UTRECHT MICROPALEONTOLOGICAL BULLETINS

P. SPAAK

Project no. 1

ACCURACY IN CORRELATION AND ECOLOGICAL ASPECTS OF THE PLANKTONIC FORAMINIFERAL ZONATION OF THE MEDITERRANEAN PLIOCENE

28

UTRECHT MICROPALEONTOLOGICAL BULLETINS

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ACCURACY IN CORRELATION AND ECOLOGICAL ASPECTS OF THE PLANKTONIC FORAMINIFERAL ZONATION OF THE MEDITERRANEAN PLIOCENE

I.G.C.P. Project no. 1

P. SPAAK

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ABSTRACT

Pliocene planktonic foraminiferal associations from Cretan, Sicilian and Calabrian sections have been studied qualitatively and quantitatively in order to evaluate the Pliocene biozonation for the Mediterranean. Six zones can be clearly distinguished and in the middle part of the Pliocene a further division into subzones is possible. However, it is often difficult to assign individual samples to one particular subzone.

An investigation into the nature of the datum levels in the Mediterranean biostratigraphic scheme had to include a study of Atlantic material. It was found that all the datum levels in the Mediterranean are related with migrations of the bioprovinces in the Atlantic. Within the Mediterranean these bioevents are more or less synchronous but many of their Atlantic counterparts are not.

A large climatic deterioration during the middle part of the Pliocene must have been responsible for numerous migrations in the Atlantic and indirectly for the datum levels in the Mediterranean. However, the water temperature in the Mediterranean, as can be constructed from the *Orbulina* diameter, was not affected by this climatic deterioration until a certain moment corresponding to a level in the upper part of the Pliocene.

Laminated sapropelitic and diatomaceous sediments are regularly present in our sections. The fauna associations from these sediments indicate that stagnant conditions, which led to laminite-formation, were due to good stratification of the water column. A process of periodically increased run-off is thought to be responsible for this condition during the Pliocene.

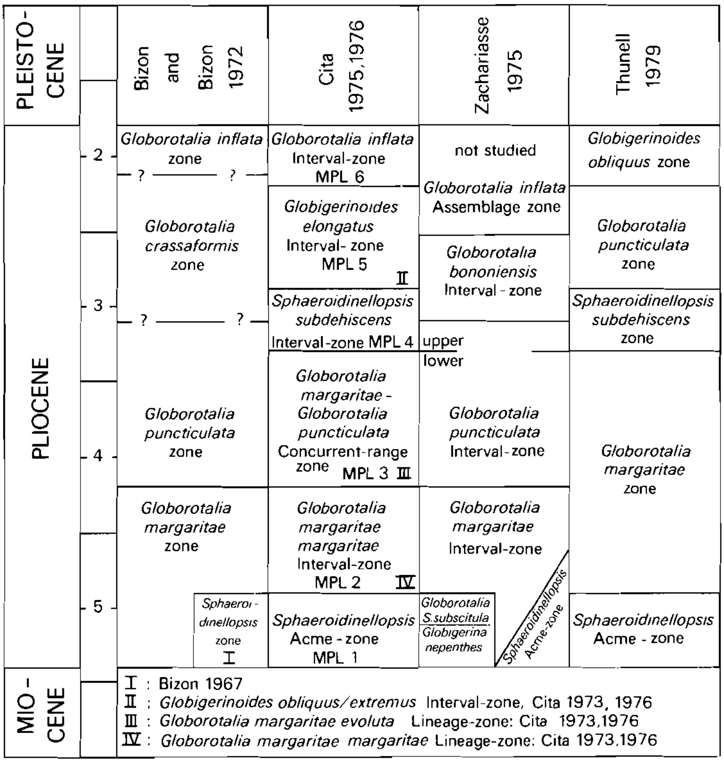

Fig. 1 Regional zonations for the Mediterranean Pliocene.

Chapter 1

INTRODUCTION

The application of planktonic foraminifera in biostratigraphy received a great impetus from the work of the "Trinidad school". The studies between 1950 and 1970 based on material from Trinidad and Venezuela resulted in the biostratigraphic schemes of Bolli (1966) and Blow (1969), which are often referred to as the "standard zonations".

The application of these "standard zonations" in areas outside the tropical region in which they had been established proved to be difficult, owing to the ecology-controlled absence or scarcity of index taxa or to the inter-regional morphological differences of these taxa. Such difficulties increase for younger Neogene sediments, as the tropical realm became more and more restricted to lower latitudes during the later part of the Tertiary. Therefore various regional zonations have been made over the years, which form a valuable addition to the tropical "standard zonations". For the Mediterranean Pliocene, for instance, several regional zonations providing a useful biostratigraphic framework are now available. (fig. 1)

This investigation initiated as a part of I.G.C.P. project no. 74/1/1 "Accuracy in time", was intended to give an evaluation of the planktonic foraminiferal zonations for the Mediterranean Pliocene. Since every zonation is based on changes in the faunal (or floral) composition the second goal of our investigation was to unravel the processes that underlie these changes in faunal composition and consequently the biostratigraphic framework. Such a study is expected to increase our knowledge about the reliability and the accuracy of biozonations in general.

MATERIAL AND METHODS OF INVESTIGATION

Marine sediments of the Mediterranean Pliocene are particularly well exposed in Sicily and Calabria and in the Aegean region (especially Crete). Material from both these areas is incorporated in our study, so that we could obtain sets of data from two fairly remote areas, which should enable us to construct a representative picture of the Pliocene planktonic foraminiferal faunas at successive time levels and to detect possible intra-Mediterranean differences. Many sections from both areas were examined; for this paper we used only a selection of these sections, but these nevertheless cover the Pliocene sequence in both areas as completely as possible.

During the Pliocene the Mediterranean was continuously connected with the Atlantic. We thought it useful to incorporate in this study the data from an Atlantic Pliocene succession, close to the Straits of Gibraltar (D.S.D.P. Site 397, Cape Bojador, off north-west Africa).

After being washed over a set of sieves (595,125 and 63 μ), at least 1400 samples were investigated qualitatively. As a standard procedure we examined two picking trays (9 × 5 cm) with carefully spread particles for each sample. Counts were performed on the foraminifera from the fraction 125–595 μ of a smaller set of samples from the Mediterranean only. For this purpose the wash-residues were reduced by an Otto-microsplitter until only a few hundred specimens per sample were left; 200 planktonic foraminifera were picked at random, identified and counted per taxon. In addition the average diameter of individuals of *Orbulina universa* was calculated for a great number of samples; these cover the Pliocene successions in Sicily-Calabria, in the Aegean region and at Cape Bojador. The procedure used to arrive at these average diameter values was the same for all samples: a separate split was made from which 30 *Orbulina* specimens were picked at random and measured.

SPECIES CONCEPT

In this paper we have used an assemblage-based species concept (Zachariasse, 1975), in which an assemblage is regarded as an inseparable, morphologically homogeneous group of individuals. The morphological variation within an assemblage may be considerable and typologically its individuals can be classified under different names. The taxonomic units which have been distinguished will be discussed in chapter 9. At this point we shall only enumerate these taxonomic units with minor comments:

Candeina nitida (found at Cape Bojador only)
Globigerina apertura
Globigerina nepenthes
Globigerina quinqueloba
Globigerinella aequilateralis
Globigerinoides elongatus (including *G. ruber* types)
Globigerinoides obliquus (including *G. extremus* types)
Globigerinoides trilobus (including *G. sacculiferus* types)
Globoquadrina altispira
Globorotalia crassaformis (in the qualitative analysis we have distinguished between assemblages with dominantly sinistral or dextral coiling; these assemblages include weakly and well-keeled specimens and high and low-convex forms)

Globorotalia margaritae

Globorotalia menardii (found at Cape Bojador only)

Globorotalia scitula

Neogloboquadrina acostaensis (including *N. dutertrei* types, which were found especially in the material of Cape Bojador)

Neogloboquadrina atlantica (found in the Mediterranean material only)

Orbulina universa

Pulleniatina spp. (found at Cape Bojador only)

Sphaeroidinella dehiscens

Sphaeroidinellopsis spp.

Globigerina bulloides and *Globigerina falconensis* which are members of morphologically homogeneous assemblages. In the qualitative examination of the samples the fluctuations in their relative frequencies were so striking that we decided to treat them as separate taxonomic units in the quantitative analysis.

Three closely related *Globorotalia* taxa: *Globorotalia puncticulata, Globorotalia bononiensis* and *Globorotalia inflata* have been taken together as the *Globorotalia inflata* group (Spaak, 1981b). In this paper we will continue to do this; however, in order to trace the range and the numerical behaviour of the three stratigraphically important members of this *G. inflata* group, we have handled them individually in both the qualitative and quantitative analyses.

ACKNOWLEDGEMENTS

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The pleasant and fruitful cooperation with H. A. Jonkers, B. W. M. Driever and G. J. van der Zwaan deserves a special mention. The results presented in this thesis could not have been achieved without the use of the computer programs of M. M. Drooger.

I am indebted to G. J. van 't Veld, G. C. Ittmann and C. W. van den Dood, who prepared the samples, and to A. van Doorn, T. van Hinte, P. Hoonhout and W. den Hartog, who skilfully made the figures and the plates. S. M. McNab is thanked for making linguistic improvements in the text.

The Netherlands Organisation for the Advancement of Pure Research kindly gave me financial support during a two year period. The DSDP Board enabled the investigation of the material from Site 397. The manuscript was typed by my wife Irène, and this thesis is dedicated to her and to my parents.

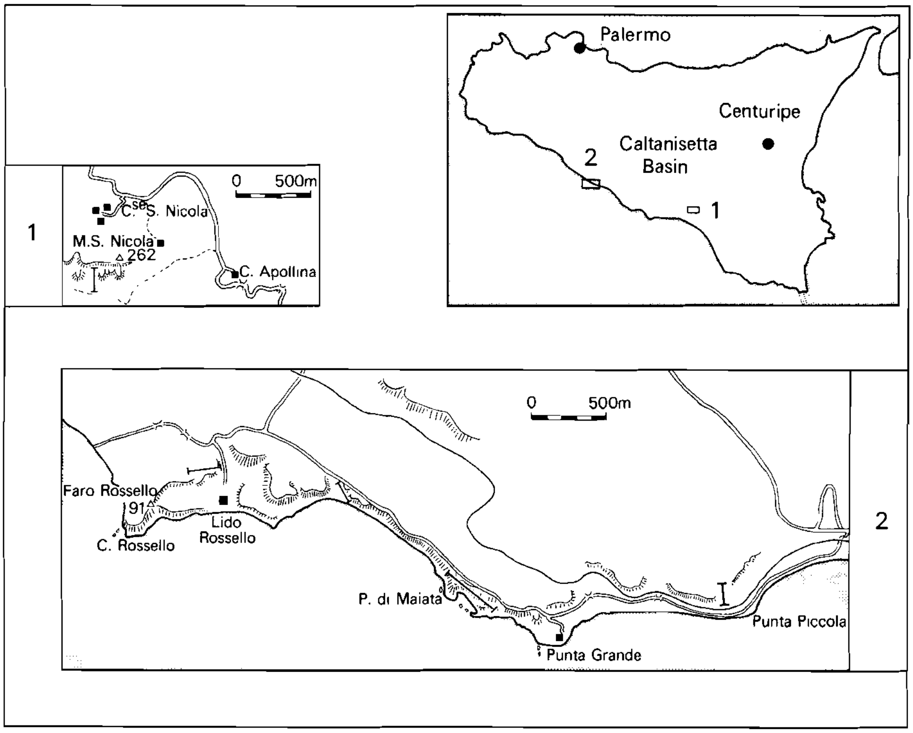


Fig. 2 Location of the Sicilian sections.

Chapter 2

PROVENANCE OF THE MATERIAL

INTRODUCTION

During the Neogene the Mediterranean was a more or less isolated basin in a tectonically active region. Movements of several continental blocks have played a role in bringing about its recent configuration (McKenzie, 1970; Van den Berg, 1979). In spite of its apparent uniformity, the Mediterranean consists of a number of larger and smaller basins, each with its own history (Biju-Duval, 1978).

The separation of the Mediterranean and Indo-Pacific realms in the Early Miocene (Berggren and Van Couvering, 1974; Drooger, 1979) and the restriction of the Atlantic-Mediterranean connection in the course of the later Miocene (cf. Hsü and Bernoulli, 1978) were important events for the water-mass structure in the Mediterranean during the Neogene. Together with sea-level fluctuations these changes are thought to be responsible for the ultimate deposition of large amounts of evaporites during the Messinian (cf. Van der Zwaan, 1982). The nature of the lowermost Pliocene sediments in the Mediterranean points to a sudden flooding, the result of the re-establishing of a good Atlantic-Mediterranean connection.

A remarkable feature in the Mediterranean Neogene sediments is the regular occurrence of laminated sapropelic deposits. Such laminites are known from the Middle Langhian upwards (e.g. in Sicily) but they do not occur in all places. In younger deposits they are known especially from the eastern part of the Mediterranean. These laminites originated because of oxygen depletion at the bottom of the basins; this oxygen reduction was caused by a good stratification in the water-column and/or a high organic production. For the Plio-Pleistocene an important instrument in this process is the occurrence of an increased run-off but for the Miocene other processes have been suggested (cf. Van der Zwaan, 1982). The basin configuration seems to play a decisive role as well (Meulenkamp et al., 1979b).

SICILY

Pliocene sediments of Sicily are found mainly in the relatively large Caltanisetta Basin (fig. 2). A good and fairly representative Pliocene sequence can be studied near the village of Lido Rossello; the sediments from this area have been used in several studies on the Pliocene (e.g. Cita and Gartner, 1973; Cita, 1975; Brolsma, 1978; Chamley, 1978). White calcareous marls (Trubi) are found with a sharp contact on top of grey clastic sediments of the Messinian (Arenazzolo). Upwards the calcareous marls pass into grey marls with dark-brown laminated intercalations (Monte Narbone Formation). Higher in the sequence the marls of the Monte Narbone Formation become more clayey and silty; following a short but gradual transition the latter are capped by sands (Agrigento Formation).

The sharp lithological contact between the Messinian and lowermost Pliocene sediments is the reflection of the sudden Pliocene flooding. The Pliocene sediments as a whole represent one large coarsening-upward sequence, caused by the uplift of the island. The difference in the biostratigraphic position of the marl-sand transition near the village of Centuripe (fig. 2) in the north (MPl 4) and at Lido Rossello in the south (Pleistocene) indicates that the uplift started in the northern part of Sicily and progressed southwards. Besides the diachronous character of this lithological transition, other evidence of the differential uplift in the Caltanisetta Basin, is the large scale southwards sliding of sediments, causing allochthonous bodies and slump-masses.

The sections we used in this study are all situated near the south coast of the island, where the most complete marine sequences are exposed. All sections except one (fig. 2) are located near the village of Lido Rossello.

Section **Capo Rossello** (figs. 2, 3)

The Capo Rossello section consists of 64 metres of white calcareous marls (Trubi) on top of grey clastic sediments (Arenazzolo). The lower 5 to 10 metres of the calcareous marls are rather compact and uniform. Upwards, bedding becomes more distinct through differences in induration. Approximately 30 metres above the base of the Trubi six laminated intercalations occur in an eight metre interval. This interval has been used for a detailed study on counting methods and techniques, within the framework of the "Accuracy in time" project (Zachariasse et al., 1978). The Capo Rossello section as used in this study corresponds to exposure 3 of Brolsma (1978).

In this section the first appearance levels of *Globorotalia margaritae* and *Globorotalia puncticulata* are found. *Globoquadrina altispira* is present in short intervals.

Section **Punta** di **Maiata** (figs. 2, 4)

The 98 metres of the Punta di Maiata section consist mainly of grey marls of the Monte Narbone Formation. The calcareous marls in the lower part of the section can be correlated in the field with the upper part of the Capo Rossello section. Upwards this type of lithology disappears; in the upper part of the section brown laminated sediments are intercalated. In addition to the samples given in fig. 4, several closely spaced samples were taken in the lower part of the section. These samples with a, b, c codes are not indicated in fig. 4; they have been used for the recognizability calculations of chapter 4.

In the Punta di Maiata section the following succession of bio-events can be constructed: the entry of G. *puncticulata*, the exit of G. *margaritae*, the disappearance of G. *puncticulata*, which is followed by an absence interval of the entire *Globorotalia inflata* group. Further up there is an intermittent return of the members of the latter group, first of G. *puncticulata*, later on of *Globorotalia bononiensis*. The appearance of *Globorotalia crassaformis* was found slightly below that of G. *bononiensis*. G. *crassaformis* assemblages

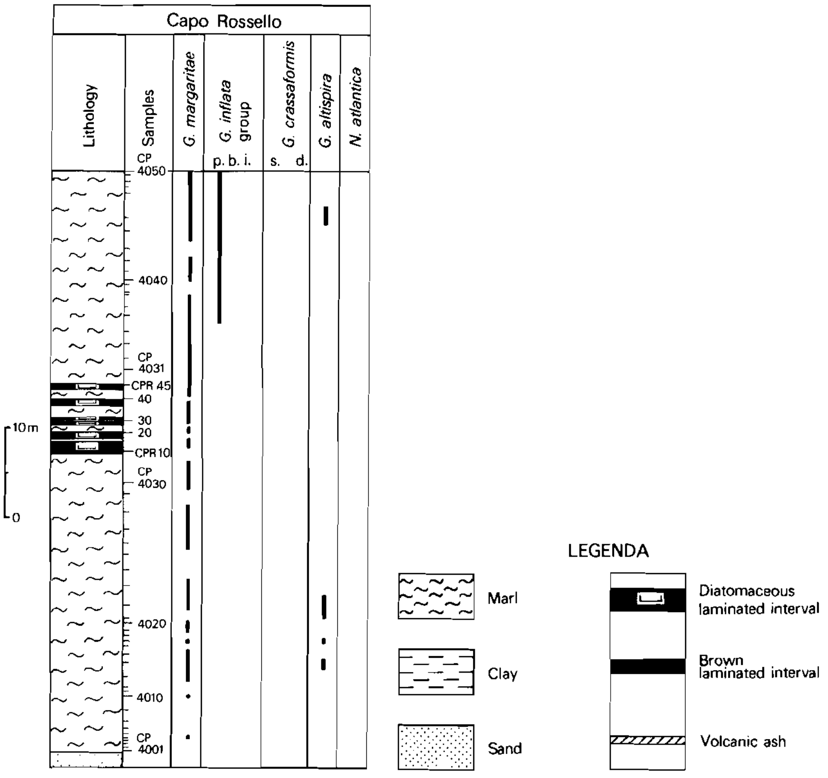


Fig. 3 Lithological column of, and the distribution of some selected taxa in the Capo Rossello section.

with dominantly sinistral or dextral coiling were found to alternate. *G. altispira* was found in a few scattered samples only.

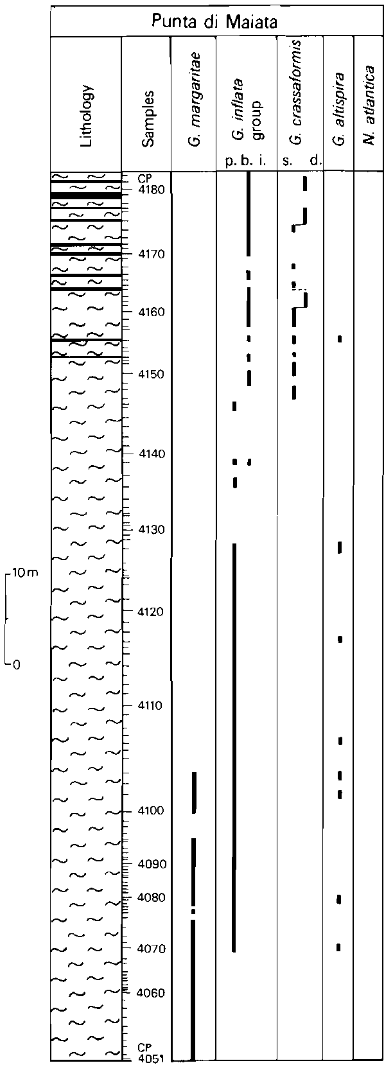


Fig. 4 Lithological column of, and the distribution of some selected taxa in the Punta di Maiata section; legend see fig. 3.

Section Punta Piccola (figs. 2, 5)

The lower seven metres of this section consist of homogeneous marls; in the following 37 metres many dark laminites are intercalated.

In this section, which corresponds to Brolsma's Punta Piccola section (1978), *G. bononiensis* and *G. crassaformis* are discontinuously present. Dominantly dextrally coiled *G. crassaformis* are found only in some samples from the lower part of the section.

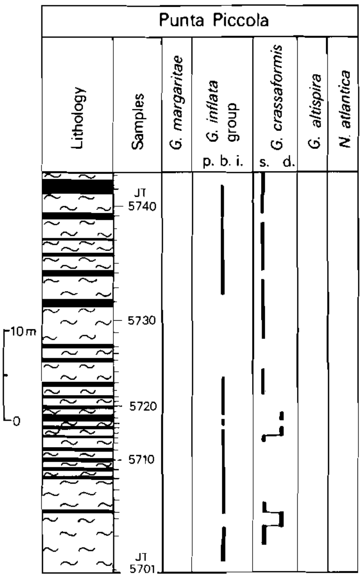


Fig. 5 Lithological column of, and the distribution of some selected taxa in the Punta Piccola section; legend see fig. 3.

Section Lido Rossello (figs. 2, 6)

North-west of the village of Lido Rossello a section of 85 metres of grey marls has been sampled. Upwards these grey marls become more clayey and silty; in the lower part of the section three darker laminated layers are present. The section of Lido Rossello is thicker than the 85 metres used in our investigation. However, higher up, the section was considered unsuitable for detailed sampling, because the stratification became hard to distinguish and (sub)recent sliding was considered quite possible.

In the lower part of this section there is an interval with *Neogloboquadrina atlantica*. This taxon disappears at the same level as *G. bononiensis*;

above this level a fairly long absence interval of the entire *G. inflata* group could be discerned. In the upper part of the section *G. inflata* s.str. is discontinuously present. Assemblages of sinistrally coiled *G. crassaformis* occur without continuity up to a level somewhat below the entry of *G. inflata* s.str.; the species is usually absent in samples with *N. atlantica*. Finally *Sphaeroidinella dehiscens* was found in some samples from the upper part of the section.

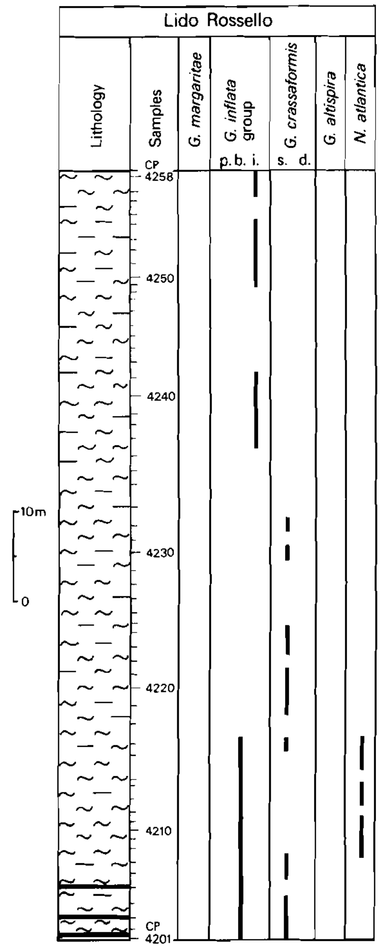


Fig. 6 Lithological column of, and the distribution of some selected taxa in the Lido Rossello section; legend see fig. 3.

Section Monte Sante Nicola (figs. 2, 7)

The Monte Sante Nicola section is about 100 metres thick, and located south of the Casa di Monte Sante Nicola, on the road from Gela to Butera. The Pliocene succession lies on top of Argille Scagliose, a scaly, clayey sediment present at many places in the Caltanisetta Basin at the base of the

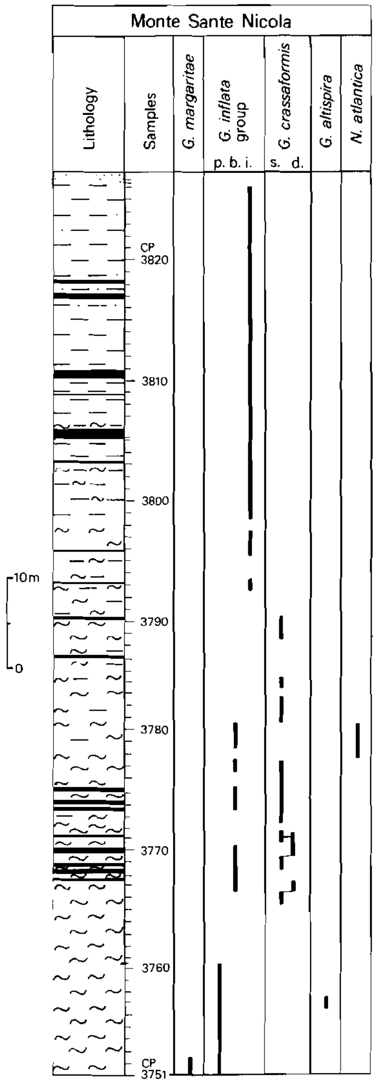


Fig. 7 Lithological column of, and the distribution of some selected taxa in the Monte Sante Nicola section; legend see fig. 3.

Neogene (Miocene) sequence. The Argille Scagliose type of sediments, which is in fact known all along the Apennines, is in some places (like at Monte Sante Nicola) also intercalated in the Neogene sequence itself. It is thought to have served as a gliding agent in several stages of its history; this gliding caused its scaly character. In the Monte Sante Nicola area it acted as a lubricant for a Pliocene allochthonous body. Especially in the lower part of the section several small, normal, south-vergent faults occur, which may have caused some minor gaps in our Pliocene section. They may indicate that at least the lower part of the section is allochthonous. Nevertheless we have incorporated this section in our study because the greater part of the Pliocene turned out to be present in its 100 metres.

The lower 20 metres of the Pliocene sequence consist of homogeneous marls; upwards dark laminites occur in the marls which themselves become clayey and silty. The laminated beds are less regularly intercalated than in the area near Lido Rossello, but they remain present up to the upper part of the section. The top of the section is formed by sand of the Agrigento Formation.

As can be inferred from fig. 7, the following succession of bio-events and ranges can be constructed: the last occurrence of *G. margaritae*, the disappearance of *G. puncticulata,* followed by a first absence interval of the *G. inflata* group. Next the appearances of *G. crassaformis* and *G. bononiensis* are found; these taxa remain irregularly present. As to *G. crassaformis* some dominantly dextrally coiled assemblages were observed in the lower part of its range. *N. atlantica* is present in a few samples only; it disappears at the same level as *G. bononiensis; G. crassaformis* has not been found in the samples with *N. atlantica.* A second longer absence interval of the *G. inflata* group follows on top of the disappearance level of *G. bononiensis. G. crassaformis,* discontinuously found in this interval, disappears from the faunal record of Monte Sante Nicola just below the entry of *G. inflata* s.str. The latter taxon remains continuously present to the top of the section, with the exception of some samples in the lower part of its range. *G. altispira* was found in the range interval of *G. puncticulata* only.

CALABRIA

None of our Sicilian sections allows us to carry out a detailed study of the uppermost part of the Pliocene. Therefore we collected material from the badlands south of Crotone in Calabria (fig. 8), the stratigraphy of which was described and discussed by Selli et al. (1977). According to their description

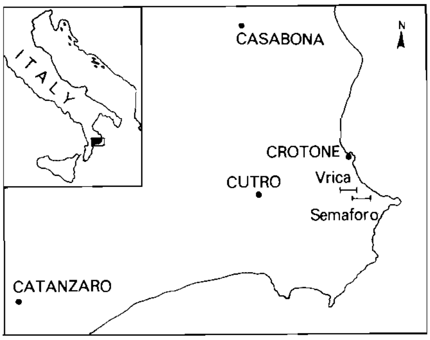


Fig. 8 Location of the Calabrian sections.

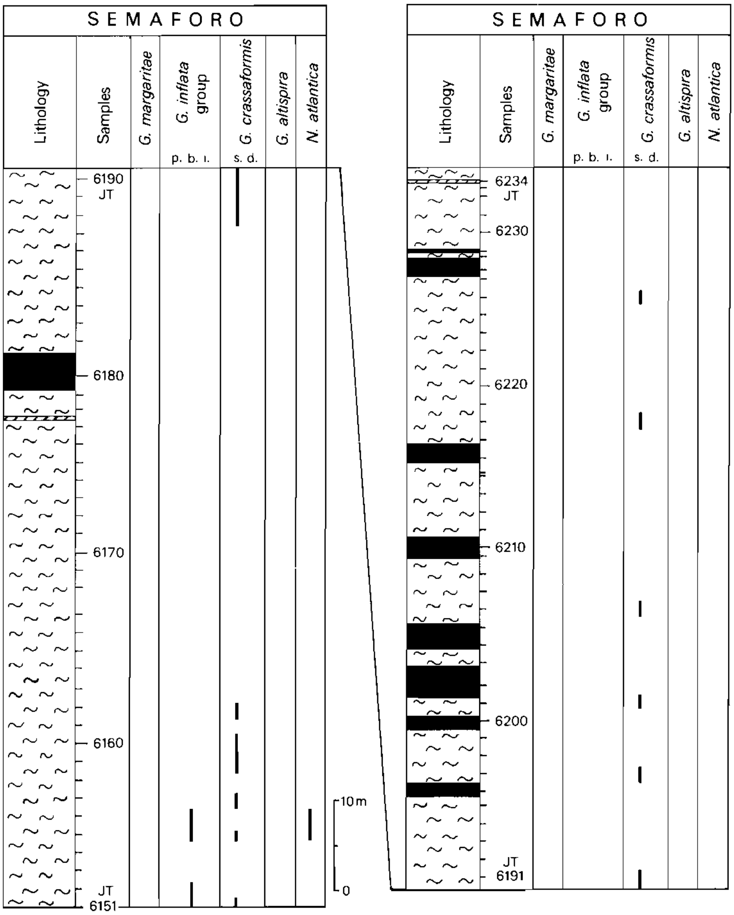


Fig. 9 Lithological column of, and the distribution of some selected taxa in the Semaforo section; legend see fig. 3.

the uppermost part of the Pliocene and possibly the Pliocene-Pleistocene boundary are both present in this area.

In the Vrica area, south of Crotone, two continuously exposed sections have been sampled. The Vrica section (fig. 10) is largely equivalent to the one published by Selli et al. (1977); the section we have sampled consists

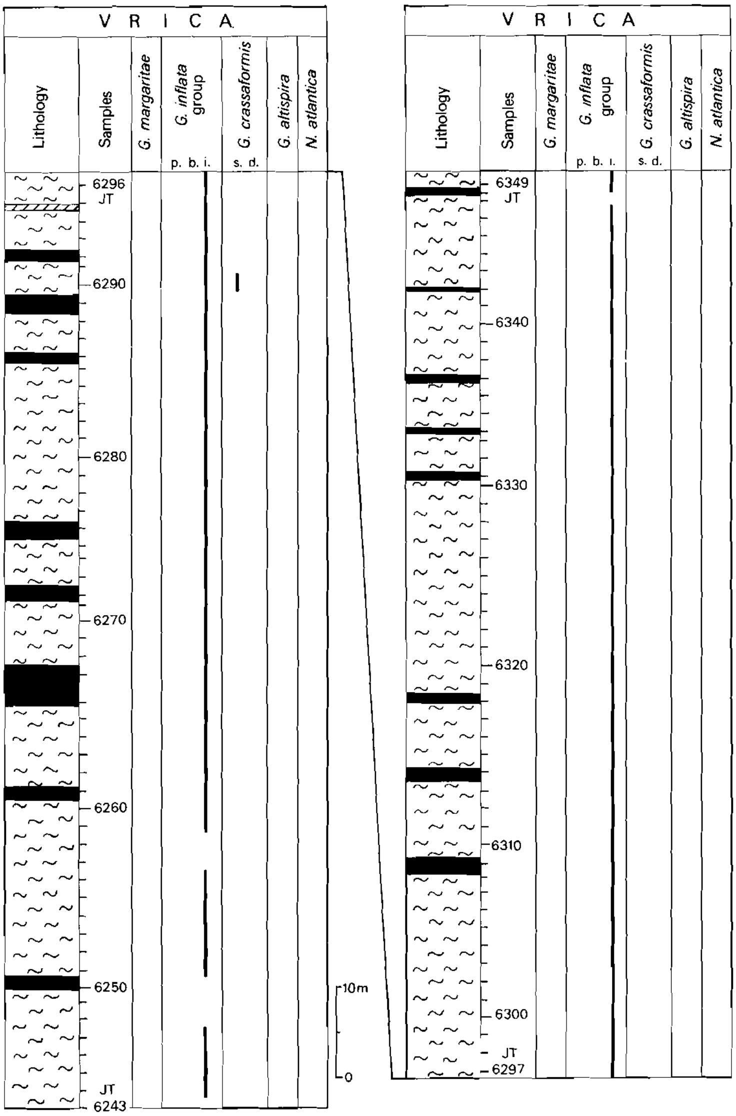


Fig. 10 Lithological column of, and the distribution of some selected taxa in the Vrica section; legend see fig. 3.

of 204 metres of grey homogeneous clays with several dark laminated intercalations. The Semaforo section (fig. 9), situated a few hundred metres south of the Vrica section in the same badland area, covers a lower part of the Pliocene. Lithologically the Semaforo section is identical to the Vrica section. From our field data it is clear that there is a small gap between the top of the Semaforo section and the base of the Vrica section. We started the sampling of the Semaforo section some 50 metres below the volcanic ash layer mentioned by Selli et al. (1977, p. 196).

In the lower part of the Semaforo section *G. bononiensis* and *N. atlantica* were found. Both taxa disappear at the same level. A few assemblages of *G. crassaformis* with sinistral coiling occur discontinuously all through the section. *S. dehiscens* has been found in several samples from the top of the Semaforo section.

G. inflata s.str. is found in most samples from the Vrica section; it is absent in a few samples from the lower part only. In two samples halfway along the Vrica section *G. crassaformis* was found again; the benthonic foraminiferal species *Hyalinea balthica* enters the biorecord in the upper part of the section (sample JT 6328).

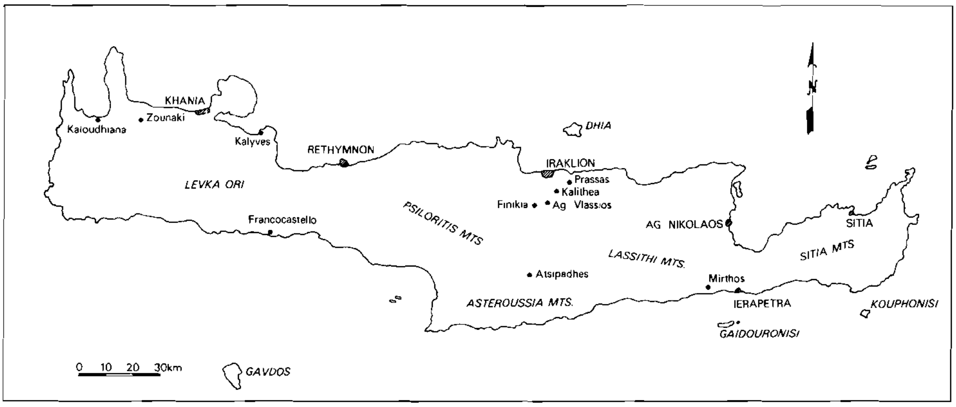


Fig. 11 Location of the Cretan sections.

CRETE

The lithostratigraphy of the Cretan Neogene has been subject of many field studies carried out by members of the Department of Stratigraphy of Utrecht University. We shall give a short review of the Pliocene sedimentary history. For more detailed descriptions and discussions the reader is referred to Meulenkamp (1979), Meulenkamp et al. (1979c) and Jonkers (in prep.).

In contrast with the deposits in Sicily, the Cretan Pliocene sediments had been deposited in several smaller basins. Nevertheless the lowermost Pliocene deposits are rather uniform all over the island, owing to the impact of the Pliocene transgression. They consist of Trubi-like calcareous marls. Only in marginal areas are limited amounts of clastic sediments found in the lowermost Pliocene. Soon after this beginning of the Pliocene sedimentation we have to acknowledge a differentiation in the structural development and sedimentary history of the individual small basins. A process of differential uplift in some areas caused the re-sedimentation of lowermost Pliocene deposits together with older Neogene rocks, in the form of marl-breccias. Such marl-breccias were transported to the deeper parts of the basins and at some places they form the base of the Pliocene.

Some parts of Crete (western Khania, central Iraklion) started to emerge in the late Early Pliocene and marine sedimentation in these areas stopped. Marine conditions continued to be present in other areas like northern Iraklion, where most of the sections that we used for our study are situated. This particular area formed a fairly large sedimentation realm during the Pliocene, but in fact is composed of several sub-basins separated by shallow ridges (Jonkers, in prep.). In the Middle Pliocene the larger part of Crete was affected by an overall uplift. The youngest Pliocene sediments of Crete are found in narrow strips along the south coast.

In most Cretan sub-basins, contrary to Sicily, laminated sapropelic and diatomaceous sediments are continuously present in the Pliocene, from levels just above the marl-breccias upwards. A detailed picture of the position and distribution of the laminites in the Pliocene of the Iraklion province will be given by Jonkers (in. prep.).

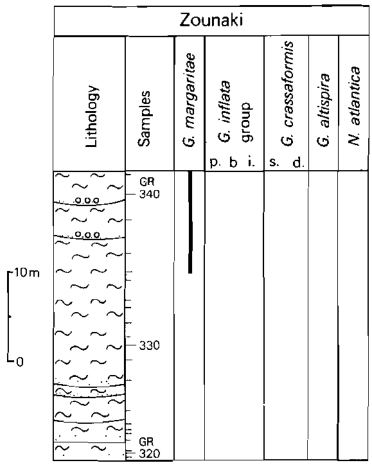


Fig. 12 Lithological column of, and the distribution of some selected taxa in the Zounaki section; legend see fig. 3.

Section Zounaki (figs. 11, 12)

The Zounaki section is 32 metres thick and is located in the western part of the Khania province (Meulenkamp et al., 1979c; Spaak, 1981a). The lower 10 metres of the Pliocene sequence are formed by an alternation of sands and calcareous marls. Calcareous marls dominate the upper part of the section although near its top coarse clastic intercalations are a reflection of the late Early Pliocene uplift of this part of Crete.

The entry level of *G. margaritae* is to be found in this section.

Section Kalithea (figs. 11, 13)

A number of exposures west of the village of Kalithea (northern Iraklion)

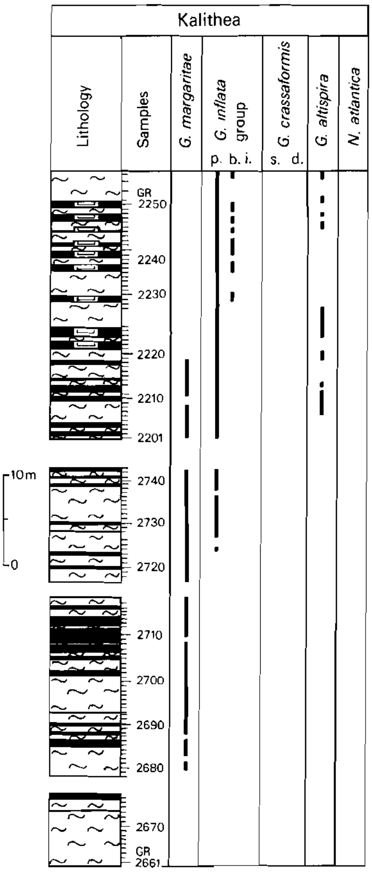


Fig. 13 Lithological column of, and the distribution of some selected taxa in the Kalithea section; legend see fig. 3.

can be well correlated in the field and together they form the 77 metres of the composite Kalithea section. The Pliocene sequence lying on top of a marl-breccia, consists of grey-white homogeneous marls with brown sapropelic interbeds and towards the top of the section diatomaceous intercalations.

The Kalithea section contains successively the entry of *G. margaritae*, the first appearance of *G. puncticulata* and the exit of *G. margaritae*. *G. altispira* is found in several samples from the appearance level of *G. puncticulata* upwards.

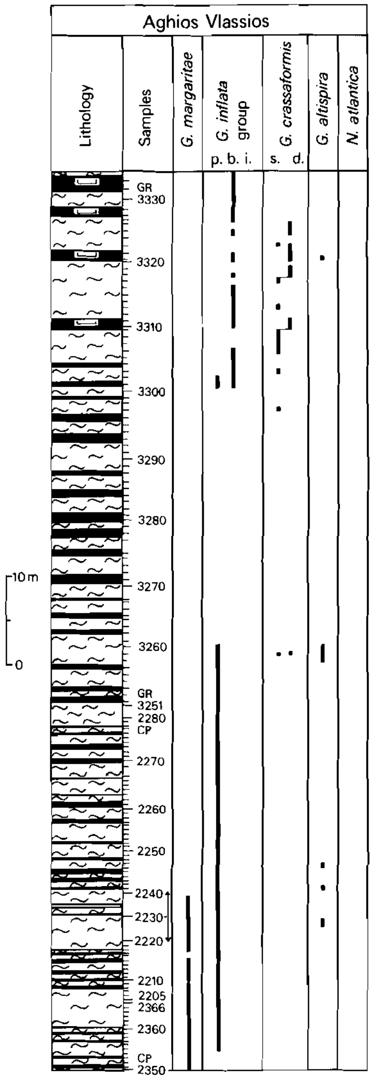


Fig. 14 Lithological column of, and the distribution of some selected taxa in the Aghios Vlassios section; legend see fig. 3.

