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Calcareous plankton analysis in the pre-evaporitic sediments of the ODP Site 654 (Tyrrhenian Sea, Western Mediterranean)

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ABSTRACT: High and low resolution analyses on Calcareous nannoflora were performed in Tortonian-Messinian sediments of the ODP Site 654 immediately prior to the Salinity crisis. The main changes in the assemblage were compared with variations in the association of keel Globorotaliids and calibrated with the magnetostratigraphic interpretations proposed for this interval.

Around 6.8 Ma an increase in *Geminilithella rotula* over *G. jafarii* was observed immediately prior to the reduction of sinistral keel Globorotaliids (group 1 of *Globorotalia menardii*). The FOD of *Amaurolithus primus* coincide with a coiling change from sinistral to dextral in the unkeeled *Globorotalia*, around 6.5 Ma, whereas the FOD of *Amaurolithus delicatus*, approximately coinciding with the Tortonian/Messinian boundary, is synchronous with the entry of conic planoconvex *Globorotalia* (group of *G. miotumida/G. conoidea*) into the Mediterranean. The estimated age for this event is 6.43 Ma, which slightly predates the FOD of *Reticulofenestra rotaria*.

The variations in the total abundance of nannoliths in the sediments enabled us to recognize 5 intervals. Nannoliths in interval A were probably affected by taphonomic processes in a shallow water environment. The low abundance, local absence of nannoflora in interval B, may be due to the action of bottom currents winnowing fines. Towards the top of this interval the effect of currents decrease, but the assemblages are different from that of the adjacent Atlantic probably due to a restriction in the communication with the open ocean. This may be the reason for the later occurrence of *Eu-discoaster quinqueramus* and *Eu-discoaster berggrenii* in the Mediterranean. Interval C assemblages are of Oceanic affinity showing an asterolith association similar to that of the adjacent Atlantic. On the other hand, strong fluctuations have been observed in interval D, which may be related to changes in salinity, or water stratification, after a probable reduction in the exchange of Atlantic/Mediterranean waters prior to the Salinity crisis.

The progressive increase of *Dictyococcites antarcticus* along the hole, was related to the decreasing temperatures in surface waters from the late Tortonian to the early Messinian.

INTRODUCTION

The latest Miocene, which culminated with the Messinian Salinity crisis, has been the object of numerous stratigraphic (Cita 1982; Cita and Mackenzie 1986, Ryan 1973, Cita and Ryan 1973, Van Couvering et al., Hsü et al. 1973, 1977, 1978, etc.), biostratigraphic (Cita 1979, Rio et al. 1976), isotopic (Loutit and Keigwin 1982), or magnetostratigraphic (Langereis et al. 1984, Channell et al. 1990) studies. Likewise, the problem has been analysed from the paleoceanographic point of view, considering in particular the Atlantic-Mediterranean connection prior to the beginning of the crisis. Besides the above mentioned authors, Feinberg and Lorenz 1970, Benson 1976, Berggren and Haq 1976, Bossio et al. 1976, Sierro 1984, Flores 1985, Hodell et al. (1989), Müller and Hsü 1987, Benson et al. (1991), among others have also worked on this subject. Some of the writers of this report have also studied sediments of the Upper Tortonian-Messinian interval in the Guadalquivir basin (Spain) and DSDP Sites of the Adjacent Atlantic (Flores and Sierro 1987, 1989, Sierro and Flores 1989, Sierro et al., in press.)

ODP Hole 654A (Leg 107) was drilled in the western Sardinia margin (50°34.76'/10°41.80') at 2217m depth (text-figure 1). Sediments from Upper Tortonian to Pleistocene were recovered in a continuous section, including deposits related to the Salinity crisis. The calcareous nannoflora have been studied by Müller (1990), who established a biostratigraphic scheme. The planktonic foraminifera have been studied in a previous report by Glaçon et al. (1990).

The purposes of this study are: 1) the definition of the principal biostratigraphic events of hole 654 A, including the calcareous nannoplankton and planktonic foraminifera analysis and its calibration with the geochronologic scale of Berggren et al. (1985), using the paleomagnetic data of Channell et al. (1990) for this Site; 2) comparison with conventional biostratigraphic scales and with the results of the Guadalquivir basin and NE Atlantic; 3) the paleoecologic characteristics of the region (surface water masses); and 4) the paleoceanographic interpretation related to the Atlantic/Mediterranean communication during the interval immediately before the Salinity crisis.

The cores of ODP Site 654 show a sequence similar to that recorded in the Spanish and Moroccan sections (Civis et al. 1988, Flores and Sierro 1989, Benson et al. 1991). The lithostratigraphic study was carried out by Borsetti et al. (1990) who, from bottom to top, recognized the following units (text-figure 2): Unit 6, consisting of a conglomerate layered with red beds; overlain by Unit 5, bioturbated glauconitic sands (interpreted as deposited in a shallow water environment); passing to Unit 4, a nannofossil ooze in core section 45R-5 (a change takes place from a shallow water to a deep water environment); overlain by Unit 3, dolomitic dark shales, very poor in calcareous microfossils and nannofossils; continuing with Unit 2, interbedded gypsum and carbonate layers. Only Units 5 and 4 have been studied in this work.

