraminiferal assemblages. The examined deposits have been previously referred to the transgressive part of the Bradanic Cycle, late Pliocene to early Pleistocene in age.

Despite the presence of a considerable amount of pre-Pliocene and Pliocene reworked specimens and the rarity or the absence of some marker species, the quantitative approach to calcareous nannofossil biostratigraphy as well as the integration with foraminiferal data allow to recognize several biozonal events within the early Pliocene and the late middle to late Pliocene record. The first occurrences of *Bulimina basispinosa* and *Bulimina marginata* among the benthic foraminifera were also detected; these events permit to recognize the intervals VII and VIII of Spanak (1983), respectively. Two horizons characterized by abundant diatoms and silicoflagellates, well correlatable in two sections, have been observed.

The biostratigraphic results allow to assert that in the studied area the conglomeratic-sandy and silty-clayey deposits are referable to the nannofossil Zone MNN14-15 and to the Globorotalia puncticulata planktonic foraminiferal Zone of early Pliocene age; the expanded clayey succession, that overlies the middle Pliocene conglomeratic and calcarenitic-sandy deposits, is middle to late Pliocene in age and spans the interval from the upper part of the nannofossil Zone MNN16a to Zone MNN19a – the Globorotalia crassaformis (partim) and Globorotalia inflata planktonic foraminiferal Zones. It is worth mentioning that the interval spanning the upper lower Pliocene to the lower middle Pliocene is not represented in the studied area. The biostratigraphic results, compared to previous stratigraphic data, suggest that the studied deposits are correlatable with two different sedimentary cycles, recognized in other areas at the outer border of the Southern Apennines.

RIASSUNTO – [Biostratigrafia integrata basata sui nannofossili calcarei e foraminiferi dei depositi terrigeni pliocenici dell'Appennino meridionale (Lucania)] – Vengono esposti i risultati di uno studio biostratigrafico integrato a nannofossili calcarei e foraminiferi planctonici condotto su depositi terrigeni pliocenici affioranti in prossimità del margine esterno dell'Appennino lucano (Italia meridionale), nell'area compresa tra S. Mauro Forte e Stigliano (Basilicata). Tali depositi, secondo la cartografia ufficiale, rappresentano la fase trasgressiva suprapliocenico-infrapleistocenica del Ciclo bradanico sulle unità pre-plioceniche.

Nonostante la consistente presenza di fenomeni di rimaneggiamento pre-pliocenico e pliocenico e la rarità o assenza di alcune specie marker, lo studio quantitativo sulle associazioni a nannofossili calcarei e il confronto con le associazioni a foraminiferi ha permesso di riferire i sedimenti analizzati a precisi intervalli biozonali, compresi tra il Pliocene inferiore ed il Pliocene superiore. Ai fini di una migliore risoluzione stratigrafica sono state inoltre considerate le distribuzioni di alcune specie di foraminiferi bentonici: in particolare la prima comparsa di *Bulimina basispinosa* e di *Bulimina marginata*. Viene inoltre segnalata la presenza di due orizzonti contenenti abbondanti diatomee e silicoflagellate ben correlabili in due delle sezioni analizzate.

I risultati biostratigrafici indicano che nell'area in esame i depositi sabbioso-conglomeratici e argilloso-siltosi infrapliocenici sono attribuibili alla Zona MNN14-15 (nannofossili) e alla Zona a Globorotalia puncticulata (foraminiferi planctonici), mentre le estese successioni argillose meso-supraplioceniche, poggianti stratigraficamente su depositi conglomeratici e calcarenitico-sabbiosi del Pliocene medio, sono riferibili ad un intervallo compreso tra la parte alta della Zona MNN16a e la Zona MNN19a – Zona a Globorotalia crassaformis e Zona a Globorotalia inflata. Nell'area indagata risulta assente l'intervallo compreso tra la parte alta del Pliocene inferiore e la parte inferiore del Pliocene medio. I risultati ottenuti, e il confronto con studi precedenti in aree prossime a quella in oggetto, suggeriscono che i depositi pliocenici esaminati sono correlabili a due cicli sedimentari distinti, riconosciuti in altre località ubicate in prossimità del margine esterno dell'Appennino meridionale.

INTRODUCTION

Pliocene and Pleistocene terrigenous clayey deposits crop out widely along the outer border of the Southern Apennines. They proved to be suitable for a biostratigraphic study of the calcareous plankton assemblages, allowing good correlations at a regional scale. The Pliocene and Pleistocene integrated calcareous plankton biostratigraphy is well established at present and provides a high biostratigraphic resolu-

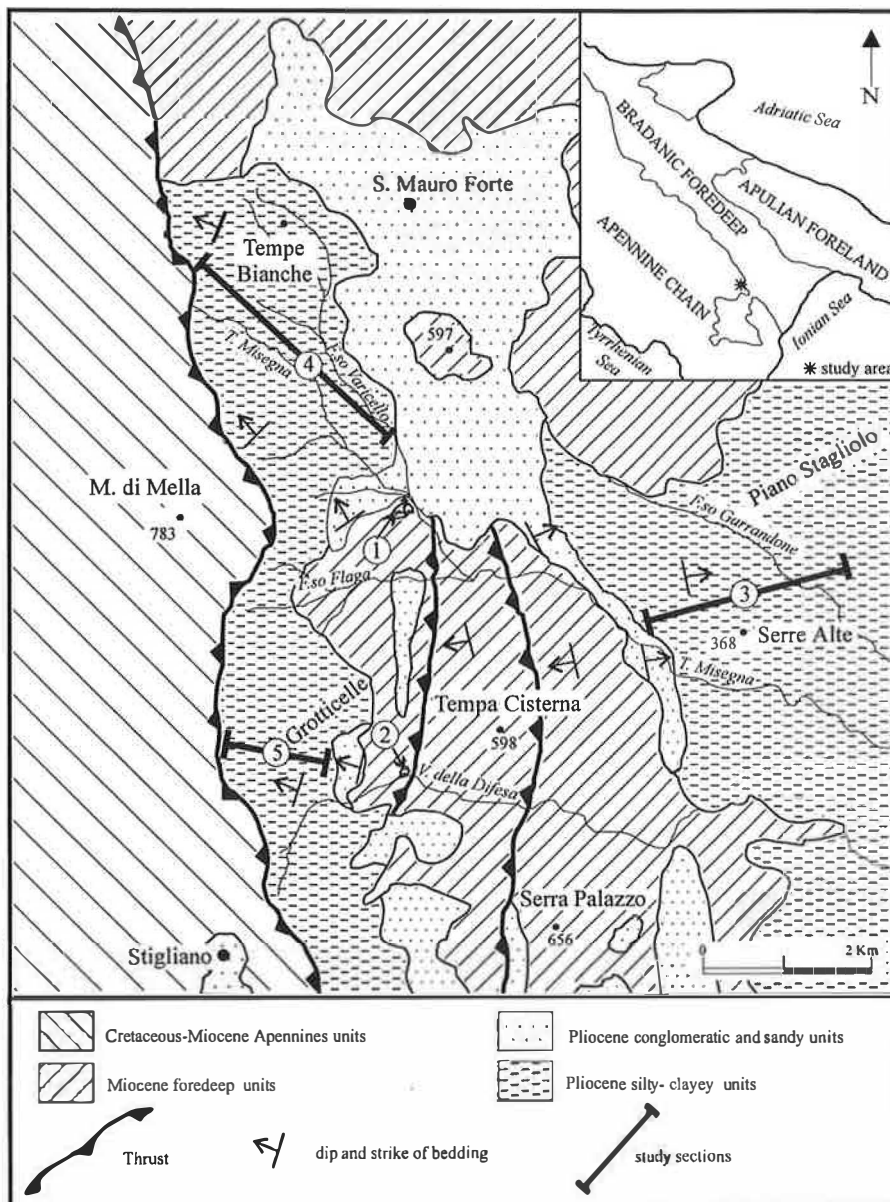
tion of the geological record of the Mediterranean area. Few papers (Marino, 1992, 1994; Amore *et al.*, 1996) have already discussed the possibility of applying the recent Mediterranean Pliocene and Pleistocene biozonal schemes to the Southern Apennines terrigenous deposits. Since strong reworking and dilution of calcareous plankton due to the great amount of inorganic detritus may bias biostratigraphic data, in this study an integrated biostratigraphic approach on calcareous nannofossils and planktonic forami-

fera, implemented by a quantitative analysis on calcareous nannofossils, highly improved the biostratigraphic resolution of the Pliocene record from the Southern Apennines Foredeep. Stratigraphic studies on these deposits are still in progress in order to clarify the evolution of the Pliocene-Pleistocene Bradanic Foredeep.