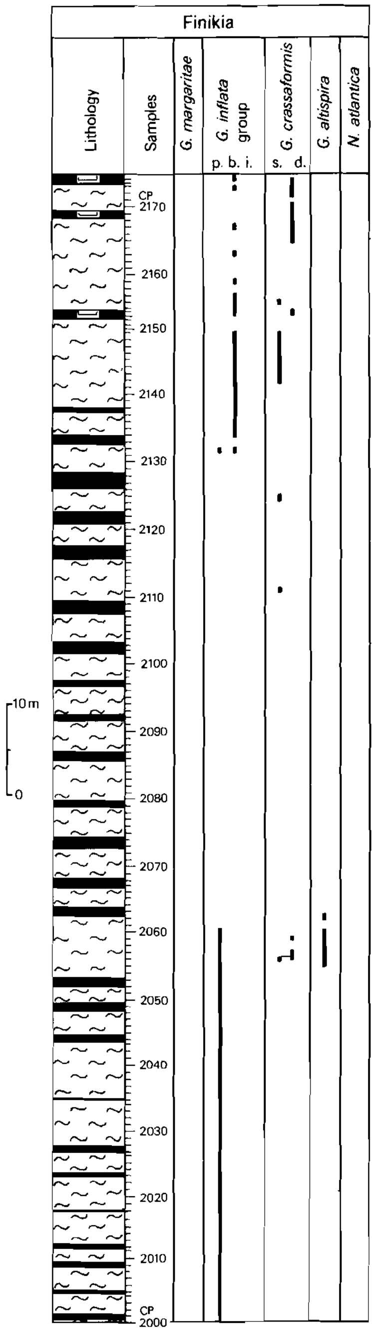


Fig. 15 Lithological column of, and the distribution of some selected taxa in the Finikia section; legend see fig. 3.

Section Aghios Vlassios (figs. 11, 14)

The Aghios Vlassios and Finikia sections are located in the northern part of the Province of Iraklion; the sediments of both sections were deposited in the same sub-basin. Section Aghios Vlassios corresponds to a shallower part close to a ridge, whereas the Finikia section was situated in the more central deeper part of the sub-basin.

Section Aghios Vlassios (north of the village of that name) is formed by a 100 metre thick alternation of grey homogeneous marls and brown laminated sediments. In the top part of the section four diatomites are intercalated.

This section has been sampled twice. The quantitative data, presented in chapter 5, are based on material obtained during the first sampling trip. The numbers of the samples used for these 200-counts are not given in fig. 14. The more detailed set of samples from the second expedition was used for the qualitative faunal analysis and is indicated in fig. 14.

In the Aghios Vlassios section we can construct the following succession of bio-events: the entry of *G. puncticulata*, the exit of *G. margaritae*, the disappearance of *G. puncticulata* and (after a longer absence interval) the reappearance of the *G. inflata* group with nondescript morphotypes and *G. bononiensis*. The first *G. crassaformis* were found near the disappearance level of *G. puncticulata*. In the absence interval of the *G. inflata* group *G. crassaformis* has not been found either; it re-enters the record just below the reappearance level of the *G. inflata* group. Both dextrally and sinistrally coiled *G. crassaformis* assemblages have been found. *G. altispira* is present in several samples in the *G. puncticulata* interval and in one sample in the upper part of the section.

Section Finikia (figs. 11, 15)

West of the village of Finikia the 127 metres of the Finikia section are exposed. Both lithologically and faunistically this section is identical to the Aghios Vlassios section. However, the homogeneous as well as the laminated lithotypes are thicker in Finikia than in Aghios Vlassios due to a larger sedimentation rate. A second difference is that the Finikia section starts above the exit level of *G. margaritae*. *G. altispira* is found in the lower part of the section only.

Section Prassas (figs. 11, 16)

East of the village of Prassas (northern Iraklion) a number of road exposures reveal the composite section of Prassas with a thickness of 72 metres (corresponds to section Prassa II, Thomas, 1980). Overlying a marl-breccia, the Pliocene sequence can be subdivided into two parts, separated by a sandy interval with many concretions and mollusc fragments. The lower part (41 metres) consists of an alternation of homogeneous and dark laminated marls. The upper part consists mainly of diatomaceous sediments with some homogeneous marl intercalations.

In the lower part of the section we recognized the successive first appearances of *G. margaritae* and *G. puncticulata*; these species remain present up to the sandy interval. In the upper part *G. bononiensis* and *G. crassaformis* (mainly dextrally coiled) are irregularly present.

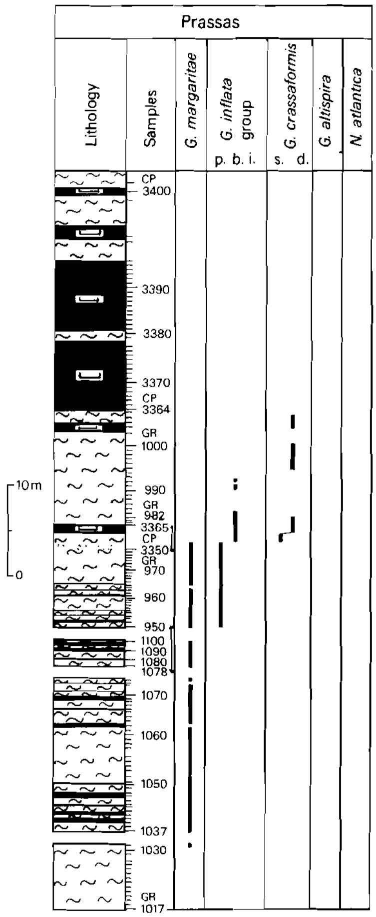


Fig. 16 Lithological column of, and the distribution of some selected taxa in the Prassas section; legend see fig. 3.

Section Francocastello (figs. 11, 17)

The 35 metres of the Francocastello section, on the south coast of the Province of Rethymnon (Meulenkamp, 1969), are made up of silty, clayey marls with several sapropelic, laminated intercalations.

G. bononiensis and *G. crassaformis* show an irregular vertical distribution. *N. atlantica* is present in several samples from the upper part of the section.

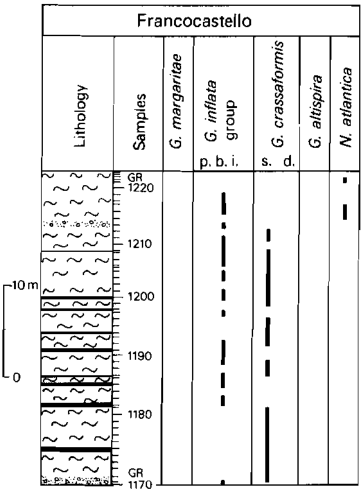


Fig. 17 Lithological column of, and the distribution of some selected taxa in the Francocastello section; legend see fig. 3.

REVIEW OF THE MEDITERRANEAN SECTIONS

The position of the Mediterranean sections relative to the datum levels used in most of the regional biozonations for the Mediterranean Pliocene is shown in fig. 18. The Sicilian-Calabrian sections cover a greater part of the Pliocene than the Cretan sections; however, the latter repeatedly cover the lower part of the Pliocene. Furthermore it can be inferred from fig. 18 that there is a hiatus in section Prassas.

In addition to the Mediterranean sections one set of our samples has an Atlantic provenance. From DSDP Site 397 near Cape Bojador, situated off the west coast of Africa (26°N, 15°W), 73 samples, covering a 275 metre thick Pliocene succession, were examined. The distribution of the planktonic foraminifera in this site will be given and discussed in the next chapter.

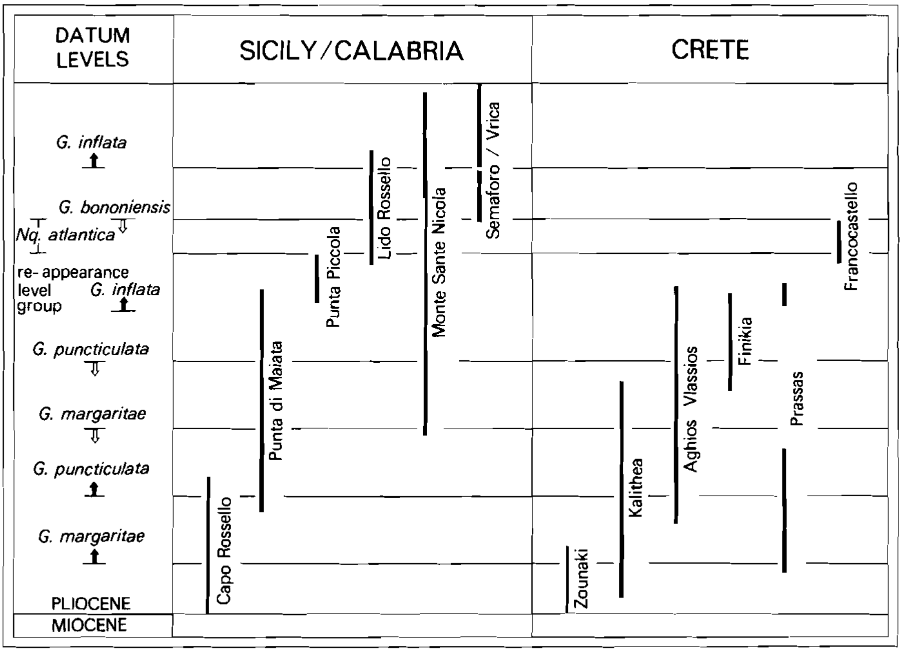


Fig. 18 Position of the studied sections, relative to planktonic foraminiferal datum levels used in regional zonations for the Mediterranean Pliocene.

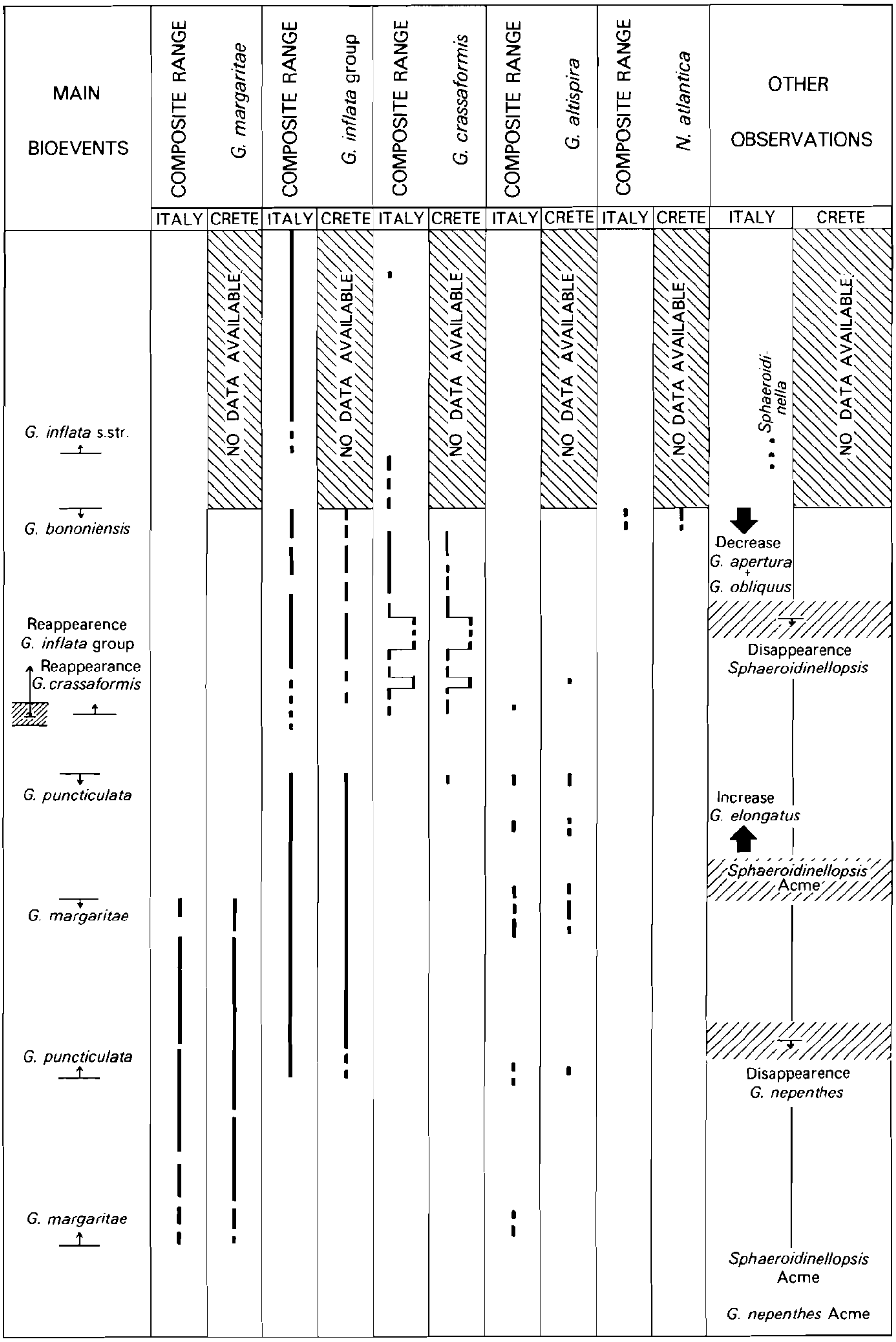


Fig. 19 Composite ranges of the index-taxa in the Mediterranean Pliocene.

Chapter 3

QUALITATIVE FAUNAL ANALYSIS

Over 1400 samples have been studied qualitatively. The number of planktonic foraminifera examined was not the same for all samples, due to differences in the plankton-benthos ratio and in the relative numbers of non-foraminiferal particles. On average, however, we looked at 14,500 to 18,000 planktonic foraminiferal specimens per sample.

The planktonic foraminifera of the Mediterranean Pliocene can be divided into two categories. One consists of species which are continuously present, the other is formed by taxa which have a limited range. Here we shall pay special attention to the distribution of the taxa of the second category; the frequency fluctuations of all taxa will be dealt with in chapter 5.

FAUNAL DISTRIBUTION IN THE MEDITERRANEAN

The composite ranges of several taxa in the Sicilian-Calabrian and Cretan areas are visualized in fig. 19.

Globorotalia margaritae

In Sicily and in Crete the appearance level of *G. margaritae* is always found a couple of metres above the Mio-Pliocene boundary; its exit is always later than the entry of *Globorotalia puncticulata.* In both areas *G. margaritae* is rather scarce in the samples immediately above its appearance level. A relatively long absence interval is found in Italy towards its last occurrence; a similar pattern is shown for the Pliocene of the Tyrrhenian Sea (D.S.D.P. Site 132, Thunell, 1979a). The species has been observed in 329 of the 361 samples (= 91%) within its range (fig. 20).

Globorotalia inflata group

In our concept the *G. inflata* group consists of three morphologically similar taxa: *Globorotalia puncticulata*, *Globorotalia bononiensis* and *Globorotalia inflata.* The discontinuous vertical distribution of this group in the Mediterranean Pliocene has been the subject of a separate paper (Spaak, 1981b), which will be briefly summarized below.

Three presence intervals of the *G. inflata* group have been found. In the first, in the Lower Pliocene, the assemblages are distinctly dominated by *G. puncticulata.* In Sicily *G. puncticulata* enters the fauna suddenly in large numbers during the range of *Globorotalia margaritae*, and it remains continuously present up to the level of its disappearance. In Crete *G. puncticulata* enters the fauna at the same biostratigraphic level but in the very first part of its range it is scarce and in three samples it has not been found at all. In some of the samples of the first presence interval, especially in those from laminated sediments, relatively large numbers of *G. bononiensis*-types have been found in the *G. puncticulata* assemblages.

From this first presence interval of the *G. inflata* group 375 samples were examined; in 372 (= 99%) the group has actually been found (fig. 20).

Following a first period of absence the *G. inflata* group re-appears in the sections and a second presence interval can be discerned, in which the assemblages are generally dominated by the *G. bononiensis* type. The first newly appearing assemblages however are still dominated by *G. puncticulata* or by nondescript morphotypes. In the upper part of this second presence interval an increasing relative number of the individuals have a *G. bononiensis-G. inflata* intermediate morphology. This morphological change is especially noticeable in successive samples from homogeneous sediments; in samples from laminated sediments of this interval, *G. bononiensis*-types strongly dominate the assemblages. This gradual development from *G. bononiensis* to *G. inflata* is interrupted by the second disappearance of the entire *G. inflata* group from the Mediterranean record for a longer period.

In comparison to its first and third presence intervals the *G. inflata* group is (very) discontinuously present in this second interval. Only in 181 samples of the 325 (= 56%) examined have representatives of the group been found (fig. 20). Especially in the Cretan section Prassas the group is very scarce (observed in 17 of the 70 samples only).

Typical *G. inflata* types distinctly dominate the assemblages of the *G. inflata* group in its third presence interval in the Upper Pliocene. Apart from some samples in the lower part of its range, the *G. inflata* group is continuously present in our material after its third appearance. It has been found in 144 of the 163 samples examined from this range-interval (= 88%; see fig. 20).

Globorotalia crassaformis

The first specimens of *G. crassaformis* have been found at the end of the *G. puncticulata* range zone (first presence interval of the *G. inflata* group) in our Cretan material only. In this part of the Pliocene *G. crassaformis* was

SECTIONS	*Globorotalia margaritae*		1e presence interval *G. inflata* group *G. puncticulata*		2e presence interval *G. inflata* group *G. bononiensis*		3e presence interval *G. inflata* group *G. inflata*		*Globorotalia crassaformis*	
	Number of samples in range	Number of samples in which observed	Number of samples in range	Number of samples in which observed	Number of samples in range	Number of samples in which observed	Number of samples in range	Number of samples in which observed	Number of samples in range	Number of samples in which observed
Capo Rossello	38	29	16	16						
Punta di Maiata	82	70	85	85	44	30			36	19
Punta Piccola					42	30			42	20
Lido Rossello					17	17	22	13	32	14
Monte Sante Nicola	2	2	10	10	14	5	34	31	25	15
Semaforo					6	4			75	15
Vrica							107	100		
Zounaki	5	5								
Kalithea	82	77	74	71						
Aghios Vlassios	56	53	98	98	32	23			36	18
Finikia			61	61	44	27			51	22
Prassas	96	93	31	31	70	17			70	26
Francocastello					56	28			56	32
Total	361	329	375	372	325	181	163	144	423	181
Presence	91%		99%		56%		88%		43%	

Fig. 20 Presence of index-taxa in their ranges; to establish these data, on average we looked at 14,500 to 18,000 planktonic foraminiferal specimens per sample.

probably present in small numbers only and/or during a short period. It is more regularly, but still discontinuously, found in Crete as well as in Sicily from a level, near the base of the second presence interval of the *G. inflata* group, upwards. In most sections this (re-)appearance level of *G. crassaformis* precedes the onset of the second interval of the *G. inflata* group; however in section Punta di Maiata the order is reversed. *G. crassaformis* remains regularly present up to a level just below the first appearance of *G. inflata* s. str. Among the 423 samples from the interval in which *G. crassaformis* is regularly present, this taxon has been found in 181 (= 43%; see fig. 20).

In the still higher Pliocene *G. crassaformis* occurs in two of our samples from the Vrica section only. The assemblages of *G. crassaformis* show predominantly sinistral coiling; in the lower half of the second presence interval of the *G. inflata* group assemblages with dextral coiling are present.

Globoquadrina altispira

In Sicily as well as in Crete *G. altispira* has a very discontinuous distribution; in both areas the last scarce occurrence of this taxon has been found in the lower part of the second presence interval of the *G. inflata* group. Whenever *G. altispira* is present, it is usually represented by a fair number of specimens. The occurrences of *G. altispira* seem to be concentrated in certain intervals. Its first assemblages occur immediately after the entry of *G. margaritae*, but in Sicily only. In both areas the species is found near the appearance level of *G. puncticulata*, close to the exit level of *G. margaritae* and then higher, up to the exit level of *G. puncticulata*. In the Mediterranean Pliocene *G. altispira* is most numerous just before the last occurrence datum of *G. margaritae*.

Neogloboquadrina atlantica

Assemblages of *N. atlantica* entered the Mediterranean at the end of the *G. bononiensis* range and they are present in a small interval only. They disappear from our record at the same level as *G. bononiensis*. There are no indications of a transition between N. *atlantica* and *Neogloboquadrina acostaensis* in the Mediterranean; the latter species is found throughout the sections.

Globigerina nepenthes

This taxon is present in the lower part of the Pliocene only. Preceding the entry level of *G. margaritae* it is very numerous (Zachariasse et al., 1979; Spaak, 1981a); upwards its frequencies decrease and it disappears from the Mediterranean shortly after the appearance of *G. puncticulata*. In the top part of its range *G. nepenthes* is (very) scarce and as a consequence its disappearance level cannot be pinpointed exactly (fig. 19). Another problem in this context is that *G. nepenthes* and tightly coiled specimens of the *Globigerina apertura* assemblages are very much alike.

Sphaeroidinellopsis spp.

The presence of relatively large numbers of *Sphaeroidinellopsis* in the Mediterranean Pliocene below the entry level of *G. margaritae* is well known (e.g. Cita, 1975; Zachariasse, 1975; Thunell, 1979a). A second less pronounced acme of *Sphaeroidinellopsis* can be found in an interval immediately above the disappearance level of *G. margaritae*; during the range of *G. margaritae*, *Sphaeroidinellopsis* specimens are very scarce or even absent, however. Higher in the Pliocene *Sphaeroidinellopsis* becomes scarce again;

its exact disappearance level, somewhere in the lower part of the second presence interval of the *G. inflata* group is hard to indicate.

Sphaeroidinella dehiscens

Distinct specimens of *S. dehiscens*, with a well developed cortex and two apertures with crenulated lips, have been found only in some samples close to the base of the third presence interval of the *G. inflata* group. Its presence at that biostratigraphic level has been reported from the Tyrrhenian and Ionian Sea as well (Thunell, 1979a).

In addition to the above taxa with partial presence in our Mediterranean Pliocene sections, some of the other taxa, which occur throughout, show peculiarities in their frequency distribution.

Globigerinoides elongatus, which always outnumbers the *Globigerinoides ruber*-type in our material, has been found in Crete from the lowermost Pliocene upwards. At first the numbers of *G. elongatus* are very low, but upwards they gradually increase and at the entry level of *G. puncticulata* this taxon is already distinctly present. In Sicily, however, *G. elongatus* is extremely scarce and sometimes it is even absent up to a level just below the last occurrence datum of *G. margaritae*; at this level it is suddenly represented by relatively large numbers. In an interval close to the appearance level of *G. inflata* s. str. we found many large, thick-walled morphotypes, resembling *Globigerinoides conglobatus* in the assemblages of *G. elongatus*.

Globigerinoides obliquus and *Globigerina apertura* are continuously present in all samples. As to the relative frequencies they both (but especially *G. obliquus*) strongly diminish in number just above the level of disappearance of *G. bononiensis* and *N. atlantica*.

Globigerinoides trilobus is regularly present in low numbers. Twice it deviates from its average. Between the first and second presence interval of the *G. inflata* group, *G. trilobus* is relatively more numerous; between the second and the third presence interval of the *G. inflata* group, in contrast, it is extremely scarce and in several samples it has not been found at all.

In their interval of co-occurrence *G. margaritae* and *G. puncticulata* display a remarkable frequency pattern. In the individual samples only one of the two taxa is usually present in relatively large numbers, whereas the other is scarce, although it remains present.

FAUNAL DISTRIBUTION OF CAPE BOJADOR

The Pliocene sequence of Cape Bojador (fig. 21) starts in core 42 section 2

(42/2) and ends in core 15/3. In contrast with the Mediterranean sections the Mio/Pliocene boundary is not marked in this Atlantic site neither lithologically nor faunistically (Salvatorini and Cita, 1979; Mazzei et al., 1979). By extrapolating certain datum levels that are found near the Mio/Pliocene boundary in the Mediterranean to the succession of Cape Bojador, these authors concluded that the boundary is situated in core 42/2 or at its base. We observed the transition between *Globorotalia tosaensis* and *Globorotalia truncatulinoides* in core 15. The latter species is distinctly present in our material from core 15/3 upwards; consequently we consider core 15/3 to belong to the Pleistocene.

The evolutionary appearance of *G. margaritae* has been reported from core 45/1 (Salvatorini and Cita, 1979). In our material (from core 43/6 upwards)

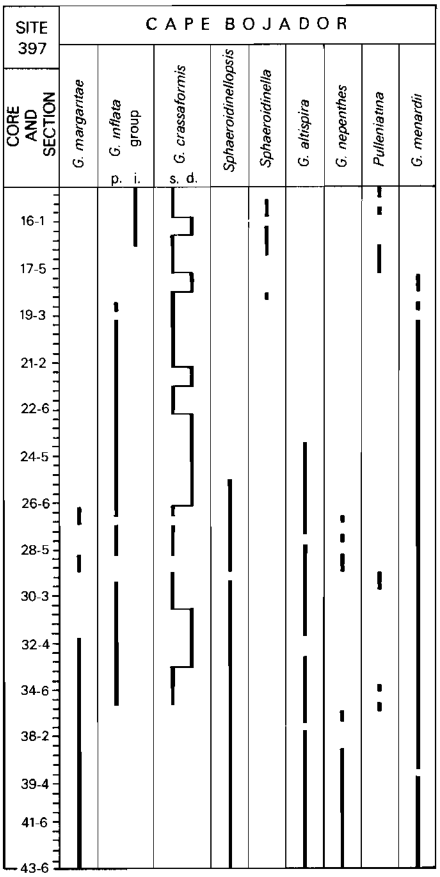


Fig. 21 Distribution of some selected index-taxa at Cape Bojador (DSDP Site 397).

this taxon is continuously present up to core 32/4. Above this level *G. margaritae* has been encountered in two more intervals (core 29/3-29/1 and core 27/4-27/2). According to Mazzei et al. (1979) the exit level of *G. margaritae* is in core 29/1 and occurrences above this level should be interpreted as due to reworking.

G. puncticulata and *G. crassaformis* enter the fauna at the same level: core 35/1. These taxa remain continuously present apart from two intervals (above core 32/4), in both of which *G. margaritae* has been found. Several changes in coiling direction have been observed in the assemblages of *G. crassaformis*. This species is continuous to the top of the investigated sequence, whereas *G. puncticulata* disappears at some level in core 19/1. After a distinct absence interval the *G. inflata* group re-appears in core 16/5, but now with assemblages dominated by *G. inflata* s. str..

Sphaeroidinellopsis specimens and *G. altispira* are more continuously present in Cape Bojador than in the Mediterranean. They disappear successively near core 25. *Sphaeroidinella dehiscens* has been found discontinuously in the upper part of the sequence from core 18/5 upwards. *G. nepenthes* is fairly continuously present up to core 37/2. Above this level it has been found discontinuously in the interval from core 29/3 to core 27/2.

The *Globorotalia menardii* group has not been found in any sample from the Mediterranean Pliocene. In Cape Bojador it is almost continuously encountered up to the level of core 18/1. Other taxa which are found in the samples from Cape Bojador only are *Candeina nitida* and *Pulleniatina* spp.. The former taxon is extremely scarce, found in core 38/4 only. *Pulleniatina* specimens occur discontinuously in the Lower Pliocene between cores 36/2 and 30/1, and again in the Upper Pliocene from core 17/5 upwards.

DISCUSSION

If we compare our observations from Sicily and Crete with the data in the literature the successions of the deduced Mediterranean Pliocene bio-events are consistent. In our own data there is only one exception. The order of the first re-appearance level of the *G. inflata* group and the (re-)appearance level of *G. crassaformis* is not the same in all sections, although these levels are always close together.

By far the most distinct and reliable datum levels are linked with the bioevents of the *Globorotalia* taxa. In the Mediterranean all these taxa appear suddenly without a gradual evolutionary beginning. Their disappearance is usually equally instantaneous. The gradual intra-Mediterranean transitions between some of these taxa (from *G. puncticulata* via *G. bononiensis* to *G.*

inflata), as suggested by Colalongo and Cita (1967) and by Brolsma (1978), have not been observed. Gradual evolutionary introductions of *G. margaritae*, *G. puncticulata*, *G. inflata* and *G. crassaformis* have been reported in studies of Atlantic material (e.g. Berggren and Amdurer, 1973; Poore and Berggren, 1974; 1975b; Berggren, 1977; Salvatorini and Cita, 1979). Therefore we assume that migration-events from the Atlantic to the Mediterranean probably played a predominant role, as far as the distribution patterns of the *Globorotalia* taxa in the Mediterranean Pliocene are concerned.

The absence of gradual transitions and the sudden character of appearances and disappearances of these taxa give a great reliability to the corresponding datum levels in stratigraphic correlations. Because of their very nature there may be a time-lag between these migration-related events in Sicily and Crete. The exact duration of such time-lags is hard to determine, but if existing, they do not influence the reliability of the datum levels in correlations. The order of datum levels is consistent and also the ratios between the sediment thicknesses between these datum levels are comparable in Sicily and Crete! Yet some faunal phenomena may be a reflection of migration peculiarities, such as the difference between the *G. puncticulata* entry in Sicily (suddenly present in large numbers) and in Crete (scarce and occasionally absent) and the inconsistent order of superposition of the reappearance levels of the *G. inflata* group and *G. crassaformis*.

Just like the *Globorotalia* taxa, *Globoquadrina altispira*, *Neogloboquadrina atlantica* and *Sphaeroidinella dehiscens* appear suddenly in the Mediterranean and these entries seem to be caused by migration as well. The presence intervals of these taxa can potentially be used for biostratigraphic correlations. In practice however, this does not apply as far as *G. altispira* is concerned. First of all there are several presence intervals and it is sometimes impossible to tell one from the other; furthermore, some of these intervals are very small and they were not found consistently. In this context it is remarkable that the presence interval of *G. altispira* following the entry of *G. margaritae* is found only in Sicily, although more Cretan sections cover this part of the Pliocene. This negative record may be caused by chance sampling or by the scarcity of *G. altispira* in Crete, but it is equally plausible to assume that this influx of *G. altispira* did not reach further than the central Mediterranean. Only single presence intervals of *N. atlantica* and *S. dehiscens* have been found in the Mediterranean Pliocene. The former species is encountered in several sections in Sicily, Calabria and Crete; the latter is found in five samples (from Sicily and Calabria) only! As a consequence we regard *S. dehiscens* to be of little correlation value, whereas the distribution pattern of *N. atlantica* provides a more reliable biostratigraphic tool.

As to *G. nepenthes* and *Sphaeroidinellopsis*, these taxa are no more than sporadically present in the later part of their Mediterranean range. Therefore their disappearance levels are not suitable for detailed stratigraphic correlations. *G. nepenthes* as a marker for the lower part of the Pliocene (apart from its high frequencies prior to the entry of *G. margaritae*) should be applied with caution, due to the resemblance of its individuals with tightly coiled specimens in the *G. apertura* assemblages.

Most taxa from the Mediterranean Pliocene faunas have been found at Cape Bojador as well, but *N. atlantica* and *Globorotalia* assemblages dominated by *G. bononiensis* are present in the Mediterranean only, whereas the *G. menardii* group, *C. nitida* and *Pulleniatina* are restricted to our material from Cape Bojador. As the latter three taxa are generally regarded as low latitude or warm water species and as *N. atlantica* is a common faunal element of the northwest Atlantic (Poore and Berggren, 1975a, b) these differences seem to be primarily dependent on the geographic position of the two areas.

In contrast with the Mediterranean data the appearance of *G. margaritae* at Cape Bojador is reported from a level below the Mio/Pliocene boundary; it is described as gradual and evolutionary (Salvatorini and Cita, 1979). At Cape Bojador *G. puncticulata* and *G. crassaformis* suddenly enter the fauna and their appearances are probably caused by migrations as in the Mediterranean. Their appearance at the same level is remarkable; it is strikingly different from our Mediterranean data. The same holds for the fact that at Cape Bojador only one distinct absence interval of the *G. inflata* group has been found (in the Upper Pliocene). This absence interval possibly corresponds to the second Mediterranean one; in both absence intervals *S. dehiscens* appears suddenly and in both areas the re-appearing assemblages are dominated by distinct *G. inflata* types. The assemblages of the *G. inflata* group below this absence interval are dominated by *G. puncticulata* at Cape Bojador and by *G. bononiensis* in the Mediterranean. In this period stagnation of bottom waters is common in the Mediterranean (Kidd et al., 1978). Furtherdown *G. bononiensis* types are relatively numerous in *G. puncticulata* assemblages recovered from laminated sediments. Consequently *G. bononiensis* is regarded (Spaak, 1981b) as an ecophenotype of *G. puncticulata,* which is numerous or even dominates the assemblages during periods of formation of sapropelic or diatomaceous beds.

In the Mediterranean dextrally coiled *G. crassaformis* assemblages are limited to a small part of the Pliocene. In the material of Cape Bojador several more changes in coiling direction occur all through the Pliocene. Consequently the *G. crassaformis* assemblages with dextral coiling are useful for intra-Mediterranean correlations, but for correlations from the Atlantic to the Mediterranean they cannot be used.

The Mediterranean and Cape Bojador sections are comparable as far as the last occurrences of *G. altispira* and *Sphaeroidinellopsis* are concerned. In both areas these biohorizons are close together, although the order of superposition is not the same.

There are more problems about the disappearance levels of *G. margaritae* and *G. nepenthes.* According to Driever (pers. comm.), who studied the calcarous nannofossils of our samples, there are indications for reworking for the intervals of core 29/3-29/1 and core 27/4-27/2. In both these intervals *G. margaritae* and *G. nepenthes* have been found, at a distinctly higher level than their disappearance levels in cores 32/4 and 37/2, respectively. According to Mazzei et al. (1979) only the occurrences of *G. margaritae* above core 29/1 should be regarded as being due to reworking. Our own observations on the foraminiferal faunas from these intervals with recurrences of *G. margaritae* and *G. nepenthes* give no other indications for reworking apart from the low average values of the *Orbulina universa* diameter (see chapter 6), which are comparable to the values of the Lower Pliocene.

No clear solution can be offered and the data from these two intervals can be interpreted in different ways. If we regard the fauna as reworked this explains the absence in these intervals of *G. puncticulata* and *G. crassaformis;* it furthermore places the last occurrence of *G. nepenthes* and the first appearance of *G. puncticulata* at Cape Bojador close together; this position is comparable to that indicated by the Mediterranean data. Secondly if we interpret the fauna as autochthonous this means that after a period of absence *G. margaritae* and *G. nepenthes* returned to the area of Cape Bojador. Consequently the last occurrences of *G. margaritae* and *G. nepenthes* and the ones of *G. altispira* and *Sphaeroidinellopsis* come closer together and the exit level of *G. nepenthes* and the appearance of *G. puncticulata* wider apart than in the Mediterranean. We prefer the solution in which reworking plays a major role.

Summarizing, the order of superposition of the datum levels in the Mediterranean is consistent; the *Globorotalia* taxa are migration related and most suitable for (bio)stratigraphic correlations. Due to their geographic position the faunas of Cape Bojador contain more low latitude elements, while the order of the datum levels at Cape Bojador is to some extent comparable with the Mediterranean succession. Some differences exist however. *G. margaritae* appears below the Miocene-Pliocene boundary off Cape Bojador and above this boundary in the Mediterranean; in the former region *G. puncticulata* and *G. crassaformis* enter the fauna at the same level, in the latter area *G. puncticulata* distinctly precedes *G. crassaformis.* Furthermore only one larger absence interval of the *G. inflata* group has been found at Cape Bojador. The differences in position of the last occurrences of *G. margaritae* and *G. nepenthes* may be due to reworking.

Chapter 4

BIOSTRATIGRAPHY

In the course of our research over 1300 samples from 13 Mediterranean sections of the Pliocene have been examined. On the basis of the range charts, it is possible to recognize nine zones which are delimited by distinct datum levels. In this chapter we shall discuss these nine interval-zones.

Since we studied samples from sections with relatively long parts of the Pliocene, we were able to assign all samples to one of the nine zones, although in several samples no index taxa could be found. It we had studied these samples individually, no correct or precise allotment to one of the zones would have been possible.

In order to get an impression of the biostratigraphic value of these interval-zones, we have made calculations about their recognizability in single samples. To this end we have regarded all samples individually and we have checked whether they meet the criteria of recognition of the zones to which they belong.

In the discussion of every zone the percentages of samples which fulfil the criteria for recognition will be given as well as the potential ranges of the remaining samples. To establish these ranges we will use our results concerning the distribution of the index taxa, discussed in the previous chapter.

Zone 1

Diagnosis: Interval-zone from the base of the Pliocene to the entry level of *Globorotalia margaritae;* the interval contains relatively large numbers of *Globigerina nepenthes* and *Sphaeroidinellopsis.*

Remarks: In the Mediterranean the Miocene-Pliocene boundary is based on a lithological change and can be recognized easily. There is no paleontological criterion for the base of the Pliocene that can be used outside the Mediterranean. The first distinct marker level above this boundary is the appearance of *G. margaritae.* Apart from the index taxa with a limited range, all Pliocene fauna elements are present in this interval already, although *Globigerinoides elongatus* (especially in our Sicilian material) may be extremely scarce. *G. nepenthes* reaches its highest Pliocene proportions in this interval, especially in its lower part (Sicily 15–20%, Crete 30–35%; Zachariasse and Spaak, 1979). The relatively large numbers of *Sphaeroidinellopsis* (not exceeding 2%!) occur in the upper half of the interval, in which part of the zone *Globorotalia scitula* enters the record. The *Sphaeroidinellopsis* acme usually follows the peak of *G. nepenthes* and precedes the entry of *G. margaritae.* In long and closely sampled sections of this zone, it can be subdivided into two parts:

I. a lower interval with large numbers of *G. nepenthes* followed by
II. an upper interval with many *G. nepenthes* accompanied by *Sphaeroidinellopsis* and *G. scitula.*

Recognizability: The recognition of individual samples from this interval is based on a combination of criteria which are either negative or to some extent qualitative-subjective: 1. no *G. margaritae;* 2. large numers of *G. nepenthes* (qualitatively distinctly numerous; quantitatively: in Crete more than 10%, in Sicily more than 5%); and 3. relatively large numbers of *G. nepenthes* and *Sphaeroidinellopsis.*

In total 73% of the 63 samples from this interval could be positively recognized as belonging to this interval (table I). In the remaining 17 samples *G. nepenthes* is present but not really numerous. Because of the absence of *Globorotalia puncticulata* this means for the four Sicilian samples a possible allotment to an interval from the Miocene-Pliocene boundary to the appearance level of *G. puncticulata;* the 13 Cretan samples might be assigned to an interval between that lower boundary and a level just above the entry level of *G. puncticulata* (fig. 22), as the latter taxon is absent in some samples in the lower part of its range in Crete.

Table I: Recognizability interval-zone 1

sections	number of samples	positively recognized	percentage
Capo Rossello	12	8	67
Zounaki	18	16	89
Kalithea	19	13	68
Prassas	14	9	64
Total Italy	12	8	67
Total Crete	51	38	75
Total	63	46	73

Zone 2

Diagnosis: Interval-zone from the entry level of *Globorotalia margaritae* to the entry level of *Globorotalia puncticulata.*

Remarks: In our Sicilian and Cretan sections *G. margaritae* is discontinuously present, especially in the lower part of its range. If present its percentage varies strongly; in some Cretan samples *G. margaritae* is extremely scarce (estimated proportion less than 0.5‰) whereas maximum percentages of 17% (in Sicily) and 6.5% (in Crete) are reached.

In Sicily the top of this zone is very distinct because *G. puncticulata* suddenly enters the fauna with percentage values between 10 and 20, whereafter this taxon remains present in all samples until its disappearance. In Crete the entry level of *G. puncticulata* is less distinct because in some samples from the lower part of its range it has not been found at all, while in the other samples of this lower part it does not enter the 200-counts. In this interval-zone the proportions of *G. nepenthes* diminish strongly and in the upper part it disappears from the 200-counts. In Sicily *Globoquadrina altispira* is dicontinuously present in our samples from a short interval directly overlying the appearance level of *G. margaritae.* In Crete this presence interval of *G. altispira* has not been found.

Recognizability: The presence of *G. margaritae* combined with the absence of *G. puncticulata* forms the distinct and objective criterion for recognition of this interval-zone.

Table II: Recognizability interval-zone 2

sections	number of samples	positively recognized	percentage
Capo Rossello	22	16	73
Punta di Maiata	24	24	100
Zounaki	5	5	100
Kalithea	44	41	93
Aghios Vlassios	5	5	100
Prassas	65	63	97
Total Italy	46	40	87
Total Crete	119	114	96
Total	165	154	94

Regarding the 165 samples from this interval individually, 11 (= 7%) could not be allotted with certainty. In each of these 11 samples *G. nepenthes* has been found whereas *G. margaritae* is absent and consequently these samples might have been placed in an interval from the Miocene-Pliocene boundary to the entry level of *G. puncticulata* (Sicilian samples) or to a level just above the appearance of this taxon (Cretan samples; see table II and fig. 22).