Sedimentological characteristics to the interpretation of the micropaleontological data include: 1), the high rate of sedimentation during deposition of the upper part of Unit 4, related to productivity; 2), the low nannofossil concentration at the base of the
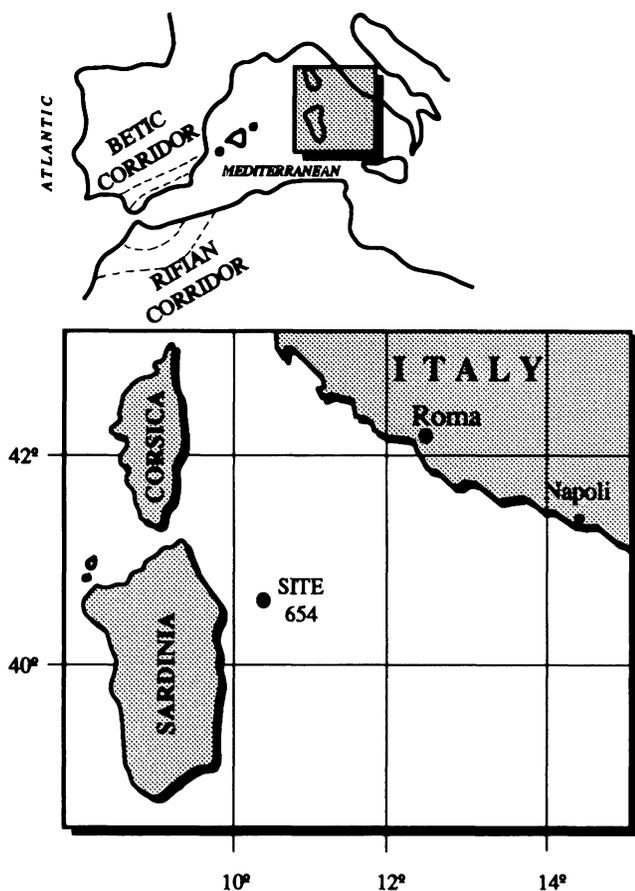
TEXT-FIGURE 1
Geographic location of ODP Site 654 and approximate paleogeographic position of Betic and Riffian corridors.

sequence; 3), the problematic interpretation of lower part of Unit 4 (under the influence of turbidity or bottom currents, Glaçon et al. 1990).

PREPARATION AND COUNTING TECHNIQUES

Nannoplankton samples were prepared following the technique proposed by Flores in 1985. The data were standardized when associations are given. The following parameters were used: weight of dry sediment, volume of enclosing fluid, setting time, volume of the extracted mixture, and surface of spreading. Slides were analysed using a light microscope, at a magnification of 1250.

Two different quantitative analysis were made: 1) a low resolution, in which 500 nannoliths were considered to identify the principal species or morphotypes of the association; 2) a high resolution, in which were counted about 20,000 nannoliths to recording taxa with biostratigrafic significance.

Counts of planktonic foraminifera were made from the 125-1000μm residue. The definition of events was based on a semi-quantitative study of keeled and unkeeled Globorotaliids (Sierro et al., in press).

NANNOFLORISTIC ASSOCIATION

Almost all the samples have a good state of preservation (Flores 1985). However, in the interval between core catcher 45-CC and core section 45-4, coinciding with Unit 5 and the base of Unit 4,

the specimens show a certain degree of overgrowth. This may be related to the different lithology of this interval (text-figure 2).

Variations of the concentration of nannoliths in the sediment; that is, the total abundance in terms of nannoliths per mm^2 (text-figure 2), show five intervals from bottom to top. The so-called intervals A and E are obviously conditioned by the lithologic characteristics of the sediment. They correspond with Units 5 and 3 respectively. Correspondingly, the amount of resedimented and poorly preserved forms is much higher in the samples of lower sections than in the upper levels.

Unit 4 is divided into intervals B, C and D. Between core sections 45-5 and 43-3 interval B, characterized by its relatively low proportion of calcareous nannoplankton (sometimes absent), is recognized. Within this interval, between core sections 44-5 and 44-2, a minimum in nannoflora is found coincident with a reduction in the sand sized particles of terrigenous or biogenic nature. A maximum abundance of nannoliths with more or less constant values is found between core sections 43-3 and 42-2 in interval C, whereas interval D is characterized by a decrease in the nannofloristic concentration from core sections 42-2 to 40-1. Fluctuating values are the most peculiar property of interval D.

In interval E nannofossils are not preserved, probably due to diagenetic effects (Müller 1990).

Low resolution analysis

The reticulofenestrids, both those with an open central area (*Reticulofenestra* s.s.), and those that have the central area closed (*Dictyococcites*), are the most abundant component of the nannofloristic association. A noteworthy characteristic of the samples analyzed is the relative uniformity in the distribution of the most abundant components of the assemblage. In numerous cases, they constitute more than 80% of the association. Following the proposal of Flores and Sierro (1989), four groups have been recognized among the Reticulofenestrids:

> *Reticulofenestra pseudoumbilicus* (Gartner 1967) s.s.
> *Dictyococcites antarcticus* Haq 1976
> Group of *Reticulofenestra haqii/minutula* [*Reticulofenestra haqii* Backman 1978 plus *Reticulofenestra minutula* (Gartner 1967)].
> Small placoliths (nannolith size smaller than 3μm, -independently of the central area properties: *Dictyococcites productus* (Kamptner 1963) emend. Backman 1980 plus *Reticulofenestrta minuta* Roth1970).

