

30. RELATIONSHIP BETWEEN THE BENTHIC FORAMINIFERS AND THE OSTRACODES IN THE PLIOCENE-PLEISTOCENE TYRRHENIAN DEEP-SEA RECORD (ODP LEG 107, SITE 654)¹

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ABSTRACT

Deep-water benthic ostracodes from the Pliocene-Pleistocene interval of ODP Leg 107, Hole 654A (Tyrrhenian Sea) were studied. From a total of 106 samples, 40 species considered autochthonous were identified. Detailed investigations have established the biostratigraphic distribution of the most frequent ostracode taxa. The extinction levels of *Agrenocythere pliocenica* (a psychrospheric ostracode) in Hole 654A and in some Italian land sections lead to the conclusion that the removal of psychrospheric conditions took place in the Mediterranean Sea during or after the time interval corresponding to the Small *Gephyrocapsa* Zone (upper part of early Pleistocene), and not at the beginning of the Quaternary, as previously stated.

Based on a reduced matrix of quantitative data of 63 samples and 20 variables of ostracodes, four varimax assemblages were extracted by a Q-mode factor analysis. Six factors and eight varimax assemblages were recognized from the Q-mode factor analysis of the quantitative data of 162 samples and 47 variables of the benthic foraminifers.

The stratigraphic distributions of the varimax assemblages of the two faunistic groups were plotted against the calcareous plankton biostratigraphic scheme and compared in order to trace the relationship between the benthic foraminifers and ostracodes varimax assemblages. General results show that the two populations, belonging to quite different taxa, display almost coeval changes along the Pliocene-Pleistocene sequence of Hole 654A, essentially induced by paleoenvironmental modifications. Mainly on the base of the benthic foraminifer assemblages (which are quantitatively better represented than the ostracode assemblages), it is possible to identify such modifications as variations in sedimentation depth and in bottom oxygen content.

INTRODUCTION

The late Pleistocene and Holocene benthic ostracode faunas of the Mediterranean Sea have been the subject of many papers, mostly dealing with ostracodes of the continental shelf. On the contrary, data concerning the Pliocene-Pleistocene Mediterranean deep-water ostracodes are rather scarce (Benson and Sylvester-Bradley, 1971; Benson, 1972a, 1973, 1975; Bonaduce et al., 1983, with references). In the present paper the ostracodes from the Pliocene-Pleistocene sediments of ODP Leg 107, Hole 654A, drilled in the Tyrrhenian Sea at a depth of 2208 m below sea level (Fig. 1), are examined.

The purposes of this paper are (1) to present the stratigraphic ranges of the ostracodes of Hole 654A with reference to the calcareous plankton biostratigraphy of this hole as reported in Glaçon, Rio, and Sprovieri (this volume, Fig. 3); (2) to detect if the faunistic changes recognized in the ostracode populations occurred at the same stratigraphic levels in which faunistic changes were observed in the benthic foraminifer populations (Hasegawa, Sprovieri, and Poluzzi, this volume); (3) to detect if the same paleoenvironmental factors may account for the modifications of both faunistic groups.

As the number of ostracodes species recovered from each sample is small (Table 2), little could be inferred about the general evolution of the Mediterranean ostracode assemblages during the Pliocene-Pleistocene time interval.

MATERIALS AND METHODS

The data discussed in this survey are based on the analysis of core-samples from ODP Leg 107, Hole 654A (Fig. 1). The qualitative and

quantitative analyses were performed on 106 core samples for the ostracode assemblages (Table 2) and on 168 core samples for the benthic foraminifer assemblages (Sprovieri and Hasegawa, this volume; Hasegawa, Sprovieri, and Poluzzi, this volume).

From each core sample about 10 cm³ of sediment were taken, washed through a 63- μ m sieve and dried at 40°C. All the specimens, including the instars of ostracodes, were picked out from the >125- μ m residue fraction, identified, and counted. The relative abundances of the various taxa in each sample were calculated and used in the factor analysis.

Computational operations in foraminifer assemblages were carried out taking into account only samples with more than 50 specimens (Hasegawa, Sprovieri, and Poluzzi, this volume). The original data set was therefore reduced to an array of 162 observations (or samples) per 47 taxonomic units (or variables), which was submitted to a Q-mode factor analysis (sample by sample confrontation).

Due to generalized paucity of specimens, in benthic ostracode assemblages we retained only samples with more than 5 specimens. A reduced array of 63 samples per 20 variables was organized and submitted to a Q-mode factor analysis.

In benthic foraminifers, the use of factor analysis was operationally dictated by the purpose of obtaining independent and ecologically significant varimax assemblages and of deriving some information on the main environmental changes recorded in the Pliocene-Pleistocene sequence of Hole 654A.

In benthic ostracodes, the factorial information strongly reflects the restriction of the input elements (small number of specimens per sample). This would compromise the reliability of independent paleoecological information from this basic faunistic group. Clustering techniques might be used in order to obtain aggregate samples and enrichment in specimens, but this criterion may be adopted only in presence of closely sampled levels. If samples are rather sparse along the cores as in Hole 654A, clustering might give not reliable results. Therefore the Q-mode factor analysis on the ostracode populations has been adopted prevalently as a "data reduction" and "data ordering" criterion. No direct statistical inference has been drawn from the results of this factorial scheme. However, despite the limitations concerning the ostracodes, we believe that some general indications can be drawn from their factorial model, especially if compared with the results obtained from benthic foraminifers.

The factorial models were produced by the CABFAC program, that optionally computes a cosine theta similarity matrix from a normalized

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

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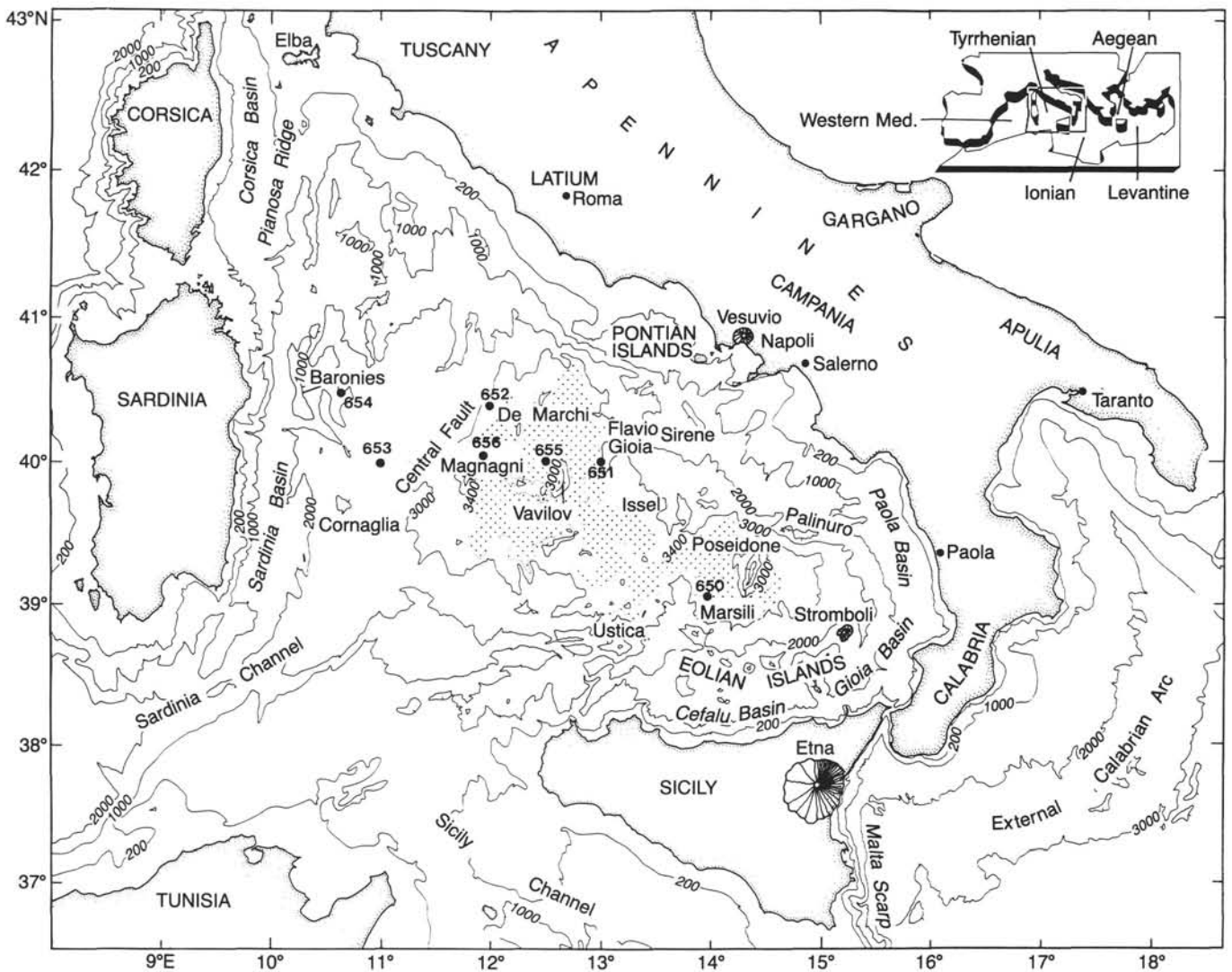