Zone 3

Diagnosis: Concurrent range-zone of *Globorotalia margaritae* and *Globorotalia puncticulata*, i.e. form the entry level of *G. puncticulata* to the exit level of *G. margaritae.*

Remarks: In Sicily *G. puncticulata* is continuously present in this and the next higher interval-zone; it enters all 200-counts ($0.5\% < P_{punct.} < 30\%$; average close to 10%). In Crete *G. puncticulata* is continuously present from a level just above its initial appearance upwards and it enters most but not all 200-counts in its range. Its maximum proportion is 9%; in most samples the proportion does not exceed 4%. The frequency pattern of *G. margaritae* is much the same as it is in interval-zone 2. Especially in our Silician material a longer absence interval in the range of *G. margaritae* can be observed just prior to its last occurrence. Immediately above its last occurrence a qualitatively distinct acme of *Sphaeroidinellopsis* ($P_{Sphaer.} = 1.5–2\%$) is present in both areas.

Table III: Recognizability interval-zone 3

sections	number of samples	positively recognized	percentage
Capo Rossello	16	13	81
Punta di Maiata	58	46	79
Monte Sante Nicola	2	2	100
Kalithea	38	33	87
Aghios Vlassios	51	48	94
Prassas	31	30	97
Total Italy	76	61	80
Total Crete	120	111	93
Total	196	172	88

In zone 3 *G. altispira* is present in several samples; it is found near the entry level of *G. puncticulata* and near the exit level of *G. margaritae*. In the lower part of this interval-zone *G. nepenthes* disappears entirely from the Pliocene Mediterranean record.

Recognizability: Single samples from this interval can be easily recognized by the co-occurrence of *G. margaritae* and *G. puncticulata.*

From this interval-zone 196 samples were investigated; 172 (88%) meet this criterion for recognition (table III). In 24 samples, which could not be recognized to belong to this interval-zone, either one or the other of the two decisive *Globorotalia* taxa is absent. If considered individually the 15 samples of Sicily which lacked *G. margaritae* might have been assigned incorrectly to zone 4; the same holds for six of the Cretan samples. Because of the absence of *G. puncticulata* three Cretan samples would have been assigned to zone 2 (fig. 22).

Zone 4

Diagnosis: Interval-zone from the exit level of *Globorotalia margaritae* to the disappearance level of *Globorotalia puncticulata.*

Remarks: In this interval *G. puncticulata* is continuously found in Sicily as well as in Crete. In the former region the taxon is numerous up to its disappearance level with percentages between 10 and 20; in the Cretan material the proportions do not exceed 6%. *G. altispira* occurs in several samples halfway up and in the upper part of this interval. *Globorotalia crassaformis* enters

Table IV: Recognizability interval-zone 4

sections	number of samples	positively recognized	percentage
Punta di Maiata	27	27	100
Monte Sante Nicola	8	8	100
Kalithea	36	36	100
Aghios Vlassios	47	47	100
Finikia	61	61	100
Total Italy	35	35	100
Total Crete	144	144	100
Total	179	179	100

the fauna towards the top of this zone; this occurrence is found in our Cretan material only. The species disappears for the first time at the same level as *G. puncticulata.*

Recognizability: As *G. puncticulata* is continuously present all 179 samples (table IV) could be positively recognized as belonging to zone 4.

Zone 5

Diagnosis: Interval-zone from the disappearance level of *Globorotalia puncticulata* to the re-appearance level of *Globorotalia crassaformis.*

Remarks: The disappearance of *G. puncticulata* marks a very distinct biohorizon, which is followed by a longer period of absence of the entire *Globorotalia inflata* group. At the end of this period of absence two bio-events occur close together: the re-appearances of *G. crassaformis* and of the *G. inflata* group. In most sections the re-appearance of *G. crassaformis* precedes the one of the *G. inflata* group; in the Punta di Maiata section the order of these datum levels was found reversed. After the re-appearance the assemblages of the *G. inflata* group are dominated at first by *G. puncticulata* or nondescript morphotypes; shortly afterwards, however, *Globorotalia bononiensis* starts to dominate the assemblages. The re-appearing taxa do not enter the 200-counts, apart from the *G. inflata* group in section Punta di Maiata.

Recognizability: Because of the negative characteristics none of the 124 samples from this interval can individually be assigned with certainty to this zone. The presence of *G. puncticulata* types below the re-appearance level of *G. crassaformis* in 3 of the 24 Sicilian samples is responsible for the fact that these samples would be assigned incorrectly to zone 4. All other samples could be placed anywhere in a large part of the Pliocene (zone 5 to basal part of zone 9) but not in zone 4 and not in the larger parts of zones 3 and 9. In these zones *G. puncticulata* or *G. inflata* are continuously present. The relatively large numbers of *Globigerinoides elongatus* in the samples from zone 5 and the absence of *G. nepenthes* would make the allotment to our zones 1 or 2 unlikely.

Zone 6

Diagnosis: Interval-zone from the re-appearance level of *Globorotalia crassaformis* to the entry level of *Neogloboquadrina atlantica.*

Remarks: This zone is characterized by the co-occurrences of assemblages of the *G. inflata* group (most of them dominated by *G. bononiensis*) and of *G.*

crassaformis. However both taxa are irregularly present and if present their frequencies vary strongly; it may be that they do not enter the 200-counts but on the other hand they may be numerous (*G. bononiensis* up to 46%, *G. crassaformis* up to 16%). The very large numbers of *G. bononiensis* are restricted to the laminated sediments from the lower part of this zone in Sicily (section Punta Piccola).

The assemblages of *G. crassaformis* in the Mediterranean show predominantly sinistral coiling. However in the lower part of this interval-zone several assemblages have predominantly dextral coiling; they seem to be restricted to two "dextral intervals". *Sphaeroidinellopsis* disappears from the Mediterranean record at an ill-defined level near the last dextral *G. crassaformis* assemblages. Furthermore we found the last extremely scarce occurrence of *G. altispira* in the lower part of this zone. In the upper part of zone 6 *G. bononiensis* types still dominate the assemblages of the *G. inflata* group but there are more and more *G. bononiensis-G. inflata* intermediate morphotypes.

Recognizability: The samples from zone 6 can be recognized with certainty by: 1. the co-occurrence of *G. crassaformis* and *G. bononiensis*, 2. the presence of dextrally coiled *G. crassaformis* assemblages and 3. the occurrence of distinct *G. bononiensis* assemblages. The third criterion is less diagnostic than the two earlier ones because determination of assemblages of the *G. inflata* group may be subjective.

Table V: Recognizability interval-zone 6

sections	number of samples	positively recognized	percentage
Punta di Maiata	36	25	69
Punta Piccola	42	28	67
Lido Rossello	7	6	86
Monte Sante Nicola	12	7	58
Aghios Vlassios	36	20	56
Finikia	51	26	51
Francocastello	45	16	36
Prassas	70	27	39
Total Italy	97	66	68
Total Crete	202	89	44
Total	299	155	52

Altogether 155 of the 299 samples from this interval (= 52%) could be recognized with certainty (table V). In 14% of the samples *G. crassaformis* is predominantly sinistral; these samples might be assigned to any place of the entire range of zones 6, 7 and 8 (fig. 22). In 10% of the samples only nondescript assemblages of the *G. inflata* group are present; assignment might be possible to the entire range of the group, but the *G. puncticulata* and *G. inflata* assemblages are morphologically very distinct and therefore the allotment to intervals 3, 4 and 9 is less likely. In the remaining 24% of the samples none of the index taxa was found. Like most samples from interval-zone 5 any assignment to a place in the range from zone 5 to the lower part of zone 9 is most plausible.

Zone 7

Diagnosis: Interval-zone from the entry level of *Neogloboquadrina atlantica* to the last occurrence levels of *Neogloboquadrina atlantica* and *Globorotalia bononiensis.*

Remarks: In this relatively small interval-zone assemblages of large *N. atlantica* specimens are distinctly present in several samples, although they do not enter the 200-counts. In our material the last occurrences of *N. atlantica* and *G. bononiensis* are found in the same samples. *G. crassaformis* is usually absent in this interval.

Recognizability: This zone can be recognized by the presence of *N. atlantica.*
On the basis of this criterion 12 of the 30 samples (= 40%) from this interval could not be recognized with certainty (table VI). In one a co-occurrence

Table VI: Recognizability interval-zone 7

sections	number of samples	positively recognized	percentage
Lido Rossello	10	8	80
Monte Sante Nicola	3	3	100
Semaforo	6	3	33
Francocastello	11	5	45
Total Italy	19	13	68
Total Crete	11	5	45
Total	30	18	60

is found of *G. crassaformis* and *G. bononiensis* and this sample would have been incorrectly assigned to zone 6. In seven samples (23%) nondescript assemblages of the *G. inflata* group were found; in four samples (13%) no index taxa are present. The most likely ranges to which these samples would be allotted are from the top of zone 5 to zone 7 for the first group and from zone 5 to the lower part of zone 9 for the second (fig. 22; see also discussion of zone 6).

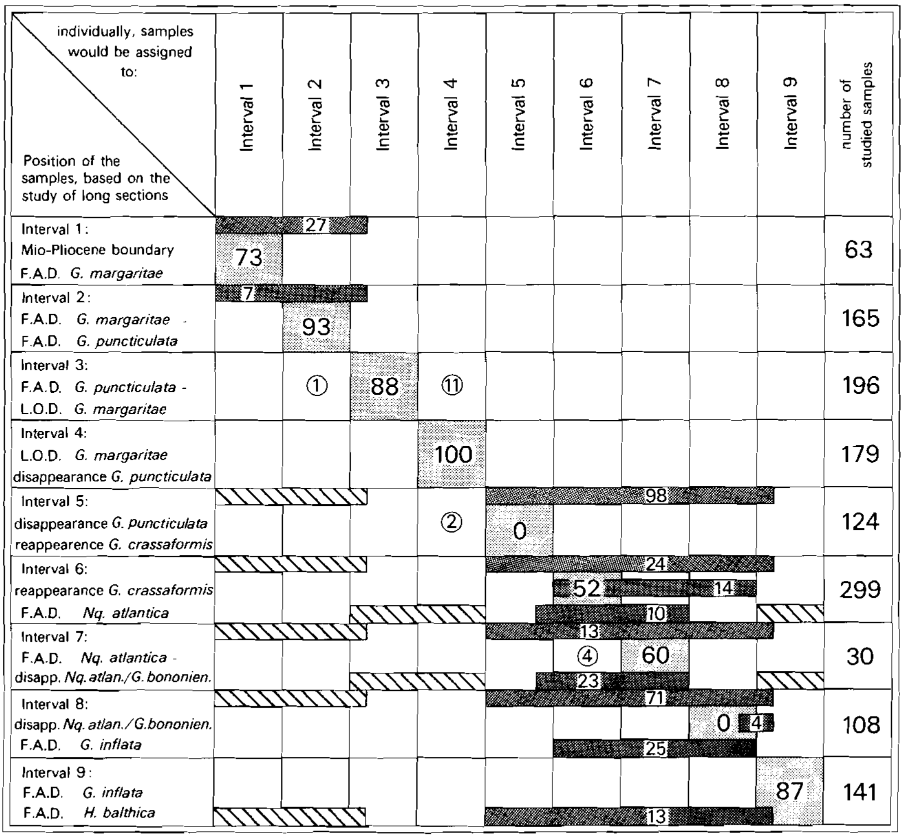


Fig. 22 Recognizability of the interval-zones for the Mediterranean Pliocene. The percentages of the samples, which individually could be assigned correctly, are indicated in the grey squares. The encircled values represent the percentage of samples, which individually would be assigned incorrectly. The possible range of the remaining samples is indicated by the bars; assignment to the dark grey intervals would be most likely.

Zone 8

Diagnosis: Interval-zone from the disappearance levels of *Neogloboquadrina atlantica* and *Globorotalia bononiensis* to the appearance level of *Globorotalia inflata* s.str..

Remarks: Zones 8 and 9 are not represented in our Cretan material. In the lower part of this second absence interval of the *G. inflata* group a frequency drop in *Globigerinoides obliquus* can be observed from 15–20% to 5–10%. Assemblages of *G. crassaformis* with sinistral coiling occur discontinuously throughout this interval-zone. In some samples from the upper part *Sphaeroidinella dehiscens* has been found. Although *G. inflata* is not continuously present in the lower part of its range in zone 9, the entry itself marks a distinct datum level.

Recognizability: Because of its negative aspects this interval-zone cannot be recognized with certainty for individual samples. *G. crassaformis* is found in 27 of the 108 samples (= 25%); these samples could be assigned to any position from zone 6 to zone 8. The presence of *S. dehiscens* in four samples allows a more detailed positioning; top of zone 8 to lower part of zone 9 (fig. 22). In the remaining 77 samples (= 71%) no index taxa were found; the large relative numbers of *G. elongatus* and the absence of *G. nepenthes* make an assignment to the range from zone 5 to the lower part of zone 9 most plausible.

Zone 9

Diagnosis: Interval-zone from the entry level of *Globorotalia inflata* s.str. to the appearance level of *Hyalinea balthica.*

Remarks: G. inflata is absent in some samples from the lower part of its range; it enters most 200-counts with proportions of up to 35% (an average between 10 and 20%). In one sample from the lower part of this interval-zone *S. dehiscens* has been found, while in the Vrica section *G. crassaformis* is present once.

Globorotalia truncatulinoides, the planktonic foraminiferal marker for the Pleistocene, was not found in our material. This taxon is scarce and discontinuously present in the Mediterranean Pleistocene. As the Pliocene-Pleistocene boundary is supposed to be present in the Vrica section (Selli et al., 1977) we decided to use the entry level of the benthonic species *H. balthica* to define the upper limit of zone 9.

Recognizability: Only 13% of the 141 samples from this interval-zone cannot be recognized with certainty because *G. inflata* is lacking (table VII). All these samples come from the lower part of the zone and might have been assigned to the interval from zone 5 to the lower part of zone 9.

Reviewing the results of the recognizability of the nine interval-zones, pictured in fig. 22, we see that the intervals 1, 2, 3, 4 and 9 can usually be well recognized in single samples. The recognizability of the intervals 5, 6, 7 and 8 is moderate to bad and many individual samples from these intervals would have been allotted to the wider range of these four zones together.

Table VII: Recognizability interval-zone 9

sections	number of samples	positively recognized	percentage
Lido Rossello	22	13	59
Monte Sante Nicola	34	31	91
Vrica	85	79	93
Total	141	123	87

COMPARISON WITH EARLIER ZONATIONS FOR THE MEDITERRANEAN PLIOCENE

Four regional schemes for the Mediterranean Pliocene, based on planktonic foraminifera (Bizon and Bizon, 1972; Cita, 1975; Zachariasse, 1975 and Thunell, 1979), will be compared with the nine zones discussed in the previous section (fig. 23).

The boundaries between our zones 1, 2, 3 and 4 are based on distinct events and the index taxa are almost continuously present in this part of the Pliocene. This explains the good recognizability of these four zones. In the zonations mentioned above, the zonal boundaries in the Lower Pliocene are formed by the same distinct marker levels and as a consequence all schemes are rather uniform, including our own subdivision. The differences can be attributed to differences in evaluation of the marker species. For instance Bizon and Bizon (1972) did not use the last occurrence of *Globorotalia margaritae,* whereas Thunell (1979) did not consider the appearance level of *Globorotalia puncticulata.* In 1972 Bizon and Bizon did not mention the *Sphaeroidinellopsis* Zone, which Bizon had used in her paper of 1967. A revision of the view that the *Sphaeroidinellopsis* Acme-zone was time equivalent with the lower part of the *G. margaritae* Interval-zone (Zachariasse, 1975), was given by Zachariasse and Spaak in 1979. Notwithstanding these differences a fairly uniform subdivision of the lower part of the Pliocene can be concluded from the literature.

In the middle part of the Pliocene the less distinct faunal changes allow us to make different subdivisions. The recognizability of every zone created in this part of the Pliocene is poor, owing to the discontinuous distribution patterns and/or the scarcity of the index taxa. It may be clear from fig. 23 that different authors have chosen different ways to make their subdivision.

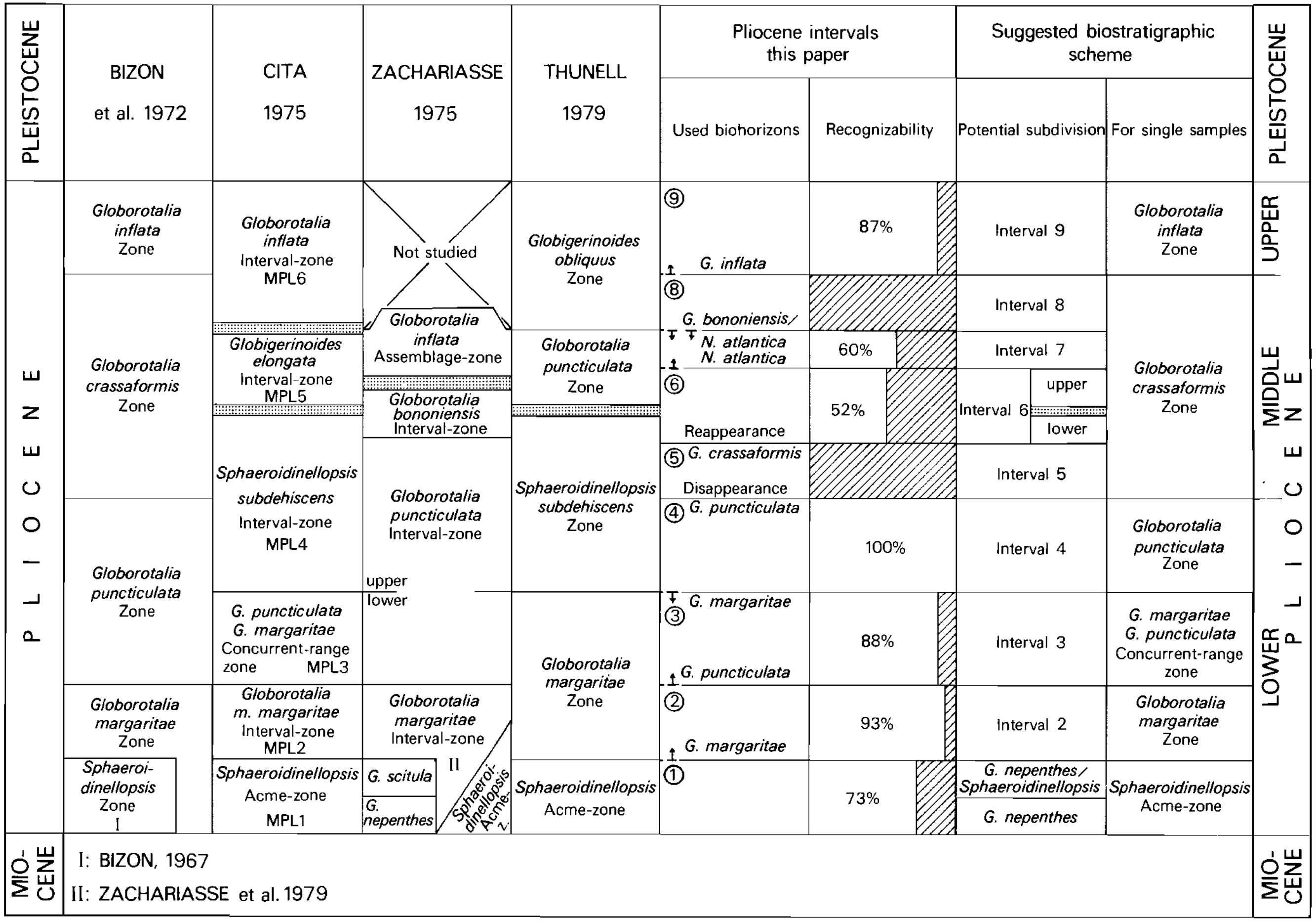
The disappearance of *Globorotalia puncticulata* was used by Bizon for the boundary between her *G. puncticulata* and *Globorotalia crassaformis* Zones; this level coincides with the boundary between our zones 4 and 5. The entry of *Globorotalia inflata* marks the base of her *G. inflata* Zone, which makes the latter equivalent to our zone 9.

Zachariasse used the entry level of *Globorotalia bononiensis* assemblages and the gradual morphological transition from *G. bononiensis* to *G. inflata* as zonal boundaries in the middle part of the Pliocene. The former datum level roughly coincides with, but is not the same as, the reappearance level of *G. crassaformis*, which we used as the boundary between zones 5 and 6. We could recognize the latter datum level of Zachariasse from the increase in *G. bononiensis-G. inflata* intermediate morphotypes, described from our zone 6.

Both Cita and Thunell used the last occurrence of *Sphaeroidinellopsis* for a zonal boundary. Because this taxon is only sporadically present in the later part of its range, its disappearance level is not a distinct biohorizon in the Mediterranean; it is somewhere in the lower half of our zone 6. The "massive" frequency decrease of *Globigerinoides obliquus extremus*, reported by Cita to discriminate between her MPl 5 and MPl 6 zones, we found roughly at the same level as the disappearance of *G. bononiensis* and *Neogloboquadrina atlantica* (boundary between our zones 7 and 8). On the basis of his zonal description and published range chart of DSDP Site 132, we are apt to conclude that Thunell's *G. puncticulata* exit is the same as the disappearance of our *G. bononiensis*.

In our paper the subdivision of the higher part of the Pliocene is based on the range of *N. atlantica* (not mentioned by any of the earlier authors) and by the ranges of the *G. inflata* group and of *G. crassaformis*. As to the two large and consistent absence intervals of the *G. inflata* group, the lower one has been recorded indirectly by Zachariasse (1975) as well. Both intervals can be found in the distribution charts of DSDP Site 132 (Cita, 1973a; Thunell, 1979a).

Summarizing, the higher part of the Pliocene can be subdivided in several different ways. Although the recognizability for individual samples of most of the suggested zones is poor, these zones are in between two distinct biohorizons. The lower boundary is linked to the disappearance of *G. puncticulata*, which has been continuously present up to the level of its disappearance. The upper boundary is connected to the first occurrence of numerous *G. inflata* s. str., a taxon which is absent in no more than a few samples dur-



	BIZON et al. 1972	CITA 1975	ZACHARIASSE 1975	THUNELL 1979	Pliocene intervals this paper: Used biohorizons	Pliocene intervals this paper: Recognizability	Suggested biostratigraphic scheme: Potential subdivision	Suggested biostratigraphic scheme: For single samples	
PLEISTOCENE									PLEISTOCENE
PLIOCENE	*Globorotalia inflata* Zone	*Globorotalia inflata* Interval-zone MPL6	Not studied	*Globigerinoides obliquus* Zone	⑨ ↑ *G. inflata*	87%	Interval 9	*Globorotalia inflata* Zone	PLIOCENE UPPER
	Globorotalia crassaformis Zone		*Globorotalia inflata* Assemblage-zone		⑧ *G. bononiensis/*	▨	Interval 8	*Globorotalia crassaformis* Zone	MIDDLE
		Globigerinoides elongata Interval-zone MPL5		*Globorotalia puncticulata* Zone	↓ ↓ *N. atlantica* ↑ *N. atlantica*	60%	Interval 7		
			Globorotalia bononiensis Interval-zone		⑥	52%	Interval 6 upper		
		Sphaeroidinellopsis subdehiscens Interval-zone MPL4		*Sphaeroidinellopsis subdehiscens* Zone	Reappearance		Interval 6 lower		
			Globorotalia puncticulata Interval-zone upper		⑤ *G. crassaformis* Disappearance	▨	Interval 5		
	Globorotalia puncticulata Zone				④ *G. puncticulata*	100%	Interval 4	*Globorotalia puncticulata* Zone	LOWER
		G. puncticulata *G. margaritae* Concurrent-range zone MPL3	lower	*Globorotalia margaritae* Zone	↓ *G. margaritae* ③ ↑ *G. puncticulata*	88%	Interval 3	*G. margaritae* *G. puncticulata* Concurrent-range zone	
	Globorotalia margaritae Zone	*Globorotalia m. margaritae* Interval-zone MPL2	*Globorotalia margaritae* Interval-zone		② ↑ *G. margaritae*	93%	Interval 2	*Globorotalia margaritae* Zone	
	Sphaeroidinellopsis Zone I	*Sphaeroidinellopsis* Acme-zone MPL1	*G. scitula* *G. nepenthes* II *Sphaeroidinellopsis* Acme-z.	*Sphaeroidinellopsis* Acme-zone	①	73%	*G. nepenthes/ Sphaeroidinellopsis* *G. nepenthes*	*Sphaeroidinellopsis* Acme-zone	
MIOCENE									MIOCENE

I: BIZON, 1967
II: ZACHARIASSE et al. 1979

Fig. 23 Relation between the regional zonations for the Mediterranean Pliocene and the interval-zones suggested in this paper.

ing its range. Like our interval-zones 1 to 4, the Pliocene zone 9, above the entry level of G. *inflata*, can be well recognized.

As a consequence five well-recognizable zones can be discerned, four in the Lower Pliocene and one at the top, which leaves a sixth zone in between which is less well-recognizable. Altogether 561 samples have been studied from this zone, 247 (44%) of which could be assigned with certainty to this zone because of:

1. The occurrence of G. *crassaformis*
2. The presence of N. *atlantica*
3. The co-occurrence of G. *crassaformis* and G. *bononiensis* or
4. The presence of distinct G. *bononiensis* assemblages.

In 35 samples (6%) non-descript assemblages of the G. *inflata* group occur and in the remaining samples none of the index taxa has been found.

It has been demonstrated in Chapter 3 that the index taxa G. *margaritae*, G. *puncticulata* and G. *inflata* are present in almost every sample during their ranges; moreover the assemblages of the latter two taxa (both members of the G. *inflata* group) are very distinct and can be recognized easily. If the samples without index taxa or with nondescript assemblages of the G. *inflata* group are assigned to the sixth zone, they stand a good chance of being allotted correctly, particularly since relatively large numbers of G. *elongatus* are present in all these samples. This taxon is extremely scarce in the four lower zones of the Mediterranean Pliocene.

Concluding, we can say that a subdivision of the Mediterranean Pliocene into six well-recognizable zones seems applicable for single samples (fig. 23).

1. *Sphaeroidinellopsis* Acme-zone:

from the Miocene-Pliocene boundary to the first appearance of G. *margaritae*. A zone with relatively large numbers of G. *nepenthes* and *Sphaeroidinellopsis* (= interval-zone 1)

2. G. *margaritae* Zone:

from the appearance of G. *margaritae* to the appearance of G. *puncticulata* (= interval-zone 2)

3. G. *margaritae* – G. *puncticulata* Concurrent range zone:

from the appearance of G. *puncticulata* to the exit of G. *margaritae* (= interval-zone 3)

4. G. *puncticulata* Zone:

from the exit of G. *margaritae* to the disappearance of G. *puncticulata* (= interval-zone 4)

5. G. *crassaformis* Zone:

from the disappearance of G. *puncticulata* to the entry of G. *inflata* s.str. (= interval-zones 5, 6, 7 and 8)

6. *G. inflata* Zone:
from the entry of *G. inflata* to the "Pliocene-Pleistocene" boundary, in this paper the entry of *Hyalinea balthica* (= interval-zone 9)

A refinement of this biostratigraphic scheme is possible (fig. 23), especially when it can be applied to sections with a longer stratigraphic range. The *Sphaeroidinellopsis* Acme-zone can be subdivided into two subzones, a lower part with relatively large numbers of *G. nepenthes* and an upper part with relatively large numbers of *G. nepenthes* and *Sphaeroidinellopsis* and the presence of *Globorotalia scitula*. The *G. crassaformis* Zone can be subdivided into four (sub)zones, identical to the subdivision into the zonal intervals 5, 6, 7 and 8. Finally the interval-zone 6 can be split into a lower and an upper part. In the lower part *Sphaeroidinellopsis* is still present, *Globoquadrina altispira* may be found and there are several assemblages of *G. crassaformis* with dextral coiling. These taxa are absent in the upper part of zone 6, but this part contains more *G. bononiensis* – *G. inflata* intermediate morphotypes than the *G. bononiensis* assemblages lower down.

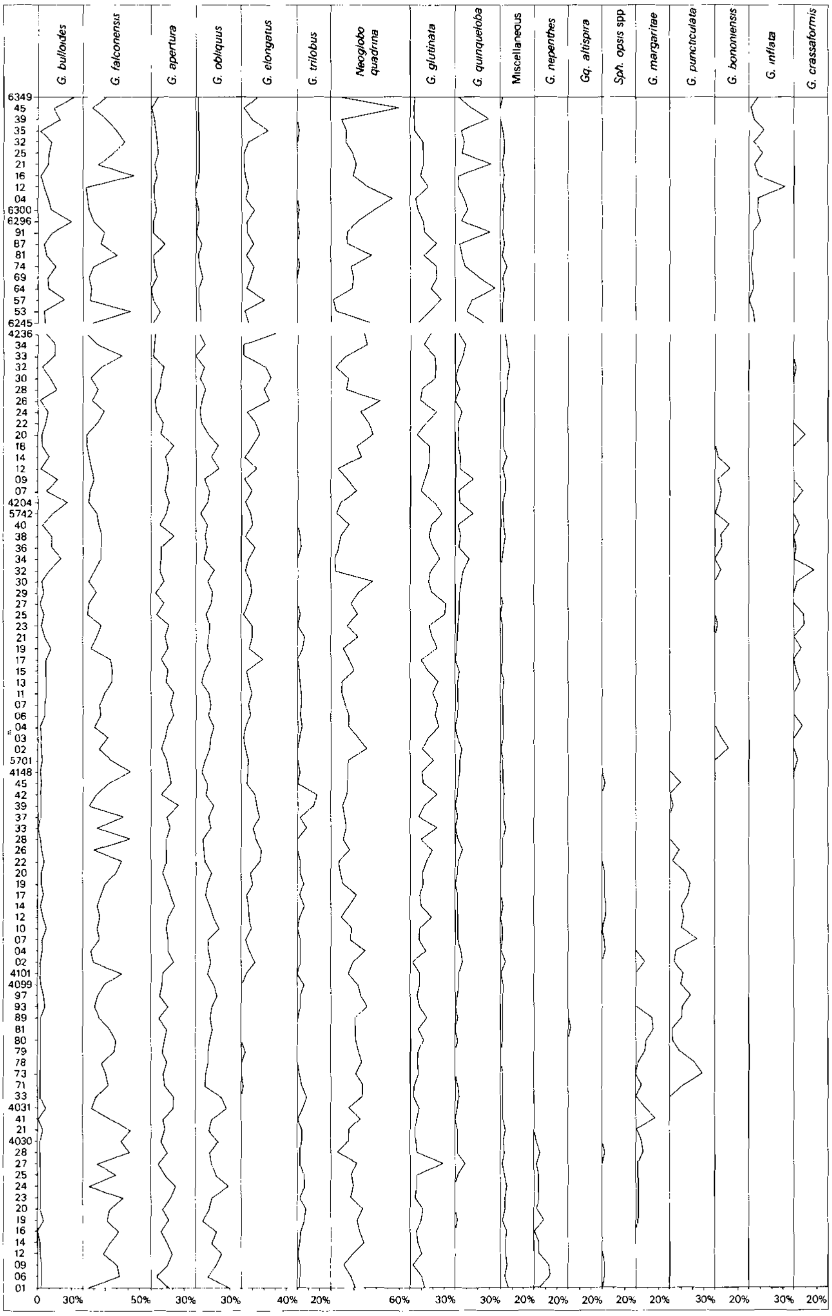


Fig. 24 Relative frequencies of the planktonic foraminifera in the Italian composite section.

Chapter 5

QUANTITATIVE FAUNAL ANALYSES ON THE BASIS OF THE HOMOGENEOUS SEDIMENTS

INTRODUCTION

In order to obtain an impression of the environmental changes on the basis of the quantitative composition of the successive faunas and of the frequency fluctuations along the stratigraphic columns we made 200-counts for many samples. As this quantitative method is time-consuming, we were unable to count all the samples that had been studied qualitatively. We had to make a selection.

The purpose of our quantitative investigation was twofold. Firstly we wanted to reconstruct the overall development of the Mediterranean fauna throughout the Pliocene. To this end we created composite Pliocene sections for Italy (Sicily and Calabria) and for Crete, using samples from homogeneous sediments only. Secondly we wanted to unravel the response of the Mediterranean Pliocene faunas to the processes that caused the alternation of homogeneous and laminated sediments. And of course we wanted to speculate on the nature of these processes. The results of the faunal analyses of the sections with such alternations will be presented and discussed in chapter 7.

Two hundred specimens were picked for each sample and the frequencies of the individual taxa were determined. Some of our taxa (*Orbulina universa, Globorotalia scitula* and *Globigerinella aequilateralis*) are so scarce that they occur irregularly in the 200-counts with meaningless numbers; they have been taken together with the indeterminable specimens to form the group Miscellaneous.

To establish trends and correlations the numerical data and the sediment type of each sample (either homogeneous or laminated) were computer-analyzed, using the BALANC- and DISTUR-programs, developed and discussed by M. M. Drooger (1982). The results of these analyses are very much the same for both programs as far as the composite sections are concerned. For the analyses of the sections with laminated sediments, in which the frequencies of some taxa fluctuate strongly, the results of the BALANC-program proved to be more satisfactory than those obtained with the repeated use (omitting the strongly fluctuating taxa) of the DISTUR-program. Consequently the results presented for the sections with laminated intercalations in chapter 7 are based on the computer-runs of the BALANC-program only.

THE COMPOSITE SECTIONS

The Italian composite section is constructed mainly on the basis of samples from the sections near the village of Lido Rossello (Sicily), which together cover the greater part of the Pliocene: Capo Rossello, Punta di Maiata, Punta Piccola and Lido Rossello. Using the entry of *Globorotalia inflata* s.str. as a correlation horizon we expanded the Italian composite section with several samples from the Vrica section (Calabria). Together these five sections cover the entire Pliocene, reaching beyond the entry level of *Hyalinea balthica.* The frequency diagram of the Italian composite section and the results of the computer analyses are given in figs. 24 and 25, respectively.

The Pliocene sequence of Crete is less complete than the Sicilian-Calabrian one, because it only reaches up to the level of the *Neogloboquadrina atlantica* influx (see chapter 2). Due to lack of time we had to limit our Cretan composite section even more. It consists of samples from the sections Kalithea and Finikia (fig. 27), both situated in the northern part of the Iraklion province; it covers most of our intervals 1 to 6.

THE RESULTS OF THE ANALYSES

The trends derived from the computer analyses of the Italian composite section are shown in fig. 25. Two major groups of taxa, all showing a trend, can be discerned. Some of these taxa are continuously present throughout the Pliocene and their trend seems to correspond to an overall frequency increase or decrease. Others however, are present during a part of the Pliocene only. The positive trend of *G. inflata* for instance is caused by its distribution, being limited to the upper part of the Pliocene. Similar reasoning applies to the negative trends of *Globorotalia margaritae, Globorotalia puncticulata, Sphaeroidinellopsis* spp. and *Globigerina nepenthes* of the Lower Pliocene, although the latter species displays a relative frequency decrease in addition. No trend was found for *Globorotalia bononiensis* or *Globorotalia crassaformis,* evidently because they are present in the middle part of the Pliocene only.

The partial Pliocene ranges are likely to be responsible for the correlations between these taxa as well. The positive correlations must be caused by the fact that species which are restricted to the lower part of the Pliocene share so many samples with the same zero scores higher up. One should be cautious in interpreting such correlations in terms of (paleo-) biological relations. This applies to the positive correlations between *G. margaritae* and *Globoquadrina altispira,* between *G. puncticulata* and *Sphaeroidinellopsis* spp., between *Sphaeroidinellopsis* and *G. nepenthes* and possibly also to the one between

Italy

correlations

+ **−** 1% level

+ − 5% level

	G. apertura	G. obliquus	G. trilobus	G. puncticulata	Sph. opsis	G. nepenthes	G. falconensis	G. margaritae	Gq. altispira	G. elongatus	G. glutinata	G. bononiensis	G. crassaformis	G. quinqueloba	G. bulloides	G. inflata	Neogloboqua-drina
G. apertura																	
G. obliquus	**+**																
G. trilobus	**+**	**+**															
G. puncticulata	+	+															
Sph. opsis	+			**+**													
G. nepenthes		**+**			**+**												
G. falconensis	+					**+**											
G. margaritae		+															
Gq. altispira								**+**									
G. elongatus		−				**−**		−									
G. glutinata						−		−		**+**							
G. bononiensis																	
G. crassaformis											+	+					
G. quinqueloba	**−**	**−**	−								**+**						
G. bulloides	**−**	**−**	**−**					−		+	**+**			**+**			
G. inflata	**−**	**−**												+	+		
Neogloboqua-drina																+	
TRENDS	G. apertura	G. obliquus	G. trilobus	G. puncticulata	Sph. opsis	G. nepenthes	G. falconensis	G. margaritae	Gq. altispira	G. elongatus	G. glutinata	G. bononiensis	G. crassaformis	G. quinqueloba	G. bulloides	G. inflata	Neogloboqua-drina
1% level	−	−	−	−		−	−	−		+	+			+	+	+	
5% level					−												

Fig. 25 Matrix of correlation coefficients and trends (BALANC) of the data from the Italian composite section.

G. bononiensis and *G. crassaformis* and the negative one between *G. nepenthes* and *Globigerinoides elongatus.*

Amongst the long ranging taxa there are some with positive trends (*Globigerina bulloides, Globigerina quinqueloba, Globigerinita glutinata* and *G. elongatus*) and others with negative trends (*Globigerina apertura, Globigerinoides obliquus, Globigerinoides trilobus* and *Globigerina falconensis*). Positive correlations are common between species with a similar trend, whereas negative correlations are found only between taxa with different trends. The most obvious negative correlations are present between three taxa of the second group (*G. apertura, G. obliquus* and *G. trilobus*) and two of the first group: *G. bulloides* and *G. quinqueloba* (and *G. inflata*). The rather frequent *Neogloboquadrina* spp. category stands apart, showing no trend and a positive correlation with *G. inflata* only.

A subdivision into the same two groups of species also emerges from a cluster analysis on the basis of all correlation coefficients. For this cluster analysis we used the unpublished DENDRO-program of M. M. Drooger (which he used for his 1979 paper) and the results are presented in fig. 26; in this figure the extinct taxa are indicated with an asterisk. Apart from *G. bononiensis* these extinct species occur in the group whose representatives have a negative trend. The extreme groups which we concluded from fig. 25 are at both ends of the dendrogram.

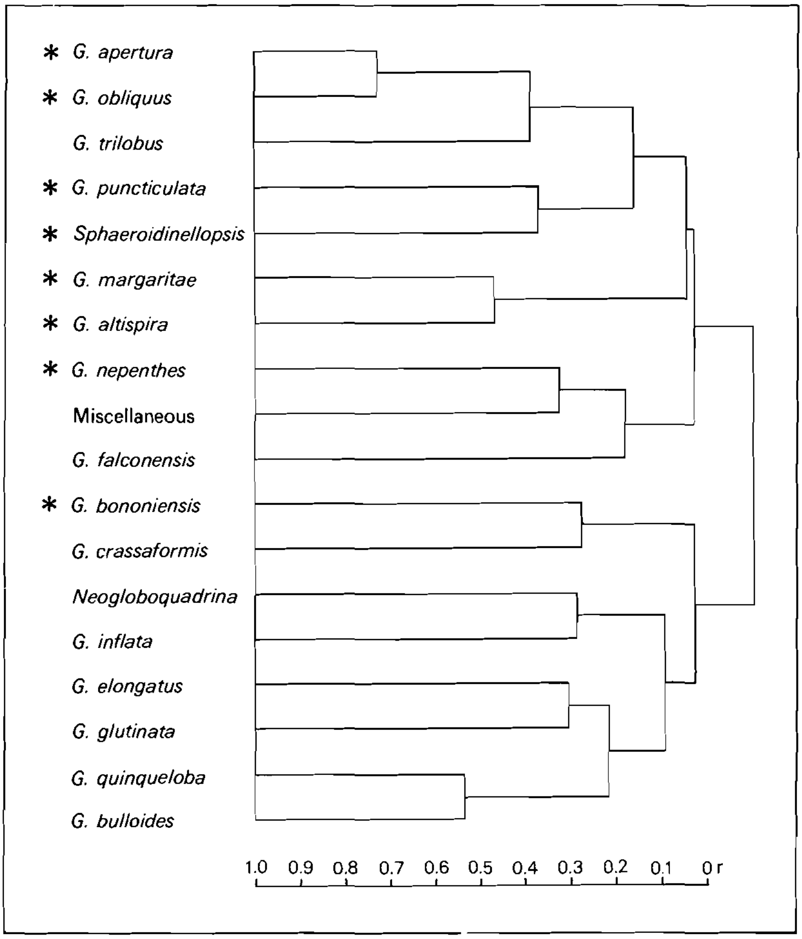


Fig. 26 Dendrogram of the planktonic foraminiferal taxa from the Italian composite section, based on the correlation coefficients according to the BALANC-output of this section.