This paper deals with the biostratigraphic results based on calcareous nannofossil and planktonic foraminiferal assemblages from five Pliocene terrigenous sections. These sections were surveyed at the outer border of the Southern Apennines between S. Mauro Forte and Stigliano in the Basilicata region (Text-fig. 1). New data on Pliocene biostratigraphy from Mediterranean terrigenous sediments are discussed.

GEOLOGICAL FRAMEWORK

The investigated area is located at the transition between the eastern side of the Southern Apennines and the Bradanic Foredeep (Text-fig. 1) where Plio-Pleistocene terrigenous clayey deposits are widely exposed. The Apennines units are here represented by Cretaceous to Miocene flysch deposits referable to the Flysch Rosso Formation (Scandone, 1967) and the Flysch Numidico Formation (Ogniben, 1963). The Bradanic Trough represents a Plio-Pleistocene domain located between the Southern Apennines thrust belt and the Apulian foreland units. In various localities at the outer border of the Southern Apennines, the Pliocene and lower Pleistocene



Text-fig. 1 - Geological sketch map of the studied area and location of the investigated sections. After: Geological map of Italy 1:100.000, Foglio 200 "Tricarico" (Boenzi *et al.* 1971), Maiorano (1991) and Gallicchio & Maiorano (1999). 1) Torrente Miscogna-Fosso Varicello section; 2) Valle Difesa section; 3) Serre Alte section; 4) Fosso Varicello section; 5) Grotticelle section.

deposits have been referred to two different sedimentary cycles, early-middle Pliocene and middle/late Pliocene-early Pleistocene in age, respectively (Centamore *et al.*, 1971; Maggiore & Walsh, 1975; Boenzi *et al.*, 1979; Maggiore *et al.*, 1981; Sabato, 1984; Caldara *et al.*, 1993; Sabato & Marino, 1994; Amore *et al.*, 1996; 1997), on the basis of the presence of an angular unconformity and/or a stratigraphic gap between the lower and upper cycle.

According to Boenzi *et al.* (1971, F° 200 of the "Geological map of Italy", 1:100.000), the studied deposits in the investigated area are ascribed to the transgressive part of the Bradanic Cycle, dated to the late Pliocene-early Pleistocene. From a lithostratigraphic point of view, they consist of conglomerates and calcarenitic sands, referred to the "Sabbioni di Garaguso" Formation, in the lower part, stratigraphically overlain by silty-clayey deposits referred to the "Argille di Gravina" Formation (Boenzi *et al.*, 1971). As a whole, these sediments are considered as an ingressive hemicycle of Plio-Pleistocene age. In several localities adjacent to the examined area, other researchers recognized two different sedimentary cycles within the Plio-Pleistocene deposits on the basis of stratigraphical evidences (Maggiore & Walsh, 1975; Sabato, 1984; Caldara *et al.*, 1993; Sabato & Marino, 1994). In particular, the lowest cycle was referred to the lower Pliocene nannofossil Zone MNN14-15 (Sabato & Marino, 1994), somewhere extending higher to the lower part of Zone MNN16a (Caldara *et al.*, 1993); the uppermost one, which lies unconformably on lower Pliocene deposits or on pre-Pliocene flysch deposits, is assigned to the upper part of Zone MNN16a to Zone MNN16b-17 (Sabato & Marino, 1994) or spans the interval from the middle Pliocene Zone MNN16a to the lower Pleistocene *Calcidiscus macintyre* Zone (Caldara *et al.*, 1993).

In this study, five sections have been sampled in the Pliocene clayey deposits (Text-fig. 1). In particular, the sediments in the Torrente Misegna-Fosso Varicello and Valle della Difesa sections lie unconformably on the Miocene foredeep units and consist mainly of silty-clays with a conglomeratic-sandy interval in the basal part. They have a monoclinal setting dipping towards the north, are areally limited and their thickness does not exceed 20 m. The Serre Alte, Fosso Varicello and Grotticelle sections are mainly composed of clayey sediments, 100-360 m thick, that are widely outcropping. The succession lies stratigraphically on a middle Pliocene conglomeratic and calcarenitic-sandy body, about 50-60 m thick, transgressive on pre-Pliocene units. In the western sector, the clayey deposits have a NW dipping and are truncated and overthrust by the Cretaceous-Miocene Apennines Units; in the eastern sector, they display mainly a monoclinal setting with a NE dipping towards the outer part of the Bradanic Trough.

MATERIAL AND METHODS

Clays and silty clays are the main lithologies in the studied sections. They bear abundant calcareous nannofossils and foraminifera; moreover, an abundant biogenic siliceous content (diatoms, silicoflagellates and sponge spicules) has been recorded in two silty levels in the lower part of the Serre Alte and Fosso Varicello sections. These two levels, white-grey in colour, are few centimetres thick and show a weak parallel lamination.

The calcareous nannofossil study has been performed on smear slides observed with an optical microscope at 1000X magnification. The quantitative methods of Backman & Shackleton (1983) and Rio *et al.* (1990) have been followed: a) the abundance patterns of discoasters were constructed starting from counting 50 to 100 taxonomically related forms, then the abundance of various discoaster taxa was plotted as a number of specimens per mm². Although discoasters are often rare in the studied sections, this method was of great utility in the middle and upper Pliocene interval allowing to identify reliably the last occurrences (LO) of *Discoaster tamalis*, *D. pentaradiatus* and *D. brouweri* and to critically evaluate the amount of reworking. Within the *Dictyococcites productus* Zone (MNN 19a), numerical occurrences of all reworked discoasters have been detected by scanning an area of 20 mm². In addition, in the lower Pliocene, the abundance patterns of *Reticulofenestra pseudumbilicus* and *Sphenolithus* spp. have been identified by counting 500 specimens > 4 µm in size from the total assemblage and then plotted as percentages. Estimated abundances of the species not considered in the countings are reported in the range charts (Tables 1-5); they result from qualitative analyses of about 3000 specimens.

Planktonic foraminiferal assemblages have been studied qualitatively on washed residues from the fraction >125 µm (sample total weight 350 g). Few marker species among benthic foraminifera have also been identified in order to improve the biostratigraphic resolution.

BIOSTRATIGRAPHY

Several Pliocene and Pleistocene calcareous plankton biostratigraphic schemes have been proposed so far for regional correlations within the Mediterranean area (Schmidt, 1973; Müller, 1978; Ellis, 1979; Raffi & Rio, 1979 for calcareous nannofossils; Cita, 1973, 1975; Colalongo & Sartoni, 1979; Iaccarino & Salvatorini, 1982; Spaak, 1983; Iaccarino, 1985; Sprovieri, 1992 for planktonic foraminifera).