Figure 1. Location map of Site 654.

array of percentage data. In the following paragraphs, a short summary of the quantitative procedure is given. For more detailed explanations, the reader is referred to Imbrie and Kipp (1971).

OSTRACODE BIOSTRATIGRAPHIC EVENTS

A biostratigraphic scheme generally accepted for the Mediterranean Pliocene and Pleistocene ostracode faunas does not yet exist. On the other hand the ostracode faunas from Hole 654A are too poor in species and specimens (Table 2) to allow constructing such a scheme. Moreover deep-water ostracode assemblages, as the ones found in Hole 654A, are not only less rich in specimens, but have been also less studied up to now than the shelf assemblages.

In this chapter only the species which—on the basis either of data gathered from literature or of unpublished data of two of the present authors (M.L.C. and G.P.)—seem to have significant stratigraphic ranges will be considered from a biostratigraphic point of view. All the statements in this chapter for which authors are not mentioned derive from unpublished data of M.L.C. and G.P.

The stratigraphic ranges of the ostracodes will be compared with the most important calcareous plankton biostratigraphic events (Figs. 2 and 3) recognized in Hole 654A by Glaçon, Rio, and Sprovieri (this volume).

In the following pages we will consider separately the ostracode events recorded in the Pliocene and in the Pleistocene sediments of Hole 654A. The abbreviations FO, LO, FAD, and LAD mean first occurrence, last occurrence, first appearance datum, and last appearance datum, respectively.

The Pliocene/Pleistocene boundary has been recognized by Glaçon, Rio, and Sprovieri (this volume) within sample 107-654A-10R-1, 70–72 cm, 79.7 mbsf (meters below seafloor), as corresponding with the beginning of dominance of the left-coiling specimens of *Neogloboquadrina pachyderma* with respect to the right-coiling specimens: in fact in the Vrica section, this event is penecontemporaneous with the Pliocene/Pleistocene boundary stratotype (Aguirre and Pasini, 1985; Pasini and Colalongo, in press).

Pliocene Ostracode Fauna

In the Pliocene stratigraphic interval—stretching from 242.7 to 79.7 mbsf (Glaçon, Rio, and Sprovieri, this volume)—the ostracode assemblages are in general poor in specimens and species, among which the most frequent are *Krithe aequabilis* Ciampo (Pl. 1, Figs. 5–6), *K. sinuosa* Ciampo, *Agrenocythere pliocenica* (Seguenza), and *Henryhowella asperrima* (Reuss).

Zone MP11 (*Sphaeroidinellopsis* Zone) and the lowermost part of Zone MP12 (*Globorotalia margaritae* Zone) are particu-

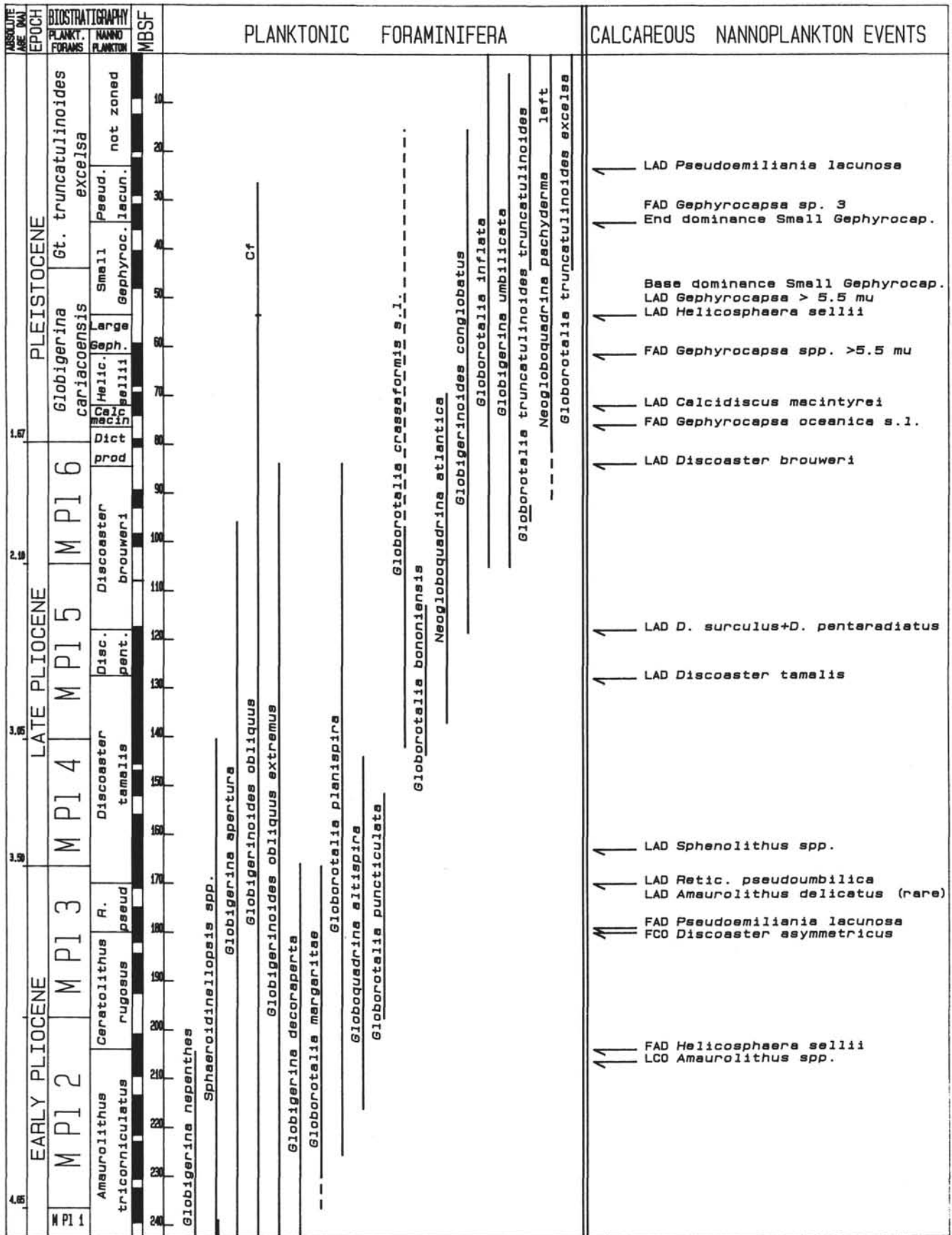


Figure 2. Planktonic foraminifer ranges and calcareous nannoplankton events in the Pliocene-Pleistocene interval of Hole 654A (from Glaçon, Rio, and Sprovieri, this volume).

