

## 31. NANNOPLANKTON BIOSTRATIGRAPHY AND PALEOENVIRONMENTAL INTERPRETATIONS FROM THE TYRRHENIAN SEA, ODP LEG 107 (WESTERN MEDITERRANEAN)<sup>1</sup>

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### ABSTRACT

This paper summarizes the nannoplankton biostratigraphy and the paleoenvironmental interpretations obtained from Leg 107 in the Tyrrhenian Sea. Marine sediments are ranging in age from late Tortonian to Recent.

The Mediterranean as a semiclosed adjacent sea of the Atlantic is strongly controlled by paleoceanographic changes in the Atlantic which are related to the global climatic evolution. This influence of the Atlantic is more pronounced in the western than in the eastern Mediterranean. The occurrence of sapropels and sapropelic layers also in the western Mediterranean was shown for the first time.

### INTRODUCTION

Age determinations given in this paper are based on the standard nannoplankton zonation (Martini, 1971) which can be applied with minor changes in the Mediterranean (Müller, 1978). A more detailed subdivision of the lower Pleistocene (zone NN19) was possible by using the zonal scheme for the Quaternary by Gartner (1977). More details are given in Kastens, Mascle, et al. (1987).

Some more recent biostratigraphic studies based on nannoplankton and paleoenvironmental interpretations from the Mediterranean area were published by Bizon and Müller (1977, 1978), Müller (1978, 1985), Ellis (1979), Driever (1981), Backman et al. (1983), and Rio et al., (1984).

Nine holes were drilled at seven sites shown in Figure 1. The biostratigraphy based on nannoplankton studies is summarized in Figures 2 and 3. Distribution and abundance of the species from selected samples are given in the range charts (Tables 1–5). No range charts were established for Sites 650 and 656 because of the abundance of turbidites and slumps within these sequences.

### BIOSTRATIGRAPHIC REMARKS

Oldest marine sediments recovered during Leg 107 in the Tyrrhenian Sea are of late Tortonian age (zone NN11a). They are underlain at Hole 654A, drilled on the upper margin of Sardinia, by shallow water glauconitic sands of probably late Miocene age and continental red clays including conglomerates.

The Tortonian sediments are rich in slightly overgrown nanofossils of zone NN11a (Martini and Müller, 1986) with *Discoaster calcaris* and *Discoaster quinqueramus*. These sediments were deposited in an outer shelf to upper slope environment. The Tortonian/Messinian boundary at Hole 654A was determined by the first occurrence of *Amaurolithus delicatus*, *A. primus*, and *A. tricorniculatus* at about 6.5 m.y. (Mazzei et al., 1979). The appearance of these species predates slightly the first occurrence of *Globorotalia conomiozea*. The Miocene/Pliocene boundary in the Mediterranean region is characterized by the reestablishment of continuous open-marine conditions (Cita,

1975). However, this boundary is not necessarily time-equivalent with the Miocene/Pliocene boundary determined in the open ocean. Complete Pliocene sequences were recovered at Site 652 and Holes 653A and 654A. Nanofossils are common to abundant. They are slightly overgrown within the lower Pliocene due to the higher carbonate content, whereas they are well preserved in the upper Pliocene sediments characterized by an increase in clay and fine-grained detrital material. A slight decrease in nanofossil abundance and the occurrence of tiny carbonate fragments were observed at all sites within the latest Pliocene (uppermost part of zone NN18). The Pliocene zonal boundaries were determined by using the standard nannoplankton zonation. The determination of the *Amaurolithus tricorniculatus*/*Ceratolithus rugosus* zone boundary (NN12/NN13) is sometimes difficult due to the scarcity of *Ceratolithus rugosus* (Müller, 1978). *Amaurolithus delicatus* seems to become more common near the top of zone NN14 just before its extinction. According to Backman and Shackleton (1983) this species has its last occurrence at about 3.7 m.y.

Some difficulties turned out with the determination of the *Reticulofenestra pseudoumbilica*/*Discoaster surculus* zone boundary (NN15/NN16). This boundary is defined by the last occurrence of *Reticulofenestra pseudoumbilica* and *Sphenolithus abies*. The latter generally becomes very rare near the top of zone NN15. Müller (1978) mentioned that small specimens of *Reticulofenestra pseudoumbilica* are characteristic of the uppermost part of zone NN15 in the Mediterranean together with *Sphenolithus abies*. Backman and Shackleton (1983) used the extinction of only the large variety of *Reticulofenestra pseudoumbilica* dated at about 3.6 m.y. which is followed by the presence of smaller species of this genus. Rio et al. (1984) gave an age of 3.5 m.y. for this event and Gartner (1973) 3.2 m.y. It seems very difficult to distinguish different species of the genus *Reticulofenestra* in the light microscope by using only the size which is strongly controlled by ecological factors. Recent observations in the Aegean Sea have shown that *Reticulofenestra pseudoumbilica* is only represented by the small variety throughout the lower Pliocene (Müller, unpubl. data) Only small *Reticulofenestra pseudoumbilica* are known from almost all land sections of shallow-water deposits or series characterized by a high input of detrital material. Changes in size of *Reticulofenestra pseudoumbilica* can be observed throughout the Miocene and Pliocene. In piston cores taken south of Crete, a first disappearance of the large variety of *Reticulofenestra pseudoumbilica* has been observed, followed by a second one higher up in the stratigraphic column (Müller, unpubl. data).