In spite of the above mentioned uniformity of distribution, some differences exist. The ranges of certain groups coincide with the intervals defined according to the abundance of nannoliths. The distribution of *R. pseudoumbilicus* is the best example of this pattern. *D. antarcticus* is proportionally reduced during interval B and progressively increases from core section 44-3 upwards. *Coccolithus pelagicus* (Wallich 1877) shows an almost opposite distribution to *D. antarcticus*. It occurs abundantly (with some breaks) up to the core section 44-2 where it starts a progressive and irregular decrease.

The distribution of *Geminilithella* is particularly significant. In interval A, up to the middle part of interval B, *Geminilithella jafarii* (Müller 1974) is clearly dominant over *Geminilithella* rotula (Kamptner 1948). But from this point upwards, *G. rotula* again becomes an important representative of the assemblage.

The rest of the taxa do not show important changes, if we exclude the sphenoliths and helicoliths, with their relatively abundant

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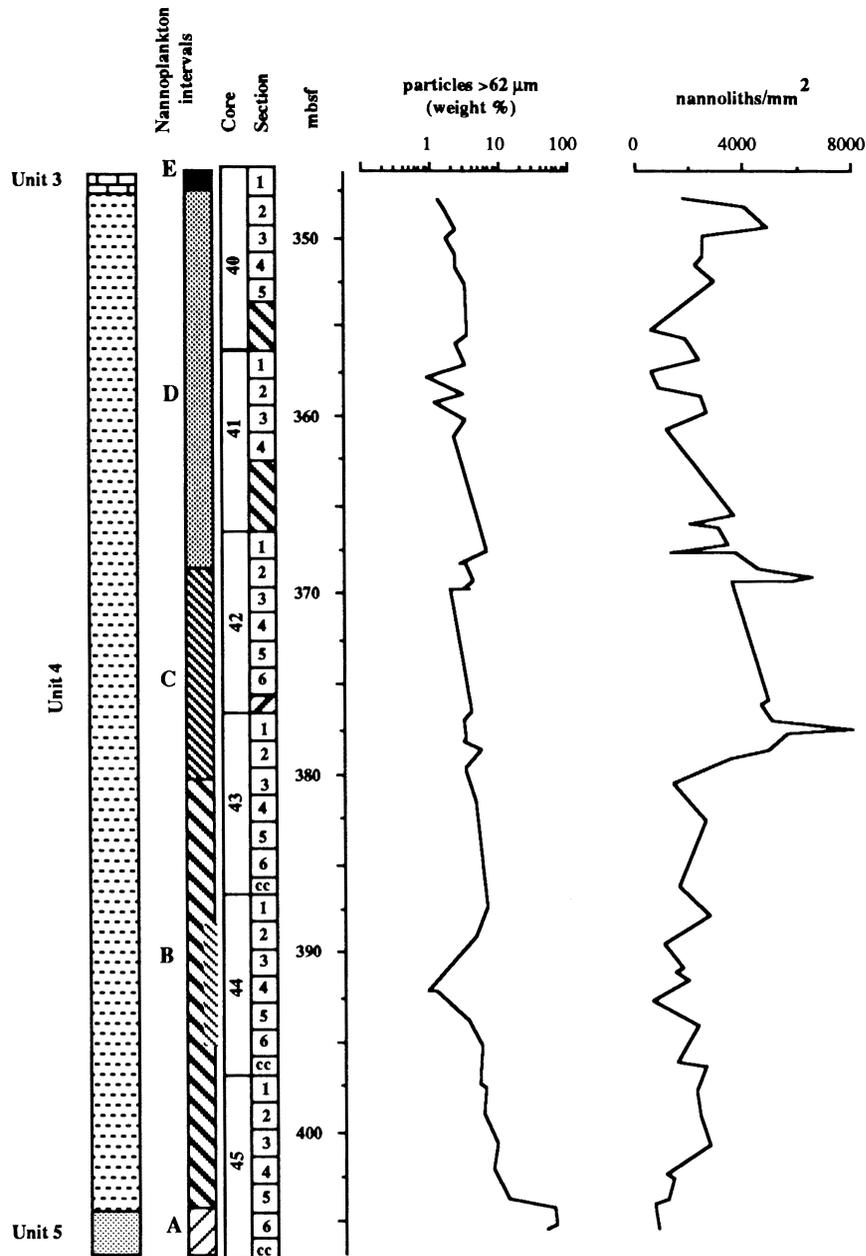
TEXT-FIGURE 2
Lithological units (Borsetti et al. 1990), weight percentage of particles larger than 62μm (Glaçon et al. 1990), and nannoliths per mm2, in ODP Site 654. Differences in nannoplankton abundance permit to establish 5 intervals.

occurrence in the basal intervals. This special distribution could be related to the lower bathymetry of these sediments.

High resolution analysis

In high resolution analysis, only those rare taxa with a stratigraphic or paleoenvironmental importance have been taken into consideration. A total of 35 species were identified.