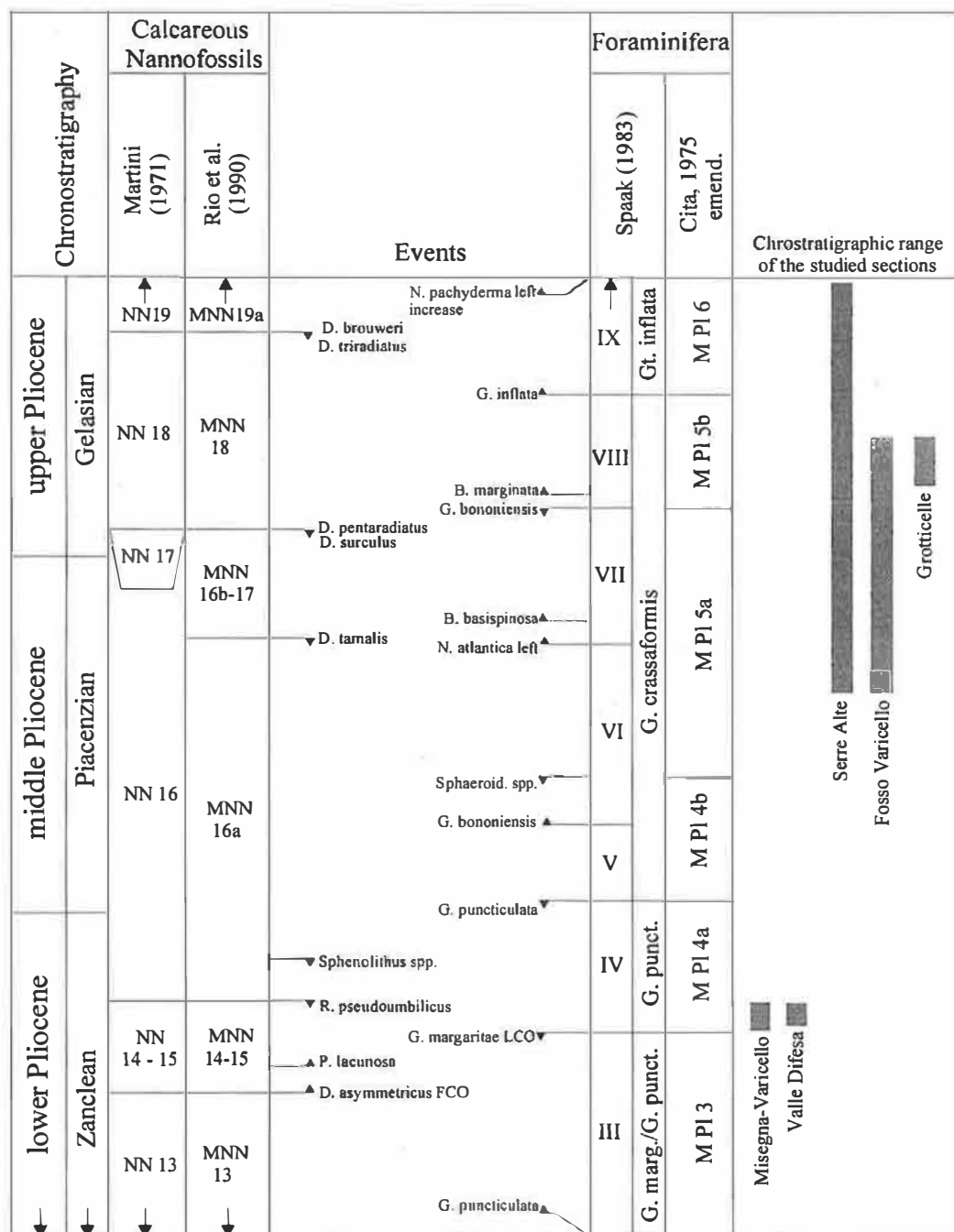
The calcareous nannofossil biozonal scheme of Rio *et al.* (1990) has been followed in the present work (Text-fig. 2), as it has been largely adopted by various authors within the Mediterranean region both in pelagic and terrigenous land sections as well

as in deep-sea records. The scheme provides a quantitative definitions of zonal boundaries and is of great utility for a critical evaluation of the distribution of species, reliability of calcareous nannofossil events and reworking.

In Text-fig. 2 the chronostratigraphic range of the studied sections is also shown. According to the above mentioned zonal scheme, the following biozones have been identified, (a) the *Reticulofenestra pseudoumbilicus*

Zone (MNN14-15) in the lower Pliocene; (b) the upper part of Zone MNN16a and Zones MNN16b-17, MNN18 and MNN19a in the middle and upper Pliocene.

Concerning the planktonic foraminifera, the biostratigraphic scheme of Spaak (1983) has been adopted in this study (Text-fig. 2). The biozonal scheme of Cita (1975), emended by Rio *et al.* (1984) and Sprovieri (1992), could not be applied since the iden-



Text-fig. 2 - Mediterranean Pliocene calcareous nannofossil and foraminiferal biostratigraphic schemes adopted in this study and comparison with calcareous nannofossil standard zonation. The chronostratigraphic range of the studied sections is also shown.

tification of the last occurrence (LO) of *Sphaeroidinellopsis* spp., which defines the base of Zone MPL5a, was prevented by the absence of these taxa in the studied sections. Moreover, the rare and scattered occurrence of *Globorotalia bononiensis* in the studied interval prevented a reliable identification of the LO of this taxon, which defines the base of Zone MPL5b (Text-fig. 2). On the other hand, the co-occurrence of *Globorotalia crassaformis* and *G. bononiensis*, even rare, in the absence of *Globorotalia puncticulata* allows to recognize the *G. crassaformis* Zone of Spaak (1983); the base of the *Globorotalia inflata* Zone is recognized on the first occurrence (FO) of *G. inflata* (Spaak, 1983) in the upper Pliocene.

Correlation between the calcareous nannofossil scheme of Rio *et al.* (1990) and the foraminiferal biozones of Spaak (1983) results in a well established calcareous plankton biostratigraphic scheme for the Pliocene record within the Mediterranean area (Rio *et al.*, 1990, 1994; Sprovieri, 1993) (Text-fig. 2). Chronostratigraphic boundary have been traced according to Rio *et al.* (1998) and Castradori *et al.* (1998). Chronology of the Pliocene events, according to the time scale of Hilgen (1991) and Cande & Kent (1992; 1995), is also available in Sprovieri (1993) and Berggren *et al.* (1995), respectively.

Two benthic foraminiferal events, the FOs of *Bulimina basispinosa* and *Bulimina marginata*, have also been plotted against the calcareous plankton scheme (Text-fig. 2). These two events, previously proposed by Colalongo & Sartoni (1979) and Colalongo *et al.* (1982), have been dated by Sprovieri (1985) and Sprovieri & Hasegawa (1990) and re-calibrated to the GPTS of Cande & Kent (1995) by Maiorano *et al.* (in prep.), allowing a more precise correlation of the FOs of *B. basispinosa* and *B. marginata* with the integrated calcareous plankton biozonal events (Text-fig. 2). The FOs of *B. basispinosa* and *B. marginata* resulted to be important additional biostratigraphic events. In particular, the FO of *Bulimina basispinosa* slightly postdates the base of interval VII of Spaak (1983), defined on the FO of left coiled *Neoglobobulimina atlantica* (a taxon not recorded in the studied sections) and, in agreement with Sprovieri (1985), occurs just above the LO of *Discoaster tamalis*; the FO of *B. marginata* was identified between the LO of *D. pentaradiatus* and the FO of *G. inflata* and slightly postdates the base of interval VIII of Spaak (1983), defined by the LO of *G. bononiensis*. Consequently, the FOs of *B. basispinosa* and *B. marginata* can be used for identifying the intervals VII and VIII of Spaak (1983).

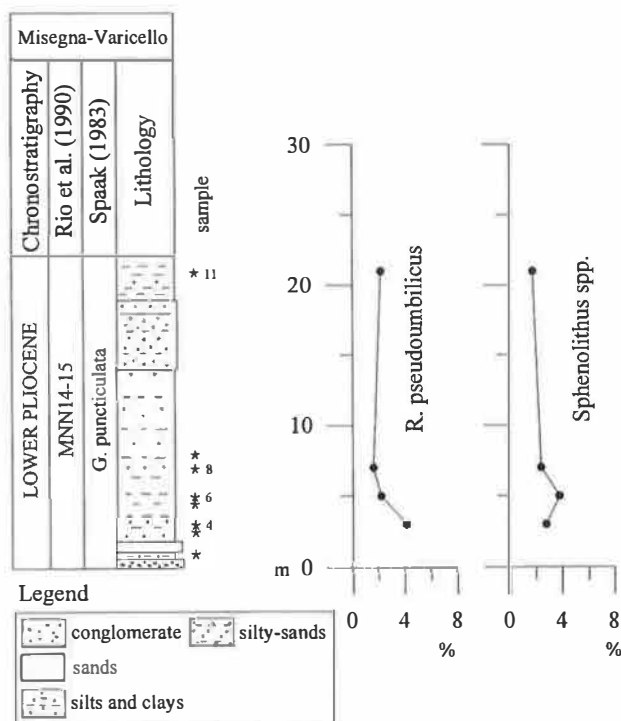
LOWER PLIOCENE DEPOSITS

TORRENTE MISEGNA – FOSSO VARICELLO SECTION

This section crops out at the confluence of the Torrente Misegna with Fosso Varicello (Text-fig. 1). It

is about 20 m thick and consists of a conglomeratic-sandy interval about 2 m thick (Text-fig. 3), transgressive on the pre-Pliocene units, passing upwards to a silty-clayey succession.