Summarizing, the planktonic foraminiferal taxa from the Italian composite section can be subdivided into two groups on the basis of the analyses of the faunas. The first group consists of taxa with an overall frequency decrease (*G. apertura, G. obliquus, G. trilobus, G. falconensis*) and of taxa which occur in the lower part of the Pliocene only (*G. nepenthes, Sphaeroidinellopsis, G. margaritae, G. puncticulata, G. altispira*). Most of these taxa are extinct; together they dominate the faunas in the lower part of the Pliocene. Most representatives of the second group are still living today and several of them display a positive trend. Some have an overall frequency increase like *G. bulloides, G. quinqueloba, G. elongatus* and *G. glutinata,* although the latter taxon seems to decrease again in the uppermost part of the Italian sequence (fig. 24). *G. inflata* occurs in the Upper Pliocene only.

Three taxa (*Neogloboquadrina, G. bononiensis* and *G. crassaformis*) display no trend and hardly any significant correlation. *G. bononiensis* and *G. cras-*

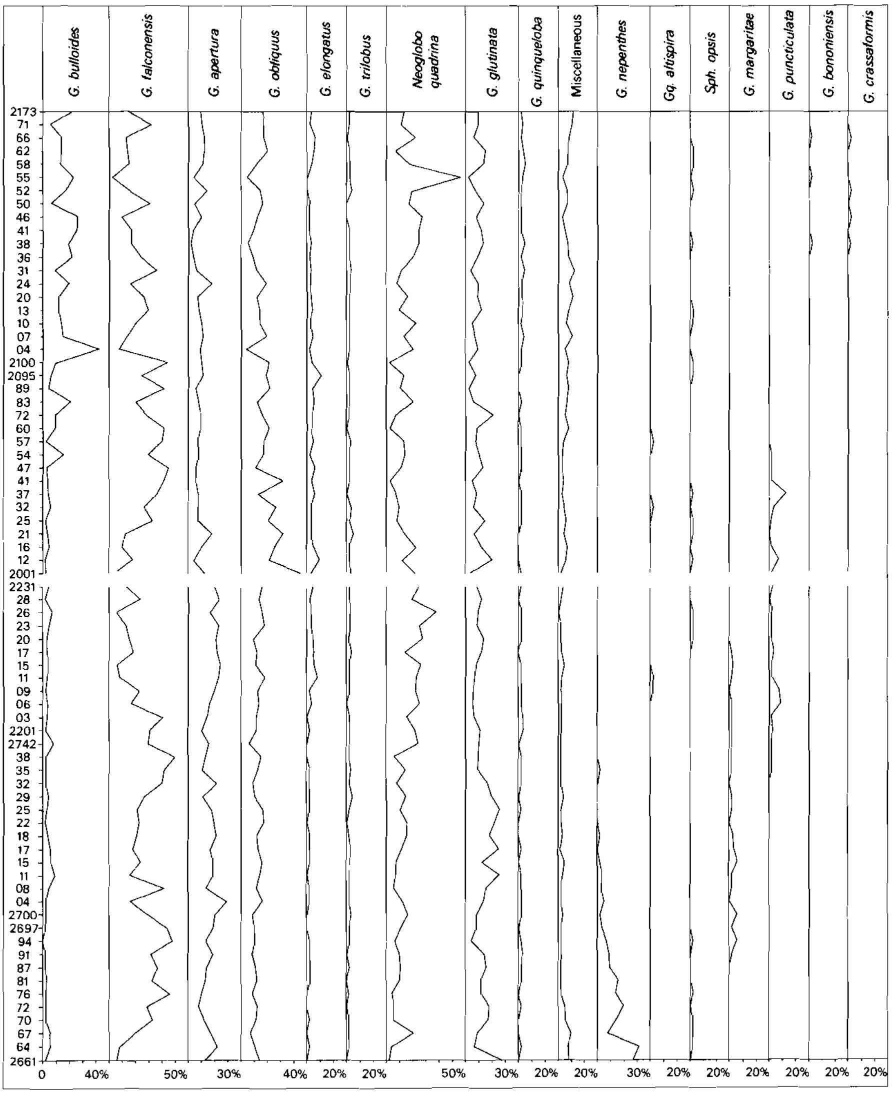
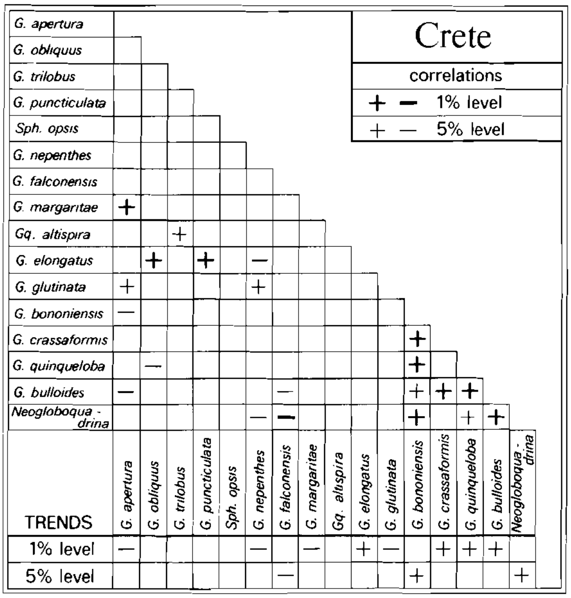


Fig. 27 Relative frequencies of the planktonic foraminifera in the Cretan composite section.

saformis occur in the Middle Pliocene and they have a positive correlation; the latter taxon has a positive link with *G. glutinata* as well ($P < 0.05$). *Neogloboquadrina* is continuously present with strong frequency fluctuations in the upper part of the Pliocene and is positively correlated with *G. inflata.* The few positive correlations of these taxa and the result of the cluster analysis (fig. 26) suggest that the frequency patterns of *Neogloboquadrina* and these two *Globorotalia* species are closest to the frequency patterns of the taxa of the second group.

The results of the computer analyses of the faunal data in the Cretan composite section (fig. 28) are quite different. However, a reliable comparison of the Italian and Cretan correlation matrices and trends is not possible. The Cretan composite section covers only the lower-middle part of the Pliocene up to some level in the *G. crassaformis* Zone (approximately halfway along interval 6, see chapter 4), whereas the Italian sequence is complete even including the lowermost part of the Pleistocene. It is especially the changes in the faunal composition in the higher part of the Italian sequence which influenced the picture of correlations and trends. In order to compare our Cretan and Italian data on a more realistic basis, we analyzed the Italian data again, but now up to the level of sample JT 5723 (Punta Piccola section).



Crete	
correlations	
+ **−**	1% level
+ −	5% level

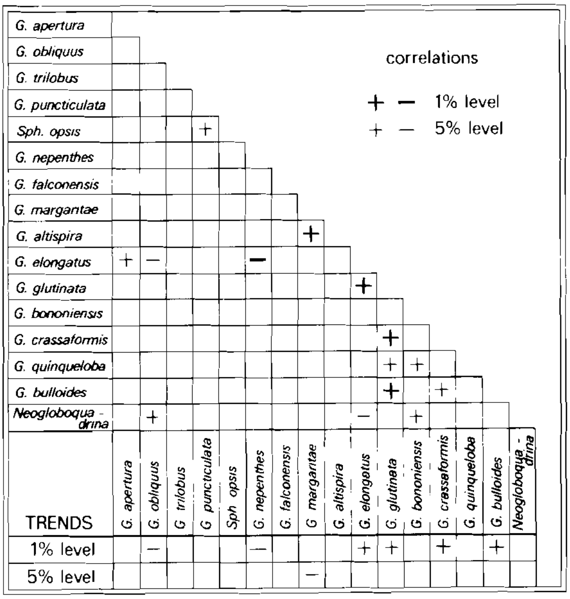
	G. apertura	*G. obliquus*	*G. trilobus*	*G. puncticulata*	*Sph. opsis*	*G. nepenthes*	*G. falconensis*	*G. margaritae*	*Gq. altispira*	*G. elongatus*	*G. glutinata*	*G. bononiensis*	*G. crassaformis*	*G. quinqueloba*	*G. bulloides*	*Neogloboquadrina*
G. apertura																
G. obliquus																
G. trilobus																
G. puncticulata																
Sph. opsis																
G. nepenthes																
G. falconensis																
G. margaritae	**+**															
Gq. altispira			+													
G. elongatus		**+**		**+**		**−**										
G. glutinata	+					+										
G. bononiensis	−															
G. crassaformis												**+**				
G. quinqueloba		−										**+**				
G. bulloides	**−**						−					+	**+**	**+**		
Neogloboquadrina						−	**−**					**+**		+	**+**	
TRENDS																
1% level	−					−		−		+	−		+	+	+	
5% level							−					+				+

Fig. 28 Matrix of correlation coefficients and trends (BALANC) of the data from the Cretan composite section.

This level corresponds to approximately the middle of interval-zone 6. The results of this analysis are presented in fig. 29.

The Cretan and corresponding Italian matrices show a limited number of correlations and trends in comparison with the results of the analysis of all Italian data. Yet the negative trends of *G. margaritae* and *G. nepenthes* are consistent, as both taxa are clearly restricted to the lowermost part of the Pliocene. In addition, negative trends are found for *Globigerinoides obliquus* in Italy and for *G. apertura*, *G. falconensis* and *G. glutinata* in Crete. Especially *G. glutinata* is remarkable because it displays a positive trend in Italy. Moreover, in Italy *G. glutinata* has a positive correlation with several other taxa with a positive trend (*G. bulloides*, *G. elongatus* and *G. crassaformis*), whereas in Crete it is positively correlated with *G. nepenthes* and *G. apertura*, with similar negative trends.

Many positive correlations between taxa with a negative trend in the set of all Italian data appear to be absent in the faunal sequence from Crete as well as from the comparable part from Italy. Evidently the negative trends for these taxa in the longer data set have been induced by frequency data above the *G. crassaformis* Zone. As far as this scarcity of positive correlations is concerned, the results of the contemporaneous parts of the Pliocene from both areas are comparable.



	G. apertura	*G. obliquus*	*G. trilobus*	*G. puncticulata*	*Sph. opsis*	*G. nepenthes*	*G. falconensis*	*G. margaritae*	*G. altispira*	*G. elongatus*	*G. glutinata*	*G. bononiensis*	*G. crassaformis*	*G. quinqueloba*	*G. bulloides*	*Neogloboquadrina*
G. apertura																
G. obliquus																
G. trilobus																
G. puncticulata																
Sph. opsis				+												
G. nepenthes																
G. falconensis																
G. margaritae																
G. altispira								**+**								
G. elongatus	+	—				**—**										
G. glutinata										**+**						
G. bononiensis																
G. crassaformis											**+**					
G. quinqueloba											+	+				
G. bulloides											**+**		+			
Neogloboquadrina		+								—		+				
TRENDS																
1% level		—				—				+	+		+		+	
5% level								—								

correlations

+ **—** 1% level
\+ — 5% level

Fig. 29 Matrix of correlation coefficients and trends (BALANC) of the data from the Italian composite section up to sample JT 5723 of the Punta Piccola section.

We find the positive trend of *G. elongatus* and its negative correlation with *G. nepenthes* in both areas. However, the other correlations of *G. elongatus* found for one area are not present in the other and the ones with *G. obliquus* are even opposite (negative in Italy, positive in Crete).

G. bulloides has a positive trend in Crete as well as in the corresponding part of the section of Italy. In Crete a positive trend is also found for *G. quinqueloba*; in Italy this taxon has a significant positive trend in the complete section only. *G. bononiensis* and *G. crassaformis* occur in the upper part of the equivalent Pliocene sequences in both areas, which may account for their positive trends. In Crete the latter four taxa have several positive correlations of which the ones between *G. bulloides* and *G. crassaformis* and between *G. quinqueloba* and *G. bononiensis* are found in the short Italian section as well.

Finally, *Neogloboquadrina* has a positive trend in Crete; it is positively correlated with *G. bulloides, G. quinqueloba* and *G. bononiensis.* In Italy such a pattern of *Neogloboquadrina* is less distinct although here too the genus has a positive correlation with *G. bononiensis* (and *G. obliquus*) while it has a negative correlation with *G. elongatus.*

Summarizing, the faunal pattern from Crete and from the stratigraphically equivalent part of Italy show on the whole a similar picture of correlations and trends, although there are several differences in detail.

Some other differences can be noticed if we compare the Cretan and Italian frequency diagrams (figs. 24, 27). In Italy the relative numbers of the *Globorotalia* taxa are distinctly higher than in Crete, whereas *G. nepenthes* reaches its highest scores in the eastern area. *G. elongatus* is absent or extremely scarce in the lower part of the Pliocene in Italy, whereas in Crete this taxon regularly enters the 200-counts in this part of the Pliocene, although with low numbers. Near the exit of *G. margaritae* (cf. chapter 3) the numbers of *G. elongatus* show a distinct increase in Italy and above this level its relative frequencies are higher in Italy than in Crete. Another difference can be observed in the counted numbers of *G. bulloides* of both areas. In the lower part of the sections they are comparable and low. Although the species has a positive trend in both areas the relative numbers are distinctly larger in the upper part of the Cretan section than in the equivalent part in Italy.

Notwithstanding these differences, the Cretan and Italian data from contemporaneous parts of the Pliocene are fairly similar, especially in comparison with the results from the analyses of all Italian data. Moreover, in both areas we find a similar distribution of the so-called index taxa (cf. chapter 3). This suggests that the development of the Pliocene fauna in Crete and Italy is comparable although several differences are superimposed on this uniform development. We therefore suppose that the faunal pattern in the Italian composite section, which ends in the Pleistocene, may give a fair indication of the fauna development of the entire Mediterranean during the Pliocene.

Concentrating again on the frequency diagram of the Italian composite section (fig. 24) and the results of the computer analyses of these data (figs. 25, 26), we see that the composition of the Lower Pliocene fauna is different from that of the Upper Pliocene and the Lower Pleistocene. A number of taxa disappear and others appear in the course of the Pliocene. However, apart from the *Globorotalia* taxa in Italy and *G. nepenthes* in Crete these taxa do not form a large part of the Mediterranean faunas. The bulk of these faunas is formed by taxa which remain continuously present throughout the Pliocene. Amongst these taxa only *Neogloboquadrina* is continuously present with percentage values between 10 and 30. The others have a negative or positive trend and consequently their frequencies change during the Pliocene. Notwithstanding the fact that almost all these taxa show a trend, it is not possible to point to one single level at which "the" alteration in the Pliocene fauna took place.

G. bulloides (figs. 24, 30) starts to increase in relative numbers in the middle part of interval-zone 6 (cf. chapter 4). The decrease of *G. falconensis* appears to be gradual and long-term, with strong fluctuations in the Lower and Upper Pliocene. *G. apertura* and *G. obliquus* have their frequency drop at the disappearance level of *G. bononiensis* (boundary between interval-zones 7 and 8). *G. elongatus* shows a distinct increase in the top part of interval-zone 3, although its increase in Crete is not at all as spectacular as in Italy! *G. trilobus* occurs regularly up to the upper half of interval-zone 6; its larger numbers are present in interval-zone 5. Above interval-zone 6 it is often absent and it re-enters our 200-counts with very small numbers in interval-zone 9 only. The positive trend of *G. glutinata* in Italy (not present in our Cretan material) is a very gradual one from the Lower Pliocene up to the lower part of interval-zone 9. In the upper part of the Italian sequence its numbers seem to decrease. Finally, a slight increase in the numbers of *G. quinqueloba* can be observed in interval-zone 6 but its large numbers occur especially above the entry level of *G. inflata* s.str.

The above enumeration of faunal changes reveals that the planktonic foraminiferal fauna altered "step by step" during the Pliocene towards its Late Pliocene composition. A consistent pattern in these changes is the disappearance or frequency decrease of the taxa which no longer occur in today's assemblages. In the course of the Pliocene the Mediterranean fauna came to resemble its recent composition more and more.

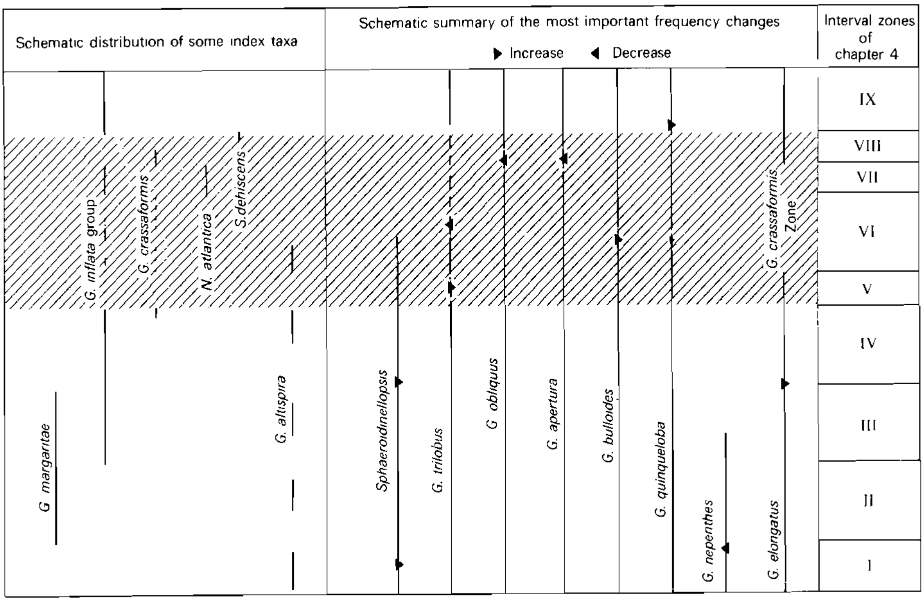


Fig. 30 Schematic review of the distribution of some index-taxa and the major frequency changes relative to the zonation of chapter 4.

Although there is not one level at which "the" change in the Pliocene fauna took place, most of the changes are concentrated in the *G. crassaformis* Zone (fig. 30), between the disappearance of *G. puncticulata* and the appearance level of *G. inflata* s.str.

DISCUSSION

The west-east gradient

At present the Mediterranean is an almost isolated basin situated in a region where evaporation exceeds precipitation and input from river run-off (Lacombe and Tchernia, 1972). The loss of water, which is also increased by a considerable outflow of bottom water, is compensated by a continuous inflow of relatively cool and less saline Atlantic surface water through the Straits of Gibraltar. Under the Mediterranean climatic influence this water loses its "Atlantic" character and becomes warmer and more saline as it progresses into the Mediterranean. Apart from local and seasonal variations west to east temperature and salinity gradients are present in the Mediterranean. Moreover, the concentration of nutrients in the western Mediterranean is about twice as high as in the eastern basin (McGill, 1960).

Studies on the recent distribution of planktonic foraminifera in the Mediterranean (e.g. Parker, 1955; Cifelli, 1974; Thunell, 1978) revealed a distinct difference between the associations from the eastern and western parts. The main differences are formed by the larger numbers of *Globorotalia* taxa (*G. inflata* and *Globorotalia truncatulinoides*) in the western part and of *Globigerinoides ruber* in the eastern part, although the latter taxon is also quite numerous in the west. Moreover, *Globigerinoides sacculiferus* is most numerous in the eastern part, to which region *Globigerinoides tenellus* is almost entirely restricted.

The west-east gradient or at least a difference between the eastern and western Mediterranean basins is reported in studies of the Late Quaternary as well (Blanc et al., 1976; Thunell, 1979b; cf. Herman, 1980). According to Thunell a strong west-east gradient did not exist prior to the Late Pleistocene. Yet the differences we found between our Italian and Cretan Pliocene faunas suggest a situation throughout the Pliocene similar to the recent west-east gradient. The large numbers of our *Globorotalia* taxa are restricted to our Italian material and similar differences in frequency emerge from the investigation of Pliocene faunas from the Tyrrhenian and Ionian Basins (Thunell, 1979a).

The group of spinose and fine-cancellated taxa

Two more differences between our Cretan and Italian data may be a reflection of this supposed west-east gradient. Firstly there are the large numbers of *G. nepenthes* which occur in our Cretan material and in several other sections in the eastern part of the Mediterranean as well (Zachariasse and Spaak, 1979), suggesting this feature to be an eastern Mediterranean one. Secondly the frequency pattern of *G. elongatus* in Crete is quite different from that in Italy.

G. elongatus and *G. nepenthes* have a similar, rather fine-cancellated wall structure (see chapter 9), which they share, amongst our Pliocene taxa, with *G. apertura* and *G. obliquus*. It is worthwhile paying some attention to the frequency patterns of these four morphologically similar taxa.

G. obliquus, *G. apertura* and *G. nepenthes* co-occur in the Mediterranean from approximately the Middle Miocene upwards. Not only do they have a similar wall structure, but at times their outline and chamber arrangement are comparable as well, especially in small individuals. The morphological resemblance is greatest between *G. apertura* and *G. obliquus*, and in our material these taxa show a similar frequency pattern. They have a simultaneous frequency drop near the exit level of *G. bononiensis* and they show a positive correlation in the Italian composite section as well as in several Cretan sections with small stratigraphic ranges. Also in the Upper Miocene *G. obliquus* and *G. apertura* have a positive correlation and they are associated with *G. nepenthes* (Van der Zwaan, 1982). In general the assemblages of *G. nepenthes* are clearly separable from those of *G. apertura* and *G. obliquus*, although sometimes differentiation may be difficult. In contrast, it appears that the distribution and frequency patterns of *G. nepenthes* in the Pliocene are distinctly different from the patterns of the other two taxa. *G. nepenthes* has a frequency drop near the entry of *G. margaritae* and disappears shortly after the entry of *G. puncticulata.*

Contrary to the negative trends of *G. apertura, G. obliquus* and *G. nepenthes,* we observe that *G. elongatus* displays an increase during the Pliocene. The level at which *G. elongatus* appears is difficult to point out, because in the assemblages of *G. obliquus* there are always tightly coiled specimens, which show a morphology similar to *G. elongatus.* In the literature such morphotypes have received different names such as *Globigerinoides bollii* or *Globigerinoides kennetti,* although the resemblance with *G. elongatus* is always quite obvious. One might conclude that the ability of a transition towards *G. elongatus* was potentially always present in the assemblages of *G. obliquus.* In the Pliocene this transition actually took place, not only in the Mediterranean but apparently on a world-wide scale. A reflection of this transition in our Mediterranean material may be the presence of morphotypes intermediate between *G. obliquus* and *G. elongatus* (see chapter 9). However, it is remarkable that we never found assemblages dominated by such intermediate morphotypes.

The exit of *G. obliquus* has often been reported to occur at or near the Pliocene-Pleistocene boundary. In our material *G. obliquus* remains present, but in very small numbers, in samples in which *G. elongatus* is numerous. This suggests the existence of *G. obliquus* types in *G. elongatus* assemblages, although hardly any intermediate morphotypes were found in this part of the sequence.

Transitions from *G. apertura* to *Globigerina rubescens* have been reported from levels near the Pliocene-Pleistocene boundary. In our material from Cape Bojador such a transition was observed as well. In our Mediterranean samples from the Upper Pliocene *G. apertura* becomes very scarce; here such a transition could not be ascertained although *G. rubescens* is reported from the Mediterranean Pleistocene.

Summarizing, from the Middle Miocene to the Pliocene-Pleistocene boundary a co-occurrence can be found in the Mediterranean of *G. obliquus* and *G. apertura.* These two taxa show a similar frequency pattern. Up to the

Lower Pliocene they are present together with G. *nepenthes*. During the Pliocene these three taxa decrease in relative numbers, whereas G. *elongatus*, which probably evolved from G. *obliquus*, increases. In the Upper Pliocene G. *apertura* shows a transition towards G. *rubescens*.

Amongst these five taxa mentioned above only G. *elongatus* and G. *rubescens* are found as Recent species. The modern distributions of G. *elongatus* (G. *ruber*) and G. *rubescens* point to a common affinity for tropical and subtropical waters (Zobel, 1971; Bé et al., 1971; 1977; Cifelli et al., 1974; 1976; Bé, 1977; Coulbourne et al., 1980). Notwithstanding this common affinity, G. *elongatus* is often the most abundant species in these waters, whereas G. *rubescens* occurs in small numbers. Moreover, G. *elongatus* is found in waters associated with a wide range in temperature, salinity and dissolved phosphate (Bé and Hutson, 1977), while in the Pacific Ocean it is an important constituent of the Transitional Fauna (Bradshaw, 1959) together with for instance G. *bulloides* and G. *quinqueloba*. Furthermore it occurs with large numbers in the Pacific up to latitude 40° N (Coulbourne et al., 1980). The relative large numbers of G. *rubescens* occur below latitude 25° N and in the Indian Ocean (Bé and Hutson, 1977) this species shows a scattered distribution associated with low values of dissolved phosphate. The distribution and frequency patterns of G. *elongatus* and G. *rubescens* give the impression that G. *elongatus* is a species with a wider tolerance range than G. *rubescens*.

Regarding their morphological similarities and observed gradual transitions it seems justified to extrapolate the common affinity with tropical and subtropical waters of G. *elongatus* and G. *rubescens* to their Pliocene relatives G. *obliquus* and G. *apertura* and possibly to G. *nepenthes*.

During the Pliocene the sum of the above-mentioned taxa decreases significantly (negative trend, $P < 0.01$). In addition G. *apertura*, G. *obliquus* and G. *nepenthes* are equally numerous in the Lower Pliocene, apart from some large numbers of the latter species in Crete. Upwards G. *elongatus* dominates the sum of these taxa more and more. This may be an indication that the "tropical-subtropical" character of the Mediterranean diminished during the Pliocene. Simultaneously, the taxon with a wide tolerance range started to dominate this group.

As the large numbers of G. *elongatus* appear after the disappearance of G. *nepenthes*, while G. *obliquus* and G. *apertura* are still present, one may speculate that G. *nepenthes* had the narrowest tolerance range.

If one bears in mind the tropical-subtropical affinity of these taxa, it is now conceivable that the large numbers of G. *nepenthes* (and the presence of G. *elongatus*) in the eastern basin may indeed be related to west-east gradients comparable to those present in the recent Mediterranean.

Further indication for the west-east gradient

After the disappearance of G. *nepenthes* and approximately at the exit level of G. *margaritae*, the relative numbers of G. *elongatus* in Italy increase distinctly and the taxon seems to become more numerous than in Crete. A similar increase is found in the quantitative analysis of DSDP Site 132 in the Tyrrhenian Sea (Thunell, 1979a), at the same stratigraphic level. It is tempting to speculate that the disappearance of G. *nepenthes* and of G. *margaritae* and the increase in G. *elongatus* in the western basin were both caused by the same environmental change. As a matter of fact the first two taxa disappear from the eastern basin as well but here such a distinct relative frequency increase in G. *elongatus* is not present. Yet another event can be considered in this connection. Near the disappearance level of G. *nepenthes* the first assemblages of the G. *inflata* group enter the Mediterranean. It has been demonstrated (Spaak, 1981b) that this event was caused by a southward extension of the Atlantic distribution area of the G. *inflata* group, which had originated at higher latitudes. The disappearance of G. *nepenthes* and G. *margaritae* seem to fit in with the assumption of the southward migration of taxa in the Atlantic, probably as a consequence of a cooling trend. G. *nepenthes* is supposed to be a "tropical-subtropical" taxon with a narrow temperature range, while G. *margaritae* is probably a lower latitude taxon as well, as its gradual evolutionary appearance has been reported from low latitudes (Salvatorini and Cita, 1979). Obviously the southward migration of these taxa is a consequence of the extension of cooler North Atlantic water toward the south. This process seems to have had an influence on the distribution of some low-latitude taxa and may have brought cooler water into the Mediterranean. However, at this level of the Pliocene no reaction can be found in the sum of our G. *obliquus* group of "tropical-subtropical" taxa (cf. fig. 24). This may indicate that under the prevailing climatic conditions the cooler Atlantic water was rapidly warmed up as it progressed into the Mediterranean. Yet in Italy the change in character of the inflowing waters was still weakly noticeable, for among the "tropical-subtropical" taxa G. *elongatus*, with its wide tolerance range, started to increase; no such change was found in Crete any more.

The absence intervals of the *Globorotalia inflata* group

In the lower absence interval of the G. *inflata* group (G. *crassaformis* Zone, interval 5) the Cretan fauna does not show any conspicuous frequency change. However, in Italy G. *trilobus* becomes very numerous reaching its highest Pliocene frequencies. G. *trilobus*, being a "tropical" taxon, its relative increase seems to point to a stronger "tropical" influence in the Mediterranean (e.g. higher water temperatures) for the lower absence interval.

In the second major absence interval of the *G. inflata* group the frequency and distribution pattern of several other taxa, in addition to those of *G. trilobus*, display a remarkable pattern. From a level in the second half of the *G. crassaformis* Zone upwards to a level above the entry level of *G. inflata* s.str. (which part of the Pliocene includes this second absence interval) *G. trilobus* does not enter the 200-counts any more and in many samples it was not found at all. Also the numbers of *G. obliquus* and *G. apertura* are smaller than in the lower absence interval. In contrast *G. elongatus* reaches its highest numbers. The frequency drop of *G. obliquus* and *G. apertura* was found to coincide approximately with the beginning of the second absence interval of the *G. inflata* group (exit *G. bononiensis*) and near this level the influx of *Neogloboquadrina atlantica* is found as well. The latter taxon formed a characteristic Pliocene faunal element of the northern Atlantic (Poore and Berggren, 1975a, b). Although no frequency data are available from Crete for the higher part of the Pliocene, the influx of *N. atlantica* has still been found.

Near the second reappearance level of the *G. inflata* group (entry of *G. inflata* s.str.) it is *Sphaeroidinella dehiscens* which enters the Mediterranean, remaining present during a short period. The data from the Tyrrhenian and Ionian Sea (Thunell, 1979a) also show the presence of *S. dehiscens* near the entry of *G. inflata* s.str.

Unlike *N. atlantica*, the taxa *G. trilobus* and *S. dehiscens* occur at lower latitudes; they are numerous in equatorial waters (Bé, 1977; Bé et al., 1977). If one considers these additional elements, it implies that the beginning and the end of this second absence interval might be connected with more "temporate" and more "tropical" conditions respectively. If translated into terms of temperature the corresponding cooling and warming phases seem to be hard to reconcile with the absence of the "cooler" *G. inflata* group.

We must conclude that the circumstances under which the *G. inflata* group disappeared twice for a longer period were not identical. In the discussion of chapter 8 we shall try to explain these differences.

The overall Pliocene changes

We have seen that the Mediterranean fauna changed step by step towards its Late Pliocene composition, which closely resembles the modern one. If we take a closer look at the overall result of the change, it becomes clear that the early "tropical-subtropical" aspect of the fauna diminished during the Pliocene. In the Lower Pliocene *G. apertura*, *G. obliquus*, *G. nepenthes* and

G. margaritae are numerous and together with *Neogloboquadrina* and *G. falconensis* they dominate the fauna. *Neogloboquadrina* remains frequent throughout the Pliocene, but on the average *G. falconensis* shows an upwards decrease. Furthermore, *G. trilobus* is regularly present in the 200-counts in the lower part of the Pliocene, while *Sphaeroidinellopsis* and *G. altispira* occasionally enter the counts as well.

In the upper part of the Pliocene all these taxa, which indicate "tropical-subtropical" conditions, have disappeared or diminished in relative numbers (cf. sum of *G. obliquus* c.s.). Step by step a larger part of the fauna is formed by taxa which are characteristic for more temperate conditions, for instance *G. bulloides* and *G. quinqueloba* and the members of the *G. inflata* group. In addition to these taxa indicative of temperate conditions, species like *G. trilobus* and especially *G. elongatus* create a fauna with a "mixed (temperate-subtropical) label". This is in good agreement with the composition of the modern Mediterranean fauna, which is also a co-association of northern and subtropical species (Cifelli, 1974).

Superimposed on the large-scale transition from a fauna with a dominantly "tropical-subtropical" aspect to a fauna with a "mixed" character several events took place, which seem to be related with faunal migrations from the Atlantic. Most of these events occurred during the time of the *G. crassaformis* Zone, for instance the absence intervals of the *G. inflata* group, the influxes of *N. atlantica* and *S. dehiscens* and perhaps the scatter in the distribution patterns of *G. crassaformis* and *G. bononiensis*. One would expect that in connection with these migrations the Atlantic water conditions at the "gate" and consequently those of the water flowing into the Mediterranean would have changed as well. In one of the previous sections we have seen that some of these events (entry of *G. puncticulata* and exit of *G. margaritae*) had only a limited (frequency-)effect on the Mediterranean fauna, i.e. in the western basin only (increase of *G. elongatus*). A similar restricted effect may be assumed for the relatively large numbers of *G. trilobus* in Italy only during the first major absence interval of the *G. inflata* group.

Although the fauna changed step by step to the "mixed" composition, our quantitative data give the impression that the fauna changed fairly gradually. The numerous migration events had a limited, sometimes short frequency effect.

It seems likely that the isolated Mediterranean basin had, at least during the Pliocene, a certain buffer capacity that reduced the effect of the influences from the Atlantic.

Chapter 6

THE TEST DIAMETER OF ORBULINA UNIVERSA

The test diameter of O. *universa* was found to be latitude-related in the Indian Ocean (Bé et al., 1973) as well as in the Atlantic (Hecht, 1976); in both areas an increase in mean diameter was observed towards lower latitudes. In addition Bé and Duplessy (1976) demonstrated that the variations in the *Orbulina* diameter have a fair correlation with the changes in the isotopic composition of *Globigerinoides sacculiferus* in a set of Quaternary samples from the Indian Ocean. It is generally thought that there is a positive correlation between *Orbulina* size and temperature of the water. Consequently variations in average test diameter of O. *universa* in a stratigraphic column may be a reflection of ecological changes in time.

In addition to the relation with the water temperature, there seems to be a positive correlation between the *Orbulina* diameter and the nutrient content (Hemleben, oral comm.). This relation is not (yet) so well documented as the one with the water temperature.

During the last few years some paleoecological studies have been published in which the changes in test diameter of O. *universa* have been used to reconstruct paleoclimatic variations (Vismara Schilling and Stradner, 1977; Cita and Colombo, 1979; Colombo and Cita, 1980; Van Gorsel and Troelstra, 1981).

In order to get an impression of the changes in test diameter of O. *universa* in our Pliocene sections, we measured the *Orbulina* diameter in 435 samples. Per sample 30 specimens, picked at random, were measured to calculate the mean value of the diameter.

From our Italian samples we composed two (partly) parallel sequences. One is formed by 73 samples of the section Monte Sante Nicola (fig. 31), that covers the larger part of the Pliocene; 130 samples are used for a second, composite sequence (section Capo Rossello-section Vrica, fig. 32), which covers the whole of the Pliocene up to and including the entry level of *Hyalinea balthica.*

A third Pliocene sequence is formed by 122 samples from Greece (fig. 32). For this composite sequence we used the samples of the Cretan sections Kalithea and Finikia. In order to trace the further development of the *Orbulina* diameter in the upper part of the Aegean Pliocene we included several samples from two small sections on the islands of Karpathos (section Pigadia) and

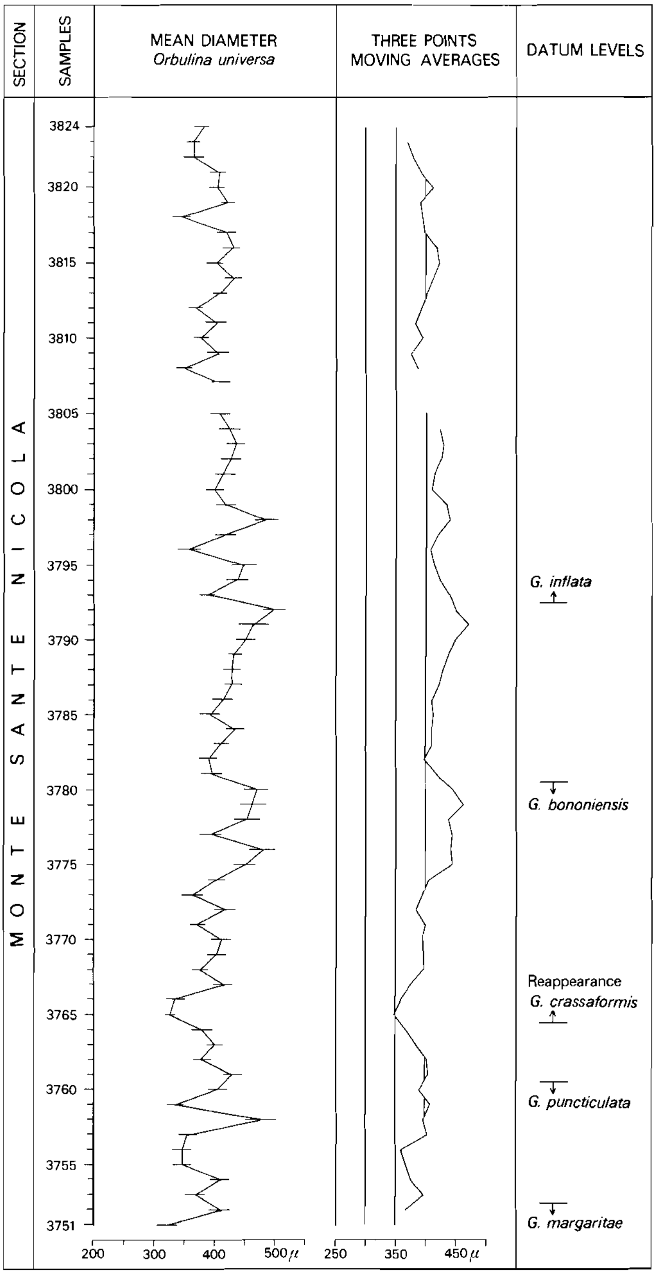


Fig. 31 Mean values ± SE and three-points moving averages of the *Orbulina* diameter in section Monte Sante Nicola.

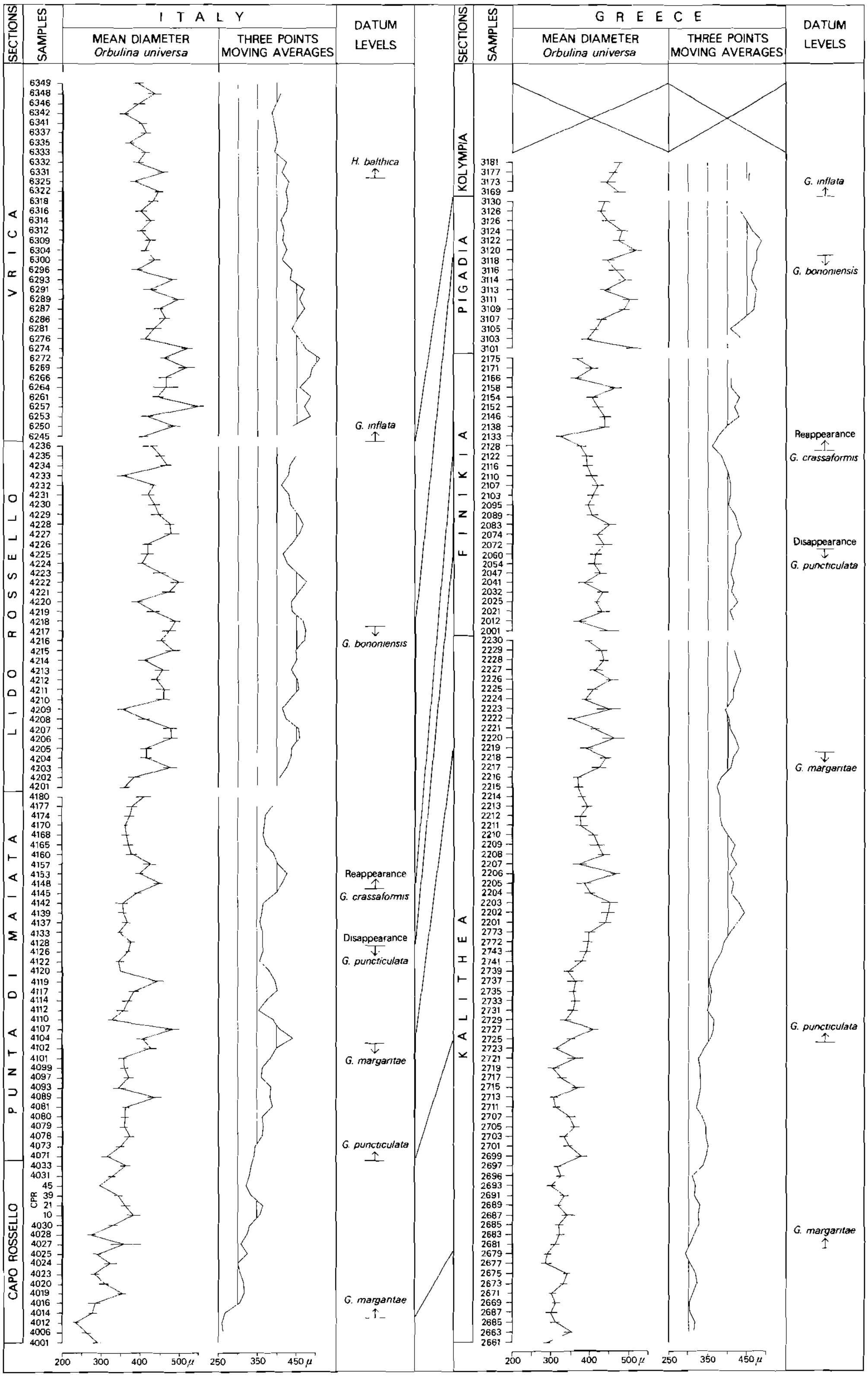


Fig. 32 Mean values ± SE and three-points moving averages of the *Orbulina* diameter in the composite sections of Italy and Greece.