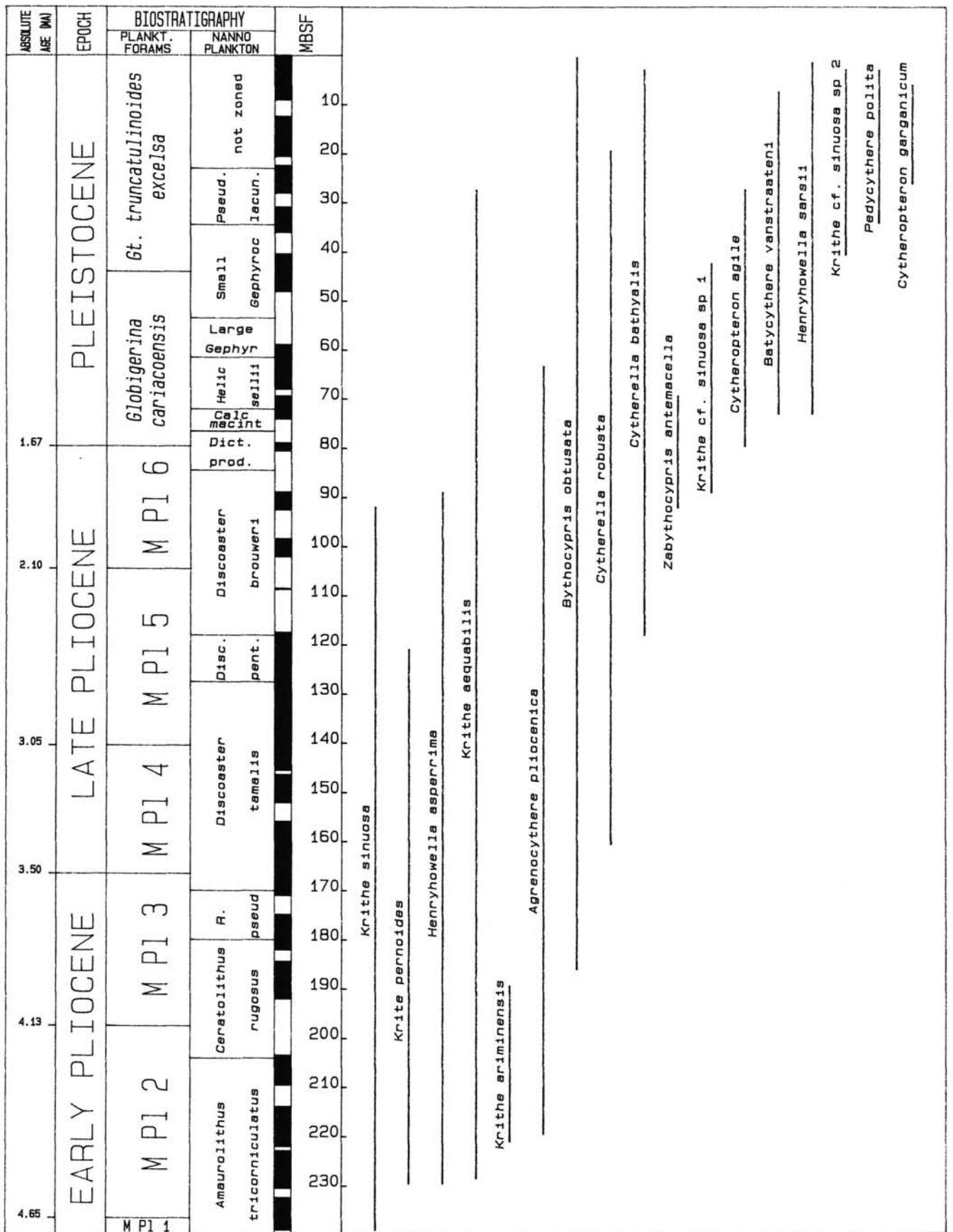


Figure 3. Stratigraphic ranges of the main taxa of ostracodes in the Pliocene-Pleistocene interval of Hole 654A.

larly poor in species (Table 2), as in the Italian land sections (from which a greater amount of sediments per samples is obviously available). This is probably due to the delay of the ostracodes benthic fauna in the repopulation of the Mediterranean Sea at the beginning of the Pliocene, after the Messinian salinity crisis (Ruggieri, 1967a; Hsü et al., 1973).

Brief considerations about the species most significant from a biostratigraphic point of view, listed in alphabetical order, follow below.

Agrenocythere pliocenica (Seguenza) (Benson, 1972b, Text-figs. 44–50; Pl. 3, Figs. 3–4; Pl. 5, Figs. 3–4). In Hole 654A, the first occurrence of this species is in the MPI2 Zone (Sample 107-654A-24R-5, 10–12 cm); the last occurrence is in the uppermost part of the *Helicospaera sellii* Zone (Sample 107-654A-8R-4, 10–12 cm) and slightly postdates the disappearance of the benthic foraminifers characteristic of the modern North Atlantic Deep Water (NADW, see Assemblage Cc, discussed below and represented in Fig. 6). In some sections of the Marche and the Calabria regions (Italy) the last occurrence of *A. pliocenica* is recorded in the Large *Gephyrocapsa* Zone or in the lower part of the Small *Gephyrocapsa* Zone (Colalongo and Pasini, unpubl. data), whereas in the Le Castella section (Calabria), this event takes place a little above the lower boundary of the *Globorotalia truncatulinoides excelsa* Zone (upper part of the Small *Gephyrocapsa* Zone, Fig. 2) (compare Colalongo, 1965, with Colalongo et al., 1981).

Among the ostracodes found in Hole 654A, *A. pliocenica* is the only taxon considered by Benson and Sylvester-Bradley (1971) and Benson (1972a, 1973) as strictly psychrospheric. The above-mentioned authors regarded as psychrospheric also *Bathycythere vanstraateni* (present in Hole 654A), but recently Benson (pers. comm., 1986) was very doubtful about this assumption.

Considering what we stated above and accepting—as assumed by many authors—that *A. pliocenica* is a psychrospheric ostracode, it follows that the removal of psychrospheric conditions took place in the Mediterranean Sea during or after the time interval corresponding to the Small *Gephyrocapsa* Zone, and not at the beginning of the Pleistocene as stated by Benson and Sylvester-Bradley (1971) and Benson (1972a, 1973, 1984).

Bythocypris obtusata (Sars) (Sars, 1923, Pl. XXX, Fig. 1). It was generally found in several Italian sections from Zone MPI6 (*Globorotalia inflata* Zone) upward (Colalongo and Pasini, 1980, and unpubl. data). The first occurrence of this species in Hole 654A was recognized in older levels; in fact it is recorded within Zone MPI3 (*Globorotalia margaritae*-*G. puncticulata* Zone), more exactly within the upper part of *Ceratolithus rugosus* Zone, in Sample 107-654A-21R-2, 10–12 cm, 186.2 mbsf (Fig. 3). The frequency of *B. obtusata* increases in the Pleistocene interval of Hole 654A; the same feature was recognized in several cores collected from Tyrrhenian Sea by the Istituto di Geologia Marina of CNR (Bologna) and in numerous Italian land sections.

Cytherella bathyalis Bonaduce, Ciliberto, Masoli, Minichelli, and Pugliese (Bonaduce et al., 1983, Pl. 2, Fig. 5). This species was found up to now only in Recent sediments (Bonaduce et al., 1983). Its first occurrence in Hole 654A is in Sample 107-654A-14R-1, 10–12 cm (117.8 mbsf), near the top of Zone MPI5 (*Globigerinoides elongatus* Zone).