Calcareous nannofossils and foraminifera recovered in 8 samples (Table 1) from the pelitic interval are generally rare and poorly diversified. Nevertheless, the section could be referred to the lower Pliocene based on the identification of the MNN14-15 Zone and *G. puncticulata* Zone (= interval IV of Spaak, 1983). Few to rare specimens of *Pseudoemiliania lacunosa*, the FO of which is considered a secondary event in the zonal scheme within the MNN14-15 Zone (Rio *et al.*, 1990), have been recorded in this section. *Helicosphaera sellii* is also present in the assemblages. Abundance patterns of *R. pseudumbilicus* and *Sphenolithus* spp. have been monitored in the section. The relative abundance of *R. pseudumbilicus* (Text-fig. 3; Table 1) seems to indicate an interval below the LO of this species, which, according to Rio *et al.* (1990), is defined by a drop in abundance below 2%; in this section, with the exception of sample 8, *R. pseudumbilicus* displays percentages higher than 2%. Moreover, Rio *et al.* (1990) equated the LO of *Sphenolithus* spp. to a drop in abundance of these taxa below 1%; in this section the abundance of *Sphenolithus* spp. ranges from 1.8% to 3.8% suggesting that the entire section predates the LO of these taxa. Discoasters are extremely rare in the section and



Text-fig. 3 - Abundance patterns of *R. pseudumbilicus* and *Sphenolithus* spp. in the T. Misegna-Fosso Varicello section.

MISEGNA - VARICELLO	Sample							
	1	3	4	5	6	8	9	11
Calcareous Nannofossils								
Total Abundance	F	C	F	C	F	F	C	F
Preservation	M	M	P	M	P	P	P	M
<i>Amaurolithus delicatus</i>	R	*	*	*	*	*	*	*
<i>Calcidiscus leptoporus</i>	F	C	F	C	R	R	C	R
<i>C. macintyre</i>		R	F	*	R	*	*	*
<i>Coccolithus pelagicus</i>	C	A	F	A	C	C	C	C
<i>Dictyococcites productus</i>	F	C	R	C	F	*	*	*
<i>Discoaster brouweri</i>	*	*	*	R	R	*	*	R
<i>D. intercalaris</i>	R	R	*	*	*	R	*	*
<i>D. pentaradiatus</i>	*	R	R	*	R	*	*	R
<i>D. surculus</i>	*	*	*	R	*	*	*	*
<i>D. triradiatus</i>	*	*	*	R	*	R	*	*
<i>D. variabilis</i>	R	R	R	*	R	*	R	*
<i>Discoaster</i> spp.	*	*	*	R	*	R	*	*
<i>Helicosphaera carteri</i>	*	R	*	*	R	R	R	R
<i>H. sellii</i>	*	F	F	F	R	F	R	F
<i>Pontosphaera</i> spp.	*	F	*	R	*	R	R	R
<i>Pseudoemiliania lacunosa</i>	*	R	*	R	*	R	R	R
<i>Reticulofenestra minuta</i>	*	A	C	A	C	F	C	*
<i>R. minutula</i>	C	C	C	C	C	C	F	C
<i>R. pseudumbilicus</i>	F	F	4.2	F	2.2	1.6	F	2.2
<i>R. small pseudumbilicus</i>	*	*	F	C	F	F	F	F
<i>Sphenolithus</i> spp.	F	C	2.8	F	3.8	2.4	F	1.8
Planktonic Foraminifera		B		B			B	
<i>Globigerina bulloides</i>	*	*	*	*	*	*	*	x
<i>Globorotalia puncticulata</i>	*	*	x	*	x	x	*	x
<i>Globigerinoides trilobus sacculifer</i>	*	*	*	*	x	x	*	*
<i>G. trilobus trilobus</i>	*	*	*	*	*	*	*	*
<i>Orbulina universa</i>	*	*	x	*	x	x	*	x
Nannofossil biozone	MNN14-15							
Foraminiferal biozone	Globorotalia puncticulata							
AGE	EARLY PLIOCENE							

Tab. 1 - Distribution of calcareous nannofossils and foraminifera in the T. Misegna-Fosso Varicello section. Total abundance: C = 10-20 specimens/field of view; F = 2-10 specimens/field of view; B = Barren. Relative abundance: A = 2-10 specimens/field of view; C = 0.5-1 specimens/field of view; F = 0.02-0.5 specimens/field of view; R = 0.005-0.02 specimens/field of view; X = present. Preservation: P = poor; M = moderate. Percentage abundances of *Sphenolithus* spp. and *R. pseudumbilicus* are based on countings of 500 nannofossil specimens.

no quantitative analysis has been performed on this group; only rare and scattered specimens of *D. brouweri*, *D. intercalaris*, *D. pentaradiatus*, *D. surculus* and *D. variabilis* have been recorded.

Planktonic foraminiferal assemblages are very poor and only few species have been recorded; the presence of *G. puncticulata* in the absence of *Globorotalia margaritae* allows the identification of the *G. puncticulata* Zone, confirming the assignment to the lower Pliocene.

VALLE DIFESA SECTION

This section has been sampled in Valle della Difesa (Text-fig. 1) and consists of a silty-clayey succession, about 15 m thick, transgressive on Miocene turbidite deposits.

The calcareous nannofossil and foraminiferal assemblages recorded in 5 samples (Table 2) allow the identification of the MNN14-15 Zone and *G. puncticulata* Zone.

Reticulofenestra pseudumbilicus and *Sphenolithus* spp. display abundance values generally higher than 2% and 1%, respectively (Text-fig. 4), suggesting an interval that precedes the LOs of these taxa. Very rare and scattered occurrences of *Pseudoemiliania lacunosa* are recorded in the assemblages as well as very rare *D. asymmetricus*, *D. pentaradiatus* and *D. intercalaris*.

A very poor, low diversity foraminiferal assemblages are recorded in this section; nevertheless, the occurrence of *G. puncticulata* allows to recognize the *G. puncticulata* Zone in good agreement with calcareous nannofossil data.

MIDDLE AND UPPER PLIOCENE DEPOSITS

SERRE ALTE SECTION

This composite section has been sampled from the Torrente Misegna to Piano Stagliolo locality (Text-fig. 1). It is about 380 m thick, lies stratigraphically on a middle Pliocene calcarenitic-sandy succession, about 40 m thick, and is composed mostly of clays and silty clays (Text-fig. 5). Two weakly laminated clayey levels, few centimetres thick, occur in the lower part of the section.

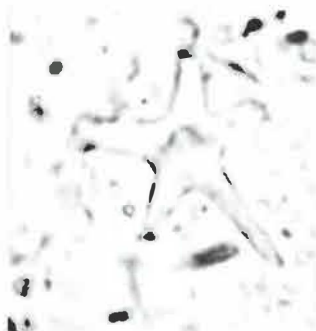
EXPLANATION OF PLATE 1

XP = crossed polarized light, PL = parallel light. Micrographs = 2500X, except where otherwise indicated.

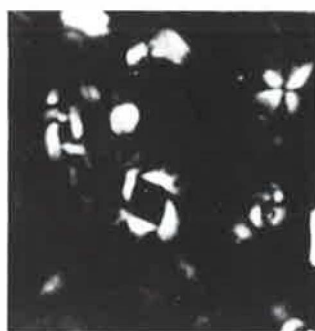
- Fig. 1 - *Helicosphaera sellii* Bukry & Bramlette. XP, Fosso Varicello section, sample 15.
- Fig. 2 - *Discoaster asymmetricus* Gartner. PL, Serre Alte section, sample 1.
- Fig. 3 - *Pseudoemiliania lacunosa* (Kamptner) Gartner. XP, Fosso Varicello section, sample 12.
- Figs. 4-5 - *Discoaster pentaradiatus* (Tan) Bramlette & Riedel. 4) PL, 5) XP, Fosso Varicello section, sample 6.
- Figs. 6, 9 - *Calcidiscus macintyre* (Bukry & Bramlette) Loeblich & Tappan. 6) PL, 9) XP, Fosso Varicello section, sample 12.
- Fig. 7 - *Reticulofenestra pseudumbilicus* (Gartner) Gartner. XP, Misegna-Varicello section, sample 11.
- Fig. 8 - *Discoaster tamalis* Kamptner. PL, Serre Alte section, sample 1. 3250X.
- Fig. 10 - *Discoaster brouweri* (Tan) Bramlette & Riedel. PL, Fosso Varicello section, sample 12.
- Fig. 11 - Small *Gephyrocapsa* Gartner. XP, Serre Alte section, sample 34. 3250X.
- Fig. 12 - *Discoaster triradiatus* Tan. PL, Grotticelle section, sample 13. 3250X.