<sup>1</sup> Kastens, K. A., Mascle, J., et al., 1990. Proc. ODP, Sci. Results, 107: College Station, TX (Ocean Drilling Program).

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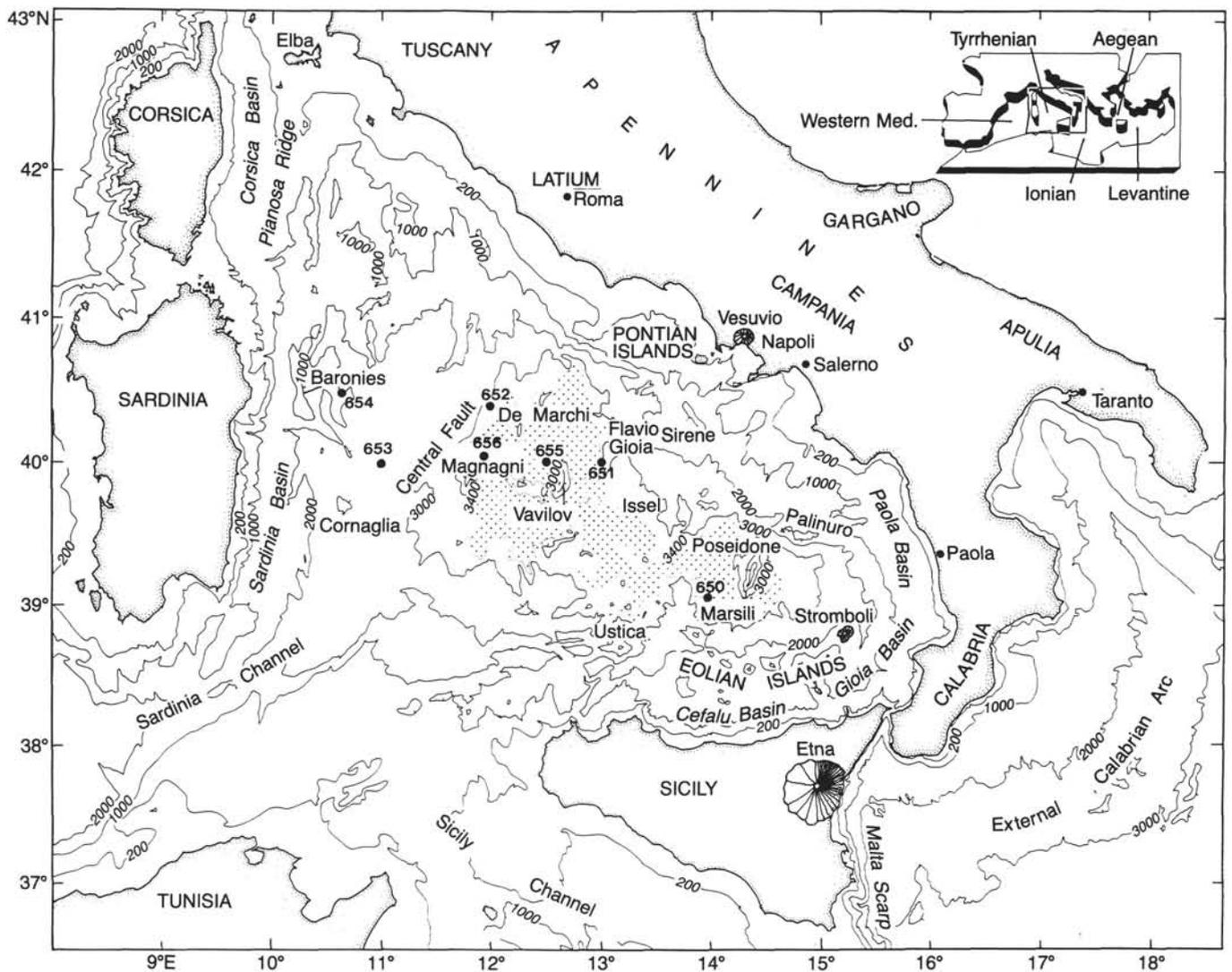


Figure 1. Location map of the sites drilled in the Tyrrhenian Sea.