Cytherella robusta Colalongo and Pasini (Colalongo and Pasini, 1980, Pl. 10, Figs. 4–7). The first occurrence of this species is in Sample 107-654A-18R-4, 10–12 cm (160.7 mbsf), within the MPI4 Zone (*Sphaeroidinellopsis subdehiscens* Zone). This event is recorded approximately in the same stratigraphic position also in the Italian land sections.

Krithe ariminensis Ruggieri (Ruggieri, 1967b, Text-figs. 6–9). It has been found in Italian upper Miocene (Ruggieri, 1967b; Ciampo, 1985) and lower Pliocene sediments (Colalongo, 1968).

In Hole 654A *K. ariminensis* is present—but rather rare—in MPI2 Zone and in the basal portion of MPI3 Zone.

Krithe sinuosa Ciampo (Ciampo 1985, Pl. 17, Figs. 3–5). This species, recently erected, has been found in Italian Tortonian and lower Messinian sediments (Ciampo, 1985). *K. sinuosa* is present throughout the Pliocene interval of Hole 654A; its last occurrence is a little below the Pliocene/Pleistocene boundary. In the lower Pleistocene interval of this Hole, *K. sinuosa* is replaced by a similar form, which we name provisionally *K. cf. sinuosa* sp. 1 (Pl. 1, Figs. 3–4). This provisional species is similar in size to *K. sinuosa*, but has a slightly narrower vestibulum and a smaller number of marginal pore canals.

Zabythocypris antemacella (Maddocks) (Maddocks, 1969, Text-fig. 60i-1). The *Z. antemacella* FO is recorded in Sample 107-654A-11R-3, 10–12 cm (91.8 mbsf), a little above the *Globorotalia inflata* FO (Figs. 2, 3). In the Italian land sections, the *Z. antemacella* FO is contemporaneous with or slightly predates the *G. inflata* FO (Colalongo and Pasini, 1980, and unpubl. data).

Pleistocene Ostracode Fauna

The ostracode fauna of the Pleistocene interval of Hole 654A is poor in specimens but much richer in species than the ostracode fauna of the Pliocene interval. A remarkable increase in the number of ostracode species at the beginning of the Pleistocene was observed in some Italian land sequences sedimented in bathyal environment (Colalongo and Pasini, 1980, and unpubl. data). Both in Hole 654A and in some Italian sequences there is a noticeable increase in the number of species of the genus *Polycope* above the base of the Large *Gephyrocapsa* Zone, close to the last occurrence of *Agrenocythere pliocenica* (Colalongo and Pasini, 1980).

Also, for the Pleistocene interval of Hole 654A, we will consider the ostracodes most significant from a biostratigraphic point of view, listing them in alphabetical order.

Bathycythere vanstraateni Sissingh (Colalongo and Pasini, 1980, Pl. 4, Figs. 7–8). The first occurrence of this species is recorded near the Pliocene/Pleistocene boundary both in Hole 654A and in some Italian land sections (Colalongo and Pasini, 1980 and unpubl. data). Therefore, the *B. vanstraateni* FO can be considered a useful event to approximately recognize the Pliocene/Pleistocene boundary. The *B. vanstraateni* LO occurs in Hole 654A within the Glacial Pleistocene, above the *Pseudomilania lacunosa* LAD (Fig. 3); this event was recognized in the same stratigraphic interval also in core T 75/15, collected by the Istituto di Geologia Marina of CNR from the southeastern Tyrrhenian Sea. Consequently, the specimens of *B. vanstraateni* found by Breman (1975) and Bonaduce et al. (1983) in Holocene sediments of the Mediterranean Sea could be reworked.

Henryhowella sarsi (G. W. Müller) (Bonaduce et al., 1975, Pl. 31, Figs. 1–7). Both in Hole 654A and in some Italian Pliocene-Pleistocene sequences *H. sarsi* sensu stricto is present only in the Pleistocene sediments and seems to replace *H. asperrima* sensu stricto (Ruggieri, 1962, Pl. XXI, Figs. 16–19), which occurs only in the Pliocene sediments.

Krithe cf. sinuosa sp. 2 (Pl. 1, Figs. 1–2). Among the provisional species, *K. cf. sinuosa* sp. 2 is rather significant; its first occurrence is recorded in Sample 107-654A-6R-1, 10–12 cm (40.4 mbsf), and this species characterizes the Pleistocene sediments of Hole 654A from about the *Globorotalia truncatulinoides excelsa* FO upward (Figs. 2, 3). The first occurrence of this species is probably in the same stratigraphic position also in the Italian land sections (G. Ruggieri, pers. comm., 1987). *K. cf. sinuosa* sp. 2 (similar to *K. tumida* Brady) is characterized by a large and thick carapace, a very narrow and regular vestibulum, an anteriorly, ventrally, and posteriorly wide inner lamella and by 10–11 marginal pore canals.

Although *Cytheropteron agile* Colalongo and Pasini (Colalongo and Pasini, 1980, Pl. 10, Figs. 4–7), *C. garganicum* Bonaduce, Ciampo, and Masoli (Bonaduce et al., 1975, Pl. 55, Figs. 7–13), and *Pedicythere polita* Colalongo and Pasini (Colalongo and Pasini, 1980, Pl. 24, Figs. 7–10) are present only in few samples of Hole 654A, their stratigraphic ranges in this hole seem to confirm that these species are restricted to the Quaternary.

OSTRACODES Q-MODE FACTOR ANALYSIS

Four factors were extracted by the Q-mode factor analysis from a cosine theta similarity matrix according to a varimax rotational scheme. The four entities may be regarded as distinct ostracode assemblages, their composition being epitomized in the varimax factor scores (Fig. 5) and their vertical distribution and abundance in the varimax factor loading (Fig. 4) (Davis, 1973, among others). The retained factors account for about 69% of the compositional information (variance) contained in the raw data matrix.

Significantly high communalities and improvement of variance partition after varimax rotation indicate that the selected factorial model is appropriate for our problem.

The stratigraphic distribution of the four obtained factors, plotted against depth and a detailed biostratigraphic scheme, is reported in Figure 4.

Factor 1 (Assemblage *N*) is dominated by *Krithe aequabilis* associated with *Agrenocythere pliocenica* and *Krithe monosteracensis* (Seguenza) (Pl. 1, Fig. 7, and Fig. 5). *Agrenocythere* is considered by many authors as a typical psychrospheric genus, which lives in waters with a temperature of 4°–8°C (Benson, 1972b). The concomitant presence of the Kritinae and of the genus *Agrenocythere* should indicate a depth ranging from 1000–1200 to 4500 m (Peypouquet, 1980). The stratigraphic distribution of Factor 1 is between 227 and 63.7 mbsf, stretching from the lower part of MPI2 Zone to the middle part of the *Globigerina cariacensis* Zone (top of *H. sellii* Zone).

In Factor 2 (Assemblage *M*) *Henryhowella asperrima* and, subordinately, *Agrenocythere pliocenica* display high factor scores (Fig. 5). Specimens of *H. sarsi*, a taxon that several authors include in the *H. asperrima* group, were collected in recent sediments of the Mediterranean Sea from 300 to 2600 m, with a frequency maximum at about 800 m (Bonaduce et al., 1983). Cronin (1983) pointed out that in the Florida-Hatteras slope, species populations referred to *H. asperrima* reach high percentages at depths of 900–1070 m. The stratigraphic distribution of Factor 2 is between 229 and 136.5 mbsf, ranging from the basal part of MPI2 Zone to the basal part of MPI5 Zone.

Factor 3 (Assemblage *O*) is dominated by *Argilloecia acuminata* G. W. Müller (Bonaduce et al., 1975, Pl. 8, Figs. 1–5, and Fig. 5). As documented by Cronin (1983), the genus can thrive in poorly oxygenated waters, attaining a remarkable abundance in the Oxygen Minimum Zone below the thermocline. The stratigraphic distribution of Factor 3 is between 75 and 19.5 mbsf, stretching from the basal part of the *Globigerina cariacensis* Zone to the middle part of the *Globorotalia truncatulinoides excelsa* Zone.