1



2



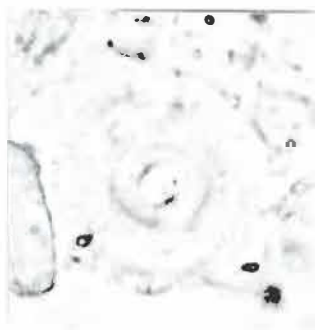
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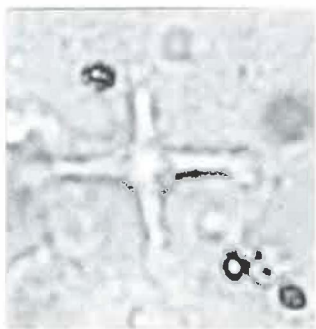
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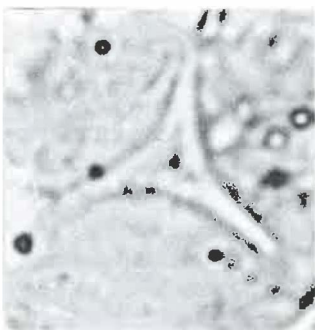
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10



11



12

VALLE DIFESA	Sample				
Calcareous Nannofossils	1	2	3	4	5
Total Abundance	F	F	F	F	F
Preservation	P	P	P	P	P
Calcidiscus leptoporus	F	C	F	C	F
C. macintyreii		R	R	R	R
Coccolithus pelagicus	C	A	A	A	A
Dictyococcites productus	F	F	C	F	C
Discoaster asymmetricus	0.08			0.08	
D. intercalaris	0.08				
D. pentaradiatus	1.28	0.25		0.08	
D. variabilis	0.17				
Discoaster spp.	0.34				
Helicosphaera carteri	F	C	F	F	F
H. sellii	F	F	F	C	F
Pontosphaera spp.		F	R	F	
Pseudoemiliania lacunosa	VR	VR			
Reticulofenestra minuta	C	C	C	C	C
R. minutula	C	C	C	C	C
R. pseudumbilicus	3	1.7	1.2	2	2
R. small pseudumbilicus	F	F	F	F	C
Sphenolithus spp.	4.6	5	4.2	3.4	5.4
Planktonic Foraminifera					
Globigerina aperture	x				x
Globorotalia puncticulata	x	x	x	x	x
Globigerinoides obliquus extremus		x			
G. obliquus obliquus	x	x		x	x
G. ruber	x				
G. trilobus immaturus	x	x	x		x
G. trilobus sacculifer	x	x	x		x
G. trilobus trilobus	x	x	x		x
Orbulina bilobata	x		x		x
O. universa	x	x	x	x	x
Nannofossil biozone	MNN14-15				
Foraminiferal biozone	Globorotalia puncticulata				
AGE	EARLY PLIOCENE				

Tab. 2 - Distribution of calcareous nannofossils and foraminifera in the Valle Difesa section. Abundances of discoasters, reported as N°/mm², refer to a scanned area of 20 mm². Symbols as in Tab. 1.

Both calcareous nannofossil and foraminiferal assemblages recognized in the collected samples (Table 3) are often abundant and well diversified. Abundance patterns of selected calcareous nannofossils, as well as the recognized foraminiferal events, are shown in Text-fig. 5. The section has been referred to the middle and upper Pliocene based on the identification of the calcareous nannofossil Zones MNN16a, MNN16b-17, MNN18 and MNN19a and the foraminiferal Zones *G. crassaformis* and *G. inflata*. Abundant diatoms and silicoflagellates, Pliocene in

age (Gersonde, pers. comm.), have been observed in smear slides of samples 3 and 4; sponge spicules also occur in the washed residues (fraction > 125 µm).

Discoasters are generally rare in the calcareous nannofossil assemblages; nevertheless, the quantitative analysis allowed to reliably identify the LOs of *D. tamalis*, *D. pentaradiatus* and *D. brouweri*. Reworked specimens of *R. pseudumbilicus* and *Sphenolithus* spp. and of pre-Pliocene taxa have been recorded throughout the section.

The LOs of *D. tamalis* and *D. asymmetricus* are well detectable between samples 2 and 3. Rare occurrences of *D. brouweri* and *D. pentaradiatus* characterize the MNN16b-17 Zone; rare specimens of *D. tamalis* and *D. asymmetricus* are recorded within this zone and are interpreted as reworked.

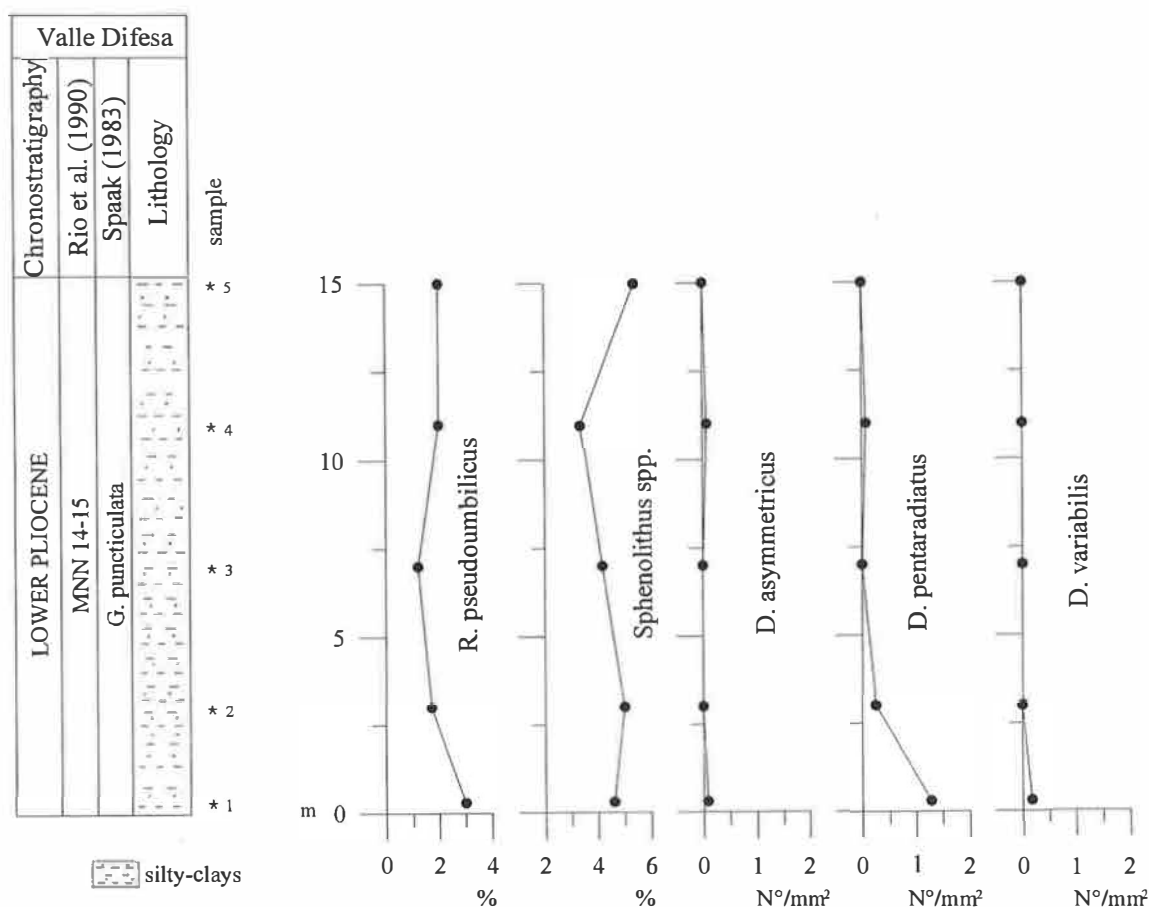
In the upper part of the section, the numerical abundance of total reworked discoasters has been compared to that of *D. brouweri* in order to detect the LO of the latter species; *D. brouweri* drops in abundance between samples 19 and 20. From sample 20 upward the total abundance of reworked discoasters becomes similar to that of *D. brouweri* indicating (1) that the latter species is also reworked, according to Backman & Shackleton (1983), and (2) a stratigraphic interval above the LO of this species. The occurrence of abundant specimens of small *Gephyrocapsa* characterizes the MNN19a Zone.