A discontinuous record of the large *Reticulofenestra pseudumbilica* was also reported by Driever (1981) from land sections on Crete and Sicily. Often there is a distinct disappearance of the large variety whereas the smaller ones continue to be present. However, among them there are also differences in size. No studies of these forms were carried out by using the scanning microscope to confirm if they belong to *Reticulofenestra pseudumbilica* or if they are really another species of this genus. By no means is the smaller size only a sufficient criterion to attribute them to another species. The extinction of *Reticulofenestra pseudumbilica* and *Sphenolithus abies* falls almost together with the extinction of the planktonic foraminifera *Sphaeroidinellopsis seminulina* (Kastens, Mascle, et al., 1987; Blechschmidt et al., 1982) at about 3.2 m.y. Rio et al. (1984) reported that the extinction of *S. seminulina* falls together with a significant turnover of planktonic and benthic foraminiferal assemblages at 3 m.y.

The first occurrence of *Globorotalia truncatulinoides* at 2.0–2.1 m.y. (Sprovieri et al., 1980) occurs just above the extinction level of *Discoaster surculus*.

The recognition of nannoplankton zone NN17 in the western Mediterranean is not possible (Müller, 1978) due to the scarcity or absence of discoasters. Therefore zone NN17 is combined with zone NN18. It can be difficult to determine the last occur-

rence of the discoasters because they are rare and restricted to certain levels within the upper Pliocene. It is also not possible to exclude in all cases the possibility of reworking.

The distribution of the different discoaster species throughout the Pliocene shows a distinct pattern which seems to be of stratigraphic value. Results obtained from Leg 107 are comparable with those given by Driever (1981) from land sections on Crete and Sicily as well as with results described by Backman and Shackleton (1983) from the Atlantic, Indian, and Pacific Oceans. Discoasters are rare or absent within the upper Pliocene (upper part of zone NN16 to NN18, about 2.5–1.6 m.y.) of the western Mediterranean due to the onset of glaciation in the northern hemisphere (Bizon and Müller, 1977, 1978). Between 2.5 and 2.0 m.y. discoasters are restricted to certain levels which are characterized by the presence of warm water planktonic foraminifers (Bizon and Müller, 1978). Between 2.0 and 1.6 m.y., they are absent from the western Mediterranean. Discoasters only become abundant within the lower part of zone NN16 where the assemblages are dominated by *Discoaster surculus* and *Discoaster brouweri*. *Discoaster pentaradiatus* shows a very short peak within this stratigraphic interval. Discoasters are abundant and often of large size around the zonal boundary NN15/NN16 at about 3.2–3.0 m.y. The acme of *Discoaster asymmetricus* and *Discoaster tamalis* lies within this interval.

Age	Nannoplankton Zones	Hole 650A	Hole 651	Hole 652A	Hole 653A	Hole 654A	Hole 655	Hole 656A	Hole 656B
Pleistocene	NN 21	1 Top to 16-5.18-20 cm	1 Top to 8CC	1 Top to 2-1.25 cm	1 Top to 2-6.14 cm	1 Top to 2-2.110 cm	1 Top to 1-2.113 cm		
	NN 20	16CC to 37CC, 25 cm	9-1.69 cm to 25-5.49 cm	2-1.70 cm to 2CC, 4 cm	3-1.22 cm to 4-6.20 cm	2-3.20 cm to 4-1.50 cm		1 Top to 6-5.30 cm	1 Top to 3CC
	NN 19	38-1 to 61CC	25CC, 30 cm to 37-2.112 cm	3-1.17 cm to 8-2.70 cm	4CC to 10-1.40 cm	4-2.50 cm to 9-3.30 cm	1-2.120 cm to 3-2.40 cm	6-5.83 cm to 6-7.12 cm	5-1 to 5-2
late Pliocene	NN 17/18	62-1.47 cm to 65CC	37-2.139 cm to 38-1.100 cm	9-1.90 cm to 9CC	10-1.70 cm to 11-3.130 cm	9-3.100 cm to 12-1.40 cm	3-3.60 cm to 3-6.52 cm	7-1.96 cm to	4CC slump
	NN 16			10-2.107 cm to 13-2.130 cm	11-4.20 cm to 14-2.80 cm	12-2.30 cm to 15-6.110 cm	4-1.50 cm to 7-5.50 cm	7-4.60 cm	
early Pliocene	NN 15			13-3.40 cm to 14-4.39 cm	14-2.130 cm to 17-6.60 cm	15CC to 19-3.30 cm	7-6.4 cm to 9-5.100 cm	7-4.90 cm to 7-5.8 cm	
	NN 14			15-1.80 cm to 15-4.130 cm	18-1.60 cm to 19-5.80 cm	19-4.50 cm to 20-2.120 cm			
	NN 13			15-5.98 cm to 17-1.120 cm	19-6.20 cm to 22-2.130 cm	20-3.120 cm to 21-5.120 cm			
	NN 12			17-2.120 cm to 20-6.90 cm	22-3.110 cm to 24-5.100 cm	21CC to 26CC			6-1.122 cm to 6-1.133 cm
late Miocene	NN 11b				25-1.25 cm to 26-1.155 cm	27CC to 43-5.92 cm			
	NN 11a					43CC to 45CC			

Figure 2. Nannoplankton biostratigraphy of holes drilled on Leg 107.