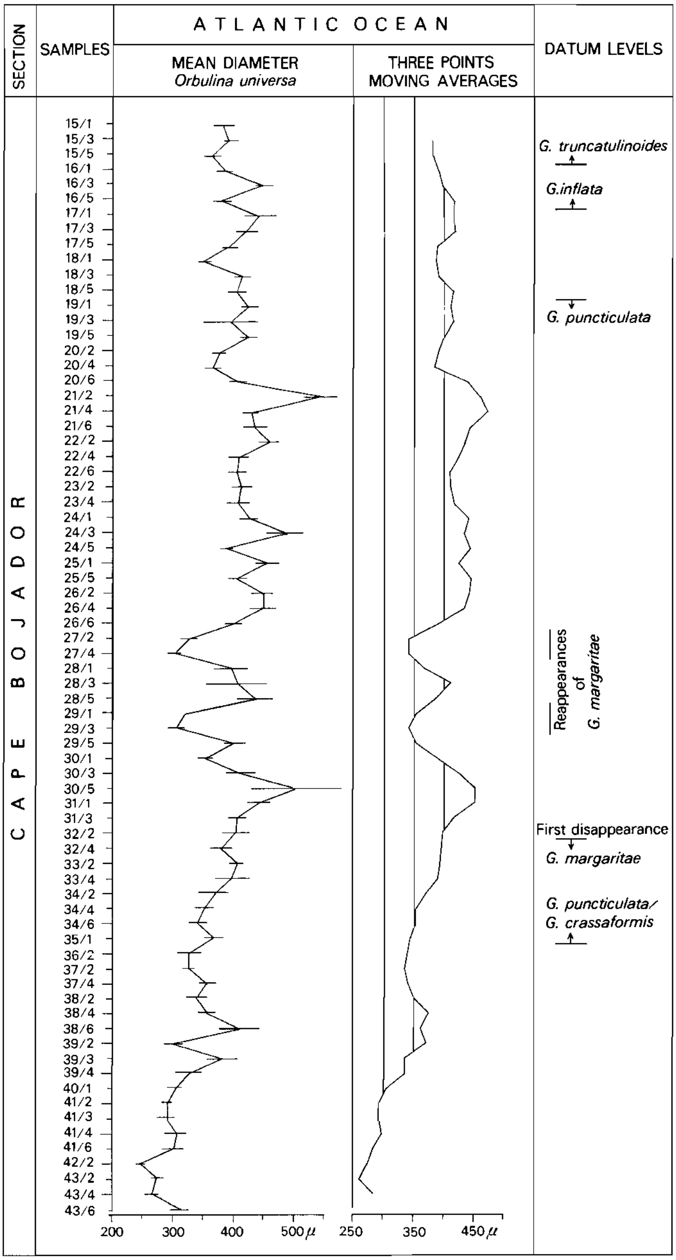


Fig. 33 Mean values ± SE and three-points moving averages of the *Orbulina* diameter in the Cape Bojador section.

Rhodos (section Kolimpia). In section Pigadia *Globorotalia bononiensis* disappears from the record whereas in section Kolimpia assemblages of *Globorotalia inflata* s.str. are present. Neither the *G. bononiensis* exit level nor *G. inflata* is present in Kalithea or Finikia and consequently Pigadia and Kolimpia are thought to cover higher parts of the Pliocene.

Finally we measured the test diameter of *O. universa* for 73 samples of DSDP Site 397 (Cape Bojador) from the Atlantic (fig. 33).

In figs. 31–33 the mean values of the *Orbulina* diameter are shown with the range of twice the standard error of the mean. Since these means fluctuate strongly, thus obscuring the general picture, we calculated three points moving averages for these mean values, the curves of which are given in figs. 31–33 as well.

As far as it is possible to compare the composite sequences of Italy and Greece (fig. 32) we see a similar development of the *Orbulina* diameter. In the lowermost part of the Pliocene the average diameter values are small; they increase upwards into the range between the *Globorotalia puncticulata* entry and the *Globorotalia margaritae* exit. From there onwards the means fluctuate without an overall change. They increase again between the re-appearance level of *Globorotalia crassaformis* and the exit level of *G. bononiensis*. An impression of the diameter values in the upper part of the Pliocene can be derived only from our Italian data. From the *G. bononiensis* exit level upwards the average diameter values fluctuate again with a possible further rise somewhat above the entry level of *G. inflata*. From there to the entry level of *H. balthica* and beyond there seems to be a decreasing trend.

The observations on the *Orbulina* diameter in the third Pliocene sequence from the Mediterranean (fig. 31; section Monte Sante Nicola) seem to confirm the trends described above. Up to a level between the re-appearance of *G. crassaformis* and the exit of *G. bononiensis* the mean diameters fluctuate. Higher in the sequence larger *Orbulina* were found while a decrease in mean values is again present in the *G. inflata* Zone.

Although the overall changes in the *Orbulina* diameter are similar in Italy and Greece, the average diameter values proper are not the same in these areas. In biostratigraphically comparable intervals the average values in Greece seem to be greater than in Italy. For a better demonstration we subdivided the Pliocene into eight intervals using successive *Globorotalia* datum levels only. For each interval we calculated the grand mean of the *Orbulina* diameter for Italy and Greece separately, using all 362 Mediterranean samples. The number of samples, the mean values and twice their standard error are shown in fig. 34. In comparable intervals the Italian values are almost always distinctly smaller than those from Greece. Although in the uppermost Pliocene a decrease in mean value can be observed, the smallest *Orbulina* are found in the lower part of the Pliocene.

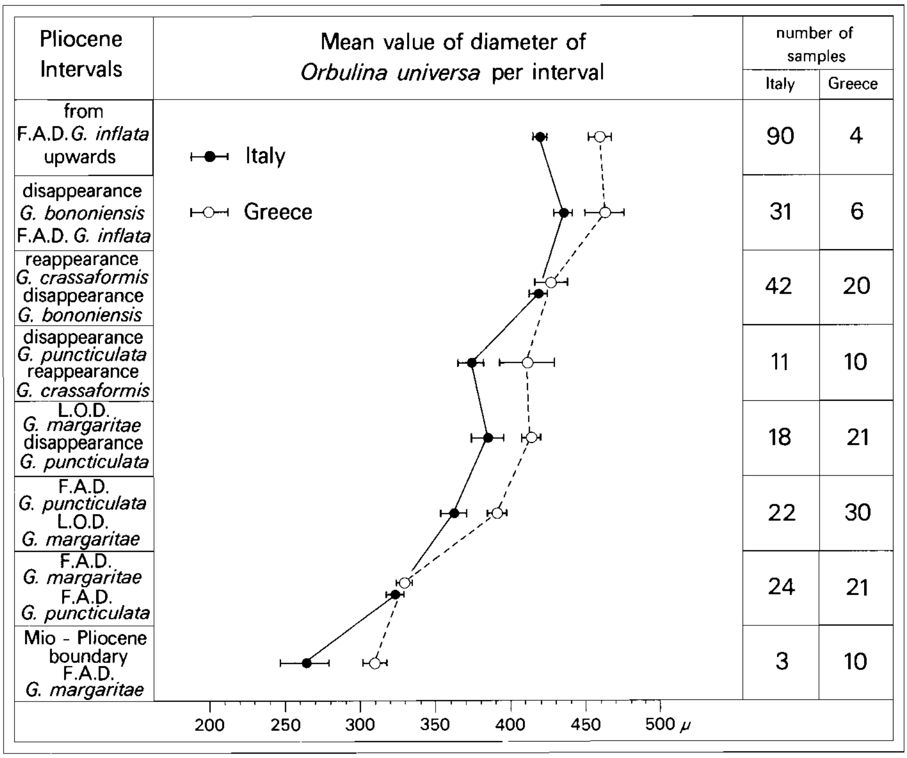


Fig. 34 Mean values ± SE of the mean values of the *Orbulina* diameter in our Italian and Aegean data, in eight successive Pliocene intervals.

At Cape Bojador (fig. 33) the smallest *Orbulina* are found in the lower part of the Pliocene as well. An increase in the mean diameter values is present up to a level above core 32/4, where *G. margaritae* disappears for the first time. On the average from here to a level below the exit of *G. puncticulata* the mean values remain high; in the upper part of the Pliocene they tend to lower values again. The average *Orbulina* values in and near both reappearance intervals of *G. margaritae* (core 29/3-29/1 and core 27/4-27/2) are markedly low, suggesting that we are dealing with reworking.

Because we have no close biostratigraphic correlation it is impossible to compare the diameter values of Cape Bojador and those of the Mediterranean in the same detail as we did for the sequences of Italy and Greece. A fair comparison is only possible for the upper part of the Pliocene, because in both areas we found an absence interval of the G. *inflata* group, after which the re-appearing assemblages are dominated by G. *inflata* s.str.; moreover, in both absence intervals *Sphaeroidinella dehiscens* occurs for the first time. In and above this interval the average diameters at Cape Bojador are distinctly smaller than the Mediterranean ones. Lower down, however, the Atlantic values seem to fall within the range of the Mediterranean values; they are usually smaller than those from Greece and comparable to or slightly larger than the Italian values.

DISCUSSION

Reviewing the data from the Mediterranean (Italy and Greece) and the Atlantic (Cape Bojador), we can say that the general development of the test diameter of *Orbulina universa* seems to be the same during the Pliocene. The smallest *Orbulina* diameters are found in the lower part of the Pliocene. In the uppermost Pliocene the diameter values decrease again, but the *Orbulina* do not attain as small a size as in the Lower Pliocene. This pattern of the smallest *Orbulina* diameter in the lower part of the Pliocene has been reported earlier by Vismara Schilling and Stradner (1977) for the Buonfornello section in Sicily, while the scattered data of Cita and Colombo (1979) from Cape Bojador indicate the same pattern.

Notwithstanding the similarity in the general development of the *Orbulina* diameter, there are many distinct and significant fluctuations between the mean values of successive samples (fig. 31–33). From a biometrical point of view our means are of dubious value, however; the randomly chosen individuals may well be regarded as belonging to some kind of "growth cline". Furthermore, although we always picked 30 specimens at random, it was sometimes difficult to obtain an equal distribution of the globular *Orbulina* specimens in our picking tray. In order to check whether these problems had an influence on our mean values and whether these values are reproducible, we examined the *Orbulina* of section Pigadia twice, going through exactly the same procedure. The results of the two sets of measurements are presented in fig. 35. The reproducibility of the procedure of *Orbulina* measurements seems to be fairly good, although in 4 of the 16 samples (= 25%) the standard errors of the two mean values still do not overlap! Reviewing the results of fig. 35, we can say that the major fluctuations recur in the second set of data but the sequences differ in detail as well as in the position of the three-points-moving-average curve. The differences give the impression of being systematic. Consequently it is certainly unrealistic to try to give an ecological explanation for all statistically significant differences in figs. 31–33; we shall restrict ourselves to more general conclusions.

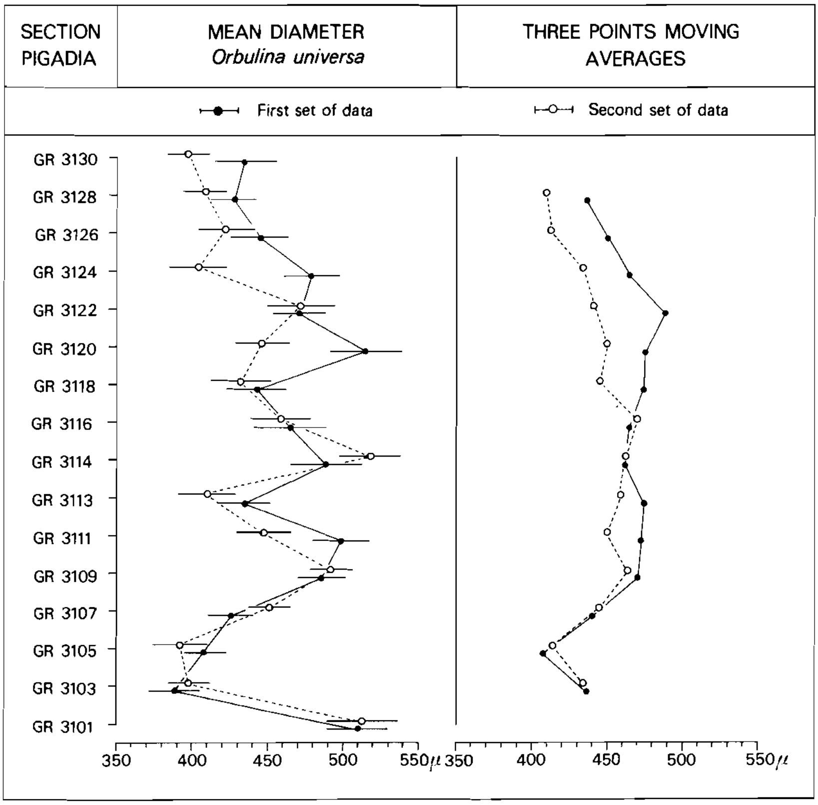


Fig. 35 Mean values ± SE and three-points moving averages of the *Orbulina* diameter from two sets of measurements of section Pigadia.

The number of significant fluctuations between successive samples seems to be larger in Italy (composite section: 68 out of 130 = 52%; Monte Sante Nicola: 33 out of 73 = 45%) than in Greece (45 out of 122 = 37%). If we compare the curves of the three points moving averages of the composite sections of Italy and Greece, we find more and stronger fluctuations in Italy. Although with some hesitation we are inclined to conclude that there are more fluctuations in Italy. If our conclusion is correct, the larger number of significant fluctuations in Italy may have been caused by (temperature) variations of the inflowing Atlantic water, which affected the fauna (*Orbulina* diameter) most distinctly in the western Mediterranean.

As the diameters from Italy are almost always significantly smaller than those from Greece, there seem to have been intra-Mediterranean size gradients in *Orbulina* during the Pliocene. This indicates that the environmental conditions were not the same throughout the Mediterranean. The size gradients may have been caused by a west-east Pliocene temperature gradient which is present in the recent Mediterranean as well. Other physical parameters, which are different in the eastern and western Mediterranean today are salinity and nutrient concentration. Since we think that these parameters had an influence on the formation of the laminated sediments, we checked whether a correlation could be found between the mean diameter values and the different lithotypes (homogeneous and laminated), using the values of the Vrica section. For this section such a correlation could not be ascertained ($r = 0.14$; number of samples: 37). Consequently it is most likely that temperature differences were responsible for the *Orbulina* size gradient in the Pliocene Mediterranean. As might be expected the cooler Atlantic water lost its characteristics by warming up, as it moved eastwards.

As to the general development of the *Orbulina* diameter, temperature seems to have played a role as well, i.e. there was an overall warming of the Mediterranean waters in the course of the Pliocene, and the beginning of a cooling towards the end. Additional data can be derived from other taxa. In fig. 36 we present the percentages of sinistrally coiled *Neogloboquadrina* specimens of the Italian composite section. Really large percentages of such sinistral *Neogloboquadrina* are frequent above sample JT 6274 in the Vrica section; this is exactly the level at which the decreasing trend in the *Orbulina* diameter sets in. Also in the Lower Pliocene there are relatively more *Neogloboquadrina* with sinistral coiling, whereas in the middle part of the Pliocene sinistrally coiled specimens are scarce. Today large numbers of sinistrally coiled *Neogloboquadrina* are invariably found at higher latitudes in cooler waters (e.g. Bé, 1977; Keller, 1978). In the Pliocene Mediterranean such larger relative numbers occur together with smaller *Orbulina*.

The general development of the *Orbulina* diameter in the Mediterranean indicates and overall temperature increase up to a level above the entry of *G. inflata* s.str. and a temperature decrease from there onwards. A similar temperature trend can be deduced for the Pliocene at Cape Bojador, but here the temperature decrease started earlier (before the absence interval of the *G. inflata* group) than in the Mediterranean.

The similarity of the *Orbulina* trend in the Lower Pliocene in the Mediterranean and in the Atlantic at Cape Bojador indicates that the temperature increase occurred in a large area and was directly related with a climatic warming. However, towards the end of the Pliocene the introduction of smaller *Orbulina* and consequently of lower temperatures was earlier at Cape Bojador than in the Mediterranean. In this case we are probably not dealing with a general cooling. The introduction of smaller *Orbulina* in the eastern Atlantic, south of the Straits of Gibraltar is in an interval in which the *Globorotalia*

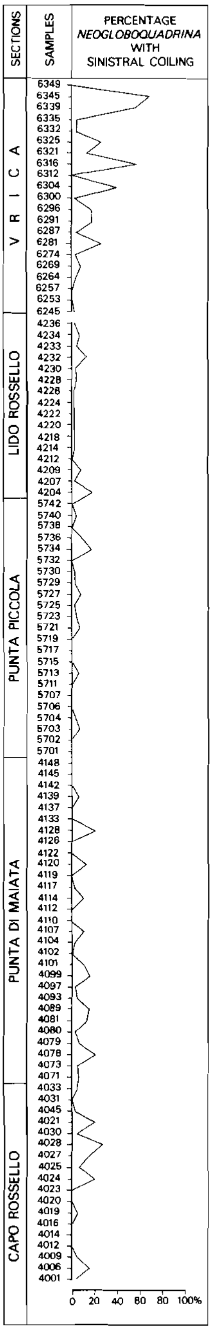


Fig. 36 Percentages of sinistrally coiled *Neogloboquadrina* in the Italian composite section.

menardii group disappeared from Cape Bojador. These events were probably the result of a further southward transport of cooler water along the eastern side of the Atlantic, which transport is also thought to be responsible for the entry of *Neogloboquadrina atlantica* into the Mediterranean. Such a current system is known from the recent Atlantic as well. The influence of this cooler water in the Mediterranean can be concluded also from the absence of scarcity of *G. trilobus* and the frequency drop of *G. obliquus* and *G. apertura*, whereas the more tolerant "subtropical" taxon *G. elongatus* attained relatively large numbers. Also in the *Orbulina* diameter several significant fluctuations can be observed but on the average the mean diameter values remain constant. A decrease in the *Orbulina* diameter values occurs later in the Mediterranean Pliocene.

This time lag in the diameter decrease between the Mediterranean and the Atlantic seems to indicate that such a southward migration of cooler water in the Atlantic influenced the distribution area of some taxa in its own realm and consequently their range in the Mediterranean, but the Atlantic migration did not necessarily affect the Mediterranean environment. A southward advance of cooler water in the Atlantic did not automatically or instantaneously lower the temperature of the Mediterranean watermasses.

Chapter 7

THE LAMINATED INTERVALS

In Sicily the alternation of homogeneous and laminated sediments is well represented in our section Punta Piccola. The planktonic foraminifera from all samples of this section have been counted except those from sample JT 5709, the lithology of which was uncertain. A selection of 37 samples from the Vrica section (Calabria) has been counted as well. Furthermore, we analyzed the samples of three Cretan sections with alternations of homogeneous and laminated sediments. Seventeen samples were used out of the first set of samples from the Aghios Vlassios section from the interval between the levels of the *Globorotalia puncticulata* entry and the *Globorotalia margaritae* exit. A selection of 57 samples from section Finikia and another one of 63 samples from section Prassas complete our quantitative analyses of sections with laminated intervals.

The results of the computer analysis of the quantitative data from these five sections are based on the BALANC-program (see chapter 5).

CRETE

The frequency diagram of a small part of the Aghios Vlassios section is presented in fig. 37. The number of correlations which have been found in the computer analysis of these data (fig. 38) is very small, which may be due

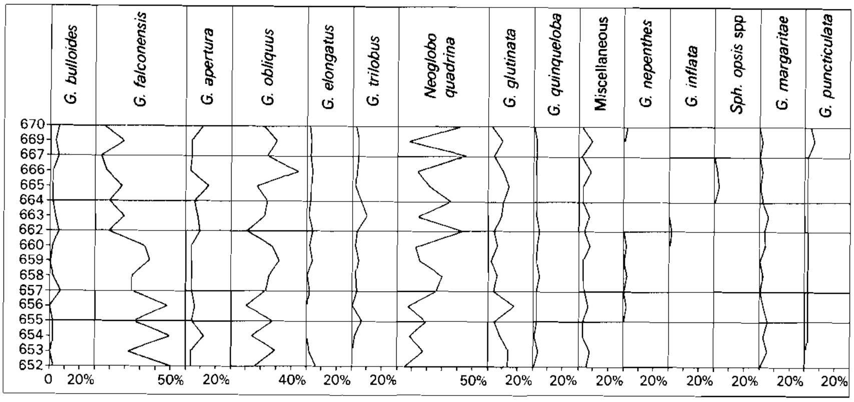
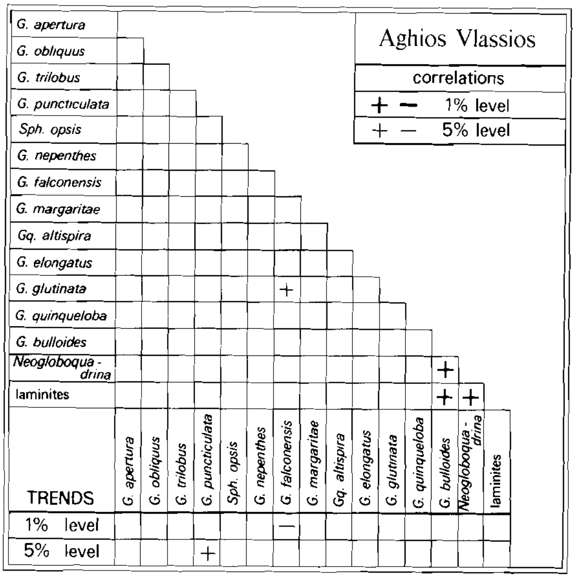


Fig. 37 Relative frequencies of the planktonic foraminifera in the Aghios Vlassios section.

to the fact that N (number of samples) and M (number of taxa) of the matrix are nearly equal. Strong positive correlations ($P < 0.01$) are present between the laminated sediments, *Neogloboquadrina* and *Globigerina bulloides.*



Aghios Vlassios

correlations

+ — 1% level

+ — 5% level

TRENDS	*G. apertura*	*G. obliquus*	*G. trilobus*	*G. puncticulata*	*Sph. opsis*	*G. nepenthes*	*G. falconensis*	*G. margaritae*	*Gq. altispira*	*G. elongatus*	*G. glutinata*	*G. quinqueloba*	*G. bulloides*	*Neogloboqua-drina*	laminites
G. apertura															
G. obliquus															
G. trilobus															
G. puncticulata															
Sph. opsis															
G. nepenthes															
G. falconensis															
G. margaritae															
Gq. altispira															
G. elongatus															
G. glutinata							+								
G. quinqueloba															
G. bulloides															
Neogloboqua-drina													**+**		
laminites													**+**	**+**	
1% level							**—**								
5% level				+											

Fig. 38 Matrix of correlation coefficients and trends of the data from the Aghios Vlassios section.

In chapter 2 we have seen that in section Prassas there is a distinct hiatus at sample level CP 3354. In the laminated sediments below this level the faunas are not dominated by any taxon (fig. 39). Only in sample GR 960 is there a peak frequency of *Neogloboquadrina.* Above this level, however, *G. bulloides* and *Neogloboquadrina* distinctly dominate most faunas. According to the BALANC-output the laminites of section Prassas have a positive correlation with *Neogloboquadrina, G. bulloides* and *Globigerina quinqueloba,* while positive correlations between these taxa exist as well (fig. 40). *G. quinqueloba* is also positively correlated with *Globorotalia bononiensis.* Negative correlations have been found between the laminations and *Globigerina apertura, Globigerinoides obliquus, Globigerina falconensis, Globigerinoides elongatus* and *Globigerinita glutinata.* Between these taxa there are various positive links, and negative correlations exist especially with *G. bulloides.*

In addition to the analysis of all data of section Prassas, the data below and those above the hiatus were analyzed separately. We shall not present the results of these analyses in separate figures but we shall enumerate the results.

The analysis of the lower part of the section revealed no correlations of taxa with the laminated sediments and only a small number of inter-taxon correlations; these relations also occur in the analysis of the whole section. The positive correlations between *Neogloboquadrina* and *G. bulloides* and between *G. apertura* and *G. obliquus* are significant ($P < 0.01$). The low number of correlations may again be partly due to the size of the N X M matrix.

The results of the analysis of the longer upper part of the section are very much the same as those for the whole section. The differences are that for

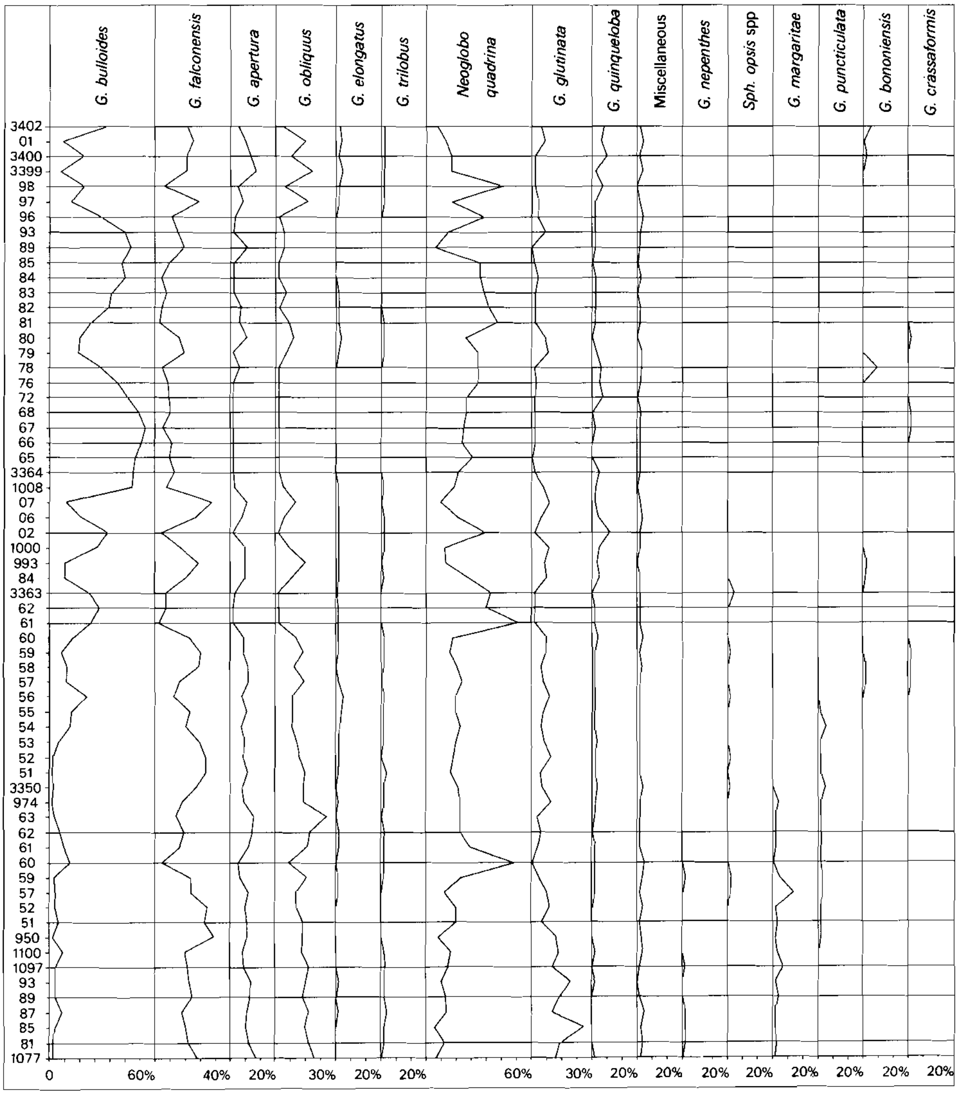
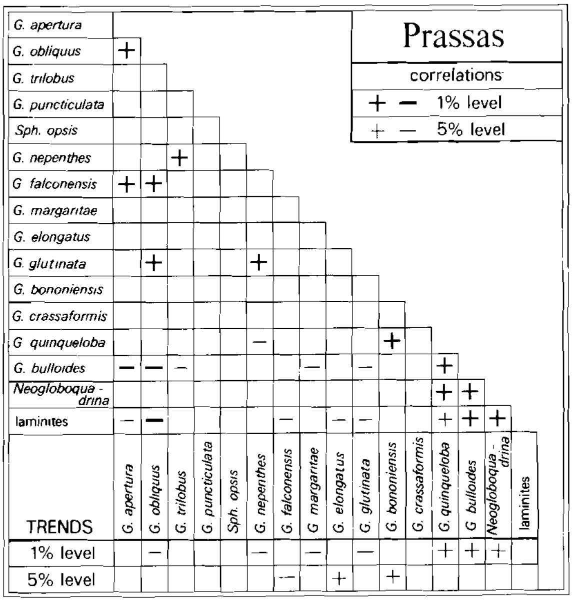


Fig. 39 Relative frequencies of the planktonic foraminifera in the Prassas section.

the upper part of the section also *G. trilobus* has a negative correlation with the laminates and that between taxa with such negative correlations the number and level of significance of mutual positive correlations have increased. Although we used the (open) BALANC-program to establish these correlations, disturbing effects may have played a role in the analysis because of the very large combined numbers of *G. bulloides* and *Neogloboquadrina.* Since we are primarily interested in the correlations with the laminites, no additional computer runs were made with these taxa eliminated. Practice has shown that the main results remain unaltered (M. M. Drooger, 1982).



Prassas

correlations

+ − 1% level

+ − 5% level

	G. apertura	*G. obliquus*	*G. trilobus*	*G. puncticulata*	*Sph. opsis*	*G. nepenthes*	*G. falconensis*	*G. margaritae*	*G. elongatus*	*G. glutinata*	*G. bononiensis*	*G. crassaformis*	*G. quinqueloba*	*G. bulloides*	*Neogloboquadrina*	laminites
G. apertura																
G. obliquus	+															
G. trilobus																
G. puncticulata																
Sph. opsis																
G. nepenthes			+													
G. falconensis	+	+														
G. margaritae																
G. elongatus																
G. glutinata		+				+										
G. bononiensis																
G. crassaformis																
G. quinqueloba						−					+					
G. bulloides	−	−	−					−		−			+			
Neogloboquadrina													+	+		
laminites	−	−					−		−	−			+	+	+	
TRENDS																
1% level		−				−		−		−			+	+	+	
5% level							−		+		+					

Fig. 40 Matrix of correlation coefficients and trends of the data from the Prassas section.

In the laminated sediments of the Finikia section (fig. 41) *G. bulloides* and *Neogloboquadrina* are again the dominating faunal elements. Larger numbers of the former taxon occur especially from sample CP 2073 upwards, whereas the latter taxon has peak frequencies all through the section. The computer analysis shows that as in section Prassas the laminated sediments have positive correlations with *Neogloboquadrina, G. bulloides* and *G. quinqueloba* (fig. 42). In addition, we find that *Neogloboquadrina* and *G. bulloides* are positively correlated with *Globorotalia crassaformis,* while the former taxon and *G. quinqueloba* have positive ties to *G. bononiensis.* These two *Globorotalia* taxa are positively correlated with each other as well. In Finikia, only *G. falconensis* shows a negative correlation with the lamination, whereas *G. trilobus* has a positive link with these sediments, which is not the case in Prassas. Moreover, *G. trilobus* has a negative correlation with *G. glutinata.* In Finikia this is the only significant negative correlation between taxa with a positive link with the laminites and the remaining taxa. As in Prassas there are several positive correlations among these remaining taxa.

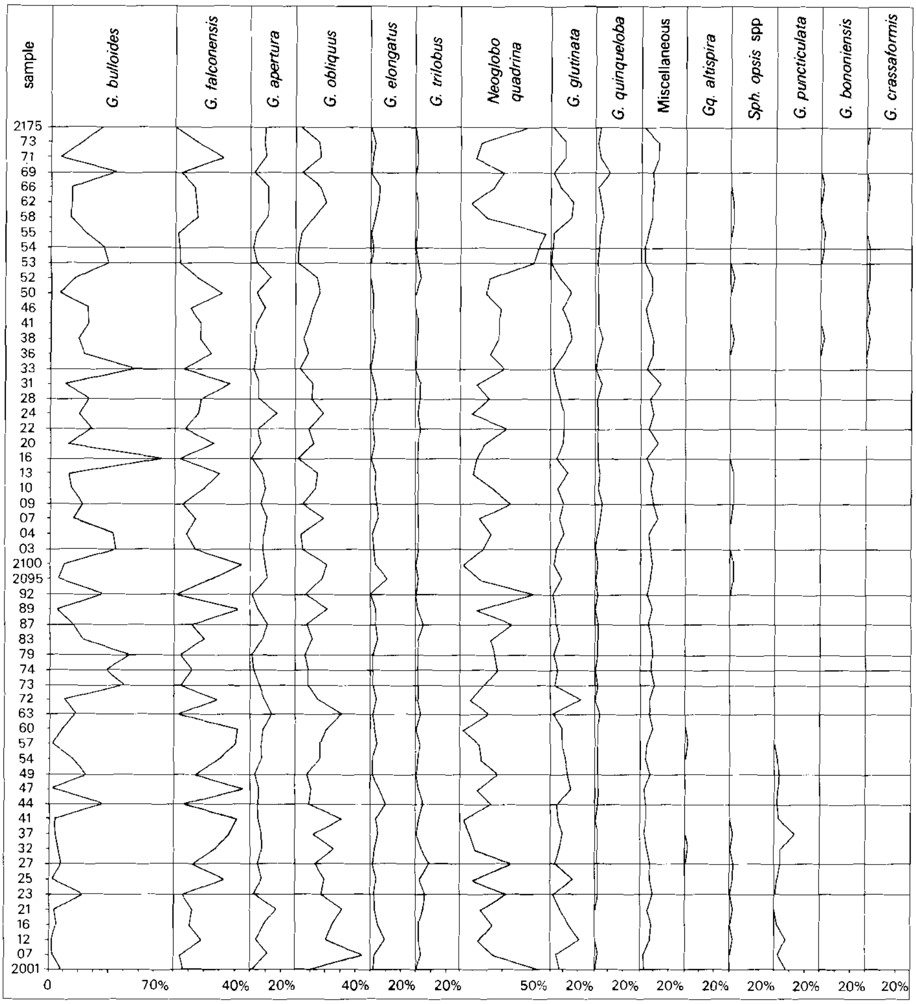
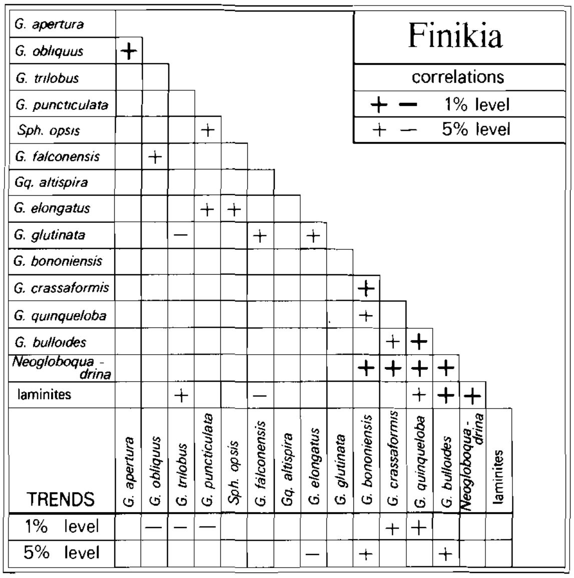


Fig. 41 Relative frequencies of the planktonic foraminifera in the Finikia section.

Reviewing the frequency diagrams of these three Cretan sections, we can make a difference between the laminites below and above the disappearance level of *G. puncticulata.* Above this level the faunas in these sediments are



Finikia

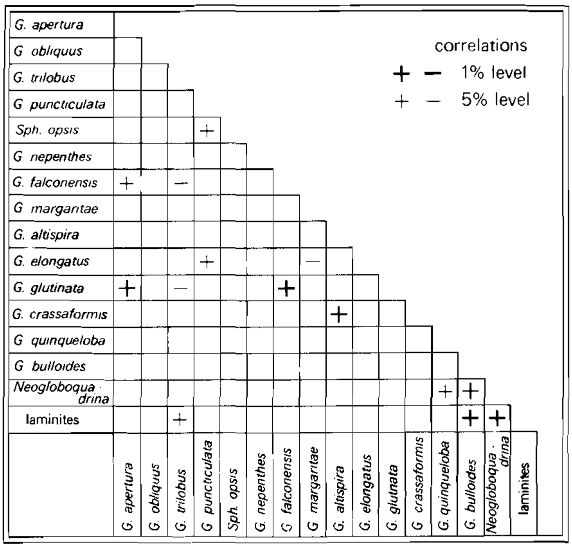
correlations

+ — 1% level

+ — 5% level

	G. apertura	*G. obliquus*	*G. trilobus*	*G. puncticulata*	*Sph. opsis*	*G. falconensis*	*Gq. altispira*	*G. elongatus*	*G. glutinata*	*G. bononiensis*	*G. crassaformis*	*G. quinqueloba*	*G. bulloides*	*Neogloboqua - drina*	laminites
G. apertura															
G. obliquus	**+**														
G. trilobus															
G. puncticulata															
Sph. opsis				+											
G. falconensis		+													
Gq. altispira															
G. elongatus				+	+										
G. glutinata			—			+		+							
G. bononiensis															
G. crassaformis										**+**					
G. quinqueloba										+					
G. bulloides											+	**+**			
Neogloboqua - drina										**+**	**+**	**+**	**+**		
laminites			+			—						+	**+**	**+**	
TRENDS															
1% level		—	—	—							+	+			
5% level								—		+			+		

Fig. 42 Matrix of correlation coefficients and trends of the data from the Finikia section.



correlations

+ — 1% level

+ — 5% level

	G. apertura	*G. obliquus*	*G. trilobus*	*G puncticulata*	*Sph. opsis*	*G. nepenthes*	*G falconensis*	*G margaritae*	*G. altispira*	*G. elongatus*	*G. glutnata*	*G crassaformis*	*G. quinqueloba*	*G. bulloides*	*Neogloboqua - drina*	laminites
G. apertura																
G obliquus																
G. trilobus																
G puncticulata																
Sph. opsis				+												
G nepenthes																
G. falconensis	+		—													
G margaritae																
G. altispira																
G. elongatus				+				—								
G. glutinata	**+**		—				**+**									
G. crassaformis									**+**							
G quinqueloba																
G bulloides																
Neogloboqua - drina													+	**+**		
laminites			+											**+**	**+**	

Fig. 43 Matrix of correlation coefficients based on all Cretan data below the G. *puncticulata* exit.

correlations

+ – 1% level

+ – 5% level

	G. apertura	*G. obliquus*	*G. trilobus*	*G. puncticulata*	*Sph. opsis*	*G. falconensis*	*G. elongatus*	*G. glutinata*	*G. bononiensis*	*G. crassaformis*	*G. quinqueloba*	*G. bulloides*	*Neogloboqua - drina*	laminites
G. apertura														
G. obliquus	**+**													
G. trilobus														
G. puncticulata														
Sph. opsis														
G. falconensis		**+**	–											
G. elongatus		**+**												
G. glutinata						+								
G. bononiensis														
G. crassaformis														
G. quinqueloba									**+**					
G. bulloides		**–**					**–**				**+**			
Neogloboqua - drina										**+**	**+**	**+**		
laminites	**–**	**–**				**–**	**–**	**–**			**+**	**+**	**+**	

Fig. 44 Matrix of correlation coefficients based on all Cretan data above the G. *puncticulata* exit.

seen to be dominated by *Neogloboquadrina* and *G. bulloides;* below this level we only see peak frequencies of *Neogloboquadrina* with some small peaks of *G. bulloides* or no peak frequencies of any taxon at all (e.g. the lowermost part of section Prassas). In order to check whether this visual difference between the faunas from the laminites could be substantiated by computer analysis we divided the counted Cretan samples into two groups, one consisting of all data below and the other of all data above the exit of *G. puncticulata.* The significant correlations of these computer analyses are presented in figs. 43 and 44. The results of these analyses clearly indicate that throughout the Pliocene *Neogloboquadrina, G. bulloides* (and indirectly *G. quinqueloba*) are linked with the laminites. Above the disappearance level of *G. puncticulata* two *Globorotalia* taxa (*G. bononiensis* and *G. crassaformis*), which are restricted to this part of the Pliocene, are associated with the above mentioned taxa as well. Below this level a correlation between the laminated sediments and *G. trilobus* is present in addition to the correlations with *Neogloboquadrina* and *G. bulloides.* Only above the exit level of *G. puncticulata* do the laminites have significant negative correlations with *G. apertura, G. obliquus, G. falconensis, G. elongatus* and *G. glutinata;* below this level there is not a single negative correlation.

The effect on the planktonic foraminifera of the processes causing the laminites evidently became stronger in the course of the Pliocene.

In the Sicilian Punta Piccola section (figs. 45, 46) *G. bononiensis* has a distinct positive correlation with the laminated sediments (see also Brolsma, 1978). The peak frequencies of *G. bononiensis* occur up to the level of JT 5725; above this level we get the visual impression that it is *Neogloboquadrina* which has peak frequencies in the laminites, but a separate computer analysis of the top part of the Punta Piccola section did not confirm this impression by revealing a significant positive correlation. Instead we found a positive correlation between *G. trilobus* and the laminites.