Factor 4 (Assemblage *P*) is dominated by *Bythocypris obtusata* and *Agrenocythere pliocenica* (Fig. 5). The stratigraphic distribution of Factor 4 is from 175 to 118 mbsf and from 21.5 mbsf to the top of the sequence. In the lower interval, ranging from the upper part of MPI3 Zone to the middle part of MPI5 Zone, the assemblage is dominated by *A. pliocenica*. In the upper interval, belonging to the upper part of the *Globorotalia truncatulinoides excelsa* Zone, the assemblage is dominated by *Bythocypris obtusata* with a significant presence of *Krithe cf. sinuosa* sp. 2. In the Mediterranean area, *B. obtusata* has a frequency maximum around 2600 m (Bonaduce et al., 1983). *K. cf.*

sinuosa sp. 2 shows—as we said above—a very narrow vestibulum and a large and thick carapace; according to Peypouquet (1979, 1980) these morphologic features are an adaptive response to well-oxygenated conditions in deep waters.

BENTHIC FORAMINIFERS Q-MODE FACTOR ANALYSIS AND PALEOECOLOGICAL RESULTS

Since the ostracode assemblages are generally poor in specimens and therefore not particularly suitable from which to draw paleoecological results, these are essentially based on the benthic foraminifer assemblages. As far as the benthic foraminifers are concerned, a quantitative raw data matrix was processed by a Q-mode factor analysis (Hasegawa, Sprovieri, and Poluzzi, this volume). The species abundances were resolved in seven varimax assemblages with distinct stratigraphic distribution, accounting for about 79% of the original variance (Fig. 6). The most salient paleoecological and paleoenvironmental results obtained by Hasegawa, Sprovieri, and Poluzzi (this volume) are reported in this chapter. The varimax factor scores on which the factors are epitomized are reported in Table 1. The bathymetric indications are used with reference to Wright (1978).

Assemblage *A* is defined by the third factor and is well represented in MPI1 and in the basal part of MPI2 Zones, from the base of the Pliocene to 227 mbsf. The assemblage is characterized by costate *Uvigerina* and by *Globocassidulina* spp., indicative of an upper epibathyal environment, presumably with a slightly reduced bottom oxygen content. Subassemblage *Bb* can be recognized as the positive portion of Factor 6. It is dominated by *Parrelloides robertsonianus* and *P. bradyi* (more frequent), and is present only in the lower part of MPI2 Zone.

Subassemblage *Bb* is considered by Hasegawa, Sprovieri, and Poluzzi (this volume) as indicative of a lower epibathyal environment with a depth of about 800–1000 m.

Subassemblage *Ba*, typified by the predominance of *Siphonina reticulata* and by the subordinate presence of *Parrelloides* spp. and *Pullenia* spp., is referred to the first factor. It ranges approximately from the base of MPI2 to the lower part of MPI5 zone, more exactly from 229 to 127 mbsf. Living specimens of *Siphonina reticulata* have been recovered in the Mediterranean Sea from depths not exceeding 1000–1200 m (Parker, 1958; Bizson and Bizson, 1984). *Parrelloides* spp. are not living today in the Mediterranean Sea (Parker, 1958; Wright, 1978), but are present in the oceans and in the Gulf of Mexico with an upper depth limit (*P. bradyi*) of about 450–500 m (Pflum, Frerich, and Sliter, 1976). These elements delineate a well-oxygenated lower epibathyal environment in a depth range of about 500–1200 m.

Subassemblage *Cc* is represented by the second factor and is dominated by taxa with positive scores (*Sigmoilopsis schlumbergeri*, *Miliolina*, *Parrelloides* spp., *Oridorsalis* spp., and *Cibicides pachyderma*) together with a species with negative score, *Siphonina reticulata*. The stratigraphic extension of Subassemblage *Cc* encompasses the lower part of MPI5 Zone and the lowermost part of the *Globigerina cariacensis* Zone, from 132 to 70 mbsf. Many of the above-quoted forms characterize the modern water masses of NADW (North Atlantic Deep Waters) (Lohmann, 1978), whose depth range is between 1300 and 3000 m (Lutze and Coulbourn, 1984). The varimax Subassemblage *Cc* is therefore related to an environment similar to modern NADW with a depth exceeding 1300 m.

Subassemblage *Da* is defined by Factor 6, based on the negative contributions of dominant *Miliolina* and *Bolivina* groups, and on the positive contributions of *Parrelloides* spp. It is generally not well represented in the sequence of Hole 654A. Relatively high factor loadings (near or greater than the absolute value of 0.5) are present essentially from the topmost part of the late Pliocene (upper part of MPI6 Zone) to the lowermost part of the Pleistocene (base of *Globigerina cariacensis* Zone), prac-

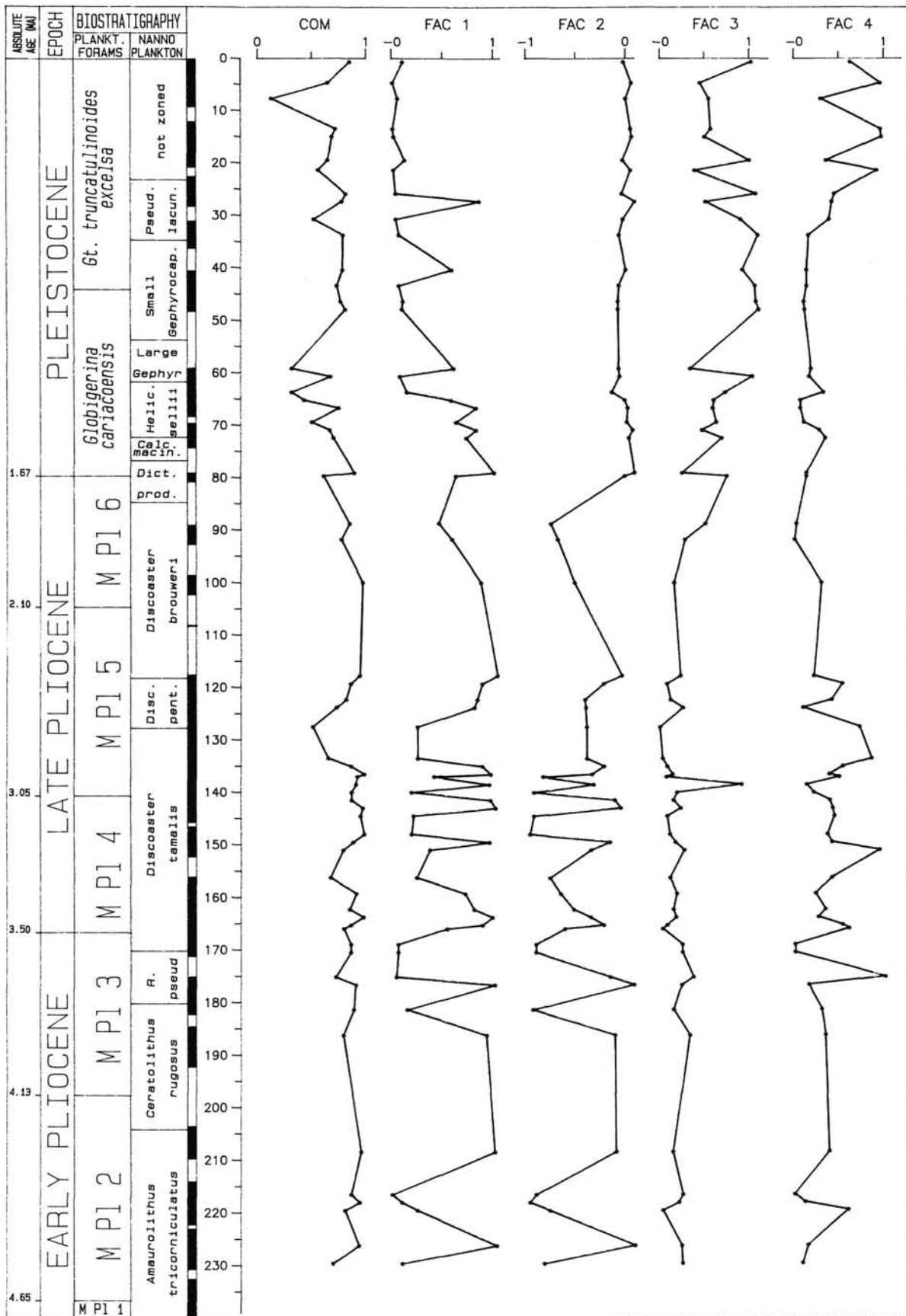


Figure 4. Communalities and varimax factor loadings of the four factors (ostracode assemblages) recognized in Hole 654A, plotted along their stratigraphic ranges.