The co-occurrence of these two species within this interval is also described by Driever (1981) and Backman and Shackleton (1983). *Discoaster surculus* and *Discoaster brouweri* are common whereas *Discoaster pentaradiatus* is almost absent from nannoplankton zone NN15 as also mentioned by Driever (1981). In the material recovered from the Tyrrhenian Sea, the presence of *Discoaster variabilis* is almost restricted to nannoplankton zone NN13 and the lower part of zone NN14 (about 4.3-3.9 m.y.) as also observed from other areas of the Mediterranean. Above this level *Discoaster variabilis* is absent. Within this interval other discoasters are only rare with exception of *Discoaster pentaradiatus* which can become common in zone NN13. Comparable observations were given by Driever (1981) from land sections. Backman and Shackleton (1983) show also an important increase of *Discoaster variabilis* within the upper Gilbert paleomagnetic event. Above this species is practically absent.

According to Bizon and Müller (1977, 1978), the Pliocene/Pleistocene boundary is determined by the extinction of *Cyclcoccolithus macintyreii* at about 1.6 m.y. near the top of the Olduvai paleomagnetic event. Comparable data (1.59 m.y.) were recently published by Monechi et al. (1985) from the Pacific. Backman et al. (1983) considered also the extinction of *Cyclcoccolithus macintyreii* as the most reliable event for the determination of the Pliocene/Pleistocene boundary in the Vrica section (southern Italy). The last occurrence of *Cyclcoccolithus macintyreii* falls together with the last occurrence of *Globigerinoides obliquus* (Bizon and Müller, 1978), the appearance of *Globigerina cariacensis* and the first occurrence of *Gephyrocapsa oceanica*. According to results from the northeast Atlantic and from Leg 107, the extinction of *Cyclcoccolithus macintyreii* lies slightly above an important increase in left-coiled *Globigerina pachyderma* which is situated within the Olduvai event

(Pujol and Duprat, 1985). A very distinct decrease of *Coccolithus pelagicus* upsection is time-equivalent with the disappearance of *Cyclcoccolithus macintyreii* at the Pliocene/Pleistocene boundary as also observed from other areas of the Mediterranean (Müller, 1978, 1985). The rather long stratigraphic interval represented by nannoplankton zone NN19 can be subdivided by several events described by Gartner (1977). More details are given in Kastens, Mascle, et al. (1987). The last occurrence of *Helicosphaera sellii* lies slightly below the acme of the small *Gephyrocapsa* sp. and was dated 1.2 m.y. (Gartner, 1977). *Helicosphaera sellii* is common throughout the lowermost part of zone NN19 and the upper Pliocene. The zone of the small *Gephyrocapsa* sp. is characterized by the acme of this tiny species ranging from 1.2 to 0.9 m.y. (Gartner, 1977), whereas other species are rare to few. The Jaramillo paleomagnetic event (0.97-0.9 m.y.) lies within the upper part of this zone. Below the acme zone, common large specimens of *Gephyrocapsa oceanica* are present. However, the abundance of the small *Gephyrocapsa* sp. is not restricted to this stratigraphic interval, but it can be present also in certain levels within nannoplankton zones NN20 and NN21 as observed at Hole 653A and in the northeast Atlantic (Müller, unpubl. data). This indicates that the distribution of this species is strongly controlled by ecological factors. The same observations were reported recently by Gartner (1988). *Pontosphaera pacifica* and *Discolithina japonica* become common within nannoplankton zone NN19 in the western Mediterranean as well as in the northeast Atlantic (Müller, 1979). At the same time an increase of *Holodiscolithus macroporus* can be observed. Within the lowermost part of zone NN20, *Helicosphaera inversa* is present for a short time. This species seems to be restricted to this interval in the western Mediterranean. It was described by Gartner (1977) from late Pleistocene sediments in the Caribbean and