In the Vrica section (figs. 47, 48) the laminated sediments show a positive correlation with *Neogloboquadrina* ($P < 0.01$) and with *G. bulloides* and *Globorotalia inflata* ($P < 0.05$). The laminites have a negative correlation with *G. glutinata* and *G. falconensis*. Just as in the sections Finikia and Prassas, several positive correlations are present between taxa with a negative or no

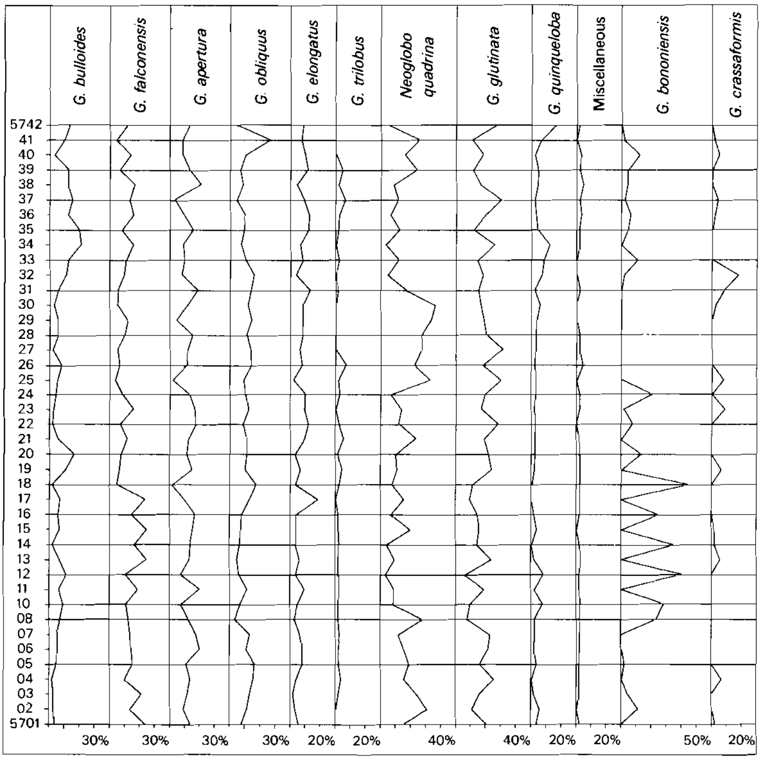


Fig. 45 Relative frequencies of the planktonic foraminifera in the Punta Piccola section.

Punta Piccola

correlations

+ − 1% level

+ − 5% level

	G. apertura	*G. obliquus*	*G. trilobus*	*G. falconensis*	*G. elongatus*	*G. glutinata*	*G. bononiensis*	*G. crassaformis*	*G. quinqueloba*	*G. bulloides*	*Neogloboqua - drina*	laminites
G. apertura												
G. obliquus												
G. trilobus												
G. falconensis												
G. elongatus												
G. glutinata												
G. bononiensis												
G. crassaformis												
G. quinqueloba												
G. bulloides									+			
Neogloboqua - drina		+										
laminites							+					
TRENDS												
1% level				−						+		
5% level					+				+			

Fig. 46 Matrix of correlation coefficients and trends of the data from the Punta Piccola section.

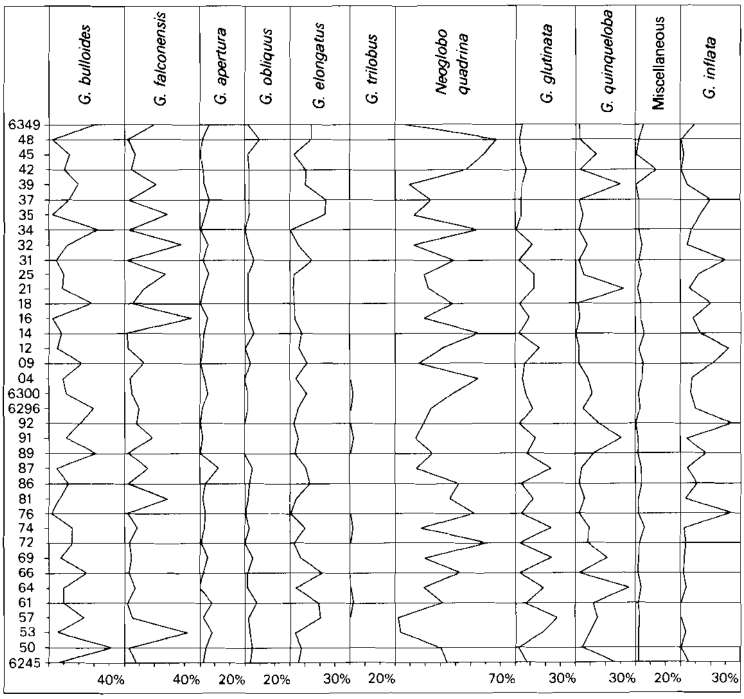
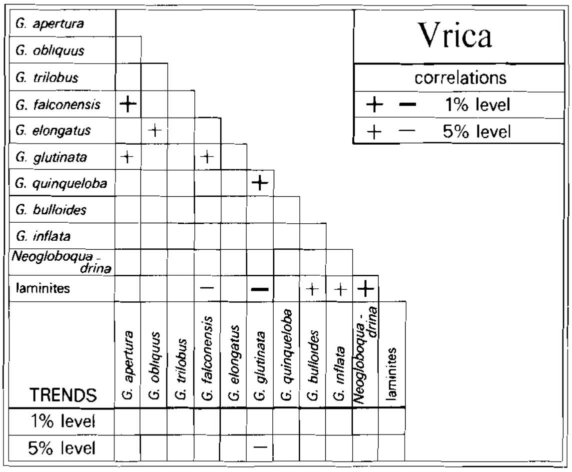


Fig. 47 Relative frequencies of the planktonic foraminifera in the Vrica section.



Vrica

correlations

+ **−** 1% level

\+ − 5% level

	G. apertura	G. obliquus	G. trilobus	G. falconensis	G. elongatus	G. glutinata	G. quinqueloba	G. bulloides	G. inflata	Neogloboqua-drina
G. apertura										
G. obliquus										
G. trilobus										
G. falconensis	**+**									
G. elongatus		+								
G. glutinata	+			+						
G. quinqueloba						**+**				
G. bulloides										
G. inflata										
Neogloboqua-drina										
laminites				−		**−**		+	+	**+**

TRENDS	G. apertura	G. obliquus	G. trilobus	G. falconensis	G. elongatus	G. glutinata	G. quinqueloba	G. bulloides	G. inflata	Neogloboqua-drina	laminites
1% level											
5% level						−					

Fig. 48 Matrix of correlation coefficients and trends of the data from the Vrica section.

correlation with the laminites. Unlike most other sections *G. quinqueloba* is not distinctly associated with the laminated sediments in Vrica.

The Punta Piccola and Vrica sections again give the impression that the effect of the stagnation on the planktonic faunas became stronger in the course of the Pliocene.

DISCUSSION

Ecology of Recent taxa found to be linked with the Pliocene laminites

In the paragraphs below we shall enumerate some general conclusions which can be drawn about the recent preferences and tolerances of our laminite-linked taxa. These taxa are *G. bulloides, Neogloboquadrina, G. quinqueloba, G. trilobus, G. bononiensis, G. inflata,* all having positive correlations, and *G. falconensis, G. apertura, G. obliquus, G. elongatus* and *G. glutinata* having negative correlations.

Today the members of the *Neogloboquadrina* plexus have a worldwide distribution (e.g. Bé, 1977; Coulbourne et al., 1980); as a consequence *Neogloboquadrina* as a group occurs within a wide range of temperature and salinity. However, its larger numbers are found especially in nutrient-rich waters like the major current systems, areas with upwelling and along continental margins (e.g. Bé et al., 1981; Thiede, 1975; Bé, 1977; Coulbourne et al., 1980); large numbers are found in addition in waters with relatively low salinities (Thunell, 1978; cf. Loubere, 1981).

The quantitative response to the formation of laminated sediments is quite distinct in our *G. bulloides – G. falconensis* combination. If we regard these morphotypes separately, *G. bulloides* is the most ubiquitous taxon of all Recent planktonic foraminifera (Bé, 1977) and it often occupies environments that are unfavourable to most other taxa (Coulbourne et al., 1980). This quality it shares with *Neogloboquadrina, G. quinqueloba* and *G. glutinata.* In general the distributional area of *G. bulloides* is larger than that of *G. falconensis.* When the distribution of large numbers of both taxa are plotted in a T-S (temperature-salinity) diagram (Loubere, 1981) for the Atlantic and the Mediterranean, the larger numbers of *G. falconensis* appear to be restricted to the areas with higher temperatures and salinities, whereas the high frequencies of *G. bulloides* occur over a much wider T-S range. Similar differences were found in the Indo-Pacific (Malmgren and Kennett, 1977; Coulbourne et al., 1980). Moreover Coulbourne et al. found that *G. falconensis* occurs in waters with a low phosphate content, whereas *G. bulloides* seems to be frequent under more fertile conditions for instance in areas with upwelling (Zobel, 1971; Bé and Hutson, 1977; Prell and Curry, 1981).

The distribution of *G. trilobus* is distinctly limited to lower latitudes. This taxon is found to be numerous in nutrient-rich waters of the equatorial belt (Bé and Hutson, 1977) and in high-productivity areas off India (Zobel, 1971).

G. quinqueloba is most numerous in polar regions although it occurs regularly at low latitudes as well (Reiss et al., 1974; Bé and Hutson, 1977). In fact this species is found over a wide temperature range but it seems to be connected with high nutrient concentrations (Coulbourne et al., 1980; Loubere, 1981). The large numbers of *G. quinqueloba* in polar regions as well as in the Mediterranean Messinian (Van der Zwaan, 1982) and its occurrence over a wide temperature range imply that this species is tolerant of a wide range of salinities.

G. glutinata is a widespread species, accumulating below both cold and warm waters (e.g. Reiss et al., 1974; Bé and Hutson, 1977; Coulbourne et al., 1980); furthermore its large numbers tend to follow high nutrient concentrations (Coulbourne et al., 1980; cf. Cifelli and Smith, 1974). However support for the latter connection is much less strong than it is for *Neogloboquadrina, G. bulloides* and *G. quinqueloba.* Zachariasse (1978) concluded that *G. glutinata* could thrive at lower nutrient-levels than other species, which might point to a certain indifference on the part of this taxon as far as nutrient content is concerned. There are indications that *G. glutinata* is tolerant of high salinities. Not only does it take the fifth place in the salinity-ranking of taxa in the Indian Ocean (although with a large range; Bé and Hutson, 1977) but it also shows a positive trend in the Mediterranean Messinian (Van der Zwaan, 1982). In the recent Atlantic and Mediterranean its large numbers occur within distinct salinity limits (35–37‰, Loubere, 1981).

G. inflata s.str. is the recent representative of the *G. inflata* group, which also includes *G. bononiensis.* At present *G. inflata* is an important element of the Transitional Fauna (Bé and Tolderlund, 1971; Bé, 1977), numerous in temperate and cool waters. Its relatively large numbers in the western Mediterranean may be directly related with its "temperate-habitat". However, the larger nutrient concentrations in this part of the Mediterranean may be held responsible as well, especially because *G. inflata* is most numerous in the southern part of the western Mediterranean (Thunell, 1978) where the phosphate concentration is greatest (McGill, 1960). In an analysis of an Atlantic fauna off Africa (Thiede, 1975), *G. inflata* turned out to be linked with high productivity (upwelling).

G. apertura, G. obliquus and *G. elongatus* are closely related as mentioned before; *G. elongatus* (*G. ruber*) and *Globigerina rubescens* are the extant representatives of this group of taxa. The latter two taxa have a tropical-subtropical habitat and in that environment *G. elongatus* is more numerous (e.g. Zobel, 1971; Bé, 1977). *G. rubescens* is scarce; its relatively large numbers show a scattered distribution and are associated with low values of dissolved phosphates (Bé and Hutson, 1977). Although *G. elongatus* occurs over a wide range of temperature, salinity and nutrient concentration, its relative numbers appear to increase in the oligotrophic parts of the Indian Ocean (Bé and Hutson, 1977). The large numbers of *G. elongatus* in the eastern Mediterranean (Parker, 1955; Cifelli, 1974; Thunell, 1978) and its all-year-round large numbers in the southern part of the Sargasso Sea (Cifelli and Smith, 1974) also point to a relation with oligotrophic conditions. These taxa thus seem to have a tropical-subtropical habitat and a tolerance of oligotrophic and high salinity conditions in common.

In recent environments the taxa that have a significantly positive correlation with the laminated sediments in the Mediterranean Pliocene occur in large numbers in fertile waters. In addition, the most frequent taxa found in the laminites (*G. bulloides* and *Neogloboquadrina*) appear to be very tolerant to a wide range of temperatures and salinities, which also applies to *G. quinqueloba.*

Four of the taxa which have a negative correlation with the laminites (*G. falconensis, G. apertura, G. obliquus* and *G. elongatus*) seem to be linked with oligotrophic, warmer and high-salinity conditions. *G. glutinata,* also with a negative correlation, is a more tolerant taxon as far as temperature is concerned. In contrast with the former four taxa the large numbers of *G. glutinata* tend to follow high nutrient concentrations in the Indian Ocean. As to salinity, G. *glutinata* seems to occur within distinct limits but it is also tolerant of and frequent under high salinities. The negative correlation of G. *glutinata* with the laminites may indicate that conditions with lower salinity played a role during the formation of these sediments.

Summarizing, the laminite-bound fauna points to eutrophic, more fertile conditions at the time of laminite formation than in the periods in between; the dominating taxa are very tolerant of several environmental parameters. There are indications that the laminites were formed during periods with less high salinities in comparison to the salinities prevailing before and after.

The succession of laminite-bound faunas

In Crete a regular alternation of homogeneous and laminated sediments is found from below the entry level of G. *margaritae* upwards. In Sicily such a regular alternation starts much higher in the sections, in the G. *crassaformis* Zone (interval 6; see chapter 4).

On the basis of their faunal characteristics the laminites can be subdivided into several stratigraphically successive groups (fig. 49).

In the Cretan Lower Pliocene up to a level just above the G. *puncticulata* entry (lower part section Prassas) none of the faunal elements shows peak frequencies in the laminites and there seem to be no correlations between any of the taxa and the lamination.

In the next higher stratigraphic interval, approximately up to the disappearance level of G. *puncticulata* (Aghios Vlassios, lower part section Finikia, section Prassas just below the hiatus), the Cretan faunas display peak frequencies of *Neogloboquadrina* in the laminites, while positive correlations were found between the laminites and *Neogloboquadrina*, G. *bulloides* and G. *trilobus;* there are no negative correlations. In this interval G. *bulloides* gradually starts to show small peaks as well.

Above the disappearance level of G. *puncticulata* (top part Finikia and Prassas above the hiatus) the faunas in the laminites are distinctly dominated by G. *bulloides* and *Neogloboquadrina.* Together with G. *quinqueloba* these two taxa show a positive correlation with the laminites. Only for these upper laminites did we find negative correlations with some of the other taxa: G. *apertura,* G. *obliquus,* G. *elongatus,* G. *falconensis* and G. *glutinata.*

The first laminites in Sicily are found from approximately the reappearance level of G. *crassaformis* upwards. They are dominated by and correlated with G. *bononiensis* only (lower part section Punta Piccola). The faunas in the contemporaneous strata in Crete are already dominated by G. *bulloides* and *Neogloboquadrina.*

The laminites of the upper half of the G. *crassaformis* Zone in Sicily are distinctly different (no Cretan data for this part of the Pliocene are available). In the upper half of the Punta Piccola section the peak frequencies of *G. bononiensis* have disappeared and *Neogloboquadrina* seems to become more frequent. In this part of the section, however, *G. trilobus* appears to be the only species with a positive correlation with the laminated sediments.

In the Calabrian Vrica section (*G. inflata* Zone) the fauna in the laminites is distinctly dominated by *Neogloboquadrina*, *G. bulloides* and *G. inflata*. Only in this Italian section did we find some taxa (*G. falconensis* and *G. glutinata*) having negative correlations with the laminites.

Besides several differences, there seems to be a parallel succession in the faunas of the Cretan and of the Italian laminites. The formation of the lowest laminites in both areas corresponded with no faunal response or with a limit-

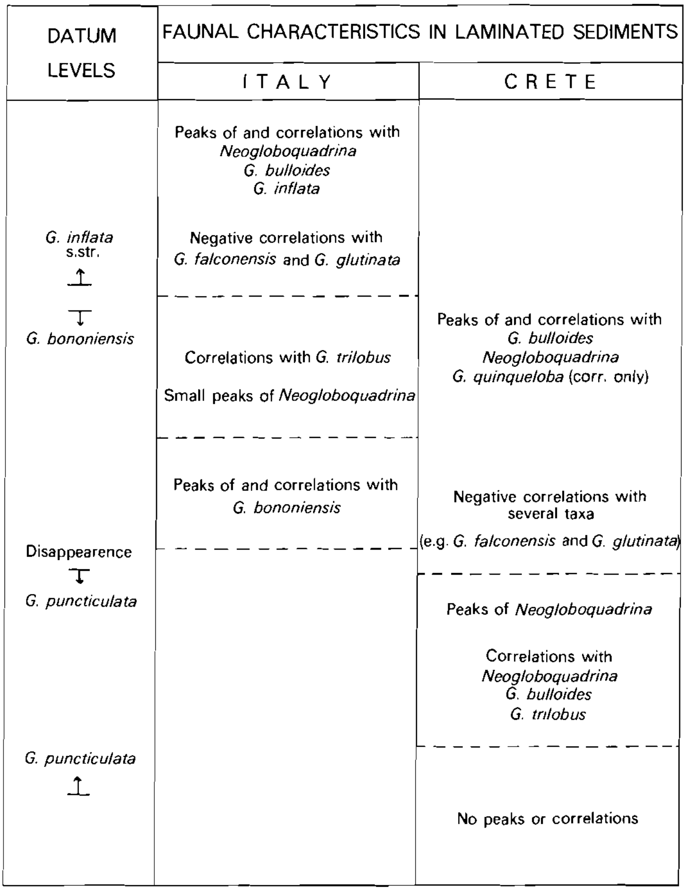


Fig. 49 Changes in the faunal characteristics in the laminated sediments of Italy and Crete.

ed correlation only (*G. bononiensis* in Sicily). Thereafter the laminite-bound faunas are characterized by large numbers of *Neogloboquadrina*, while *G. trilobus* is positively correlated with the laminations. In addition *G. bulloides* attains large numbers in the laminites in Crete. The faunas from the upper laminites of both areas are dominated by *G. bulloides* and *Neogloboquadrina* (in Italy in combination with *G. inflata*), while several taxa have a negative correlation with these laminites.

Summarizing, the laminite-bound faunas of both areas show an increase of the effect of the processes that led to the laminite formation. In addition, they point to a succession of similar conditions in both areas; each stage of this succession occurred earlier in Crete than in Italy.

Other differences between Cretan and Italian laminites

In Italy *G. bononiensis* and *G. inflata* show positive correlations with the laminites; for Crete such correlations were not found. Here *G. bononiensis* has no more than a positive link with *G. quinqueloba* and *Neogloboquadrina* (with the latter in section Finikia only); these two taxa however do have a positive correlation with the laminated sediments. These relations still give the impression that laminite-formation had a similar connection with the members of the *Globorotalia inflata* group in both areas, but that the effect was much stronger and more distinct in Italy. The last part of this conclusion may be false however; the difference may be an artefact of the computer analysis because the Cretan sections do not reach the exit level of *Globorotalia bononiensis* and the *G. inflata* Zone is not represented at all.

In the western part of the Mediterranean the *G. inflata* group is more numerous than it is in the eastern part; this difference may be seen as the consequence of the west-east temperature and especially nutrient gradients in the Mediterranean. This gradient may also be in part responsible for the positive correlation of the *G. inflata* group with the Italian laminites only. Even in periods of laminite-formation the nutrient level in the Cretan region would have been too low for the *G. inflata* group to proliferate.

In our Cretan material *G. quinqueloba* is rather scarce but it shows a distinct positive correlation with the laminites. In the Italian sections, in which *G. quinqueloba* is fairly numerous, no such clear positive correlation was found. In this context it is remarkable that *G. bulloides* reaches larger peak frequencies in the Cretan laminites (up to 70%) than in the Italian ones. We may speculate that these larger peak frequencies reflect stronger effects of the process of laminite-formation (assumedly salinity fluctuations) in the Cretan basins, which in this area caused the positive correlation with yet another tolerant taxon (*G. quinqueloba*).

Significant negative correlations of *G. apertura*, *G. obliquus* and *G. elongatus* with the laminites are found only in our Cretan material. Negative correlations of the laminites with *G. falconensis* and *G. glutinata* are found in both regions, but they occur in Italy in a later part of the Pliocene (*G. inflata* Zone) when *G. apertura* and *G. obliquus* are already very scarce. However, *G. elongatus* is numerous in the *G. inflata* Zone in Italy, but no negative correlation was found either. The confinement of so many negative correlations to Crete is probably not due to overall Pliocene frequency changes such as the frequency drop of *G. apertura* and *G. obliquus*, but to differences between the Italian and Cretan environments.

The nutrient concentration must have been lowest in the eastern part of the Mediterranean while periods of laminite-formation (partly) correspond to more fertile conditions. In a previous section we have seen that *G. apertura*, *G. obliquus* and *G. elongatus* are tolerant of oligotrophic waters. Therefore the negative correlations of these taxa with the laminites are probably the result of their relative increase in the eastern Mediterranean under oligotrophic conditions prevailing during periods of homogenous sedimentation. Apparently the conditions in between periods of laminite-formation were less oligotrophic in the western Mediterranean.

Summarizing, the differences between the Cretan and Italian laminites seem to be related with the west-east gradients in the Mediterranean. The more fertile conditions in the western part, especially at times of laminite-formation, limited the large numbers of the *G. inflata* group to our Italian material and caused the positive correlation of the group with the laminated sediments. On the other hand taxa like *G. elongatus* could thrive better than other species under the more oligotrophic conditions in the eastern Mediterranean, present during the periods in between laminite-formation.

Distribution and sedimentary features of the laminites

Laminated sapropelitic sediments are found in the Mediterranean from the Middle Miocene upwards in DSDP Sites (Kidd et al., 1978) as well as in land sections (e.g. section Giammoia, Sicily). The distribution of the laminites is fairly well documented from the Miocene-Pliocene boundary upwards. In the eastern Mediterranean these sediments occur regularly in the deeper parts of the basin (Kidd et al., 1978) as well as in marginal areas (e.g. the Cretan basins). However, in the western Mediterranean Pliocene laminites are present in a relatively shallow, marginal area only, close to the eastern part (Caltanisetta basin, Sicily). In addition they are regularly present just from the *G. crassaformis* Zone upwards.

The number of data concerning the deeper parts of the Mediterranean Miocene is limited (Kidd et al., 1978). Yet in combination with the data from land sections they give the impression that the distribution of the Miocene laminites is comparable with the Pliocene distribution. The Miocene laminites seem to occur in the entire eastern Mediterranean, whereas they seem to be restricted to the marginal areas of the western basin (e.g. Spain, Sicily).

In the deeper parts of the eastern Mediterranean no laminated sapropelitic layers were found between the disappearance levels of *G. margaritae* and *Sphaeroidinellopsis* (Kidd et al., 1978), whereas laminites are continuously present in our Cretan marginal basins of this stratigraphic interval. Evidently laminated sediments are more frequent in the marginal areas of the Mediterranean than in the central deeper parts. This observation may be supported by the fact that in a composite section of our marginal Pliocene sediments at least 96 alternations of laminated and homogeneous sediments were found, whereas a maximum of 41 sapropelitic layers is reported from the deeper parts of the basin (Kidd et al., 1978). However, it is uncertain whether the latter record is complete.

The second conclusion which can be drawn from the distribution of the laminites is that they are more frequent in the eastern Mediterranean, at least from the lowermost Pliocene upwards. This is probably related to the fact that the eastern Mediterranean was subdivided into a large number of subbasins, separated by sills (cf. the Cretan situation). Such a subdivision was not present in the western Mediterranean (e.g. Sicily).

Since the configuration of the Cretan basins was more favourable for the creation of a stratified water-column and of laminites, processes may have had a stronger effect in the Cretan basins. This would explain why laminites were formed earlier in the Pliocene of Crete and why the effect of the process of laminite-formation at a given time was stronger here than in Sicily.

Sedimentological analyses of the Cretan Pliocene sections show higher percentages of insoluble residue of the pelite fractions in the laminated sediments, while in brown laminites thin sand layers are occasionally intercalated (Jonkers, in prep.). Especially for the brown laminated sediments this relation may indicate that during periods of laminite-formation a larger supply of clastics took place. Particularly since it is unlikely that carbonates were removed because solution-susceptible taxa like *G. obliquus* and *Orbulina universa* were not affected. For diatomaceous sediments, however, such high pelite percentages may reflect an increase of organic siliceous material too.

The cause of the lamination

There is a consensus that the laminites are the consequence of an oxygen deficiency at the bottom, which was caused by a stratification of the water-column and/or by an extremely high organic production.

The Pliocene faunas indicate that during periods of laminite-formation the nutrient concentration (and probably the organic production) was indeed relatively higher because many laminites show peak frequencies of and positive correlations with *Neogloboquadrina*, *G. bulloides* and the *G. inflata* group, and negative correlations with for instance *G. elongatus*. We cannot tell definitely from these data whether organic production in the surface waters was sufficiently high to cause oxygen deficiency at the bottom but this is unlikely (see below).

There is strong evidence that stratification played an important role. For instance the faunas from the oldest laminated intervals (especially in Crete) do not show any frequency reaction in combination with the process of laminite-formation, whereas it is well known that such a reaction often appears in areas where the nutrient level is very high. These older laminites indicate that stratification must have been the dominant factor causing the laminations. Another clue to the prevailing role of stratification is the fact that laminites are widespread throughout the eastern Mediterranean and are less frequent in the western basin. Since organic production is (and was) distinctly larger in the western Mediterranean the larger numbers of laminites in the east must have been caused primarily by a good stratification of the water-column.

If the prevailing role of stratification is accepted, one wonders which phenomenon caused this stratification. The frequency pattern of the successive Pliocene faunas does not give an unambiguous answer to this question. The negative correlation of *G. glutinata* with the higher laminites might suggest that the salinity values in the top part of the water-column were lower during laminite-formation than in the periods corresponding to the homogeneous sediments. This would fit in with the negative correlation of *G. falconensis* and the laminites and the dominance of nutrient-dependent but salinity-tolerant taxa in the laminites.

The isotopic data of Pleistocene sapropels (Vergnaud-Grazzini et al., 1977; Williams et al., 1978) and of Upper Miocene laminites (Van der Zwaan, 1982) point to the existence of a more pronounced vertical salinity gradient during laminite-formation; the isotopic data of the Pliocene laminites (Jonkers, in prep.) indicate this too. Together these data suggest that a stronger vertical salinitity and density gradient was probably responsible for the stratification.

Summarizing, we have to look for a process that caused a large number of alternations in water-mass conditions; it must be one which can create a stratified water-column through the increase in the vertical salinity gradient.

For the formation of Quaternary and Upper Miocene laminites different models have been proposed in which a strong vertical salinity gradient and stratification play an important role.

Run-off model. The Quaternary laminated sapropelitic sediments are thought to have been caused by periodically increased run-off from the surrounding landmasses. Melt-water from the European continental ice-sheet at the beginning of an interglacial period is considered to have caused an important increase in the run-off (Vergnaud-Grazzini et al., 1977; Williams et al., 1978); this water seems to have entered the Mediterranean mainly via the Black and Aegean Seas. Some of the Quaternary sapropels, however, seem to have no correspondence with the beginning of interglacial periods (Thunell et al., 1977); these laminites seem to be related with smaller scale climatic fluctuations, probably more humid periods.

Atlantic-inflow model. A periodically more vigorous inflowing current from the Atlantic is thought to be responsible for the Tortonian-Early Messinian laminites (Van der Zwaan, 1982). In combination with a shallow or narrow Atlantic-Mediterranean connection such a process would have obstructed or hindered the outflow of denser water. Such vigorously inflowing Atlantic surface water would have penetrated far eastwards to the silled basins of the eastern Mediterranean as a more or less discrete surface layer, with still very much of its original, Atlantic properties and thus would have caused stratification. As inflow of the Atlantic surface water is the normal situation throughout, the alternation of conditions must be related with variations of the strength of the inflow. In this context we can think of general sea level fluctuations or of a relation with climatic fluctuations, causing stronger and weaker evaporation.

If the latter relation is valid it is important to realize that in the Atlantic inflow model the laminations would have been formed during dryer periods with strong evaporation, whereas in the run-off model laminites can be expected during more humid intervals. If sea level fluctuations controlled the Atlantic inflow, the effects of both models could have been roughly synchronous.

In addition to the good stratification, both models explain the higher nutrient concentration during periods of laminite-formation, especially in the eastern Mediterranean; nutrient-rich water from the continent or more fertile Atlantic water possibly enriched for the eastern basins by upwelling processes at the central Mediterranean sills (cf. Van der Zwaan, 1982).

If we accept the Atlantic-inflow model as being correct for the Late Miocene and the run-off model for the Quaternary, it is realistic to assume that one or both of these processes was/were responsible for the formation of the

Pliocene laminites. Either all Pliocene laminites were caused by one of the two processes or some were formed by a process of run-off, others by Atlantic inflow. It is conceivable that some of the Pliocene laminites were formed by an Atlantic-inflow process and others by increased run-off in irregular succession but it is also possible that during the Pliocene the process of run-off replaced the process of Atlantic-inflow.

Concentrating on the option that both processes played a role during the Pliocene, we may wonder whether we can recognize such different processes in the laminite-bound faunas. As both processes are thought to create similar conditions, this seems to be very difficult. If we bear in mind that the environmental conditions in two periods of laminite-formation were never exactly the same, we may even expect that small faunal differences exist between laminites that were formed by the same process. In fact fairly similar combinations of taxa dominate, or are correlated with, the laminites of the Upper Miocene (Van der Zwaan, 1982), the Pliocene (this paper) and the Quaternary (Thunell et al., 1977; 1979; Williams et al., 1979)!

The laminite-bound faunas from the Pliocene show a certain time-bound change. It points to run-off taking over from a process of Atlantic-inflow rather than to a co-occurrence of these processes throughout the Pliocene. If such a take-over actually took place during the Pliocene it is most likely to have happened at the beginning of or during the *G. crassaformis* Zone. During this zone the faunal composition starts to resemble the Quaternary and modern one (cf. chapter 8).

A change in the process of laminite-formation may be traced in the faunas from the Cretan laminites, which occur prior to and during the *G. crassaformis* Zone. The laminites below the entry level of *G. puncticulata* lack a faunal response; this fact is difficult to understand for any process that creates alternating conditions of different water-masses. Perhaps this lack of response can be understood better in an Atlantic-inflow model than by a process of run-off. An alternating more or less pronounced Atlantic influence could still bring sufficient Atlantic water in the eastern Mediterranean, so that the environments in the upper water-masses in this part of the basin did not change drastically. Furthermore the positive correlation of *G. trilobus* with the laminites below the *G. puncticulata* exit, is also present in some laminites of the Upper Miocene. Such a correlation is not found with laminites from the *G. crassaformis* Zone and it has not been mentioned for the Quaternary sapropels. These characteristics seem to point to conditions that were different before and during the *G. crassaformis* Zone. In Crete run-off might have started its predominant role during the deposition of the *G. crassaformis* Zone. Faunas from the Sicilian laminites, however, present from the *G. crassaformis* Zone upwards, still indicate conditions similar to the Cretan ones below the *G. puncticulata* exit! This would imply that while the process of run-off was taking over in Crete, variations in the inflow from the Atlantic were only starting to have an effect on the faunas in Sicily.

Except in the lowermost laminites, the process leading to lamination did cause a faunal response in Crete; the younger laminites show positive correlations with *Neogloboquadrina* and *G. bulloides.* First *Neogloboquadrina* and later *G. bulloides* attain very large numbers in the laminites, already from a level below the *G. puncticulata* exit. This pattern points to a process with an increasing effect on the fauna rather than to two different processes, or to a gradual replacement of one process by another.

In summary, if a change in the processes of laminite-formation took place in the course of the Pliocene, this probably happened at the beginning of the *G. crassaformis* Zone. However, in our opinion the variations in the laminite-bound faunas can best be explained by a single process which had an increasing effect on the fauna.

If a single process is responsible for the formation of all Pliocene laminites, we have to discuss the feasibility of run-off versus Atlantic-inflow. The laminite-bound faunas themselves cannot give sufficient evidence for a choice between these models. Therefore we shall review the feasibility of these two models in the light of other observations.

The continuously present west-east gradients in the Mediterranean would fit in very well with the Atlantic-inflow model. Since laminites can be formed under low as well as high temperature conditions, they probably have a connection with alternations of dryer and more humid conditions. An increasing temperature, as reconstructed for the Pliocene (cf. chapter 6), would have made evaporation stronger during dryer periods in the younger part of the Pliocene and thus enhanced the processes of Atlantic-inflow. This could explain the stronger impact on the younger faunas. Yet the accentuation of the local basin configuration in the course of the Pliocene may be responsible for the stronger effect of any process on the later faunas as well.

The negative correlation of the higher Cretan laminites with taxa like *G. elongatus* indicates that during intervals of homogeneous sedimentation the surface waters of the Cretan basins became less fertile during the younger part of the Pliocene. Possibly the influence of the relatively fertile Atlantic water in the eastern Mediterranean diminished in general. One may wonder whether in such a situation the Atlantic inflow in between periods of homogeneous sedimentation brought in enough nutrients for the species we see proliferating. So we start to think of an alternative explanation. Apparently during dryer periods the regular input of nutrients decreased, whereas a more considerable input took place during the periods in between. Such a set of conditions is more in line with a process of precipitation and run-off.

Run-off which occurred mainly in the eastern Mediterranean seems to be difficult to reconcile with the west-east gradients. Yet reconstructions of the Quaternary Mediterranean show that there were distinct west-east gradients together with a wedge of cooler, less saline and originally fresh water in the Aegean and adjacent eastern Mediterranean (Thiede, 1978; 1980; Thunell, 1979). Apparently such conditions did occur simultaneously. The temperature does not seem to have played an important role; during the Quaternary sapropels were also formed during relatively warm interglacial intervals (Thunell et al., 1977). An overall increase in the intensity during the Pliocene as pointed out for the Atlantic-inflow process can be reconstructed for a run-off process as well.

Summarizing, the Atlantic-inflow model fits in very well with the west-east gradients and the temperature increase could account for a stronger impact of this process during the younger Pliocene. Neither these gradients nor the temperature increase make us reject the run-off model, however.

The higher pelite percentages in the laminated brown beds are thought to be indications of an increase of erosion and run-off. Also the concentration of the laminites in the marginal areas and the fact that these laminites are almost restricted to the eastern Mediterranean favour the choice of a run-off model.

We are inclined to believe that a change from a process of Atlantic-inflow to a process of run-off did not occur sometime during the Pliocene. If we assume that these processes were responsible for the laminite-formation during the Late Miocene and during the Quaternary, respectively, such a change must have taken place either at the Miocene-Pliocene boundary or near the Pliocene-Pleistocene boundary. According to our lithological and faunistic data no event of special importance took place near the Pliocene-Pleistocene boundary, whereas the Atlantic-Mediterranean connection changed drastically at the Miocene-Pliocene boundary.

If we look at the recent inflow and outflow pattern through the Straits of Gibraltar (Perry and Walker, 1977; Bethoux, 1979) only 4% of the inflowing water is used to compensate the loss of water by excess evaporation; the rest is compensation for the outflow. The Straits of Gibraltar are over 300 metres deep and the inflow takes place approximately in the upper 150 metres. It would seem that under the recent configuration even a strong increase in evaporation or a considerable lowering of the sea level could not create a more vigorous inflow that would obstruct the outflow. In addition, a shallow or narrow Atlantic-Mediterranean connection seems to be an absolute condition for an Atlantic-inflow model. Such a poor connection was present during the Late Miocene but not during the Pliocene. This seems to rule out the Atlantic-inflow model as a possible explanation for the repeated stagnations during the Pliocene.

Although several of our data are difficult to reconcile with a process of periodically increased run-off, we are inclined to think that such a process is the most likely one responsible for the laminite formation during the entire Mediterranean Pliocene.

Chapter 8

DEVELOPMENT OF THE MEDITERRANEAN AND ADJACENT ATLANTIC DURING THE PLIOCENE

THE MEDITERRANEAN PLIOCENE IN A WIDER PERSPECTIVE

As the earth's history neither starts nor ends in the Pliocene, one should regard the environmental evolution of the Mediterranean Pliocene within the framework of the Neogene to Recent development of the Mediterranean and adjacent Atlantic.

The main event which puts its mark on the Neogene to Recent environments is the large-scale climatic deterioration culminating in the Pleistocene glaciations. In the planktonic foraminiferal faunas this event is reflected by changes in the position of various bioprovinces. "Warm water" taxa (e.g. *Globorotalia menardii*, *Globoquadrina* spp., *Sphaeroidinellopsis* spp.) disappeared from the north-east Atlantic from the Middle Miocene onwards, whereas along the western margin these taxa remained present up to approximately the Middle Pliocene (Poore and Berggren, 1974; 1975b; Cifelli, 1976; Cifelli and Glaçon, 1979). These distributions point to a southward displacement of the gyral core, especially from the Middle Pliocene onwards (cf. Cifelli and Glaçon, 1979). In addition they indicate the presence of a "Gulf Stream-Canary Current"-like system in the North Atlantic since the Middle Miocene.

Superimposed on this general climatic deterioration distinct climatic fluctuations took place. For instance the Late Miocene seems to be characterized by distinctly cooler conditions at higher latitudes (e.g. Loutit and Kennett, 1979). Although this cooling had only a limited effect on the circum-Mediterranean climate, it may have played a role, in combination with the basinal setting, in creating the salinity crisis in the Mediterranean towards the end of the Miocene (e.g. Van der Zwaan, 1982).

With the onset of the Pliocene the good Atlantic-Mediterranean connection, which had deteriorated during the Messinian, was re-installed and has remained present ever since. The relatively warm and presumably dry Mediterranean climate of the Messinian was followed by warm but more humid conditions, as indicated by a pollen-analysis from the western Mediterranean (Cravatte and Suc, 1981). For the later part of the Pliocene a dryer steppen flora was reconstructed. Notwithstanding these fluctuations, during most of the Neogene the Mediterranean seems to have been situated, as it is today, in a rather dry climatic belt.

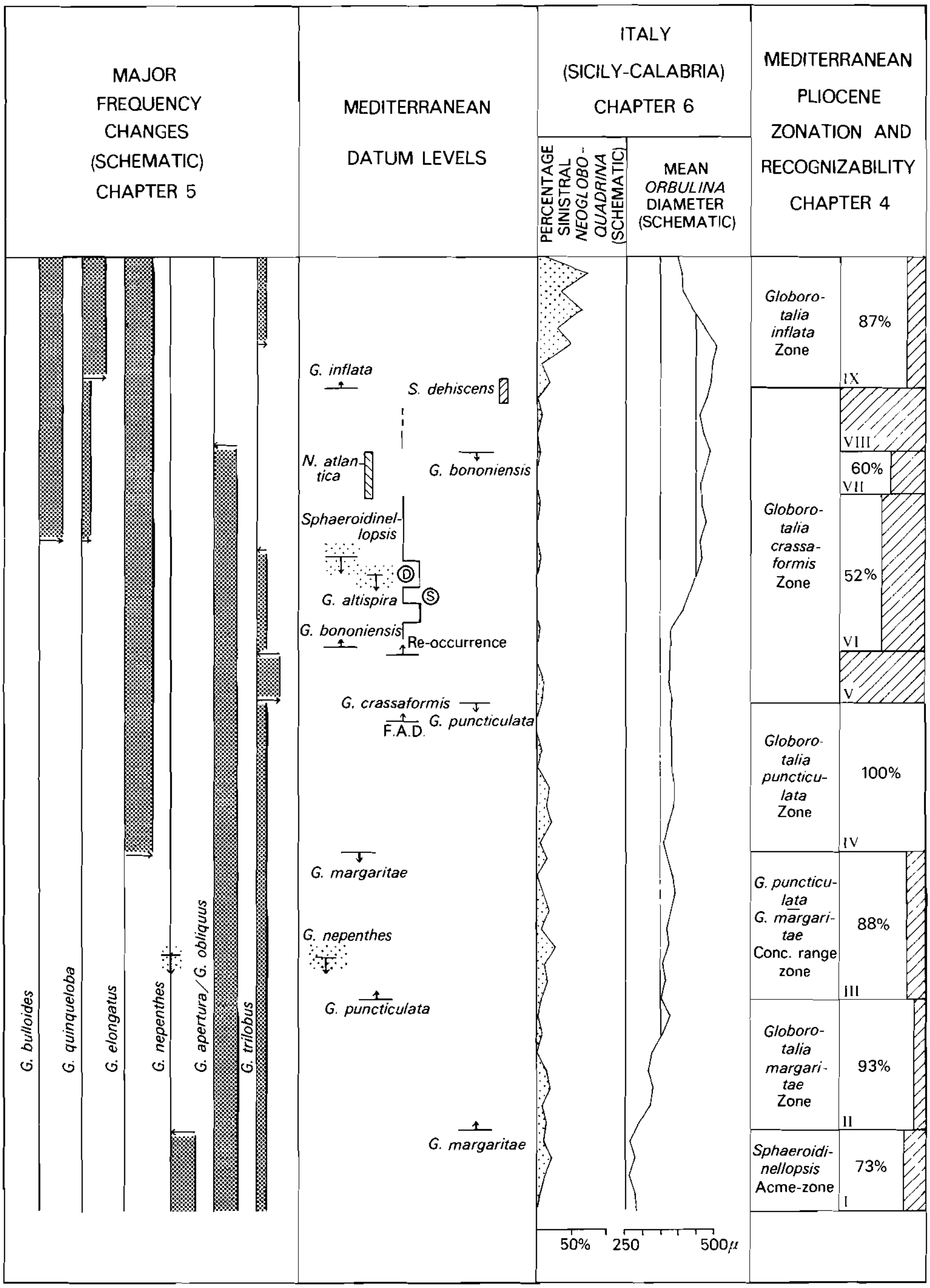


Fig. 50 Review of the Mediterranean data.