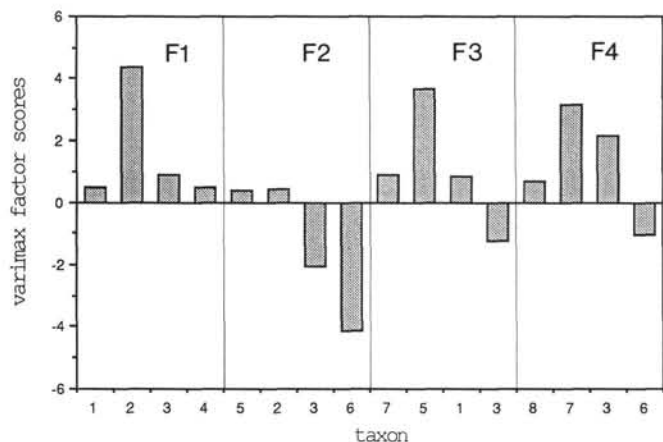


Figure 5. Scaled varimax factor scores of ostracodes on four retained factors (1-4) in the Pliocene-Pleistocene interval of Hole 654A. In abscissa, the numbers refer to dominant taxa in each assemblage: 1 = *Cytherella robusta*; 2 = *Krithe aequabilis*; 3 = *Arginocythere pliocenica*; 4 = *Krithe monosteracensis*; 5 = *Argilloecia acuminata*; 6 = *Henryhowella asperima*; 7 = *Bythocypris obtusata*; and 8 = *Krithe cf. sinuosa* sp. 2.

tically overlapping the upper part of the interval characterized by Subassemblage *Cc*. Only a single short peak is present above, at the Small *Gephyrocapsa/Pseudoemiliana lacunosa* boundary. Subassemblage *Da* includes elements of the modern NADW (as Subassemblage *Cc*), among which *Cibicoides kullebergi* is present. This species, not living today in the Mediterranean basin (Parker, 1958) but abundant below 2000 m in the Bay of Biscay (Wright, 1978), suggests for Subassemblage *Da* a deeper environment than for Subassemblage *Cc*. The depth of Subassemblage *Da* has been evaluated by Hasegawa, Sprovieri, and Poluzzi (this volume) at about 2000 m.

Subassemblage *Db* is referred to Factor 4 and stretches from just above the base to the upper part of the Pleistocene (from 75 to 15 mbsf). The dominant taxa in Factor 4 are *Articulina tubulosa* and *Gyroidina* spp. These species have been recently found in eastern Mediterranean cores within sequences of closely spaced sapropel horizons (Mullineaux and Lohman, 1981; Parisi, 1982). These evidences suggest that the bottom water was poorly oxygenated during the time interval characterized by Subassemblage *Db*.

Subassemblage *Eb* is referred to Factor 6 and is dominated by *Cibicoides pachyderma* and *Cassidulina carinata*. It essentially marks the topmost part of the recovered sequence, from 17 mbsf upward. Subassemblage *Eb* is considered indicative of well-oxygenated bottom conditions (Hasegawa, Sprovieri, and Poluzzi, this volume).

DISCUSSION

Essentially five discrete stratigraphic intervals characterized by paleoecologically significant varimax assemblages of benthic foraminifers can be distinguished in the Pliocene-Pleistocene sequence of Hole 654A (Fig. 6): (1) the interval ranging from the base of the Pliocene to 231 mbsf; (2) the interval between 231 and 127 mbsf; (3) the interval between 127 and 70 mbsf; (4) the interval between 70 and 15 mbsf; and (5) the interval ranging from 15 mbsf to the top of the sequence.

The basal interval, belonging to MPI1 and to the lowermost part of MPI2 Zones, is characterized by the foraminifer Assemblage *A*. It testifies to an upper epibathyal environment, presumably with slightly underoxygenated bottom conditions. Ostracodes are extremely rare in this stratigraphic interval, as generally recognized also in Italian land sections.

The interval between 231 and 127 mbsf, from the lower part of MPI2 to the middle part of MPI5 Zones, is characterized by the foraminifer varimax Subassemblages *Ba* and *Bb*. Subassemblage *Bb*—present only in the basal part of the interval—indicates a lower epibathyal environment and, more exactly, a depth of about 800–1000 m. Also Subassemblage *Ba*—present throughout the interval—is indicative of a lower epibathyal environment, with a depth of 500–1200 m, and of well-oxygenated bottom conditions. In the same stratigraphic interval, ostracode Assemblage *M* and *N* co-occur; in the upper part of this interval also Assemblage *P* (lower portion, Fig. 6) is present. Assemblage *M* is dominated by taxa which display maximum frequency between 800 and 1100 m in depth. Assemblage *N* is dominated by taxa indicative of depth from 1000–1200 to 4500 m, and of cold waters (as suggested also by the lower portion of Assemblage *P*). The highest loadings of Assemblages *M* and *N* repeatedly alternate along the interval. This indicates in our opinion that, during the lapse of time corresponding to this interval, the seafloor depth at Site 654 was close to the bathymetric threshold (about 1000–1100 m) which seems to separate the two different ostracode assemblages. Therefore the paleobathymetric indications provided for this interval by the benthic foraminifer assemblages are in good agreement with the ones suggested by the ostracode assemblages. The ostracode assemblages may even allow a more precise definition of the bathymetric conditions.

The interval between 127 and 70 mbsf is dominated by benthic foraminifer Subassemblage *Cc*, with overlapping occurrence of Subassemblage *Da* in its upper part. Both these subassemblages include modern NADW faunistic elements. In the Pliocene part of the interval, Subassemblage *Cc* is indicative of depth greater than about 1300 m; in the Pleistocene part of the interval, the co-occurrence of Subassemblage *Cc* and Subassemblage *Da* is indicative of depth of about 2000 m, close to the present depth of Site 654. Approximately in the same stratigraphic interval only, ostracode varimax Assemblage *N*, indicative of depth ranging from 1000–1200 to 4500 m, is present. Therefore, again, the paleoenvironmental conditions indicated by the benthic foraminifer assemblages are suitable for the ostracode assemblage recognized in the same stratigraphic interval.

In the interval between 70 and 15 mbsf, essentially benthic foraminifer Subassemblage *Db* and ostracode Assemblage *O* are present. The paleoecological meanings of these varimax assemblages are in good agreement because both of them require poorly oxygenated bottom conditions. In the upper part of the same interval also Subassemblage *Da*, indicative of a depth of about 2000 m, is represented.

In the uppermost part of the Pleistocene sequence of Hole 654A benthic foraminifer Subassemblage *Eb* and ostracode Assemblage *P* (upper portion) are present. Both assemblages are indicative of well-oxygenated bottom conditions and are therefore again in good agreement.

CONCLUSIONS

The stratigraphic ranges of the ostracodes of Hole 654A have been related to the calcareous plankton biostratigraphy of the same sequence. Such an approach has permitted us to outline or, in some cases, to confirm the stratigraphic significance of several Mediterranean deep-water Pliocene-Pleistocene ostracodes scantily studied up to now, and to ascertain that the psychrospheric conditions lasted in the Mediterranean Sea at least till the time interval corresponding to the Small *Gephyrocapsa* Zone.