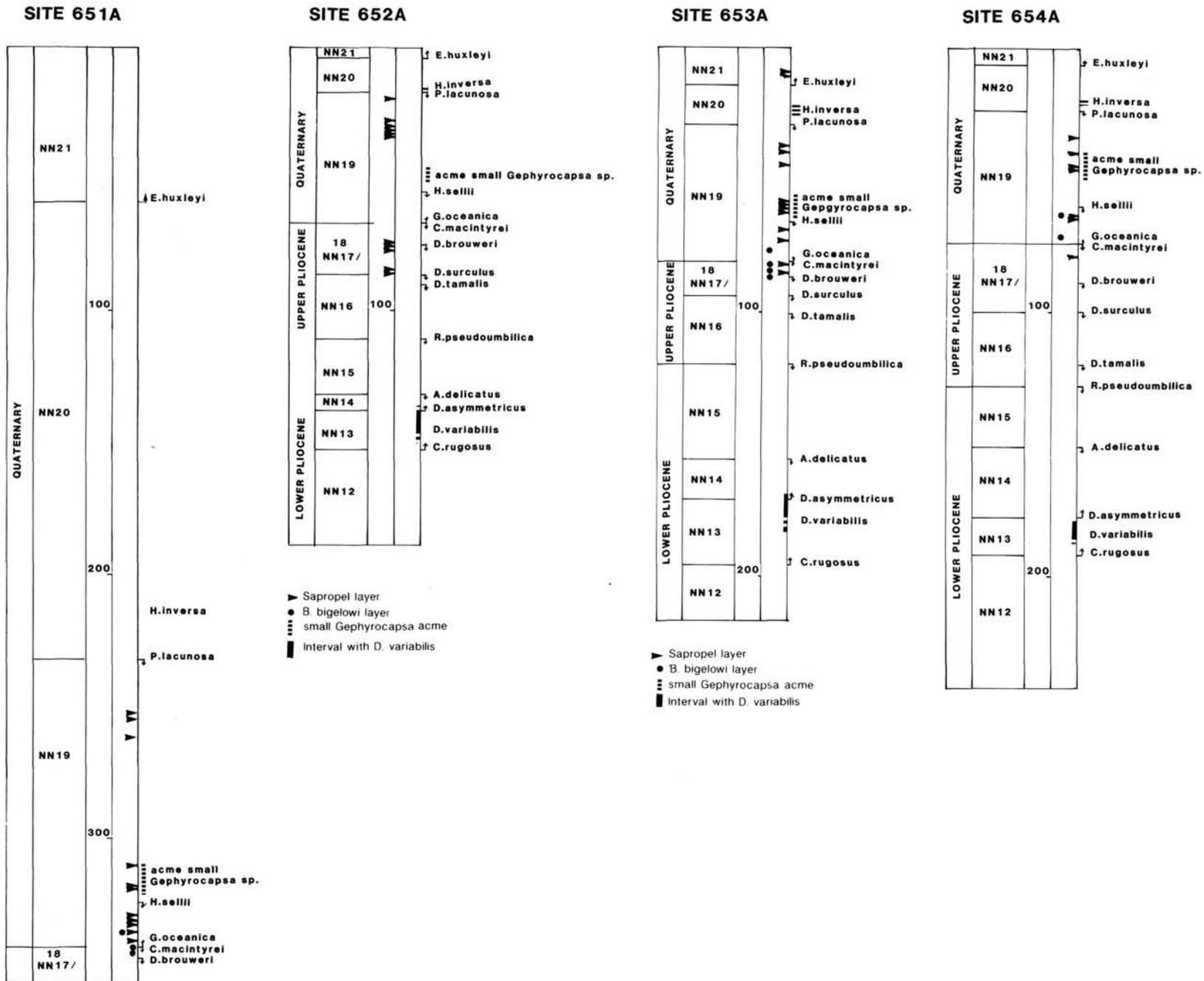


Figure 3. Distribution pattern of biostratigraphic markers in the Tyrrhenian Sea, with indication of sapropel and *Braarudosphaera bigelowi* layers.





Early Pliocene	NN 14 15R-1-80 15R-2-88 15R-3-70 15R-4-130	R F R		R C C C C C C C F C C C C C C C	F C F F F F F F R F F F	F F C F F F C F R R C F		F C C	C C C C C C	F F F F F C	F C C C C C	F F F F C	
	NN 13 15R-5-98 15R-6-40 16R-1-120 16R-2-100 16R-3-60 16R-4-140 16R-5-80 17R-1-120	R F R F F F F	R R R R R R R	R C C C F R C C C C R C C C C R C C C F R C C C F R C C C F R C C C F	R R R R R R F C C C C C C C C R R R	R R R F C C C C C C C C C C C C C C C C C	C C F F C C R C F C R C F		C C C C C C C C C C C C C C	F F F	C C C C A C C C C C	C C F C C C F C F C	C C C C C C C C C C
	NN 12 17R-2-120 17R-3-120 17R-4-120 17R-6-125 18R-1-120 18R-2-120 18R-4-50 18R-6-50 19R-1-50 19R-2-50 19R-3-50 19R-4-50 19R-5-50 19R-6-50 20R-1-70 20R-3-84 20R-5-130 20R-6-90	F F F F F F F F F F F F F F F F F F	R R F F F F F F F F F F F F F F F F	C C C F C C C F R F C F	F C F C C F F C C C C C	F F R C C R F C R C C R	F C F C C F R C C C C C		C C C C	F F F F F F F C F C	C C A A A A A A A A C C C C	C C F C C C F C C C F C C C F C C C	

1. *Amaurolithus delicatus*
2. *Amaurolithus primus*
3. *Amaurolithus tricorniculatus*
4. *Braarudosphaera bigelowi*
5. *Ceratolithus cristatus*
6. *Ceratolithus rugosus*
7. *Coccolithus pelagicus*
8. *Cyclococcolithus leptoporus*
9. *Cyclococcolithus macintyreii*
10. *Cyclococcolithus rotula*
11. *Discoaster asymmetricus*
12. *Discoaster brouweri*
13. *Discoaster calcaris*

14. *Discoaster pentaradiatus*
15. *Discoaster quinquerramus*
16. *Discoaster surculus*
17. *Discoaster tamalis*
18. *Discoaster triradiatus*
19. *Discoaster variabilis*
20. *Discolithina japonica*
21. *Emiliania huxleyi*
22. *Gephyrocapsa aperta*
23. *Gephyrocapsa caribbeanica*
24. *Gephyrocapsa ericsonii*
25. *Gephyrocapsa* sp.