Under the climatic conditions of today evaporation exceeds precipitation and run-off in the Mediterranean and in addition there is a considerable outflow. This deficit is compensated by a continuous inflow of Atlantic surface water. This inflowing water, transported to the Straits of Gibraltar by the Canary Current, is relatively cool, of normal salinity and rich in nutrients. As it proceeds into the Mediterranean this water becomes warmer, more saline and oligotrophic (e.g. Zeitsel, 1978). Similar conditions are to be expected, and in fact have been reconstructed, for the Pliocene Mediterranean (cf. chapter 5).

FACTORS CONTROLLING THE MEDITERRANEAN FAUNA DURING THE PLIOCENE

Laminite-formation. From the Middle Miocene upwards laminated sediments are regularly present in the Mediterranean, especially in the eastern part. During the Pleistocene, a process of increased run-off seems to have been responsible for the laminite-formation (Vergnaud-Grazzini et al., 1977; Thunell et al., 1977; Williams et al., 1978). On the other hand a narrow Atlantic-Mediterranean connection in combination with variations in the inflow-outflow ratio are thought to have played an important role in the formation of most laminites of the Upper Miocene (Van der Zwaan, 1982). For the entire Pliocene, however, it is most likely that a process of periodically increased run-off was responsible for laminite-formation (cf. chapter 7).

Whatever process caused the laminites their formation had a distinct impact on the faunal composition; usually these faunal changes reflect fluctuations in the nutrient content and sometimes they indicate lower salinity values during periods of laminite-formation than in the intervals in between. Finally, the regular alternation of homogeneous and laminated sediments seems to point to a large number of small-scale climatic fluctuations superimposed on the general climatic trend.

West-east gradient. In addition to the impact of the process of laminite formation on the Mediterranean fauna, differences can be observed between the Cretan and Italian faunas throughout the Pliocene (e.g. in the number of *Globorotalia* specimens; the diameter of *Orbulina,* cf. chapter 5 and 6). These differences are caused by the west-east nutrient, temperature and salinity gradients in the Mediterranean.

Climatic deterioration. If we look carefully at the vertical successions of the Mediterranean faunas during the Pliocene (fig. 50) we can recognize the effect of the southward migration of bioprovinces along the eastern side of the Atlantic. Apart from some (short-lasting) re-appearances, "warm water" taxa (*Globigerina nepenthes*, *Globorotalia margaritae*, *Globoquadrina altispira*, *Sphaeroidinellopsis* spp.) disappear from the Mediterranean record, whereas the more temperate *Globorotalia inflata* group enters. The frequency pattern of the Mediterranean fauna also seems to reflect the large-scale climatic deterioration, especially in the interval of the *Globorotalia crassaformis* Zone (cf. chapter 5). Taxa like *Globigerina bulloides* and *Globigerina quinqueloba* become relatively more numerous, whereas the sum of the "warm water" taxa (e.g. *Globigerinoides obliquus* c.s.; cf. chapter 5) decreases. Together these data point to a change from a fauna with a distinct tropical-subtropical label to a fauna with a mixed (temperate-subtropical) character, a composition that closely resembles the modern Mediterranean one.

Another factor which influences the fauna is the temperature of the Mediterranean water. The water temperature seems to affect the *Orbulina* diameter and it may have something to do with the percentage of *Neogloboquadrina* with sinistral coiling (cf. chapter 6). From the lowermost Pliocene up to a level above the entry of *G. inflata* s.str. the temperature of the Mediterranean water seems to have increased. For the uppermost Pliocene a temperature decrease can be concluded.

It is remarkable that parallel to this temperature increase, the Mediterranean fauna obtained a more and more temperate composition. Apparently the southward migrations of faunas, especially along the eastern side of the Atlantic, did not coincide with a decrease in water temperature in the Mediterranean. The faunal composition in the Mediterranean seems to be influenced by the composition of the Atlantic fauna near the Straits of Gibraltar and to a lesser extent by the water temperatures in the Mediterranean itself. These water temperatures in the Mediterranean seem to be rather independent of the conditions in the eastern Atlantic. Cool Atlantic water which entered, warmed up quickly as it proceeded into the Mediterranean and it did not affect the temperature at some distance from the entrance.

This buffer capacity of the Mediterranean may also account for the limited reaction in the frequency curves at various entry and exit levels, especially in the lower part of the Pliocene.

CAPE BOJADOR: THE ATLANTIC DEVELOPMENT

It may be clear from the previous section that migrations of bioprovinces in the Atlantic, under the influence of the Canary Current, had an important effect on the Mediterranean fauna. Although Cape Bojador is situated at a considerable distance south of the Straits of Gibraltar, it lies in the path of the East Atlantic boundary (= Canary) Current. Consequently our data from

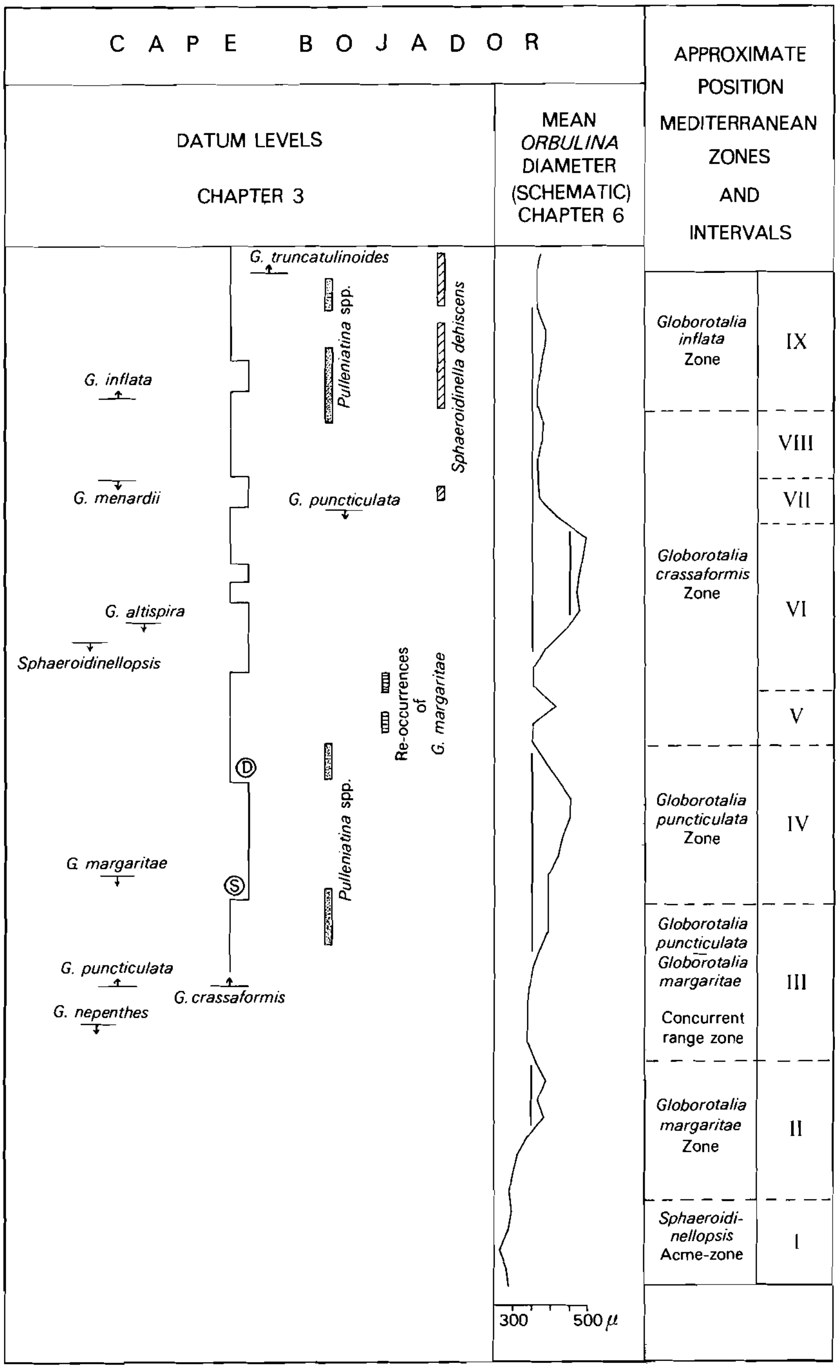


Fig. 51 Review of the data from Cape Bojador.

this site give an impression of the history of the Canary Current during the Pliocene. These data are summarized in fig. 51, together with the approximate position of the Mediterranean zonation (cf. chapter 3; Spaak, 1981b).

Notwithstanding the correlation problems, the successive disappearances of "warm water" taxa like *G. nepenthes, G. margaritae, Sphaeroidinellopsis, G. altispira* and finally of *G. menardii* and the appearance of the *G. inflata* group (and *G. crassaformis*) fit in very well with the general southward migration of bio-provinces. Although the Cape Bojador fauna gradually lost part of its tropical character during the Pliocene, the water temperature, as indicated by the *Orbulina* diameter (figs. 33, 51), increased. Apparently the southward migration of taxa was not directly linked with lower temperatures at Cape Bojador in the early part of the Pliocene either. From approximately the disappearance levels of *G. menardii* and *G. puncticulata* upwards *Orbulina* size and thus the temperature were lower. The lower temperatures started distinctly earlier at Cape Bojador than in the Mediterranean.

The sudden drop in temperature indicates that either the intensity of the Canary Current increased and cooler water was transported further to the south or that the Gulf Stream-North Atlantic Drift System migrated southwards. The conclusion that the whole current system migrated is based on the southward migration of "warm water" taxa along the western side of the Atlantic during the Middle Pliocene (Poore and Berggren, 1974; Bolli and Krasheninnikov, 1977). The initiation of the Labrador Current in the Middle Pliocene (Berggren and Schnitker, 1981) may have played an important role in connection with this migration, which in turn is thought to have increased the influence of the Canary Current at Cape Bojador.

If the whole current system did migrate it must have been the result of a cooling phase with a magnitude distinctly more important than the one in the Late Miocene, at least in the North Atlantic region. The cooling in the Late Miocene does not seem to have had such a large impact on the North Atlantic fauna, although it probably caused the entry of *Globorotalia conomiozea,* the extinction of *G. menardii* and possibly the low numbers of *G. nepenthes* in the Late Miocene Mediterranean. But in the north-west Atlantic no faunal changes occurred.

In the North Atlantic there are indeed indications that there was considerable cooling during the Middle Pliocene from a strong increase in land-ice formation (McDougall and Wensink, 1966) and in ice-rafted material (Poore and Berggren, 1975b). In the North Pacific too an extension of cooler water-masses occurred during the Middle Pliocene (Keller, 1979), which may indicate that this cooling was rather general and important.

The time-lag between the onset of the lower temperatures at Cape Bojador and in the Mediterranean reveals that this cooling phase affected the water in the North Atlantic and the Canary Current earlier than the water in the isolated Mediterranean.

Summarizing we can make a fairly detailed reconstruction of the North Atlantic current system during the Neogene. From the Middle Miocene onwards a Gulf Stream-Canary Current system was present in the Atlantic. Climatic deterioration had its influence on the Canary Current causing a southward migration of bioprovinces along the eastern side of the Atlantic. However, the central water-mass remained stationary, while "warm water" faunas occurred at high latitudes on the western side of the Atlantic.

This situation remained stable up to the Middle Pliocene, although the intensity of the Canary Current varied. During the Late Miocene cooling the influence of the Canary Current increased, causing the entry of for instance the temperate *G. conomiozea* (possibly the predecessor of the *G. inflata* group) in the Mediterranean.

During a large part of the Pliocene the temperatures in the Mediterranean and at Cape Bojador region increased again (*Orbulina*-diameter) and at first the intensity of the Canary Current decreased (entry of *G. margaritae* and of large numbers of *G. nepenthes*). However, notwithstanding the trend of increasing temperatures in this region, the influence of the Canary Current soon increased again (e.g. entry *G. inflata* group, exit *G. margaritae*) which culminated in the southward migration of the Gulf Stream-North Atlantic current system.

In the latest Pliocene the influence of the Canary Current probably diminished a little (entry of *Sphaeroidinella dehiscens* and *Globorotalia truncatulinoides*). However, the overall cooling which started in the Middle Pliocene was apparently the beginning of the final temperature decrease leading to the Pleistocene glaciations. It caused the low temperatures at Cape Bojador and shortly afterwards in the Mediterranean as well, while the Gulf Stream-North Atlantic Drift System remained in its new southern position.

THE GLOBOROTALIA CRASSAFORMIS ZONE: INTERVAL OF MAJOR CHANGES

In the Mediterranean Pliocene the largest number of entries and exits occur in the *G. crassaformis* Zone, i.e. between the disappearance level of *G. puncticulata* and the appearance level of *G. inflata* s.str. Many Pliocene frequency changes are found in this zone as well (cf. chapter 5). Evidently the major changes in the Mediterranean Pliocene fauna took place during the time span of the *G. crassaformis* Zone.

In the previous section we have seen evidence of a notable southward migration of the North Atlantic current system. This happened in the middle part of the Pliocene as a result of a distinct overall cooling phase. Although the exact stratigraphic position of this migration is difficult to pinpoint in the Mediterranean zonal scheme, it must have coincided with some part of the *G. crassaformis* Zone. The frequency changes in the Mediterranean fauna and the disappearances of *Sphaeroidinellopsis* and *G. altispira* may very well have been caused (directly or indirectly) by this southward migration and cooling. The Mediterranean water itself, however, probably did not cool until after the entry of *G. inflata* s.str. One can speculate that the southward migration caused irregularities in the current system itself. As the presence of several taxa in the Mediterranean is distinctly dependent on the Atlantic distribution of these taxa, such irregularities may account for the discontinuous record of the *G. inflata* group and *G. crassaformis* in this zone.

As a result of several changes the *G. crassaformis* Zone can be subdivided into four or even six subzones (cf. chapter 4); but due to the negative (absence) character of many changes the recognizability of these subzones (intervals) is poor, however.

The most conspicuous of these negative features are the major absence intervals of the *G. inflata* group at the beginning and the end of the *G. crassaformis* Zone (intervals 5 and 8). In between these absence intervals the group is more regularly, but still discontinuously, present.

The fauna in the first absence interval reveals an increase of the "tropical" influence (high percentages of *G. trilobus*, cf. chapter 5) in the Mediterranean, which would fit in with the absence of the "cool" *G. inflata* group. However, at Cape Bojador the group is continuously present in this part of the Pliocene. In the recent North Atlantic *G. inflata* is found mainly in the boundary currents around the central water-mass (Gulf Stream and Canary Current). This suggests that during the absence interval the "central" part of the Canary Current dit not flow close to the Straits of Gibraltar but flowed further to the west. It was rather "weak" and may have allowed the central Atlantic water-mass fauna to reach the Mediterranean. On the other hand one can speculate that the absence-presence pattern of the *G. inflata* group was caused by a patchy distribution of the group in the Atlantic, which would also have allowed the "warm" Atlantic fauna to reach the Mediterranean.

In between the major absence intervals of the *G. inflata* group the influence of the Canary Current increased but its position shifted regularly. *Sphaeroidinellopsis* and *G. altispira* disappeared from the Mediterranean and from Cape Bojador and *G. trilobus* became extremely scarce. In addition the *G. inflata* group became discontinuously present in the Mediterranean.

In the Mediterranean fauna a distinct influx from the northern part of the Atlantic (*Neogloboquadrina atlantica*) is present near the beginning of the second absence interval. In contrast to the previous absence interval no "tropical" influence can be found; on the contrary in several samples *G. trilobus* is entirely absent and *G. apertura* and *G. obliquus* show a frequency drop. The absence of the *G. inflata* group again suggests that the major part of the Canary Current flowed at a considerable distance from the Straits of Gibraltar, but now the current seems to have been stronger as it obstructed the entry of water from the central water-mass into the Mediterranean and it seems to have had a distinct influence at Cape Bojador as well. Here the water temperature dropped (*Orbulina* diameter) and *G. menardii* disappeared from the fauna. Yet, it is remarkable that *G. inflata* is not present at Cape Bojador either. Possibly the Canary Current flowed parallel to, but at a considerable distance from the African continent during this part of the Pliocene. A wedge of very cold water may have been present between the Canary Current and the European continent, causing the entry of *N. atlantica* into the Mediterranean. Such a wedge may have been responsible for the phenomena at Cape Bojador. Some data from this site (Diester-Haass, 1979) seem to indicate that there were more fertile conditions from some level between cores 25 and 21 upwards (cf. fig. 21; approximately the upper half of the *G. crassaformis* Zone). Diester-Haass interpreted these conditions as the result of an incipient or increasing upwelling process, such as is present off Africa today. One can speculate that in a cool period a wedge of cold water was present between the Canary Current and the European continent while simultaneously stronger trade winds caused a wide zone of upwelling separating the current from the African coast.

Of course this reconstruction of the position of Atlantic water-masses on the basis of the distribution of the *G. inflata* group is pure speculation. However, reconstructions of the Atlantic faunas and water-mass distribution for the cool periods corresponding to the Pleistocene glaciations (Cline and Hays, 1976; Crowley, 1981; Pflaumann, 1981) show similar variations in the position of the Canary Current, with cold (subpolar) water intruding along the European continent or occasional extensions of tropical water-masses in the direction of the Mediterranean. Of course one can argue that the Middle Pliocene cooling was not as vigorous as the Pleistocene glaciations, but the conditions during the Middle Pliocene seem to bear some resemblance to glacial intervals, also because the distribution of *Pulleniatina* shows a distinct parallel. During a Pleistocene glacial period (Prell and Damuth, 1978) *Pulleniatina* was found to be absent from the Atlantic, whereas it was continuously present in the Indo-Pacific. A similar pattern is present in the Middle Pliocene (cf. distribution of *Pulleniatina* at Cape Bojador, fig. 21; Bolli and Krasheninnikov, 1977; Krasheninnikov and Pflaumann, 1978; Brunner and Keigwin, 1981).

It can be concluded that the major changes in the planktonic foraminiferal fauna of the Mediterranean Late Neogene evidently coincided with the *G. crassaformis* Zone; these changes strongly overshadow the faunal change near the Pliocene-Pleistocene boundary.

Although the reconstruction of the details of faunal and water-mass patterns for the *G. crassaformis* Zone in the North Atlantic are speculative, the zone certainly corresponds to a major cooling. This cooling resulted in a southward migration of the entire North Atlantic current system. This shift therefore may account for the large number of datum levels and frequency changes in the Mediterranean and at Cape Bojador.

Chapter 9

TAXONOMIC NOTES

As mentioned in the first chapter we used an assemblage-based species concept. In this chapter we shall give an impression of the morphological variation observed in our assemblages, but no extensive taxonomic discussion.

The individuals of the first group of taxa (*Globigerina apertura, Globigerina nepenthes, Globigerinoides obliquus* and *Globigerinoides elongatus*) possess a spinose wall; the spine bases are connected so that a regular, cancellated pattern is present around the pores. The pores are situated in distinct pore-pits. The cancellated pattern may be obscured in later ontogeny by thickening of the wall (Zachariasse, 1978).

Globigerina apertura Cushman
Pl. 1, figs. 8–11

Globigerina apertura Cushman, 1918, U.S. Geol. Surv., Bull. 676, p. 57, pl. 12, fig. 8.

The highly arched aperture of *G. apertura* may have a pronounced rim (*G. decoraperta* type). The height of the trochospiral varies and there is variation in the tightness of coiling. Small rather tightly coiled specimens, resembling *G. rubescens*, occur in the assemblages all through the Pliocene, but they become more numerous in the upper part. Large, loosely coiled specimens are numerous in samples from laminated sediments. The latter are occasionally so loosely coiled that they have an additional aperture (*G. bulloideus* type), which makes differentiation from *Globigerinoides obliquus* very difficult. However, for our 200-counts these two taxa usually could be clearly discriminated by the more globose chambers and the large, highly arched aperture of *G. apertura.*

Globigerina nepenthes Todd
Pl. 1, figs. 1–7

Globigerina nepenthes Todd, 1957, U.S. Geol. Surv., Prof. Paper, no. 280-H, p. 301, pl. 78, fig. 7.

The specimens of the *G. nepenthes* assemblages are low-spired and (very) tightly coiled, so that the umbilical opening is extremely small or even absent. Usually a distinct apertural lip is present, and the final chamber(s) is (are) often protruding or twisted. Our assemblages include *G. nepenthes delicata* and *G. nepenthoides,* which have been discriminated because of the form and stage of wall thickening of the final chamber and because of less tight coiling, respectively.

G. nepenthes and small, tightly coiled specimens of the *G. apertura* assemblages look very much alike. For the 200-counts *G. nepenthes* could usually be clearly recognized by its lower spiral, its even tighter coiling (no umbilicus) and stronger secondary wall thickening. However, this resemblance means that the use of the last occurrence of *G. nepenthes* is less suitable for reliable detailed correlations.

Globigerinoides obliquus Bolli
Pl. 2, figs. 1–6

Globigerinoides obliquus Bolli, 1957, U.S. Nat. Mus., Bull. 215, p. 113, pl. 25, figs. 9, 10.

In the assemblages of *G. obliquus* the degree of oblique lateral compression varies from hardly present in the last chamber to very pronounced in several chambers (*G. extremus* type). The latter forms are never numerous in our material. The (usually) slightly extra-umbilical aperture may be large but it is never as highly arched as it is in *G. apertura.* Usually only one additional aperture is present; in some specimens, however, there are two apertures close together on the spiral side of the test. The additional apertures are occasionally obscured by strong secondary wall thickening. Yet most of these specimens could be labelled as *G. obliquus* instead of *G. apertura* owing to the less highly arched aperture and the oblique lateral compression of the chambers.

When tightly coiled specimens with just over three chambers in the final whorl are heavily encrusted it is difficult to differentiate between *G. obliquus* and *Globigerinoides elongatus.* We used the position of the primary aperture centered over the suture between the penultimate and antepenultimate chamber as the criterion for labelling such types as *G. elongatus.* The morphology of the tightly coiled specimens, especially those with two additional apertures, seems to be intermediate between *G. obliquus* and *G. elongatus,* suggesting that there was a gradual transition between the two species. However, assemblages dominated by such intermediate types, which meet to some extent the descriptions of taxa like *Globigerinoides bollii* and *Globigerinoides kennetti,* have not been found.

Globigerinoides elongatus (d'Orbigny)
Pl. 2, figs. 7–12

Globigerina elongata d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, tome 7, p. 277. (lectotype designated by Banner and Blow, 1960, Cush. Found. Foram. Res., Contr., vol. 11, p. 12).

Our assemblages are dominated by rather small, thick-walled specimens with occasional obliquely compressed chambers. The primary aperture is semicircular to loop-shaped. A variation towards specimens with more globose chambers and larger, more circular apertures (*G. ruber* type) is often present. Relatively large specimens with heavily encrusted test and strongly incised sutures, resembling *Globigerinoides conglobatus*, occur in our assemblages from the upper part of the Pliocene. High-trochoid forms are occasionally present all through the Pliocene.

Globigerinoides trilobus (Reuss)
Pl. 3, figs. 1–4

Globigerina triloba Reuss, 1850, K. Akad. Wiss., Math.-Natw., Bd. 1, p. 374, pl. 47, fig. 11.

Although basically having the same wall-structure as the previous taxa (spinose and cancellated) *G. trilobus* can be easily distinguished by its coarser and more pronounced cancellated pattern.

Differences in the tightness of coiling, in the size of the apertures, in the shape of the chambers (*G. sacculiferus* type) and in the wall-thickening are the main variations in our assemblages.

Sphaeroidinellopsis spp.
Pl. 3, figs. 5–11

The specimens of the *Sphaeroidinellopsis* assemblages usually have 3.5 to 4 chambers in the final whorl; the outline varies from rounded to oval. The test may be totally covered by a thick smooth cortex. As *Sphaeroidinellopsis* is probably a final growth stage of *G. trilobus*, it originally had a spinose cancellated wall structure (Bé, 1980). Occasionally this wall structure is still visible through the cortex, especially when the cortex is not fully developed. If the cortex is not distinct we used the presence of a crenulated apertural lip (which is part of the cortex if present) to discriminate *Sphaeroidinellopsis* from thick-walled *G. trilobus.*

Sphaeroidinella dehiscens (Parker and Jones)
Pl. 6, figs. 1, 2

Sphaeroidina bulloides d'Orbigny var. *dehiscens* Parker and Jones, 1865, Roy. Soc. London, Philos. Trans., vol. 155, p. 369, pl. 19, fig. 5.

This taxon has the same wall structure as *Sphaeroidinellopsis;* it occurs in our material from the Upper Pliocene only. There is no gradual and continuous transition from *Sphaeroidinellopsis* to *S. dehiscens.*

Globigerina bulloides, Globigerina falconensis and *Globigerinella aequilateralis* also have a spinose wall structure. However, a regular cancellated pattern is not present, probably because the pores and spine bases do not alternate as regularly as in the previous taxa and because the spine bases are not so often connected. Occasionally a cancellated pattern can be discerned on parts of the tests.

Globigerina bulloides d'Orbigny

Pl. 4, figs. 10–15

Globigerina bulloides d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, tome 7, p. 277, mod. 17, 76.

In our assemblages a variation can usually be found in the size and position of the aperture (umbilical to umbilical-extra umbilical). Furthermore a variation towards more loosely coiled individuals with a large umbilical opening is usually present. These variations imply that our assemblages contain specimens, which typologically could be labelled under different names such as *Globigerina pseudobesa, Globigerina calabra, Globigerina calida* and *Globigerina megastoma. G. bulloides* is most numerous in samples from laminated sediments.

G. bulloides and *Globigerina falconensis* are members of homogeneous assemblages. As their relative frequencies vary strongly, we have treated them as separate taxonomic units. Although small individuals are hard to discriminate, a separation in the fraction > 125 μ turned out to be possible. Moreover the feasibility and usefulness of such a discrimination has recently been demonstrated by Malmgren and Kennett (1977). *G. bulloides* can be recognized by its more strongly arched and usually larger aperture and its more globose chambers.

Globigerina falconensis Blow

Pl. 4, figs. 6–9

Globigerina falconensis Blow, 1959, Bull. Amer. Pal., vol. 39, no. 178, p. 177, pl. 9, figs. 40, 41.

The position of the aperture varies from umbilical to umbilical-extra-umbilical. An apertural lip is often present and may be very pronounced. *G. falconensis* reaches its highest frequencies in samples from homogeneous sediments.

Globigerinella aequilateralis (Brady)

Pl. 4, figs. 16, 17

Globigerina aequilateralis Brady, 1879, Quart. Jour. Micr. Sci., vol. 19, p. 285; fig.: Brady, 1884, Rept. Voy. Chall., Zool., vol. 9, pl. 80, figs. 18–21.

Our specimens are usually more involute than the ones figured by Brady. There seems to be a variation towards the *Globigerina pseudobesa* types in the *G. bulloides* assemblages. We labelled a specimen as *G. aequilateralis* if the greater part of the last whorl was planispiral.

Globigerina quinqueloba Natland
Pl. 4, figs. 1, 2

Globigerina quinqueloba Natland, 1938, Scripps Inst. Oceanogr., Bull. 4, no. 5, p. 149, pl. 6, fig. 7.

The assemblages consist of small individuals with usually five to six chambers in the final whorl. Occasionally higher-trochoid forms occur; the last chamber often has a flap-like extension over the umbilicus. *G. quinqueloba* has a spinose wall structure; usually the specimens have thin walls, but some have undergone considerable wall thickening.

Orbulina universa d'Orbigny
Pl. 6, fig. 3

Orbulina universa d'Orbigny, 1839, In: de la Sagra, Hist. phys. et nat. de l'Ile de Cuba, p. 2, plates published separately: Ibid., vol. 8, pl. 1, fig. 1.

The main variation of *O. universa* is in size which has been discussed extensively in chapter 6. Occasionally *O. universa bisphaerica* is present and in some specimens a small part of the trochoid pre-orbuline stage is visible.

Globigerinita glutinata (Egger)
Pl. 4, figs. 3–5

Globigerina glutinata Egger, 1893, K. Akad. Wiss., Math.-Natw., Bd. 18, p. 371, pl. 13, figs. 19–21.

G. glutinata has a spinose, microperforate wall, without pore-pits. The extremely small pores are irregularly distributed and euhedral rhombohedral crystals are found in between. The combination of these properties usually gives the wall of *G. glutinata* a characteristic silky sheen. The variation in the assemblages mainly concerns the shape of the bulla and the height of the trochospiral.

Several taxa have a non-spinose wall, with a regular pattern of pores and discrete tubercles. In early parts of the last whorl a coalescence of tubercles causes a regular, cancellated pattern of ridges around the pore-pits. The ultimate stage of wall thickening can be recognized by a radial arrangement of cristals on the tubercles (e.g. Srinivasan and Kennett, 1976; Zachariasse, 1978). This kind of wall structure has been demonstrated for *Neogloboquadrina* and is believed to be present in *Globoquadrina* as well.

Globoquadrina altispira (Cushman and Jarvis)
Pl. 9, figs. 4, 5

Globigerina altispira Cushman and Jarvis, 1936, Cush. Lab. Foram. Res., Contr., vol. 12, p. 5, pl. 1, figs. 13, 14.

The individuals of *G. altispira*, occasionally present in the Mediterranean Pliocene only, vary mainly in the width of the umbilical apertural opening and in the height of the trochospiral. Distinct apertural teeth are not present in all specimens.

Neogloboquadrina acostaensis (Blow)
Pl. 5, figs. 1–8

Globorotalia acostaensis Blow, 1959, Bull. Amer. Pal., vol. 39, no. 178, p. 208, pl. 17, figs. 106, 107.

Most assemblages of *N. acostaensis* have a predominantly dextral coiling. Only in the Mediterranean Upper Pliocene are the individuals of some of our assemblages sinistrally coiled. *N. acostaensis* is present in all our samples; the variation in the assemblages is large. On the average our specimens have 4 to 4.5 chambers in the final whorl. However, tighter-coiled (*N. pachyderma* type) as well as more loosely coiled forms (*N. dutertrei* type) are present all through the Pliocene; large loosely coiled specimens are mainly found in our material from Cape Bojador. Also various stages of wall thickening are found in most assemblages. Kummerforms and apertural lips are common; occasionally the aperture has an umbilical position.

The *N. pachyderma* types are quite numerous in the upper part of the Pliocene. As we did not count these types, we are unable to determine with certainty whether a change towards assemblages dominated by *N. pachyderma* takes place. Consequently in the previous chapters we have referred to this group of taxa as *Neogloboquadrina*.

Neogloboquadrina atlantica (Berggren)
Pl. 5, figs. 9–13

Globigerina atlantica Berggren, 1972, In: Laughton et al., Init. Rep. DSDP, vol. 12, p. 972, pl. 1, figs. 1–7, pl. 2, figs. 5–8.

N. atlantica can easily be recognized and discriminated from *N. acostaensis* by its larger size, its predominantly sinistral coiling and the umbilical position of the aperture. Moreover, *N. atlantica* is usually thick-walled and unlike *N. acostaensis* is only present in a small part of the Mediterranean Middle Pliocene.

The *Globorotalia* taxa have a non-spinose, usually finely perforated wall, without pore-pits. Short and blunt spine-like projections are often present; they are mostly concentrated near the umbilicus.

Globorotalia crassaformis (Galloway and Wissler)
Pl. 8, figs. 1–13

Globigerina crassaformis Galloway and Wissler, 1927, Journ. Pal., vol. 1, p. 41, pl. 7, fig. 12.

The variation in the *G. crassaformis* assemblages mainly concerns the character of the periphery (narrowly rounded to distinctly keeled) and the convexity of the umbilical side. Splitting on the basis of these criteria would enable us to label many specimens under different names (e.g. *G. crassula*, *G. crassacrotonensis*, *G. crotonensis*, *G. viola*). However, as these types occur in most of our assemblages we treated them as one taxonomic unit. On the other hand we did distinguish between assemblages with a dominantly sinistral and with a dextral coiling; in the Mediterranean such a discrimination has a biostratigraphic value. The sinistral and dextral assemblages both include high- and low-convex specimens, and keeled and non-keeled forms.

Globorotalia inflata group

The *G. inflata* group includes the closely related taxa *G. puncticulata*, *G. bononiensis* and *G. inflata*. All assemblages of the *G. inflata* group have a dominantly sinistral coiling. The representatives of the group are furthermore plano-convex and they have a rounded periphery and an arched aperture in common. Although most of the assemblages are dominated by one of the three mentioned taxa, the variation is considerable and in many assemblages morphotypes of all three taxa can be recognized. Regularly specimens occur with a quadrate chamber arrangement, resembling the arrangement of *G. crassaformis*. This resemblance may be a reflection of a close relation between *G. crassaformis* and the *G. inflata* group (Bergrren, 1977; Scott, 1980).

To our knowledge *G. bononiensis* dominates the assemblages of the *G. inflata* group in the Middle Pliocene of the Mediterranean only, whereas in time-equivalent assemblages outside the Mediterranean *G. puncticulata* is the dominant taxon. Consequently we regard *G. bononiensis* as an ecophenotype of *G. puncticulata;* we would like to stress that *G. bononiensis* types do occur in extra-Mediterranean assemblages (Iaccarino et al., 1978; Spaak, 1981b).

Globorotalia puncticulata (Deshayes)
Pl. 7, figs. 1, 2

Globigerina puncticulata Deshayes, 1832, Encycl. Met.; Hist. nat. des vers; vol. 2, p. 170 (lectotype designated by Banner and Blow, 1960, Cush. Found. Foram. Res., Contr., vol. 11, p. 15, pl. 5, fig. 7).

G. puncticulata is relatively tightly coiled with 4 to 4.5 chambers in the final whorl. The umbilical side may be flattened; the aperture is moderately arched.

Globorotalia bononiensis Dondi
Pl. 7, figs. 3–5

Globorotalia bononiensis Dondi, 1963, Bol. Soc. Geol. Ital., vol. 81, p. 162, pl. 4, figs. 41–45.

G. bononiensis is loosely coiled usually with 5 chambers in the final whorl. It possesses a highly arched aperture and a broadly rounded periphery.

Globorotalia inflata (d'Orbigny)
Pl. 7, figs. 6–10

Globigerina inflata d'Orbigny, 1839, Hist. Nat. des Iles Canaries, t. 2, pt. 2, p. 134, pl. 2, figs. 7–9.

G. inflata is tightly coiled usually with 3.5 to 4 chambers in the final whorl. Its aperture has a more umbilical position than the apertures of the other taxa of the *G. inflata* group. Often thick-walled specimens occur. In assemblages derived from laminated sediments, somewhat more loosely coiled specimens with a more highly arched aperture are fairly numerous; these forms meet the description of *Globorotalia oscitans.*

Globorotalia margaritae Bolli and Bermudez
Pl. 1, figs. 12–14

Globorotalia margaritae Bolli and Bermudez, 1965, Asoc. Venez. Geol. Min. Petr., Bol. Inform., vol. 8, p. 139, pl. 1, figs. 16–18.

The assemblages of *G. margaritae* are predominantly sinistrally coiled. The chambers are usually distinctly keeled and increase gradually in size, giving the test a circular outline. However, a variation occurs towards non-keeled specimens (with an imperforate band along the periphery only) and towards specimens with a strong increase of the height of the chambers, creating an elongated test. Finally a variation in the cross-section of the test can be observed from biconvex to concavo-convex.

Globorotalia menardii (d'Orbigny)
Pl. 9, figs. 6, 7; Pl. 10, figs. 1–6

Rotalia (Rotalie) menardii d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, t. 7, p. 273; figure in Parker, Jones and Brady, 1865, Mag. Nat. Hist., vol. 16, pl. 3, fig. 81.

The variations in our *G. menardii* assemblages (present in our Atlantic material only) concerns the height of the chambers, the number of chambers per whorl and the form of the cross-section of the test (plano-convex to biconvex). Furthermore thin- and thick-walled specimens occur.

The variation is widest in the lower part of the Pliocene; higher up rather small, plano-convex forms (*G. miocenica* type) dominate the assemblages.

Globorotalia scitula (Brady)
Pl. 6, figs. 4–6

Pulvinulina scitula Brady, 1882, Roy. Soc. Edinb., Proc., vol. 11, p. 176, plates in Brady, 1884, Rept. Voy. Chall., Zool., vol. 9, pl. 103, fig. 7.

The assemblages of *G. scitula* consist of rather small predominantly dextrally coiled individuals. In our Atlantic material there is a variation towards larger specimens.

Globorotalia tosaensis Takayanagi and Saito

Globorotalia tosaensis Takayanagi and Saito, 1962, Tohoku Univ. Sci. Rept., ser. 2, spec. vol. no. 5, p. 81, pl. 28, figs. 11, 12.

G. tosaensis is present in our Atlantic material only, in which a gradual transition from *G. crassaformis* to *G. tosaensis* has not been found.

Globorotalia truncatulinoides (d'Orbigny)

Rotalina truncatulinoides d'Orbigny, 1839, Hist. Nat. des Iles Canaries, t. 2, pt. 2, p. 132, pl. 2, figs. 25–27.

G. truncatulinoides is present in our Atlantic material only.

Candeina nitida d'Orbigny
Pl. 9, fig. 3

Candeina nitida d'Orbigny, 1839, In: de la Sagra, Hist. phys. et nat. de l'Ile de Cuba, p. 108, plates published separately: Ibid., vol. 8, pl. 2, fig. 27, 28.

Found in one Atlantic sample only.

Pulleniatina spp.

Pl. 9, figs. 1, 2

Most of our specimens have a thick smooth wall (cortex). A variation from more evolute (mostly in the lower part of the Pliocene, cf. *P. primalis*) to strongly involute, streptospiral forms (mainly in the upper part of the Pliocene, cf. *P. obliquiloculata*) is present. *Pulleniatina* was discontinuously found in our Atlantic material only.

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Sample	Lithology	*G. bulloides*	*G. falconensis*	*G. apertura*	*G. obliquus*	*G. elongatus*	*G. trilobus*	*Neogloboquadrina*	*G. glutinata*	*G. quinqueloba*	*G. nepenthes*	*G. altispira*	*Sphaeroidinellopsis*	*G. margaritae*	*G. puncticulata*	Miscellaneous	Total
CP 4001	0	5	9	32	61	0	2	43	26	0	9	0	0	0	0	13	200
4006	0	6	64	13	23	0	1	35	20	0	27	0	3	0	0	8	200
4009	0	7	60	30	36	0	1	24	4	0	24	0	2	0	0	12	200
4012	0	4	35	38	46	0	0	38	20	0	9	0	0	0	0	10	200
4014	0	5	48	30	27	0	1	58	13	0	8	0	0	0	0	9	199
4016	0	0	64	20	38	0	7	51	13	0	0	0	0	0	0	13	206
4019	0	10	42	33	13	0	13	46	19	3	17	0	0	2	0	3	200
4020	0	1	47	21	23	0	16	56	22	0	3	0	0	3	0	8	200
4023	0	2	70	36	28	0	3	36	9	0	7	0	0	1	0	8	200
4024	0	3	12	44	58	0	12	40	11	0	7	0	0	2	0	11	200
4025	0	4	58	26	35	0	11	37	12	1	7	0	0	1	0	8	200
4027	0	4	25	14	27	0	3	46	59	17	1	0	0	1	0	3	200
4028	0	3	82	29	24	0	1	11	13	4	10	0	1	13	0	8	199
CP 4030	0	4	67	18	40	0	8	31	10	4	5	0	0	11	0	2	200
CRP 21	0	9	85	24	23	0	8	31	9	2	0	0	0	0	0	9	200
CRP 41	0	0	50	20	27	0	0	53	11	0	0	0	0	34	0	5	200
CP 4031	0	14	15	39	55	0	9	32	16	2	0	0	0	15	0	3	200
4033	0	5	23	42	49	0	17	58	7	6	0	0	0	0	0	3	210
4071	0	3	44	24	16	1	7	57	7	2	0	0	0	11	25	3	200
4073	0	3	40	22	17	0	1	44	15	0	0	0	0	0	57	1	200
4078	0	6	32	29	21	0	0	54	13	0	0	0	0	1	44	0	200
4079	0	2	55	20	21	7	0	49	14	0	0	0	0	15	17	0	200
4080	0	3	57	23	24	0	0	44	24	5	0	0	0	17	1	2	200
4081	0	1	48	28	29	0	0	43	14	0	0	1	0	31	4	1	200
4089	0	4	29	15	25	0	0	44	30	2	0	0	0	28	21	2	200
4093	0	13	19	30	28	0	2	65	17	0	0	0	0	0	22	4	200
4097	0	11	25	16	37	0	1	52	13	3	0	0	0	0	37	5	200
4099	0	6	37	21	32	0	11	47	17	6	0	0	0	0	19	4	200
4101	0	3	69	21	21	9	0	30	17	6	0	0	0	0	24	0	200
4102	0	5	17	40	26	24	1	38	4	13	0	0	0	16	7	9	200
4104	0	7	13	30	22	14	2	60	28	10	0	0	4	0	10	0	200
4107	0	7	29	30	21	8	2	34	16	2	0	0	2	0	48	1	200
4110	0	15	24	27	42	18	0	35	16	2	0	0	0	0	20	1	200
4112	0	9	29	31	30	13	2	17	37	5	0	0	3	0	24	0	200
4114	0	4	23	41	22	12	11	31	19	4	0	0	5	0	19	1	192
4117	0	9	30	35	17	9	1	45	17	4	0	0	1	0	32	0	200
4119	0	5	38	28	20	20	10	21	22	0	0	0	1	0	36	0	201
4120	0	6	57	21	28	16	2	16	21	4	0	0	2	0	27	0	200
4122	0	11	68	27	15	33	1	13	28	2	0	0	0	0	1	1	200
4126	0	6	18	27	13	35	0	32	38	12	0	0	0	0	17	2	200
4128	0	3	83	27	12	26	0	21	19	5	0	0	0	0	0	4	200
4133	0	0	22	32	25	19	16	25	45	0	0	0	0	0	0	7	191
4137	0	2	71	29	22	32	1	23	15	1	0	0	0	0	0	4	200
4139	0	5	10	48	31	27	30	20	23	0	0	0	0	0	5	1	200
4142	0	1	23	18	18	24	34	28	47	1	0	0	0	0	0	6	200
4145	0	6	47	36	19	10	0	29	22	5	0	0	4	0	21	2	201
4148	0	1	83	32	10	11	3	29	20	7	0	0	0	0	0	4	200

TABLE VIII: Distribution chart of planktonic foraminifera in the Capo Rossello and Punta di Maiata sections.