Among traditional stratigraphic markers, *Eu-discoaster quinqueramus* (Gartner 1969) and *Eu-discoaster berggrenii* (Bukry 1971) have to be identified. The first have the FOD (First Appearance Datum) in core section 44-5; whereas the second have the FOD in core section 43-2. Other asteroliths are present, but with low diversity and abundance relative to the usual values of this parameter in the adjacent Atlantic during this interval (Flores and Sierro 1989). The FOD of *Eu-discoaster brouweri* (Tan 1929) in

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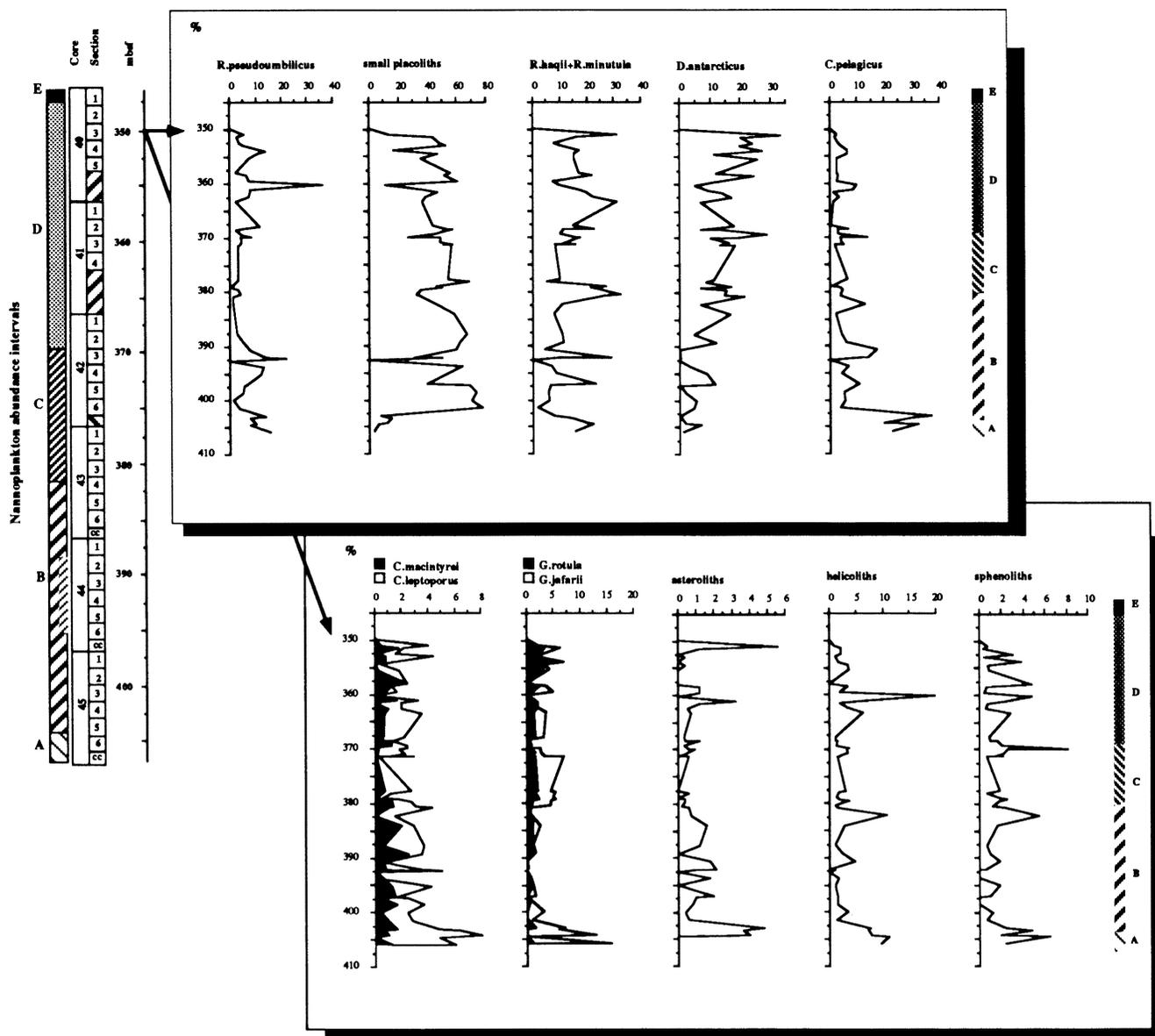
TEXT-FIGURE 3
Calcareous nannoplankton, low-resolution analysis in ODP Site 654. Five hundred nannoliths per sample have been counted.

the region, nearly synchronous with the FOD of *E. berggrenii* is noteworthy. *Amaurolithus primus* (Bukry and Perecival 1971) have the FOD in core section 43-2, while *Amaurolithus delicatus* Gartner and Bukry 1975 and *Amaurolithus tricorniculatus* (Gartner 1967) from core section 42-3 (slightly below *Amaurolithus ninae* Perch-Nielsen 1977 which appear for the first time in the top of core section 42-3). The LAD (Last Appearance Datum) of *A. ninae* is located in core catcher 41CC. *Reticulofenestra rotaria* Theodoridis 1984 have the FOD from core section 42-2 (slightly above the first appearance of *A. delicatus*). The LAD of *R. rotaria* has been recognized in core section 41-1. The continuous occurrence of *Scyphosphaera* from core section 43-6 is also noted, although its proportion is not as high as the abundance usually observed in certain locations of the NE Atlantic (Flores and Sierro 1989).

PLANKTIC FORAMINIFERA ASSOCIATION

A semiquantitative analysis of the assemblage of the planktic foraminifera has been carried out, focusing mainly on the different components of the genus *Globorotalia*. As we have cited in previous reports of the Atlantic fauna (Sierro 1985; Flores and Sierro 1987, 1989; Sierro et al., in press), this genus can be divided into various groups that have discontinuous stratigraphic distributions. The appearance, disappearance and replacement of each group have been used to define a series of events that can be correlated with those observed in the calcareous nannoflora (text-figure 4).