26. *Gephyrocapsa* sp. (very small)
27. *Gephyrocapsa oceanica*
28. *Helicosphaera carteri*
29. *Helicosphaera intermedia*
30. *Helicosphaera inversa*
31. *Helicosphaera sellii*
32. *Holodiscolithus macroporus*
33. *Oolithotus fragilis*
34. *Pontosphaera pacifica*
35. *Pontosphaera syracusana*
36. *Pseudoemiliania lacunosa*
37. *Reticulofenestra pseudumbilica*

38. *R. cf. pseudumbilica* (small)
39. *Rhabdosphaera claviger*
40. *Rhabdosphaera stylifer*
41. *Scapholithus fossilis*
42. *Scyphospheres*
43. *Sphenolithus abies*
44. *Syracosphaera mediterranea*
45. *Syracosphaera pulchra*
46. *Thoracosphaera heimi*
47. *Triquetrorhabdulus rugosus*
48. *Umbellosphaera tenuis*
49. *Umbilicosphaera mirabilis*







Tasman Seas. It was also observed from the same stratigraphic interval in the southwest Pacific (Müller, unpubl. data).

## PALEOENVIRONMENTAL INTERPRETATIONS

### Miocene

The Messinian sediments encountered in the Tyrrhenian Sea are of quite varying facies deposited under continental to restricted marine conditions. The evolution from open-marine environment during the upper Tortonian and lower Messinian (Hole 654A) to restricted conditions in the upper part of the Messinian is the result of the almost complete isolation of the Mediterranean from the Atlantic due to a general trend of climatic deterioration and tectonic events. The Messinian sediments at Site 652 drilled on the lowermost eastern continental margin of Sardinia are barren of autochthonous nannofossils, whereas reworked Cretaceous and Paleogene species are common throughout the sequence. These sediments were most probably deposited in an early-rift lacustrine environment. Interbedded conglomerates at about 335 mbsf may correlate with the intra-Messinian unconformity which was well recognized on seismic profiles (Montadert et al., 1978). At Hole 653A the Messinian strata are interrupted by red clays in Core 653A-25X barren of nannofossils. They are considered as paleosol formed during a period of emergence and subaerial alteration. Above and below this level nannofossils are few. They are sometimes of somewhat smaller size and the assemblages are of low diversity reflecting restricted marine conditions. They mainly consist of *Coccolithus pelagicus*, *Sphenolithus abies*, *Reticulofenestra pseudumbilica*, *Cyclococcolithus rotula*, *Cyclococcolithus leptoporus*, *Cyclococcolithus macintyreii*, and *Discolithina multipora*. Discoasters and *Amaurolithus delicatus* are rare and occur mainly within the uppermost part. These autochthonous species are present together with reworked Cretaceous to middle Miocene nannofossils. However, they can be rather easily distinguished from each other by their different preservation. Comparable assemblages were found within the upper part of the Messinian at Hole 654A. At both sites nannofossils occur together with common very small planktonic foraminifers. The same observation was described from the upper evaporitic Messinian sequence at Site 124 and Site 372 drilled in the western Mediterranean (Cita, 1978).

The lowermost Messinian sediments encountered at Hole 654A are rich in nannofossils. They were deposited in an open-marine environment. They are overlain by dark gray mudstones with fine laminations (Cores 654A-37R to 654A-39R) rich in pyrite, dolomite, and gypsum. There are also some plant fragments and debris of pyritized siliceous microfossils, but no nannoplankton. Accumulation of these sediments took place under marine conditions with possibly high productivity. Siliceous and calcareous microfossils are considered to be destroyed by diagenesis. This sequence might be the equivalent of the lower Messinian Tripoli facies described from Sicily. As at Hole 653A the uppermost Messinian consists of an alternation of gypsum-dominated intervals (predominantly "balatino type" gypsum) and gypsum-poor intervals. Parts of the gypsum were formed secondarily within the sediments by diagenetic processes. These alternations may indicate climatic fluctuations and sea level oscillations during latest Miocene time (Adams et al., 1977; Chamley et al., 1978; Hodell et al., 1986). According to Hsü et al. (1978) the uppermost Messinian series might have been deposited during the initial infilling phase preceding the important early Pliocene transgression related to a global warming and sea level rise. It might be possible that marine waters have been spilled over into the western basin during latest Messinian time before they reached the eastern Mediterranean. The typical latest Miocene "Lago Mare" facies known from the eastern Mediterranean and from several land sections in the western Medi-

terranean, characterized by brackish to limnic deposits with abundant *Ammonia beccari* and *Cyprideis pannonica* was not observed in the deep-sea boreholes drilled in the western region. This might show that the marine conditions during the uppermost Messinian were less restricted than in the eastern Mediterranean due to a more important influence from the Atlantic.