With regard to the foraminiferal assemblages, the presence of *Globorotalia crassaformis* and rare *Globorotalia bononiensis* in the absence of *G. puncticulata* allow to recognize the *G. crassaformis* Zone from samples 1 to 19. In the lower part of this zone, the FO of *Bulimina basispinosa* has been observed just above the LO of *D. tamalis*, in agreement with Sprovieri (1985). Between samples 13 and 14, in the upper part of the *G. crassaformis* Zone, the FO of *Bulimina marginata* has been recorded; in the Serre Alte section this event coincides with the LO of *D. pentaradiatus*, probably because of widely spaced samples in this interval. The FO of *G. inflata* falls between samples 19 and 20, at the same level as the LO of *D. brouweri*. As shown in Text-fig. 2, the FO of *G. inflata* is a much older event than the LO of *D. brouweri*. The fact that these two events coincide at Serre Alte suggests a possible stratigraphic gap.

FOSSO VARICELLO SECTION

The section has been sampled along the Fosso Varicello (Text-fig. 1). It consists of a clayey succession about 135 m thick, which lies stratigraphically on the middle Pliocene conglomeratic and calcarenitic-sandy deposits, about 45 m thick. The section is truncated and overthrust by the Apennines units. In the lower part of the section, two weakly laminated clayey levels have been recognized.

The calcareous nannofossil and foraminiferal assemblages recognized in 18 samples (Text-fig. 6;



Text-fig. 4 - Abundance patterns of selected calcareous nannofossils in the Valle Difesa section.

Table 4), allowed the assignment of this section to the middle and upper Pliocene based on the identification of the nannofossil Zones MNN16a, MNN16b-17 and MNN18 and of the foraminiferal *G. crassaformis* Zone. Abundant silicoflagellates and diatoms have been observed in samples 4 and 6 in a stratigraphic position well comparable to that recorded in the Serre Alte section.

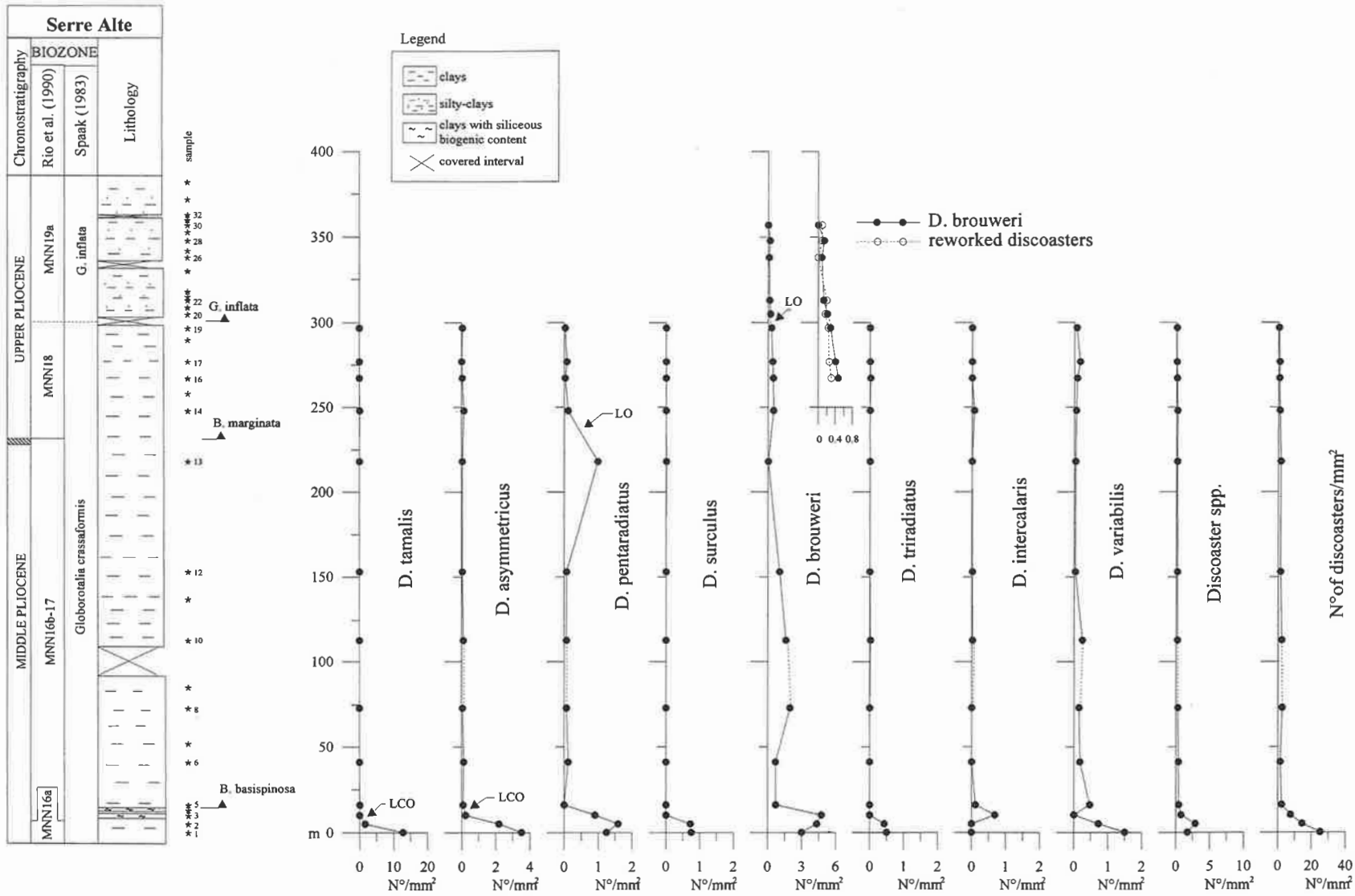
In the lower part of the section, the presence of *D. tamalis* and *D. asymmetricus*, together with *D. pentaradiatus* and *D. brouweri*, indicates the upper part of the *D. tamalis* Zone. Based on change in abundance, the LO of *D. tamalis* occurs between samples 4 and 5. The LO of *D. pentaradiatus* is placed at sample 12. Very rare occurrences of *D. brouweri* characterize the *D. pentaradiatus* and *D. brouweri* Zones. Reworked specimens of *R. pseudoumbilicus* and *Sphenolithus* spp. are recorded in all the samples, while reworked specimens of *D. tamalis*, *D. asymmetricus* and *D. pentaradiatus* are recorded only in the MNN18 Zone.

The foraminiferal assemblages confirm the middle to late Pliocene age assignment. The presence of *Globorotalia bononiensis* and *G. crassaformis*, although

rare and scattered in the section, indicates the *G. crassaformis* Zone. This zonal attribution is supported by the absence of *G. puncticulata* in the whole section. The FO of *B. basispinosa* is well detectable in sample 7, just above the LO of *D. tamalis*, and allows to recognize the interval VII of Spaak (1983), as recorded in the Serre Alte section. The FO of *B. marginata*, recorded in sample 14, occurs above the LO of *D. pentaradiatus* in agreement with Sprovieri & Hasegawa (1990); this additional benthic foraminiferal event within the MNN18 and *G. crassaformis* Zones allows to recognize the interval VIII of Spaak (1983) as in the Serre Alte section.

GROTTICELLE SECTION

The section has been sampled in Grotticelle locality and consists of a clayey succession, about 100 m thick, which stratigraphically overlies a middle-late Pliocene calcarenitic-sandy unit, about 20 m thick. The section is truncated and overthrust by the Apennines units. The calcareous nannofossil and foraminiferal assemblages are documented in Table 5. Quantitative abundance patterns of selected calcare-



Text-fig. 5 - Abundance patterns of selected calcareous nannofossils and biostratigraphic events in the Serre Alte section. LCO = Last Common Occurrence; LO = Last Occurrence. Note the first occurrence of the foraminifera *Bulimina basispinosa*, *B. marginata* and *Globorotalia inflata*.