Group I of *Globorotalia menardii* (sinistral forms morphologically close to *Globorotalia cultrata* (D'Orbigny 1839), *Globorotalia*
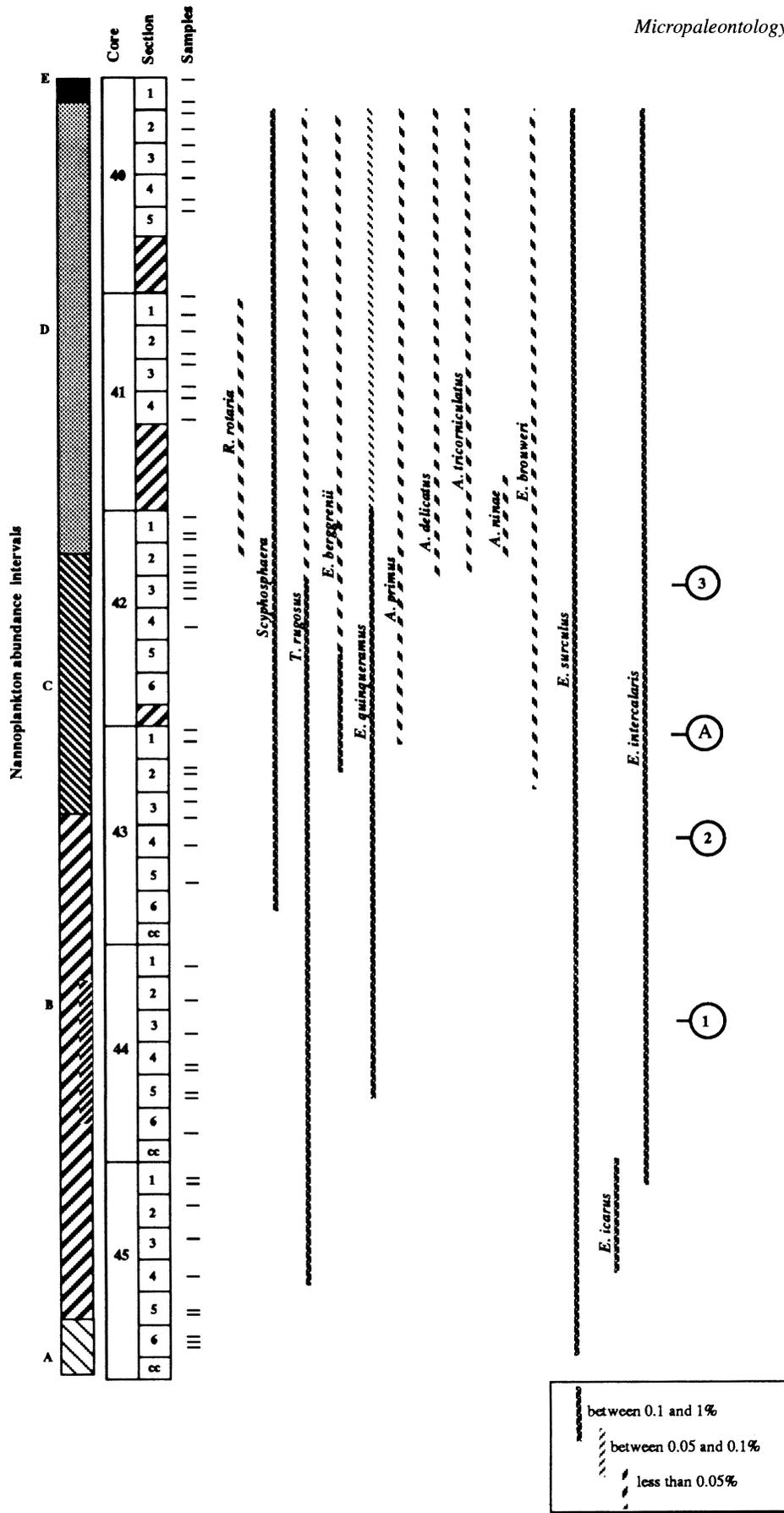
TEXT-FIGURE 4

Calcareous nannoplankton, high-resolution analysis, and situation of the main planktonic foraminifera events at ODP Site 654 (see text).For this nannofloristic study 20,000 nannoliths per sample have been counted.

merotumida Blow and Banner 1965 and *Globorotalia plesiotumida* Blow and Banner 1965) disappears stratigraphically upward between core sections 44-3 and 44-2 (Glaçon et al. 1990). This disappearance designated as event (1) has been recognized in the Eastern Mediterranean (Zachariasse 1975) in the NE Atlantic, Spain and Morocco (Tjalsma 1971, Sierro 1985, Sierro et al. in press., Benson et al. 1991), and its age in the Tyrrhenian Sea according to the magnetostratigraphic data of Channell et al. (1990; Subchron 7n1) is ca. 6.7 Ma. After an interval in which keel Globorotaliids are absent, group II of *Globorotalia menardii* (dextral forms with a more open spire and umbilicus, and less inflated chambers than the forementioned group) appears abundantly. The appearance of Group II, which is designated as event (2) has been observed in the Mediterranean (Zachariasse 1975) and adjacent Atlantic (Tjalsma 1971, Sierro et al. in press). Its estimated age is 6.56 Ma. A short interval after the aforementioned event, a sinistral to dextral change in the coiling direction of the *Globorotalia scitula* group is recorded (event A). This event has been cited in Spain, Morocco and NE Atlantic (Sierro et al. in press) and its age in the Tyrrhenian Sea is 6.5 Ma

Near the Tortonian/Messinian boundary some differences exist in the association of keeled Globorotaliids between the Atlantic and Mediterranean. Whereas in the Atlantic we observe the replacement of the group II of *G. menardii* by the group of *G. miotumida-G. conoidea*, in the Tyrrhenian (ODP Site 654) the disappearance of the first group is recorded sometime before the entry of the second. During this very short interval (20Ky) only unkeeled Globorotaliids occur in the Tyrrhenian.