### Pliocene

Climatic conditions seem to be rather stable within the lowermost Pliocene (NN12). A decrease of surface-water temperature is expected within nannoplankton zone NN13 and lower NN14 (about 4.2–3.8 m.y.) based on the scarcity of discoasters. This interval is characterized by the presence of *Discoaster variabilis*. Other discoasters are generally rare or absent. It is assumed that *Discoaster variabilis* is less sensitive against lower water temperatures like, for example, *Discoaster deflandrei*. Thunell et al. (this volume) reported variable climatic conditions for this time interval based on isotope analysis. The first occurrence of the cool-water species *Globorotalia puncticulata* at 4.1 m.y. in the Mediterranean was explained by an extension of the cool eastern Atlantic boundary current (Zachariasse and Spaak, 1983). A significant change in surface- as well as deep-water masses must be accepted at about 3.2 m.y. (boundary NN15/NN16). This interval is characterized by the acme of *Discoaster asymmetricus* and *Discoaster tamalis* as well as by the abundance of very small coccoliths and scyphospheres. It is also marked by a change in planktonic foraminiferal assemblages and a significant turnover in benthic associations (Meulenkamp et al., 1979; Rio et al., 1984). These observations indicate an important paleoenvironmental change around the lower/upper Pliocene boundary as also described from the Atlantic (Sarnthein et al., 1982). Hodell et al. (1983) interpreted a significant faunal and isotopic change at 3.2 m.y. in the Vema Channel as vertical displacement of circumpolar water masses by Antarctic Bottom Water and North Atlantic Deep Water. This might be related to a global cooling event and/or to the final closure of the Central American seaway at 3.2 m.y. A strong drop of surface-water temperature within nannoplankton zone NN16 of the upper Pliocene at about 2.5 m.y. is inferred from the significant decrease in discoasters (Bizon and Müller, 1977, 1978) due to the onset of glaciation in the northern hemisphere. It is followed by a time of distinct climatic fluctuations (2.5–1.8 m.y.) characterized by the restriction of discoasters to certain levels which fall together with the occurrence of warm-water planktonic foraminifera (Bizon and Müller, 1978). From 2.0 to 1.6 m.y. discoasters are absent from the western Mediterranean. Comparable observations have been described from the northeast Atlantic (Müller, 1979). Alternating periods of cold arid climate with stronger winds and warmer more humid climate within the interval from 2.5 to 1.8 m.y. might explain the increase of upwelling observed in the western and eastern Mediterranean land sections during this time (Meulenkamp et al., 1979; Ghidalia, 1987). Periods of upwelling are reflected by deposition of fine laminated diatomites. They show an increase in wind-transported pollen (Strick-Rosignol, 1973; Combourieu-Nebout, 1987). Off northwest Africa it is inferred from the onset of coastal upwelling and deposition of eolian-sand turbidites since 2.5 m.y. to the beginning of numerous periods of accentuated glacial-style meridional trade winds (Sarnthein, 1977; Sarnthein et al., 1982).

### Quaternary

The Pleistocene nannofossil assemblages of the western Mediterranean show a more important influence of Atlantic water masses (Müller, 1978, 1985). The general aspect of the late Pleistocene assemblages in the western Mediterranean indicates slightly lower surface-water temperatures compared with those from the eastern part. Typical warm-water species like *Disco-*









*sphaera tubifera*, *Oolithotus fragilis*, *Umbilicosphaera mirabilis*, and *Umbellosphaera tenuis* are only rare or absent in the Tyrrhenian Sea. *Coccolithus pelagicus*, a cold-water species, is present in the western Mediterranean with varying abundance throughout the Quaternary. Its distribution pattern is strongly controlled by the Atlantic surface currents. This species is generally absent from the eastern Mediterranean except for very short incursions related to stronger influx of Atlantic water masses (Müller, 1972, 1973). Nannofossil assemblages within the lower Pleistocene (NN19) are rather homogenous indicating more constant conditions up to the interval with the small *Gephyrocapsa* sp. acme which is characterized by numerous short-period cycles. The end of this interval represents the boundary between the "preglacial" and "glacial" Pleistocene at about 0.8 m.y. A significant difference exists in the sedimentary record between the lower Pleistocene (NN19) and the upper Pleistocene (NN20-NN21). This change took place at about 0.5-0.45 m.y. and is most probably related to more important climatic fluctuations as also indicated by isotope analysis (Grazzini et al., this volume; Thunell et al., this volume). The sediments deposited during the younger time interval consist predominantly of distal turbidites (Hieke et al., this volume) with reworking of nannoplankton from older strata and tunicate spines from the shelf. This difference is also clearly reflected in the accumulation rates which are strongly decreasing below 0.5 m.y. The high sedimentation rates within the upper Pleistocene are locally reinforced by the input of volcanic ashes.