Tab. 3 - Distribution of calcareous nannofossils and foraminifera in the Serre Alte section. Numerical abundances of discoasters, reported as N°/mm², derives from countings of 50-100 taxonomically related specimens, then referred to a scanned area of 20 mm² within *D. productus* Zone (MNN 19a). Symbols as in Tab. 1.

Fosso VARICELLO	Sample																	
Calcareous Nannofossils	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Total Abundance	C	B	B	C	B	C	C	C	C	C	C	C	C	C	F	C	F	C
Preservation	P	*	*	P	*	P	P	P	P	P	P	P	P	P	P	P	P	P
Reworking	C	*	*	A	*	C	F	C	C	C	C	C	C	F	A	C	C	C
Calcidiscus leptoporus	C	*	*	F	*	C	C	C	C	C	C	F	F	F	C	C	F	F
C. macintyreii	C	*	*	R	*	F	F	R	*	*	R	R	R	R	*	R	*	R
Coccolithus pelagicus	A	*	*	C	*	A	C	A	C	A	C	A	C	C	A	C	A	A
Dictyococcites productus	C	*	*	C	*	C	C	C	C	C	C	C	C	C	C	C	C	C
Discoaster asymmetricus	2.59	*	*	0.24	*	*	*	0.04	*	0.08	*	0.05	*	*	0.07	*	0.08	0.07
D. brouweri	15.28	*	*	11.58	*	1.72	R	0.22	VR	0.41	VR	0.59	VR	R	0.44	VR	0.26	0.39
D. pentaradiatus	3.10	*	*	0.24	*	3.56	VR	0.75	VR	0.62	VR	0.14	*	*	0.09	*	0.06	0.13
D. surculus	1.29	*	*	*	*	0.55	VR	0.02	*	*	VR	*	*	*	0.01	*	*	*
D. tamaris	2.59	*	*	0.12	*	*	*	0.04	*	0.04	*	*	*	*	0.01	*	0.02	0.02
D. triaradiatus	0.25	*	*	*	*	0.06	*	0.01	*	*	*	*	*	*	*	*	*	0.02
D. variabilis	0.52	*	*	*	*	0.12	VR	0.11	*	0.14	*	0.05	R	R	0.14	*	0.04	0.06
Discoaster spp.	0.25	*	*	*	*	0.12	R	0.07	*	0.14	R	0.15	*	*	0.11	*	0.06	0.14
N° of total discoasters/mm²	25.9	*	*	12.19	*	6.13	*	1.28	*	1.47	*	0.98	*	*	0.89	*	0.55	0.06
Helicosphaera carteri	F	*	*	*	*	F	C	F	F	F	F	F	F	C	C	C	F	R
H. sellii	C	*	*	F	*	R	C	F	F	F	F	R	F	F	R	F	R	F
small Gephyrocapsa	*	*	*	R	*	*	R	*	R	*	R	*	R	*	*	R	R	R
Pontosphaera spp.	*	*	*	*	*	R	*	*	*	R	*	R	*	*	F	*	F	F
Pseudoemiliania lacunosa	C	*	*	A	*	A	A	C	C	C	A	C	C	C	A	C	C	A
Reticulofenestra minuta	A	*	*	C	*	A	A	A	A	A	A	A	C	A	A	A	C	A
R. minutula	C	*	*	C	*	C	C	C	C	C	C	C	C	C	A	A	C	C
R. pseudoumbilicus	R	*	*	R	*	R	R	R	R	R	R	R	R	R	VR	R	R	*
R. small pseudoumbilicus	R	*	*	F	*	F	R	F	F	C	F	F	F	F	C	F	C	F
Sphenolithus spp.	*	*	*	R	*	R	R	R	VR	R	R	R	R	R	R	R	VR	VR
Foraminifera																		
Globigerina aperture	x	*	*	*	*	*	x	x	*	*	*	*	*	*	*	x	*	*
G. bulbosa	*	*	*	*	*	*	x	x	x	*	*	*	*	*	x	*	*	*
G. bulloides	x	*	*	*	*	*	x	*	x	x	x	*	x	*	x	*	*	x
G. falconensis	x	*	*	*	*	*	*	*	x	*	*	*	*	*	*	x	*	*
G. quadrilobata	*	*	*	*	*	*	*	*	x	*	*	*	*	*	*	*	*	*
G. quinqueloba	*	*	*	*	*	*	x	x	x	*	x	*	*	*	*	*	*	*
Globorotalia aemiliana	*	*	*	*	*	*	x	*	*	*	*	*	*	*	*	*	*	*
G. bononiensis	*	*	*	x	*	*	x	*	x	*	*	x	*	*	x	x	*	*
G. bononiensis/inflata	*	*	*	*	*	*	*	*	*	*	*	x	*	*	*	x	*	*
G. crassaformis crassaformis	*	*	*	*	*	*	*	x	x	*	*	*	x	x	*	*	*	x
G. obesa	x	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	x	*
G. puncticulata	x	*	*	*	*	*	*	*	x	*	*	*	*	*	x	*	*	*
G. scitula	*	*	*	*	*	*	*	*	*	*	*	*	x	*	*	*	*	*
Globigerinoides diminutus	x	*	*	*	*	*	*	x	x	*	*	x	x	x	x	x	*	x
G. elongatus	x	*	*	*	*	*	*	x	x	x	*	x	x	x	x	x	*	*
G. helicinus	x	*	*	*	*	*	*	x	*	*	*	x	*	*	x	*	*	x
G. obliquus extremus	x	*	*	*	*	x	x	x	*	*	*	x	*	*	*	x	*	*
G. obliquus obliquus	x	*	*	*	*	*	x	*	*	*	*	*	x	*	*	*	*	x
G. quadrilobatus	*	*	*	*	*	*	*	*	x	*	*	*	*	*	*	*	*	*
G. ruber	x	*	*	*	*	x	x	x	x	x	*	x	x	x	x	x	*	*
G. trilobus immaturus	x	*	*	*	*	*	*	*	*	*	*	*	*	*	x	*	*	*
G. trilobus sacculifer	x	*	*	*	*	x	*	*	*	*	*	*	*	*	x	*	*	*
G. trilobus trilobus	x	*	*	*	*	x	x	*	*	*	*	*	*	*	*	*	x	*
Neogloboquadrina acostaensis	x	*	*	*	*	*	x	x	x	*	*	*	*	*	x	x	*	*
Orbulina bilobata	*	*	*	*	*	x	*	*	*	*	x	x	x	*	x	*	x	*
O. suturalis	*	*	*	*	*	x	*	*	*	x	*	*	*	*	*	*	*	*
O. universa	x	*	*	x	*	x	x	x	x	x	x	x	x	x	*	x	x	*
Bulimina basispinosa	*	*	*	*	*	*	x	x	x	x	x	x	x	x	x	x	x	x
B. marginata	*	*	*	*	*	*	*	*	*	*	cf	*	*	x	x	x	x	x
Nannofossil biozone	MNN16a			MNN16b-17					MNN18									
Foraminiferal biozone	Globorotalia crassaformis																	
AGE	MIDDLE PLIOCENE								LATE PLIOCENE									

Tab. 4 - Distribution of calcareous nannofossils and foraminifera in the Fosso Varicello section. Numerical abundances of discoasters, reported as N°/mm², derive from countings of 50-100 taxonomically related specimens. Symbols as in Tab. 1.