One of the most evident events in the Tyrrhenian Sea, the whole Mediterranean and adjacent Atlantic, is the rapid invasion (event 3) of planoconvex forms included in the *G.miotumida-G.conoidea* group. This event has been generally correlated with the Tortonian/Messinian boundary. The morphology of this group is different in the Atlantic and the Mediterranean. In the Atlantic, less inflated forms with thinner walls, and fewer number of chambers in the last whorl (*Globorotalia miotumida* Jenkins 1960 morphotype) are dominant. In the Mediterranean, these forms are partially replaced in the earliest Messinian by others with a more inflated umbilical side, more chambers in the last whorl, and a thicker wall (*Globorotalia conoidea* Walters 1965 and *Globorotalia mediterranea* Catalano and Sprovieri 1969 morphotypes).

With respect to the remainder of the assemblage, it is necessary to outline that in the Tyrrhenian Sea, the typical species of warm waters are more abundant than in the contemporaneous adjacent Atlantic, Mediterranean and Betic strait. Also an alternation of cold and warm water species has been recognized during the earliest Messinian, in the upper part of unit 4.

GENERAL REMARKS

Event stratigraphy

Almost all the biostratigraphic events previously defined in deposits of the NE Atlantic, the Spanish, and the Moroccan basins have been identified in cores from Site 654 in the Tyrrhenian sea, though further comments are necessary in some particular cases.

Flores (1985) and Flores and Sierro (1987, 1989) recognized in the Atlantic the existence of a quantitative inversion between different elements of the reticulofenestrid nannofloral association. The proportion of small placoliths increased over the *R. haqii/minutula* group (larger in size). Although this event has not been observed in ODP Site 654 in the Tyrrhenian Sea other synchronous Atlantic

changes, such as the increase of *D. antarcticus* over *C. pelagicus*, are present. This change is accompanied by an evident increase of *G. rotula* (text-figure 3). However, unlike its behavior in the Atlantic, *G. jafarii* reduces its proportion over *G. rotula*. This trend is only temporary. An increase is recorded toward upper levels. This event is contemporaneous with event 1 in planktic foraminifera and it is found toward the top of Chron 7 (6.8 Ma; Channell et al. 1990; Berggren et al. 1985; text-figure 5).

An evident diachronism exists between the first record of the *E. quinqueramus* group representatives (*E. quinqueramus* + *E. berggrenii*) in the Atlantic and that recorded at Site 654 in the Tyrrhenian sea (text-figure 6). The first *E. quinqueramus* occurs a short interval below the increase of *G. rotula* and event 1 in planktonic foraminifera, whereas *E. berggrenii* is recorded from core section 43-3, up to the bottom of Chron 6n1 (Channell et al. 1990) with an estimated age of 6.5 Ma (text-figure 5). In the Atlantic, Pacific and Indian oceans this taxon usually appears ca. 8 Ma (Haq et al. 1980, Rio et al. 1990), Chron 8 anomaly 4A (Berggren et al. 1985). It is important to point out the absence of this group of pentaradiated asteroliths in the eastern Mediterranean (Theodoridis 1984), but not in the western Mediterranean (Rio, Mazzei and Palmieri 1976).

The FOD of *A. primus* is located in core section 43-2, coinciding with event A slightly above event 2. According to the magnetostratigraphy proposed by Channel et al. (1990), the age of this event may be estimated Ca. 6.5 Ma, coinciding with that proposed by Mazzei et al. (1979), Haq et al. (1980) and Berggren et al. (1985).

The FOD of *A. delicatus* is isochronous with event 3, located in core section 42-3., which approximately coincides with that observed by Müller (1990) in the same hole. Kastens and Mascle (1990a) correlated the Tortonian/Messinian boundary with the NN11a/NN11b limit as described by Martini and Müller (1986). However, Müller (1990; pp. 508), placed the NN11a/NN11b boundary, coinciding with the first record of *Amaurolithus* spp., but not the FOD of *A. delicatus* and for this reason the FOD of *G. conomiozea* is delayed. Flores and Sierro (1987, 1989) and Sierro (1985), correlated the FOD of *A. delicatus* and event 3 of planktonic foraminifera with the Tortonian/Messinian boundary which, in turn, coincides with the proposal of Mazzei (1977) for the Tortonian stratotype, where the FOD of *A. primus* occurs slightly prior to the FOD of *A. delicatus.*

In Hole 654A, the FOD of *A. delicatus* occurs around 369m depth, which is located, in accordance with the magnetostratigraphic proposal of Channell et al. (1990), towards the middle of Chron 6, with an estimated age of 6.43 Ma (text-figure 5). Our data do not support the magnetostratigraphic interpretation of Kastens and Mascle (1990b) and Kastens (1990).