The relative frequencies of benthic foraminifers and ostracodes recovered in Hole 654A were processed by the CABFAC program and resulted in seven varimax assemblages of foraminifers and four varimax assemblages of ostracodes.

Despite the small number of specimens on which the ostracode analysis is based, the paleoenvironmental indications sug-

Table 1. Scaled varimax factor scores of benthic foraminifers on six retained factors in the Pliocene-Pleistocene interval of Hole 654A. The six factors account for about 79% of the original variance (from Hasegawa, Sproveri, and Poluzzi, this volume).

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5	FACTOR 6
<i>Anomalinoidea helicinus</i>	.1798	.0841	.2324	-.0167	-.0364	.4796
<i>Articulina tubulosa</i>	.0766	-1.0800	-.6587	4.5670	1.1237	-.0573
<i>Astrononion</i> spp.	1.2226	-.1215	.7572	-.3007	-.3359	-.7411
<i>Bigenerina nodosaria</i>	.8723	1.2916	-.0309	-.2966	-.5147	.8173
<i>Bolivina</i> group	.3218	1.6404	.4474	.1904	.6230	-3.2283
Smooth <i>Bulimina</i>	.0431	.2233	.0372	-.0462	-.1073	.0453
Costate <i>Bulimina</i>	.0288	-.1562	.3334	.5908	1.0341	.1321
<i>Cassidulina carinata</i>	.0163	-.2990	-.0328	.2940	3.9317	-.1600
<i>Chilostomella</i> spp.	.0038	-.0231	-.0028	.0601	.0757	.0417
<i>Cibicides</i> spp.	.0569	.1714	.1796	-.0741	-.0104	-.3754
<i>Cibicides wuellerstorfi</i>	-.0671	.4147	.0255	-.1393	-.0756	-.0443
<i>Cibicidoides</i> spp.	.6567	.1750	.0667	-.2004	-.4373	-.9462
<i>Cibicidoides</i> (?) <i>italicus</i>	1.1296	-.3562	-.2152	.0580	-.1075	.2501
<i>Cibicidoides kullenbergi</i>	-.0033	-.0710	-.1060	.5869	.8368	.0731
<i>Cibicidoides pachyderma</i>	-.2881	1.4498	.1068	-.8028	4.4012	.4782
<i>Eggerella bradyi</i>	.2976	.6885	-.0399	.0561	.0081	.2910
<i>Globobulimina</i> group	.0169	-.0799	.0456	.1335	.5386	.1938
<i>Globocassidulina</i> group	-.1312	.7220	2.2881	.9819	-.7052	.0692
<i>Gyroldina</i> group	.5275	1.0142	1.3803	3.4574	-.7787	1.4179
<i>Hanzawaia rodhiensis</i>	.7835	1.4433	.1204	.1681	-.9068	-1.4328
<i>Hoeglundina elegans</i>	-.0028	.0079	-.0021	.0075	.0060	-.0224
<i>Hyalinea baltica</i>	.0011	-.1018	.0008	.4692	.0766	.0729
<i>Karrerella</i> spp.	.7704	.8882	.2617	.1559	.1604	.7198
<i>Laticarinina pauperata</i>	.0034	.0098	-.0062	-.0025	-.0098	-.0151
<i>Martinottiella</i> spp.	.1557	-.1028	.1860	.0797	-.0425	-.1272
<i>Miliolina</i>	.3352	2.6170	-.5525	.4712	.2469	-3.6083
<i>Nodosariidae</i>	.5348	-.0350	1.1251	.0746	-.0729	.3337
<i>Nonionella</i> spp.	.1821	.1119	.7137	-.1187	-.1462	-.0435
<i>Oridorsalis</i> spp.	1.2333	1.9719	1.3114	-.4191	1.0030	1.7494
<i>Parrelloides</i> spp.	1.5518	2.1048	-.5889	-.4906	-.5563	2.0340
<i>Planulina ariminensis</i>	.2157	.3435	-.0483	-.0991	-.1660	-.0656
<i>Pleurostomella alternans</i>	.4108	-.0437	.6769	.1007	-.1007	-1.0273
<i>Pullenia</i> spp.	1.8837	1.5958	-.4270	.2991	.4388	1.9651
<i>Pyrgo</i> spp.	.0602	.1849	-.2090	.8228	1.4591	-.3075
<i>Pseudoparrella</i> group	-.3473	1.4562	1.0338	-.5981	-.5055	-.0006
<i>Rutherfordoides tenuis</i>	.0096	-.0517	.0134	.0608	.2921	.1059
<i>Sigmoilinita tenuis</i>	.0768	.0436	.6240	2.4605	-.8140	-.5945
<i>Sigmoilopsis schlumbergeri</i>	.1201	2.8013	-.6409	.2794	-.7014	-.2474
<i>Siphonina reticulata</i>	5.7066	-2.2793	-.0756	-.4672	.3582	-1.1174
<i>Sphaeroidina bulloides</i>	.2095	-.2770	2.0303	.1875	-.1591	1.0584
<i>Stainforthia complanata</i>	.0301	.2115	-.0273	1.0009	.1399	-.1340
<i>Stilostomella</i> spp.	.0014	.0071	.3282	.8790	-.0086	-.1648
<i>Trifarina</i> spp.	.0049	-.0421	.0073	.4586	.2286	-.0275
Spinose <i>Uvigerina</i>	.0106	.1638	-.0462	.0012	-.0748	-.0987
Costate <i>Uvigerina</i>	-.3546	-.6821	5.2110	-.8243	.5977	-.8000
<i>Valvulineria</i> spp.	.1507	.1484	.3455	.1164	-.1952	.0227
<i>Textulariina</i>	.3769	.1569	-.2024	.9857	.1079	-.4223

gested by the ostracode varimax assemblages are not in conflict with the better founded paleoenvironmental indications offered by the corresponding benthic foraminifer varimax assemblages.

The varimax assemblage present in the lowermost interval of the sequence, from the base of the Pliocene to the lowermost part of MPI2 Zone, documents an upper epibathyal environment and slightly under-oxygenated bottom conditions.

The interval stretching from the lowermost part of MPI2 Zone to the middle part of MPI5 Zone is characterized by varimax assemblages indicative of a lower epibathyal environment and of well-oxygenated bottom conditions.

From the lower part of MPI5 Zone upward, new assemblages testify to further deepening of the bottom, reaching a value of about 2000 m at the Pliocene/Pleistocene boundary. An evidence of this evolving situation is represented by the entrance of

frequent modern NADW members in the foraminifer subassemblages.

From the lower part of the early Pleistocene to the late Pleistocene (a little above the *Pseudoemiliania lacunosa* extinction level) the bottom environment was poorly oxygenated, as documented by the two taxonomically distinct varimax assemblages occurring in this interval. The sapropel and the sapropelic layers detected in the same stratigraphic interval of Hole 654A substantiate this interpretation.

The two varimax assemblages present in the topmost part of the sequence document well-oxygenated bottom conditions.

In conclusion, this study suggests a close relationship between the benthic foraminifers and the ostracodes as paleoenvironmental indicators, although they pertain to very different zoological taxa.