GROTTICELLE	Sample													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Calcareous Nannofossils														
Total Abundance	C	C	C		C		F		F	C		F	C	C
Preservation	P	M	P		P		P		P	M		P	P	P
Reworking	C	F	C		F		A		C	F		C	C	C
<i>Amaurolithus delicatus</i>			R		R									
<i>Calcidiscus leptoporus</i>	C	C	C		C		C		C	C		C	C	C
<i>C. macintyreii</i>	F	F	F		F		F		R			C	C	C
<i>Coccolithus pelagicus</i>	F	C	F		C		C		C	C		A	C	A
<i>Dictyococcites productus</i>	C	C	C		C		C		C	A		C	C	
<i>Discoaster asymmetricus</i>	0.03		0.12		0.14		0.06		0.36			0.11	0.01	0.03
<i>D. brouweri</i>	1.33	0.85	0.72		1.94		0.35		0.18	0.08		0.31	0.38	0.55
<i>D. pentaradiatus</i>	0.09	0.08	0.11		0.08		0.03		1.15			0.19	0.1	0.1
<i>D. sureulus</i>	0.2		0.18		0.35		0.03		0.36	0.08		0.08		0.01
<i>D. turnalis</i>	0.03	0.08	0.07		0.11		0.01		0.01	0.08		0.04	0.01	0.03
<i>D. triadriatus</i>	0.05				0.11		0.01						0.07	
<i>D. variabilis</i>	0.03	0.08	0.09		0.05		0.03		0.03			0.04	0.02	0.01
<i>Discoaster</i> spp.	0.09		0.07		0.08				0.02				0.01	0.01
N° of total discoasters/mm ²	1.93	1.1	1.42		2.9		0.53		1.8	0.25		0.79	0.64	0.76
small <i>Gephyrocapsa</i>	R	R	R		R				R				R	R
<i>Helicosphaera carteri</i>		R	R		F		F		F	F		F	F	F
<i>H. sellii</i>	F	R	F		C		C		F	F		C	C	F
<i>Pontosphaera</i> spp.	F		F				F						C	R
<i>Pseudoemiliania lacunosa</i>	A	A	A		A		C		C	C		A	A	C
<i>Reticulofenestra minuta</i>	A	A	A		C		A		A	C		A	A	A
<i>R. minutula</i>	C	C	C		C		C		C	C		C	C	C
<i>R. pseudumbilicus</i>	R	R	R		F		R		F			R	F	F
<i>R. small pseudumbilicus</i>	R	R	F		R		R		F	F			C	C
<i>Rhabdosphaera</i> spp.		F								R		R		F
<i>Scyphosphaera</i> spp.			R											
<i>Sphenolithus</i> spp.	R	R	R		R		R		R	R		R	R	R
Foraminifera														
<i>Globigerina apertura</i>	x		x	x	x	x		x	x	x	x	x		x
<i>G. bulloides</i>	x			x	x		x	x	x		x	x	x	x
<i>G. decoraperta</i>	x			x	x	x								
<i>G. falconensis</i>				x	x	x		x				x		
<i>G. quinqueloba</i>	x	x	x	x						x	x	x		
<i>G. umbilicata</i>														
<i>Globorotalia acemiliana</i>	x		x	x										
<i>G. bononiensis</i>										x	x			
<i>G. bononiensis/inflata</i>			x			x				x	x			
<i>G. crassaformis crassaformis</i>			x		x	x			x	x	x			x
<i>G. obesa</i>	x						x	x						
<i>Globigerinoides diminutus</i>	x			x	x	x			x	x	x	x		
<i>G. elongatus</i>	x	x	x	x	x	x	x		x	x	x	x	x	x
<i>G. helicinus</i>										x				
<i>G. obliquus extremus</i>	x		x		x	x		x	x	x		x	x	
<i>G. obliquus obliquus</i>	x									x			x	
<i>G. quadrilobatus</i>	x	x												
<i>G. ruber</i>	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>G. trilobus immaturus</i>										x				
<i>G. trilobus sacculifer</i>	x		x	x						x				
<i>G. trilobus trilobus</i>	x									x				
<i>Neoglobobulimina pachyderma</i>					x									
<i>N. acostaensis</i>		x			x	x		x				x	x	x
<i>O. bilobata</i>	x	x		x		x		x	x					
<i>O. suturalis</i>						x								
<i>Orbulina universa</i>	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Bulimina basispinosa</i>	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>B. marginata</i>	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Nannofossil biozone	MNN18													
Foraminiferal biozone	Globorotalia crassaformis													
AGE	LATE PLIOCENE													

Tab. 5 - Distribution of calcareous nannofossils and foraminifera in the Grotticelle section. Numerical abundances of discoasters, reported as N°/mm², derive from countings of 50-100 taxonomically related specimens. Symbols as in Tab. 1.

ous nannofossils are shown in Text-fig. 7. The section has been referred to the upper Pliocene for the identification of the nannofossil Zone MNN18 and of the *G. crassaformis* planktonic foraminiferal Zone.

Discoaster tamalis, *D. asymmetricus* and *D. pentaradiatus* are recorded as rare and scattered specimens suggesting that they are probably reworked. On the other hand, *D. brouweri* is continuously present in the section allowing to recognize the MNN18 Zone, in agreement with foraminiferal data. In fact, the occurrence of *G. crassaformis* in the absence of *G. puncticulata* indicate the *G. crassaformis* Zone. Moreover, *B. marginata*, the FO of which falls above the LO of *D. pentaradiatus* (Sprovieri & Hasegawa, 1990), is recorded from the lowest sample allowing the recognition of the interval VIII of Spaak (1983).

CONCLUSIONS

The integrated biostratigraphy from this study results in a precise age assignments of the Pliocene terrigenous clayey sediments cropping out in the area between S. Mauro Forte and Stigliano (Basilicata region) as well as new chronostratigraphic data on the sedimentary evolution at the outer border of the Southern Apennines.

Despite the presence of significant reworking and the rarity of some marker species, quantitative analyses of the calcareous nannofossil assemblages allow to recognize the MNN14-15 Zone in the lower Pliocene sequence, the upper part of Zone MNN16a and Zones MNN16b-17, MNN18 and MNN19a in the middle and upper Pliocene interval (see Rio *et al.*, 1994). Correlation of nannofossil data with foraminiferal events greatly improves the biostratigraphic resolution in some intervals, although some marker species among planktonic foraminifera are rare (*G. bononiensis*) or absent (*Sphaeroidinellopsis* spp., *N. atlantica* sinistral). In particular, the *G. puncticulata* Zone (= Spaak's interval IV) in the lower Pliocene, and the middle-upper part of the *G. crassaformis* Zone (= Spaak's intervals VII and VIII) and the *G. inflata* Zone (= Spaak's interval IX) in the middle and upper Pliocene (Spaak, 1983) could be recognized. Specifically, Spaak's intervals VII and VIII were identified on the basis of the FOs of benthic foraminifera *B. basispinosa* (=lower part of interval VII) and *B. marginata* (=just above the base of interval VIII), respectively. In addition, the FO of *B. basispinosa* was found to fall just above the LO of *D. tamalis*, while the FO of *B. marginata* falls slightly above the extinction of *D. pentaradiatus*. At the transition between Zones MNN16a and MNN16b-17, two levels with abundant Pliocene diatoms and silicoflagellates have been found in two of the studied sections. They had never been previously recorded in the studied deposits and further investigations are needed in order to clarify their potential stratigraphical and paleoecological meaning.

The biostratigraphic results indicate that in the investigated deposits, previously referred to the transgressive part of the Bradanic Cycle and of late Pliocene to early Pleistocene age, two different stratigraphic sequences can be recognized: a) a conglomeratic-sandy and silty-clayey succession of early Pliocene age, areally very limited, lying unconformably on the Miocene Foredeep Units; and b) a middle Pliocene conglomeratic and calcarenitic-sandy body transgressive on pre-Pliocene units, passing upward to thick, clayey sedimentary succession, late middle to late Pliocene in age.

A stratigraphic gap spanning the upper lower Pliocene to the lower middle Pliocene separates the investigated deposits. The stratigraphic and chronostratigraphic data presented above are in good agreement with those of Caldara *et al.* (1993) and Sabato & Marino (1994) from adjacent localities at the outer border of the Southern Apennines, where two sedimentary cycles have been identified.

Finally, according to the obtained results, a deformative event can be precisely dated to the late Pliocene (Zone MNN18 - upper part of the *G. crassaformis* Zone) in the studied area; this event is documented by the overthrust of the Apennines units that truncates the clayey succession in the middle upper Pliocene. Clayey deposition continued up to the uppermost Pliocene in the outer part of the studied area or up to the lower Pleistocene in the outer portion of the Bradanic Foredeep.

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Patrizia MAIORANO

Dipartimento di Geologia e Geofisica,
Campus Universitario, via E. Orabona 4, 70125 Bari, Italy