According to Haq et al. (1980), the Late Miocene carbon shift is isochronous in the Atlantic and Pacific between 6.1 and 5.9 Ma, immediately after the FOD of *Amaurolithus* spp. Keigwin et al. (1987) recognized the Messinian carbon shift in several DSDP sites of the North Atlantic, with an estimated age of 6 Ma, coinciding with the younger reversed interval of Chron 6. Glaçon et al. (1990) did not observe this event at Site 654; however, they found an evident decreasing trend in ^{13}C values of planktic foraminifera between 402 and 395m depth, which is clearly prior to the FOD of *A. primus*. Maximum values of ^{13}C at the base of Hole 654 probably may be correlated with the high values observed by Keigwin et al. (1987) in the North Atlantic around 7 Ma (Glaçon et al. 1990).
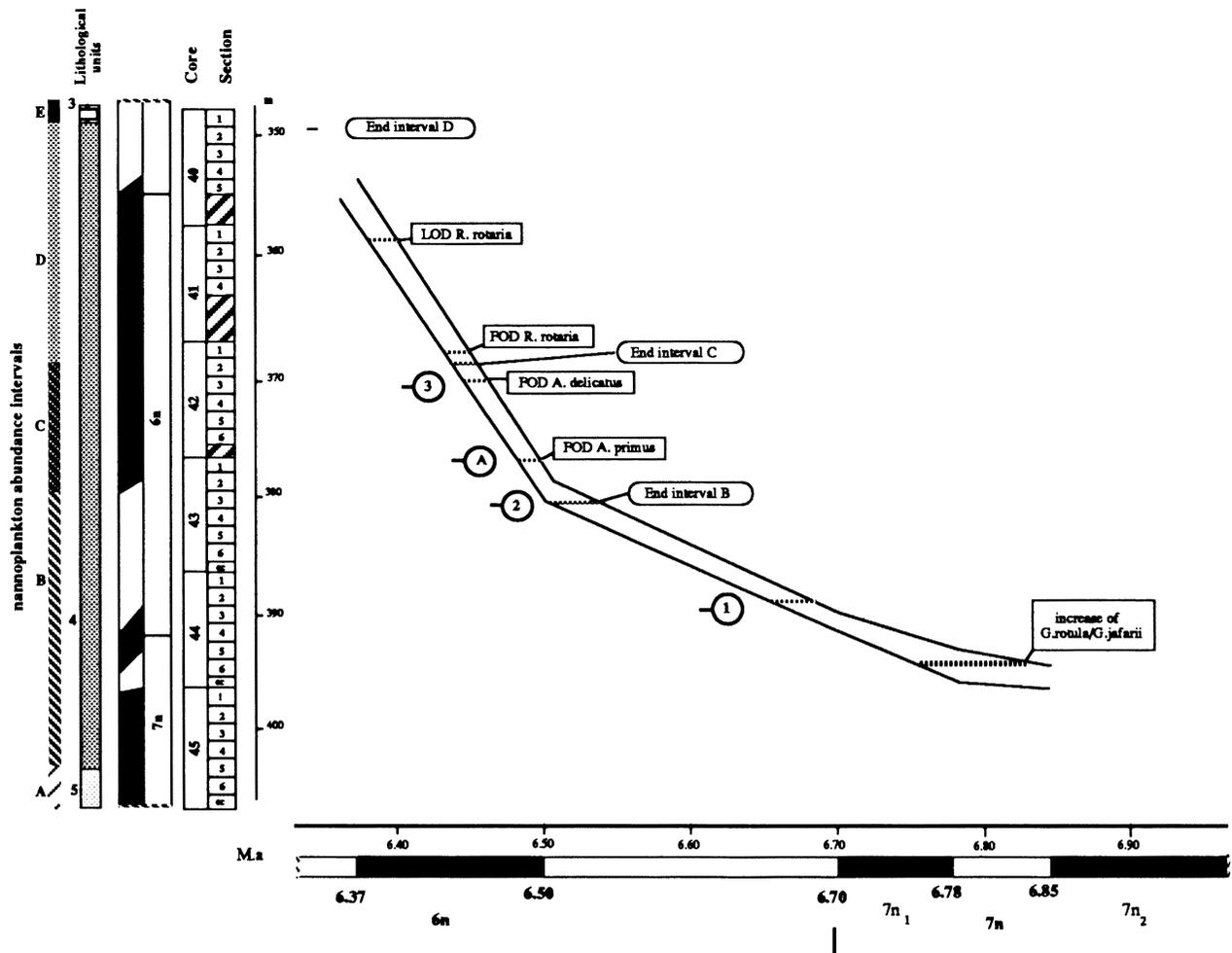
TEXT-FIGURE 5
Main biostratigraphic events with respect to the magnetostratigraphic scale (Channell et al. 1990; Berggren et al. 1985) and sedimentation rates.

The first representatives of a reticulofenestrid identified as *R. rotaria* appear some metres above event 3. This taxon shows a very short range. It disappears in section 41-1 (text-figures 4 and 5). It was used as a biostratigraphic marker in the Indian and Eastern Mediterranean (Theodoridis 1984, Young 1990), but has never been reported from the Atlantic. In Site 654 the FOD of *R. rotaria* coincides approximately with the Tortonian/Messinian boundary.