Previously, sapropels were almost exclusively described from the eastern Mediterranean (Kidd et al., 1978). They were explained by most of the authors by the high influx of less-saline water from the Black Sea and fresh water from the rivers during interglacial periods. Müller (1972, 1973) assumed that the influx of less-saline Atlantic water masses linked with the sea-level rise during interglacial periods was of greater importance for density stratification in the water column. However, there are probably various factors causing stagnant conditions in the bottom water and formation of organic-matter-rich layers. The interval with the small *Gephyrocapsa* sp. acme is characterized in the western Mediterranean by the occurrence of several sapropel layers. These sapropels as well as those within the upper Pleistocene are considered to be related to glacial-interglacial cycles.

Micropaleontological studies and isotope analysis have shown that almost all of the sapropels and sapropelitic layers were deposited during the onset of interglacial periods. However, not each climatic change was strong enough to cause stratification within the water column and anoxic conditions with formation of organic-matter-rich layers. Some stratifications were only inferred from a very high pyrite content in the sediments or from an atypical nannoplankton assemblage. The dominance of *Braarudosphaera bigelowi*, a species which indicates less-saline surface water, within few sapropels around the Pliocene/Pleistocene boundary (Fig. 3) and some thin white layers within the lowermost part of zone NN19 might be related to climatic changes with heavy rainfalls and influx of fresh water. The *Braarudosphaera bigelowi* layers are restricted to this stratigraphic interval, and they were also described from the eastern Mediterranean (Stradner, 1973; Müller, 1978, 1985) where they are, however, less pronounced. The fact that these *Braarudosphaera bigelowi* layers are more distinct in the western than in the eastern Mediterranean might show that the climate was more humid within the western area.

### SUMMARY

Investigation of about 1500 samples collected during Leg 107 in the Tyrrhenian Sea have shown that, besides some minor difficulties, the established nannoplankton zonal scheme and the correlation with biostratigraphic events based on planktonic

foraminifera can be used in the western Mediterranean. The climatic evolution and the distribution pattern of water masses in the western Mediterranean are closely related to the paleoceanographic evolution of the Atlantic which is controlled by global climatic events as demonstrated by previous observations (Bizon and Müller, 1977). Oldest marine sediments recovered during Leg 107 are of late Tortonian age. The Messinian sediments were deposited under various environmental conditions ranging from continental to restricted marine following the paleomorphology. The uppermost Messinian faunal and floral assemblages from Hole 653A and Hole 654A are comparable with those described from other boreholes in the western Mediterranean. The rather stable climate characterizing the earliest Pliocene is followed by a distinct cooling with several fluctuations within nannoplankton zones NN13 and lower NN14 (about 4.3-3.8 m.y.). An important paleoenvironmental change at about 3.2-3.0 m.y. (NN15/NN16) linked with an important turnover of faunal and floral assemblages is generally considered to correlate with a cooling. This change affected the planktonic as well as the benthic assemblages, and it is also reported from the Atlantic. A strong drop of surface-water temperature caused by the onset of the northern hemisphere glaciation at about 2.5 m.y. (within zone NN16) can easily be recognized by a distinct decrease in discoasters. Between 2.5 and 2.0 m.y., discoasters are rare to few and restricted to certain levels which at the same time are characterized by the presence of warm-water planktonic foraminifera. This indicates a number of climatic fluctuations from cold arid to warmer more humid climate. They might explain the increase of upwelling within the upper Pliocene described from the western and eastern Mediterranean land sections. Discoasters are absent in the Tyrrhenian Sea during latest Pliocene time (about 2.0-1.6 m.y.). The Pliocene/Pleistocene boundary is determined by the extinction of *Cyclococcolithus macintyreii* at about 1.6 m.y. at the top of the Olduvai paleomagnetic event. Sapropels are concentrated around this boundary. The occurrence of abundant *Braarudosphaera bigelowi* within certain levels around the Pliocene/Pleistocene boundary and within the lowermost NN19 might indicate periods of heavy rainfall and inflow of fresh water. Warmer and more stable conditions during the lowermost Pleistocene (about 1.6-1.2 m.y.) were replaced by numerous smaller climatic oscillations within the interval of the small *Gephyrocapsa* sp. acme (1.2-0.9 m.y.). This interval is also marked by several sapropel layers. The upper Pleistocene (from about 0.5 m.y.) is characterized by a change in the sedimentary record. The climatic fluctuations during this time are of higher amplitude.

Sapropels formed during the upper Pleistocene are related to density stratification in the water column due to higher influx of less-saline Atlantic water masses during interglacial periods.

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