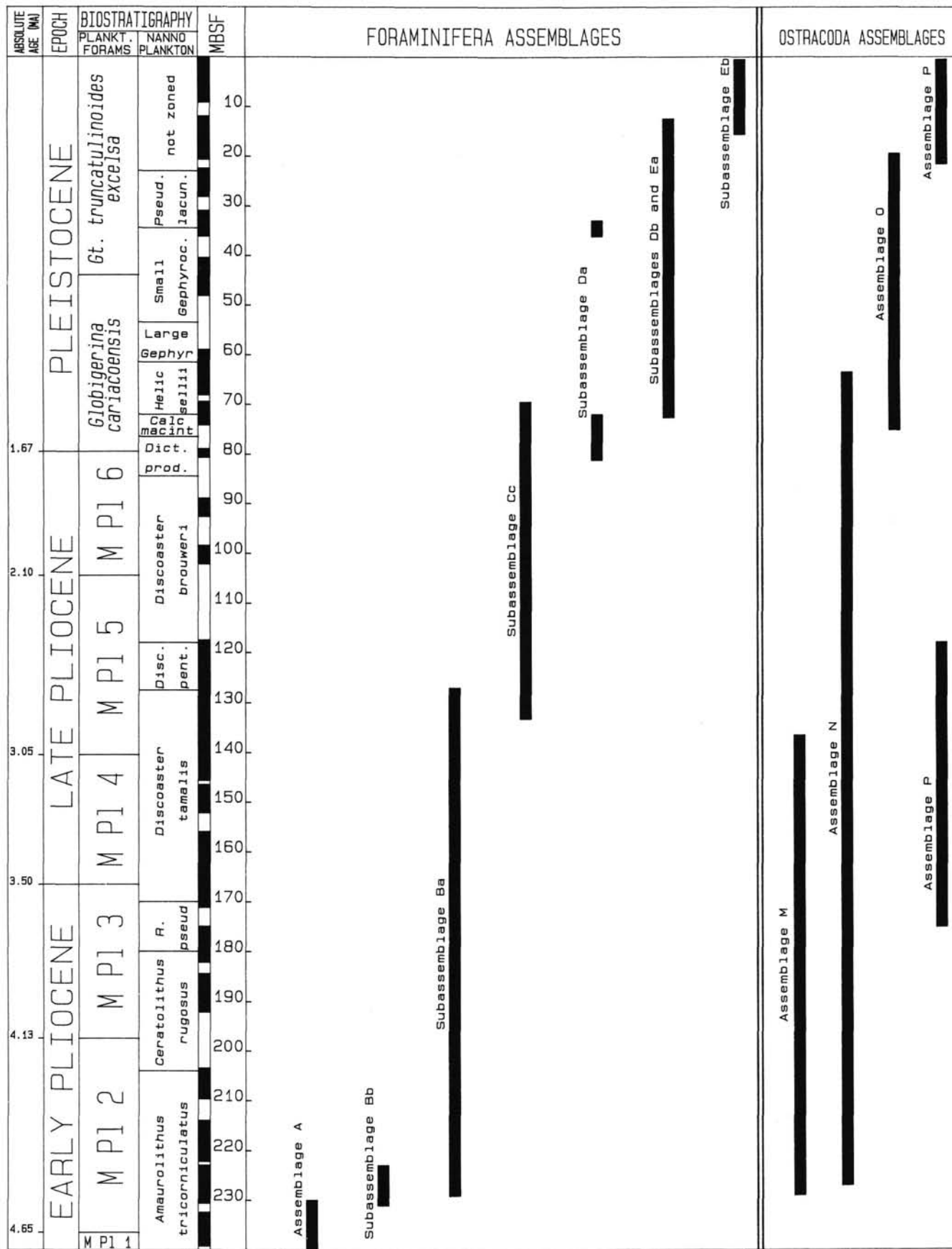


Figure 6. Stratigraphic ranges of the benthic foraminifer and ostracode varimax assemblages in the Pliocene-Pleistocene interval of Hole 654A.

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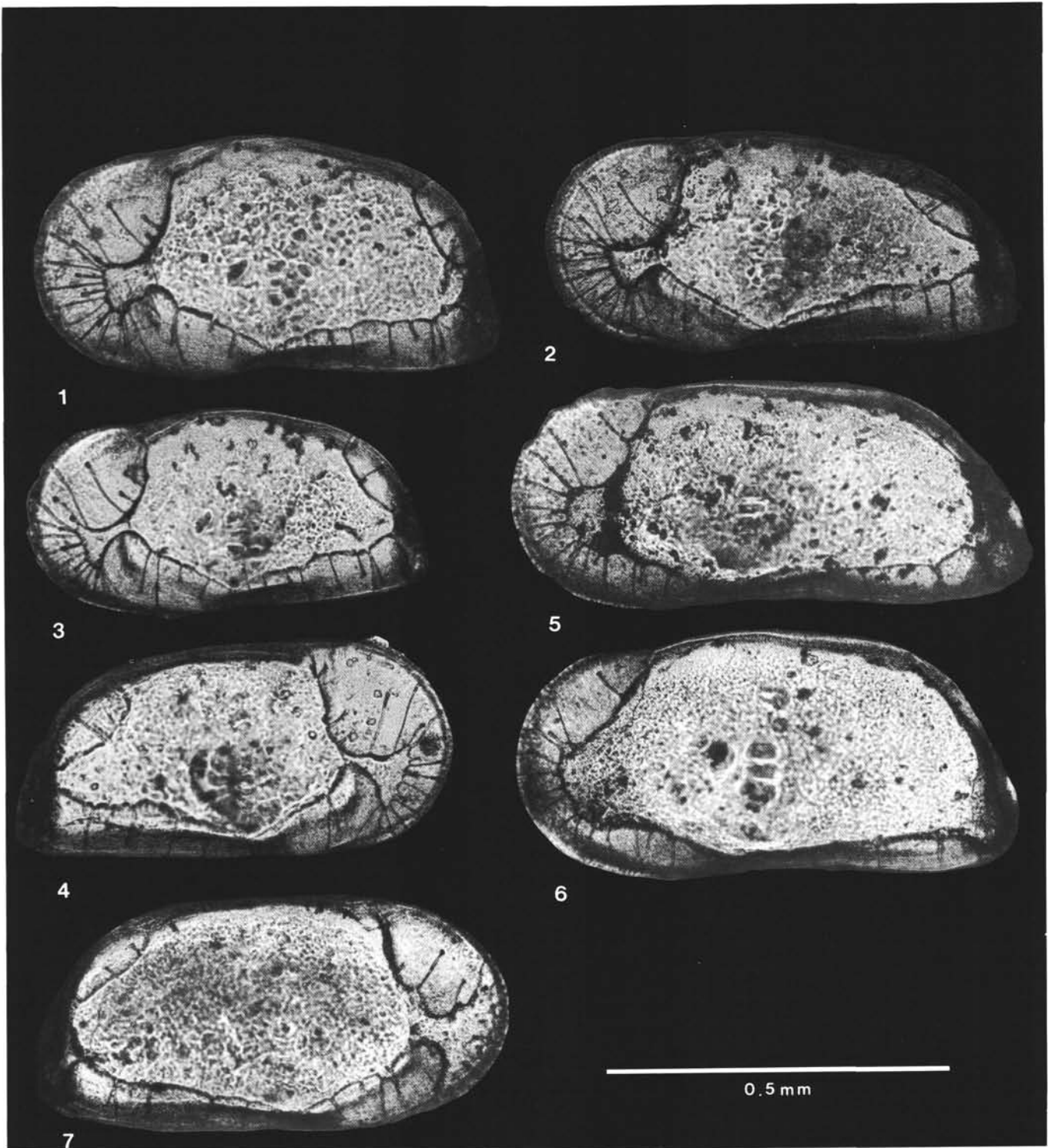


Plate 1. Pliocene-Pleistocene ostracodes of Hole 654A (lateral exterior views, transparency). 1-2. *Krithe cf. sinuosa* sp. 2; left valves; female and male, respectively; Sample 107-654A-4R-1, 69-71 cm. 3-4. *Krithe cf. sinuosa* sp. 1; left valve (female) and right valve (male), respectively; Sample 107-654A-9R-2, 10-12 cm. 5-6. *Krithe aequabilis* Ciampo; left valves; male and female, respectively; Sample 107-654A-14R-1, 10-12 cm. 7. *Krithe monosteracensis* (Seguenza); right valve of a male; Sample 107-654A-15R-7, 10-12 cm.