Nannoplankton intervals

The intervals defined by taking into account the total abundance of calcareous nannplankton seem to reflect paleoceanographic changes in the Mediterranean prior to the Salinity crisis, during a time of Global sea level rise.

The characteristics of the assemblage in nannoplankton intervals A and B are mainly controlled by the sedimentary environment, so that they are not always comparable with the contemporaneous Atlantic oceanic associations. According to Borsetti et al. (1990), interval A corresponds to a shallow water sedimentary environment, transgressive over the Basement.

Interval B can be interpreted as sediments formed under the influence of bottom or turbidite currents (Glaçon et al. 1990). The

effect of these currents is specially evident between core sections 44-5 and 44-3 (text-figure 4). Because of this, the planktic foraminiferal fauna is dominated by the small size species like *Globigerina quinqueloba* Natland 1938 and *Globigerinita glutinata* (Egger 1893). In this interval, where the action of bottom currents is not intensive, the association of asteroliths and reticulofenestrids is different from that of the adjacent Atlantic and Betic-Riffian straits. (text-figure 3). This may be due, either to the existence of special conditions in the Tyrrhenian water masses or to the reduced water exchange between the Atlantic and the Mediterranean.

Interval C sediments usually characteristic of deep environments have a higher concentration of calcareous nannoflora. Coincidence between an increase in nannoflora and the reduction of the size sand fraction in interval C suggests a decrease in bottom current velocity, which would allow a greater accumulation of fine grain particles. This interval also shows some differences with respect to the Atlantic assemblages. The proportion of *G. jafarii* in this interval is much higher than that in the adjacent Atlantic. This taxon seems related to relatively warm surface water-masses (Flores 1985) consistent with a higher abundance of *Scyphospaera* and *Globigerinoides*. The presence of assemblages with characteristics closer to their equivalent in the Atlantic, enables us to suggest that

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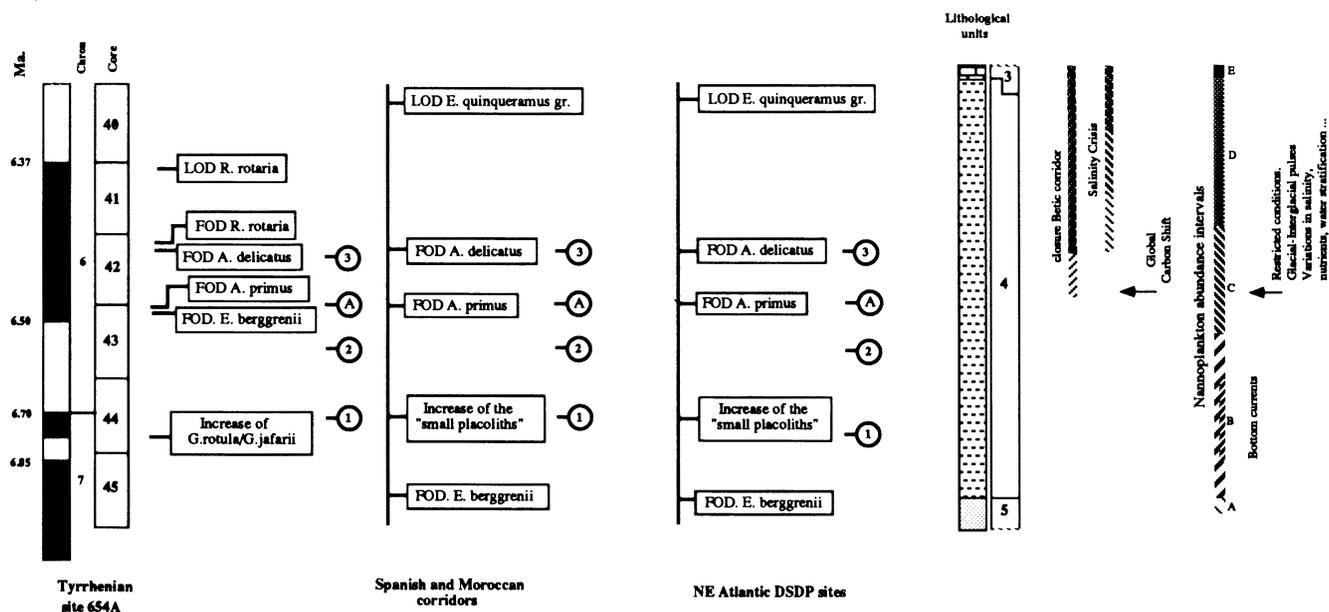
TEXT-FIGURE 6
Main biostratigraphic events of Spanish, Moroccan, and Atlantic DSDP/ODP sections with respect to changes in magnetic signals.

the Atlantic-Mediterranean communication was slightly more active during this interval.

The strong fluctuations characteristic of interval D affected not only the calcareous nannoplankton abundance, but the 18O values of planktic foraminifera. These fluctuations were explained by Glaçon et al. (1990) as probable changes of salinity or water stratification (text-figure 6). These data support the idea of Müller (1978) in Leg 42. According to the above mentioned, *R. rotaria* may be interpreted as an ecophenotype characteristic of the peculiar oceanographic conditions existing in the Mediterranean prior to the Salinity crisis (text-figure 6).

The gradual increasing of *D. antarcticus* (text-figure 3), typical of cold surface waters (Backman 1980) along Hole 654A, strongly suggest that, in spite of the reduced communication with the open ocean, temperatures of surface waters were progressively lower.

ACKNOWLEDGMENTS

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