Sample	Lithology	*G. bulloides*	*G. falconensis*	*G. apertura*	*G. obliquus*	*G. elongatus*	*G. trilobus*	*Neogloboquadrina*	*G. glutinata*	*G. quinqueloba*	*G. bononiensis*	*G. crassaformis*	Miscellaneous	Total
JT 5701	0	9	51	29	17	12	0	31	42	7	0	5	2	205
5702	0	6	28	19	23	7	0	62	21	11	23	0	0	200
5703	0	5	44	25	26	4	4	48	31	2	9	0	2	200
5704	0	4	20	29	32	9	7	31	51	0	0	14	3	200
5705	1	10	33	23	33	17	1	39	33	8	1	0	2	200
5706	0	11	31	40	22	16	1	31	43	1	0	0	4	200
5707	0	11	29	35	26	13	6	24	47	4	0	0	5	200
5708	1	15	26	26	7	4	1	59	15	1	45	0	1	201
5710	1	19	22	15	14	10	3	17	19	15	61	0	5	200
5711	0	14	37	41	22	19	6	18	38	1	0	0	4	200
5712	1	24	22	15	12	7	2	6	13	16	82	0	1	200
5713	0	14	50	27	10	13	1	19	48	1	0	11	6	200
5714	1	3	35	28	13	7	4	8	29	0	70	1	2	200
5715	0	14	51	31	15	9	1	40	31	7	0	1	0	200
5716	1	12	31	34	16	8	3	13	29	1	51	0	2	200
5717	0	14	49	19	26	37	0	32	19	0	0	0	4	200
5718	1	2	11	10	34	8	5	15	22	0	92	0	1	200
5719	0	22	14	30	20	14	9	22	48	4	0	13	4	200
5720	1	34	15	22	23	6	2	20	44	5	28	0	1	200
5721	0	12	23	25	22	19	11	47	37	1	0	0	3	200
5722	1	5	14	34	17	24	4	25	56	5	16	0	0	200
5723	0	6	32	33	24	19	0	28	33	2	2	17	4	200
5724	1	9	17	26	20	20	6	13	39	6	42	0	2	200
5725	0	11	7	10	18	4	3	66	60	6	0	15	0	200
5726	1	15	13	23	29	15	13	44	36	4	0	0	8	200
5727	0	4	10	24	27	12	0	54	62	6	0	0	1	200
5728	1	11	20	30	22	15	0	54	40	6	0	0	2	200
5729	0	11	23	9	29	17	0	67	37	7	0	0	0	200
5730	0	6	10	23	23	16	0	73	33	11	0	5	0	200
5731	1	12	12	36	28	27	1	34	30	2	0	17	1	200
5732	0	21	20	15	33	7	0	8	36	14	10	36	0	200
5733	1	27	22	19	19	16	5	25	29	16	22	0	0	200
5734	0	41	32	17	14	13	0	6	52	24	0	0	1	200
5735	1	41	15	31	18	25	3	25	23	9	9	0	1	200
5736	0	25	31	18	19	25	5	12	39	6	12	2	6	200
5737	1	30	27	6	8	18	13	22	60	3	5	7	1	200
5738	0	25	33	41	16	8	1	16	33	9	9	0	9	200
5739	1	24	13	27	13	22	8	49	24	9	9	0	2	200
5740	0	7	27	16	20	19	0	31	37	4	23	10	6	200
5741	1	19	9	17	52	14	0	50	23	12	1	3	0	200
5742	0	26	24	27	8	16	0	9	56	31	0	0	3	200

TABLE IX: Distribution chart of planktonic foraminifera in the Punta Piccola section.

Sample	Lithology	*G. bulloides*	*G. falconensis*	*G. apertura*	*G. obliquus*	*G. elongatus*	*G. trilobus*	*Neogloboquadrina*	*G. glutinata*	*G. quinqueloba*	*G. inflata*	Miscellaneous	Total
JT 6245	0	13	17	4	7	12	0	68	15	52	10	2	200
6250	1	85	6	9	10	16	0	60	2	8	0	4	200
6253	0	11	84	17	7	6	0	9	35	20	7	4	200
6257	0	45	12	5	4	39	0	1	55	30	0	6	197
6261	1	20	2	17	16	38	4	64	13	25	0	1	200
6264	0	19	14	0	1	8	0	37	37	70	7	7	200
6266	1	50	6	2	2	44	0	89	1	2	3	1	200
6269	0	17	10	10	11	15	0	39	48	43	5	2	200
6272	1	33	6	0	0	5	0	122	4	16	6	8	200
6274	0	32	18	6	6	21	1	35	47	18	4	12	200
6276	1	2	1	7	0	0	0	107	7	5	68	3	200
6281	0	15	67	2	3	9	0	82	26	13	1	7	225
6286	1	27	5	7	6	26	0	85	8	5	22	9	200
6287	0	11	32	25	10	21	0	29	47	8	9	8	200
6289	1	63	5	0	0	6	0	50	15	24	34	3	200
6291	0	24	37	2	0	10	1	28	26	61	7	3	199
6292	1	43	16	0	0	1	0	38	3	31	67	0	199
6296	0	59	19	3	2	10	0	47	23	11	20	6	200
6300	0	23	10	10	3	22	1	76	14	22	15	3	199
6304	0	19	7	6	0	7	0	111	10	16	16	8	200
6309	1	45	26	0	7	23	0	33	12	1	43	10	200
6312	0	11	5	1	0	13	0	66	33	5	65	5	204
6314	1	16	2	4	12	16	0	110	3	0	26	11	200
6316	0	4	90	10	4	6	0	39	18	6	16	7	200
6318	1	56	11	0	1	4	0	79	2	3	40	7	200
6321	0	18	26	6	1	2	0	45	23	64	11	4	200
6325	0	19	56	12	5	4	0	38	23	11	25	7	200
6331	1	10	1	3	12	31	0	79	3	1	59	1	200
6332	0	25	73	10	2	11	0	26	22	15	8	8	200
6334	1	62	5	0	0	0	0	113	0	2	14	4	200
6335	0	5	59	8	5	47	1	27	9	10	26	3	200
6337	1	28	2	13	5	48	0	49	7	2	41	5	200
6339	0	39	42	4	4	19	0	18	7	59	8	0	200
6342	1	20	10	1	5	21	0	98	15	3	0	29	202
6345	0	27	15	0	3	2	0	118	6	28	1	0	200
6348	1	2	1	1	21	28	0	135	4	4	0	4	200
6349	0	64	42	13	4	28	0	11	8	3	17	10	200

TABLE X: Distribution chart of planktonic foraminifera in the Vrica section.

Sample	Lithology	*G. bulloides*	*G. falconensis*	*G. apertura*	*G. obliquus*	*G. elongatus*	*G. trilobus*	*Neogloboquadrina*	*G. glutinata*	*G. quinqueloba*	*G. bononiensis*	*G. crassaformis*	Miscellaneous	Total
CP 4204	0	53	10	31	21	7	0	17	42	9	7	0	3	200
4207	0	15	13	25	24	19	0	45	18	6	10	16	9	200
4209	0	34	19	29	15	6	0	29	25	32	2	0	9	200
4212	0	5	14	31	40	28	0	12	31	8	26	0	5	200
4214	0	20	11	26	27	6	0	53	34	8	3	0	12	200
4218	0	8	6	41	39	20	0	45	34	2	0	0	5	200
4220	0	9	6	19	22	33	0	76	12	5	0	21	2	205
4222	0	13	25	22	11	25	0	66	27	4	0	0	7	200
4224	0	18	37	11	7	10	0	52	46	12	0	0	7	200
4226	0	3	16	9	10	51	0	87	17	0	0	0	7	200
4228	0	33	26	17	17	40	0	27	20	7	0	0	13	200
4230	0	22	13	18	9	52	0	30	43	0	0	0	13	200
4232	0	8	32	25	15	42	0	8	45	5	0	0	17	200
4233	0	31	68	3	0	3	0	26	43	14	0	0	12	200
4234	0	32	25	7	17	1	0	64	25	18	0	0	11	200
4236	0	15	5	8	7	60	0	57	35	5	0	0	8	200

TABLE XI: Distribution chart of planktonic foraminifera in the Lido Rossello section.

Sample	Lithology	*G. bulloides*	*G. falconensis*	*G. apertura*	*G. obliquus*	*G. elongatus*	*G. trilobus*	*Neogloboquadrina*	*G. glutinata*	*G. quinqueloba*	*G. nepenthes*	*G. altispira*	*Sphaeroidinellopsis*	*G. margaritae*	*G. puncticulata*	Miscellaneous	Total
GR 652	0	2	104	6	32	11	0	9	26	0	0	0	1	0	0	10	201
653	0	0	44	6	58	1	0	33	25	6	0	0	0	11	0	15	199
654	0	3	99	24	28	0	1	16	17	0	0	0	0	5	1	6	200
655	1	2	52	9	57	0	13	38	9	1	0	0	0	10	5	7	203
656	0	0	95	12	21	0	0	14	34	1	2	0	0	5	3	13	200
657	1	14	50	9	48	1	6	54	9	3	0	0	0	0	4	8	206
658	0	4	50	7	50	0	1	59	12	7	1	0	0	1	1	7	200
659	0	0	73	7	63	7	8	30	1	2	0	0	0	0	3	6	200
660	0	3	66	7	54	3	2	23	12	4	1	0	0	8	2	15	200
662	1	12	18	18	21	8	6	85	8	7	0	1	0	7	1	8	200
663	0	7	38	16	44	1	19	26	18	4	0	0	0	12	1	14	200
664	1	4	19	12	48	5	12	70	21	2	0	0	0	2	1	6	202
665	0	1	37	32	36	7	4	45	29	5	0	0	6	0	5	6	213
666	0	3	16	6	91	8	6	26	20	2	0	0	3	1	2	17	201
667	1	11	9	8	49	5	8	90	8	2	0	0	0	0	5	5	200
669	0	7	38	7	61	6	9	15	19	4	0	0	0	4	12	18	200
670	1	11	10	22	42	3	5	84	5	0	5	0	0	0	9	4	200

TABLE XII: Distribution chart of planktonic foraminifera in the Aghios Vlassios section.

Sample	Lithology	*G. bulloides*	*G. falconensis*	*G. apertura*	*G. obliquus*	*G. elongatus*	*G. trilobus*	*Neogloboquadrina*	*G. glutinata*	*G. quinqueloba*	*G. nepenthes*	*Sphaeroidinellopsis*	*G. margaritae*	*G. puncticulata*	*G. bononiensis*	*G. crassaformis*	Miscellaneous	Total
GR 1077	0	3	56	34	51	0	0	14	33	1	0	0	2	0	0	0	6	200
1081	1	4	44	24	44	0	4	25	38	0	2	0	6	0	0	0	8	199
1085	0	7	41	20	39	0	1	11	70	0	2	0	3	0	0	0	6	200
1087	0	17	36	21	44	3	8	27	29	0	2	0	3	0	0	0	10	200
1089	1	7	51	26	36	0	3	26	39	0	0	0	8	0	0	0	4	200
1093	0	7	45	28	39	3	3	20	51	1	0	0	1	0	0	0	0	198
1097	1	8	45	19	44	0	6	31	28	0	1	0	15	0	0	0	5	202
1100	0	18	41	16	35	0	2	34	37	2	0	0	6	0	0	0	9	200
950	0	3	78	23	37	0	0	17	33	0	0	0	2	1	0	0	6	200
951	1	11	67	22	37	0	0	40	14	0	0	0	6	1	0	0	2	200
952	0	7	70	19	28	0	0	39	25	0	0	0	3	1	0	0	8	200
957	0	8	49	23	28	1	0	25	21	4	0	1	29	6	0	0	5	200
959	0	6	48	13	42	2	2	47	10	1	1	4	10	6	0	0	8	200
960	1	28	11	11	18	0	2	114	0	2	0	0	0	3	0	0	10	199
961	0	20	34	25	43	1	3	58	9	1	0	0	1	4	0	0	1	200
962	1	14	41	32	48	2	2	48	12	0	0	0	2	4	0	0	4	209
963	0	7	28	33	68	0	0	46	7	2	0	0	2	2	0	0	4	199
GR 974	0	3	37	19	38	12	1	47	26	6	0	0	8	1	0	0	2	200
CP 3350	0	6	56	16	38	0	1	42	14	7	0	1	0	10	0	0	9	200
3351	0	2	69	23	40	2	7	33	13	4	0	0	0	4	0	0	3	200
3352	0	3	68	17	33	5	0	37	26	4	0	1	0	4	0	0	2	200
3353	0	12	61	19	29	4	3	40	17	7	0	0	0	3	0	0	5	200
3354	0	28	43	15	22	6	4	46	13	5	0	0	0	13	0	0	5	200
3355	0	29	47	22	25	8	1	40	15	5	0	0	0	2	0	0	5	199
3356	0	47	24	15	22	10	4	38	23	3	0	2	0	0	0	0	2	190
3357	0	23	33	25	39	5	0	49	15	3	0	0	0	3	0	1	4	200
3358	0	24	58	23	26	0	2	42	12	2	0	0	0	1	0	2	7	199
3359	0	17	61	18	38	3	1	32	19	5	0	1	0	0	0	1	4	200
3360	0	32	47	18	28	2	3	36	19	8	0	0	0	0	0	0	7	200
3361	1	57	6	4	5	1	0	122	2	1	0	0	0	0	0	0	2	200
3362	1	88	16	1	3	1	0	80	3	5	0	0	0	0	0	0	3	200
CP 3363	1	72	16	7	5	0	0	87	2	0	0	9	0	0	0	0	2	200
GR 984	0	20	43	21	22	1	3	56	19	11	0	0	0	0	1	0	3	200
993	0	21	58	21	41	4	0	26	17	7	0	0	0	0	5	0	0	200
1000	0	62	35	20	19	1	1	25	23	10	0	0	0	0	0	0	4	200
1002	1	76	10	3	1	2	1	79	3	24	0	0	0	0	0	0	1	200
1006	0	42	55	16	13	1	1	42	13	9	0	0	0	0	0	0	7	199
1007	0	23	76	22	28	4	0	19	23	4	0	0	0	0	0	0	1	200
GR 1008	0	110	15	6	10	2	1	36	15	5	0	0	0	0	0	0	0	200
CP 3364	1	114	26	1	1	0	0	43	2	11	0	0	0	0	0	0	3	201
3365	1	114	20	1	1	0	0	62	0	0	0	0	0	0	0	0	2	200
3366	1	122	22	1	3	0	0	49	2	0	0	0	0	0	0	0	1	200
3367	1	123	10	1	2	0	0	47	3	1	0	0	0	0	0	1	2	190
3368	1	118	20	1	1	0	0	54	2	0	0	0	0	0	0	2	2	200
3372	1	105	18	4	2	0	0	55	2	14	0	0	0	0	0	0	0	200
3376	1	90	16	1	1	0	0	71	6	10	0	0	0	0	0	0	5	200
3378	1	69	9	13	4	0	0	67	2	11	0	0	0	0	19	0	6	200
3379	0	37	37	5	15	2	1	68	22	6	0	0	0	0	0	0	7	200
3380	0	39	32	22	24	8	4	52	18	0	0	0	0	0	0	1	0	200
3381	1	55	7	13	18	1	1	95	4	5	0	0	0	0	0	0	1	200
3382	1	79	10	14	5	2	0	83	4	2	0	0	0	0	0	0	1	200
3383	1	83	14	3	14	2	0	77	5	2	0	0	0	0	0	0	0	200
3384	1	100	8	2	5	0	0	72	8	3	0	0	0	0	0	0	2	200
3385	1	96	19	4	4	0	0	73	4	0	0	0	0	0	0	0	0	200
3389	1	110	38	22	13	0	0	13	0	1	0	0	0	0	0	0	4	201
3393	1	101	31	1	12	0	0	30	18	3	0	0	0	0	0	0	4	200
3396	1	69	22	6	5	0	0	79	8	3	0	0	0	0	0	0	8	200
3397	0	29	57	17	44	2	2	34	9	5	0	0	0	0	0	0	1	200
3398	1	47	10	11	12	3	2	101	1	14	0	0	0	0	0	0	0	201
3399	0	14	43	34	49	9	3	34	3	3	0	0	0	0	0	0	8	200
3400	1	45	43	27	21	1	1	35	4	18	0	0	0	0	2	0	3	200
3401	0	17	50	19	41	7	2	26	18	12	0	0	0	0	0	0	8	200
3402	0	78	42	10	8	6	1	14	12	16	0	0	0	0	10	0	3	200

TABLE XIII: Distribution chart of planktonic foraminifera in the section Prassas.

Sample	Lithology	*G. bulloides*	*G. falconensis*	*G. apertura*	*G. obliquus*	*G. elongatus*	*G. trilobus*	*Neogloboquadrina*	*G. glutinata*	*G. quinqueloba*	*G. altispira*	*Sphaeroidinellopsis*	*G. puncticulata*	*G. bononiensis*	*G. crassaformis*	Miscellaneous	Total
CP 2001	1	14	13	5	24	4	0	107	12	0	0	0	15	0	0	4	198
2007	0	4	9	24	91	6	6	44	7	1	0	0	5	0	0	3	200
2012	0	3	36	8	41	19	3	23	39	0	0	1	15	0	0	11	199
2016	0	10	21	19	50	10	4	44	24	0	0	0	4	0	0	14	200
2021	0	7	25	36	64	6	10	28	13	0	0	2	0	0	0	9	200
2023	1	43	11	5	36	5	13	65	4	3	0.	0	0	0	0	15	200
2025	0	4	66	15	40	7	5	16	30	2	0	2	1	0	0	12	200
2027	1	16	25	10	28	2	18	71	6	3	0	1	7	0	0	13	200
2032	0	12	54	16	53	6	7	19	13	1	2	0	7	0	0	9	199
2037	0	8	73	15	25	11	0	14	17	2	0	4	26	0	0	5	200
2041	0	7	83	11	62	7	3	5	10	0	0	0	5	0	0	7	200
2044	1	71	9	11	19	19	10	42	9	3	0	0	1	0	0	6	200
2047	0	5	90	11	22	12	2	21	27	1	0	0	4	0	0	5	200
2049	1	52	28	6	17	1	0	52	23	1	0	0	6	0	0	13	199
2054	0	29	60	16	33	2	3	28	20	1	0	0	1	0	0	6	199
2057	0	2	81	14	34	9	6	26	15	2	3	0	0	0	0	8	200
2060	0	17	82	17	42	5	0	2	15	1	0	0	0	0	0	15	196
2063	1	33	2	27	59	2	8	39	3	6	0	0	0	0	0	11	190
2072	0	18	57	19	31	8	1	14	41	0	0	0	0	0.	0	11	200
2073	1	101	8	12	18	3	4	32	6	1	0	0	0	0	0	18	203
2074	1	72	24	5	19	2	2	49	10	0	0	0	0	0	0	14	197
2079	1	105	9	1	13	1	4	46	5	2	0	0	0	0	0	15	200
2083	0	42	40	16	24	10	2	40	11	1	0	0	0	0	0	14	200
2087	1	29	22	21	17	8	10	71	8	2	0	0	0	0	0	10	198
2089	0	9	85	11	44	7	2	21	6	0	0	0	0	0	0	15	200
2092	1	69	0	2	14	0	0	101	1	4	0	0	0	0	0	9	200
2095	0	11	50	22	37	21	1	27	15	0	0	3	0	0	0	13	200
2100	0	19	89	20	42	6	0	3	4	1	0	1	0	0	0	15	200
2103	1	89	28	17	9	4	2	29	8	0	0	0	0	0	0	13	199
2104	0	80	15	17	8	1	3	39	17	2	0	0	0	0	0	10	192
2107	0	29	28	22	38	10	1	25	13	8	0	0	0	0	0	22	196
2109	1	41	12	13	10	7	1	67	17	9	0	1	0	0	0	16	194
2110	0	29	40	20	29	6	4	45	10	5	0	4	0	0	0	12	204
2113	0	22	55	15	27	7	1	16	22	5	0	1	0	0	0	15	186
2116	1	147	7	2	2	0	1	23	8	4	0	0	0	0	0	7	201
2120	0	24	52	14	25	5	4	32	17	4	0	0	0	0	0	23	200
2122	1	55	15	9	18	3	6	62	18	4	0	0	0	0	0	11	201
2124	0	38	31	35	37	3	3	15	19	1	0	0	0	0	0	17	199
2128	1	51	36	11	23	9	6	39	13	1	0	0	0	0	0	13	202
2131	0	18	71	12	24	5	6	21	7	9	0	0	0	0	0	26	199
2133	1	112	10	4	7	0	0	61	1	0	0	0	0	0	0	9	204
2136	0	43	47	8	17	2	1	38	18	3	0	0	0	0	0	15	192
2138	0	37	34	5	10	6	1	49	27	9	0	2	0	3	2	15	200
2141	0	50	35	8	18	2	1	49	24	3	0	0	0	0	0	10	200
2146	0	49	20	19	24	3	0	53	16	3	0	0	0	0	3	6	196
2150	0	13	62	9	33	2	0	35	28	5	0	0	0	0	0	15	202
2152	0	34	29	27	28	0	7	38	13	5	0	1	0	0	1	14	197
2153	1	78	7	9	2	0	1	98	0	1	0	0	0	0	1	5	202
2154	1	73	6	3	2	1	0	105	2	4	0	0	0	2	3	4	205
2155	0	46	3	8	9	0	1	112	4	6	0	0	0	2	0	8	199
2158	0	26	29	22	24	7	4	34	28	10	0	1	0	0	0	14	199
2162	0	28	29	24	41	11	1	15	30	7	0	1	0	0	0	14	201
2166	0	27	26	23	34	11	0	43	12	2	0	0	0	1	1	15	195
2169	1	85	5	4	9	0	0	55	2	18	0	0	0	0	0	13	191
2171	0	11	63	20	34	2	3	21	19	6	0	0	0	0	0	21	200
2173	0	43	29	19	32	6	1	27	19	2	0	0	0	0	0	22	200
2175	1	70	0	21	7	0	0	91	2	7	0	0	0	0	4	5	207

TABLE XIV: Distribution chart of planktonic foraminifera in the Finikia section.

Sample	Lithology	*G. bulloides*	*G. falconensis*	*G. apertura*	*G. obliquus*	*G. elongatus*	*G. trilobus*	*Neogloboquadrina*	*G. glutinata*	*G. quinqueloba*	*G. nepenthes*	*G. altispira*	*Sphaeroidinellopsis*	*G. margaritae*	*G. puncticulata*	Miscellaneous	Total
GR 2661	0	4	12	25	29	0	0	5	54	0	54	0	0	0	0	17	200
2664	0	12	17	44	21	2	2	8	12	1	64	0	2	0	0	15	200
2667	0	11	39	34	14	0	5	41	17	0	14	0	4	0	0	21	200
2670	0	3	66	23	22	1	1	10	34	0	28	0	1	0	0	11	200
2672	0	5	57	16	24	0	0	11	36	2	39	0	0	0	0	10	200
2676	0	4	92	20	17	0	2	9	23	0	27	0	1	0	0	5	200
2681	0	6	65	26	23	1	0	20	23	4	31	0	0	0	0	1	200
2687	0	3	73	28	22	1	1	21	31	1	18	0	0	0	0	1	200
2691	0	2	63	38	18	1	0	20	29	6	18	0	0	1	0	4	200
2694	0	0	95	27	21	1	1	13	9	3	12	0	2	11	0	5	200
2697	0	2	87	37	21	0	2	22	17	0	6	0	0	1	0	5	200
2700	0	5	58	39	18	0	7	33	16	3	3	0	0	11	0	7	200
2704	0	4	32	58	33	1	2	25	28	3	10	0	0	0	0	4	200
2708	0	9	84	26	23	3	1	11	30	1	6	0	0	2	0	4	200
2711	0	18	32	37	28	0	3	14	51	2	7	0	0	1	0	7	200
2715	0	13	48	37	31	1	5	15	25	0	2	0	0	13	0	10	200
2717	0	12	36	33	26	1	6	23	50	3	0	0	0	6	0	4	200
2718	0	8	42	43	24	1	1	32	37	0	1	0	0	5	0	6	200
2722	0	4	46	39	35	0	0	31	44	0	0	0	0	0	0	1	200
2725	0	6	43	35	34	1	1	21	52	1	0	0	0	4	0	2	200
2729	0	8	54	22	21	4	9	31	41	0	0	0	0	2	0	9	201
2732	0	1	80	43	18	3	1	15	34	2	0	0	0	0	0	3	200
2735	0	5	84	21	26	2	6	29	18	1	1	0	0	2	2	3	200
2738	0	3	100	26	30	0	2	12	19	1	0	0	0	1	1	5	200
2742	0	16	59	31	12	0	3	49	20	0	0	0	0	4	4	2	200
2201	0	5	62	21	23	5	2	43	22	6	0	0	0	1	7	3	200
2203	0	7	82	29	23	0	2	30	13	7	0	0	0	3	3	1	200
2206	0	8	34	31	28	7	0	50	11	4	0	0	0	3	18	6	200
2209	0	1	50	41	28	3	3	47	13	3	0	1	0	0	16	4	210
2211	0	6	17	46	36	16	2	45	14	3	0	1	0	3	5	6	200
2215	0	8	14	49	22	11	3	53	17	5	0	0	0	6	2	10	200
2217	0	7	38	44	25	10	8	28	24	0	0	0	0	3	7	6	200
2220	0	6	31	42	19	9	2	55	28	1	0	0	3	0	1	3	200
2223	0	10	26	46	35	5	2	50	17	2	0	0	1	0	4	2	200
2226	0	14	11	33	32	5	5	75	19	2	0	0	1	0	3	0	200
2228	0	4	48	48	27	4	1	39	25	0	0	0	0	0	0	4	200
2231	0	9	27	40	33	9	4	49	18	2	0	0	0	0	4	7	202

TABLE XV: Distribution chart of planktonic foraminifera in the section Kalithea.

Plate 1

Figs. 1–7	*Globigerina nepenthes*, figs. 3, 7: Cape Bojador, core 38/4; others: Kalithea, sample GR 2670.
Figs. 8–11	*Globigerina apertura,* Kalithea, sample GR 2210.
Figs. 12–14	*Globorotalia margaritae,* Capo Rossello, sample CP 4019.

All magnifications X 80.

Plate 1

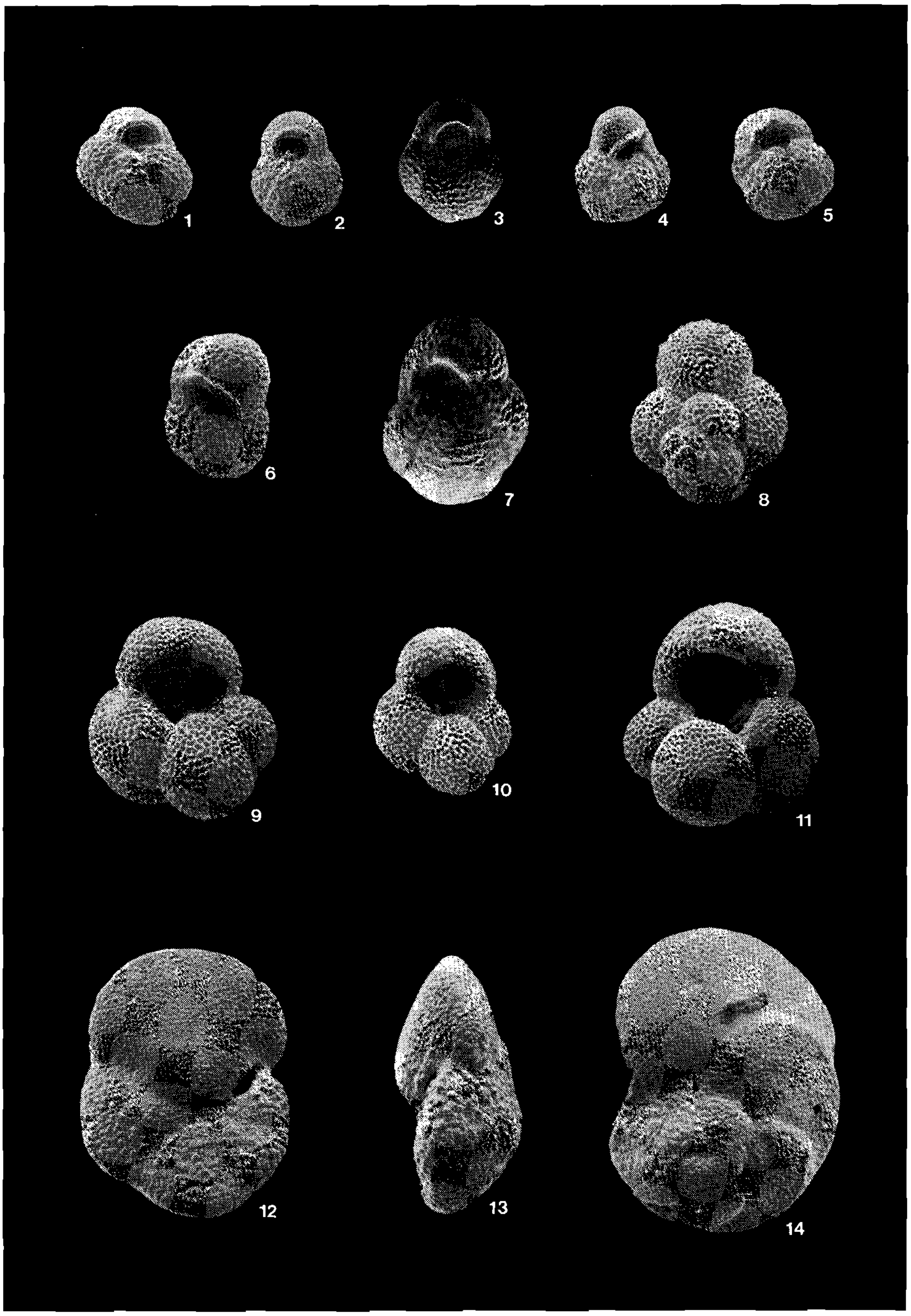


Plate 2

Figs. 1–6	*Globigerinoides obliquus,* fig. 1: Kalithea, sample GR 2210; figs. 2, 5, 6: tightly coiled specimen with two secondary apertures, Kalithea, sample GR 2681; figs. 3, 4: loosely coiled specimen from laminated interval, Kalithea, sample GR 2224.
Figs. 7–12	*Globigerinoides elongatus,* figs. 7, 10: Monte Sante Nicola, sample CP 3790; fig. 9: Monte Sante Nicola, sample CP 3825; figs. 8, 11, 12: from laminated interval, Kalithea, sample GR 2224.

All magnifications X 80.

Plate 2

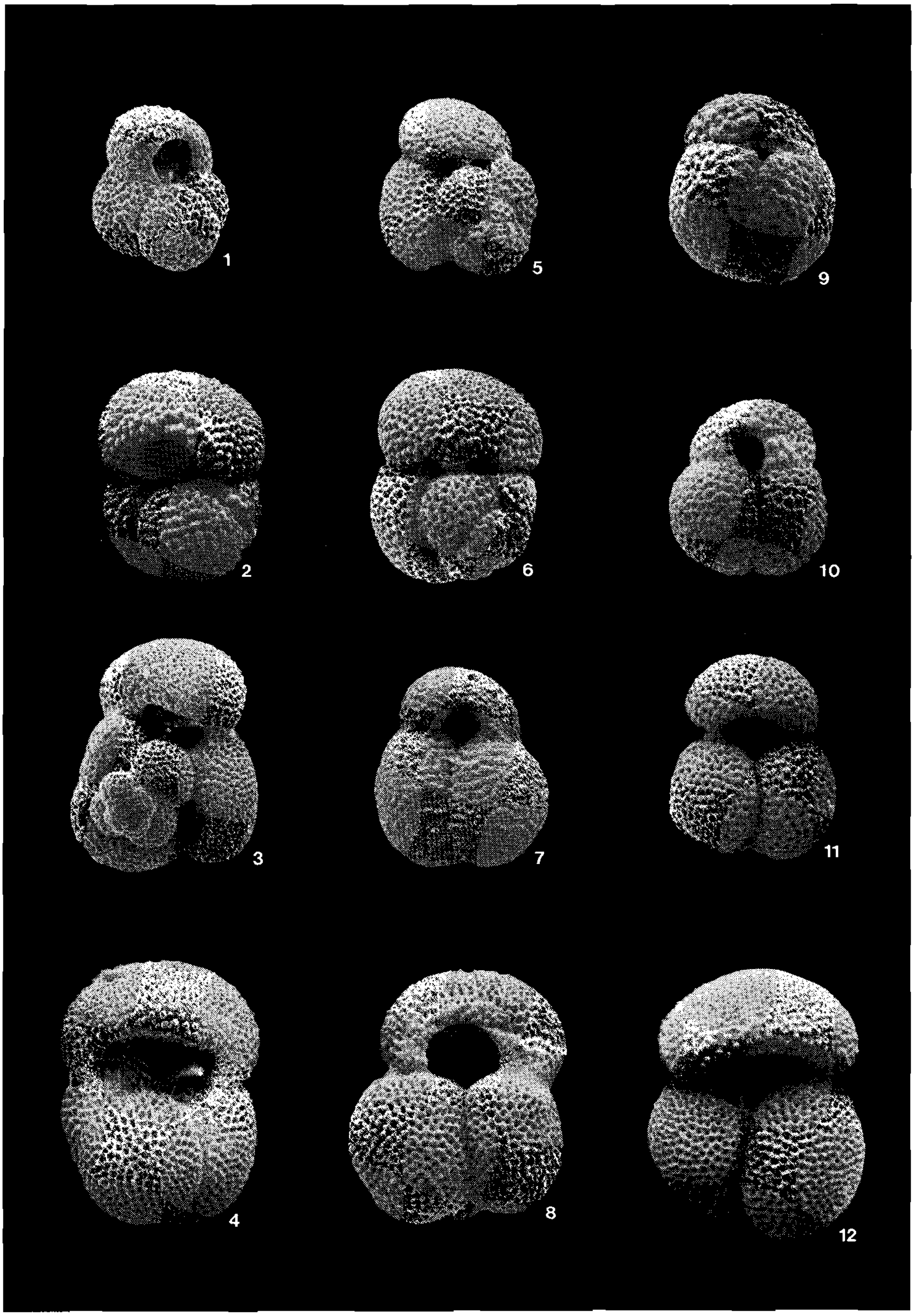


Plate 3

Figs. 1–4 *Globigerinoides trilobus,* Kalithea, sample GR 2224.

Figs. 5–11 *Sphaeroidinellopsis,* Kalithea, sample GR 2224.

All magnifications X 80.

Plate 3

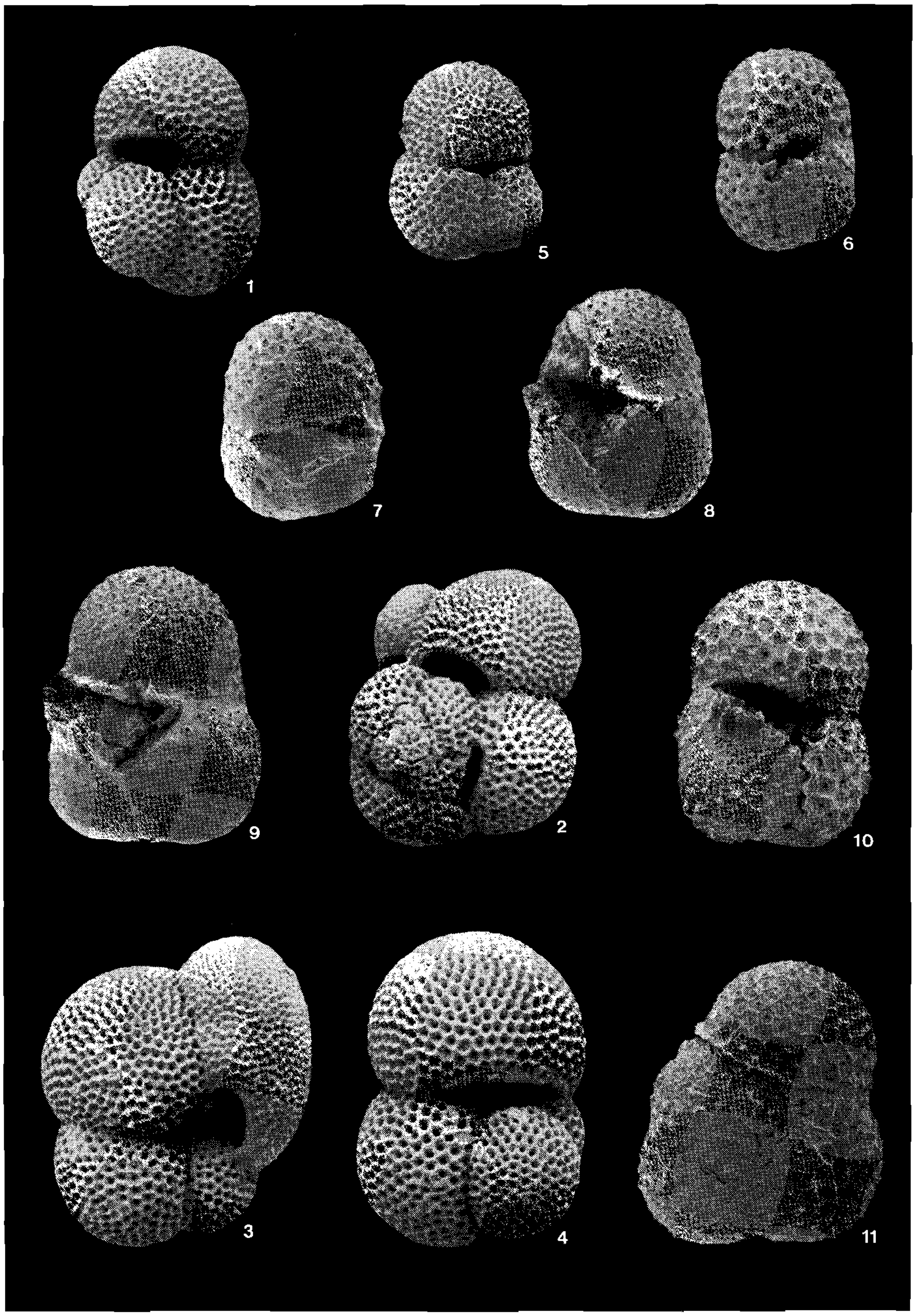


Plate 4

Figs. 1, 2	*Globigerina quinqueloba,* Punta Piccola, sample JT 5733.
Figs. 3–5	*Globigerinita glutinata,* Punta Piccola, sample JT 5733.
Figs. 6–9	*Globigerina falconensis,* Kalithea, sample GR 2681.
Figs. 10–15	*Globigerina bulloides,* figs. 10–13: Prassas, sample CP 3385; figs. 14, 15: (*G. pseudobesa* type) Kalithea, sample GR 2210.
Figs. 16–17	*Globigerinella aequilateralis,* Kalithea, sample GR 2681.

All magnifications X 80.

Plate **4**

Plate 5

Neogloboquadrina

Figs. 1, 2	*N. pachyderma* type, from the Mediterranean Upper Pliocene, Monte Sante Nicola, sample CP 3810.
Figs. 3–5	*N. acostaensis* type, from the Mediterranean Lower Pliocene, Kalithea, sample GR 2212.
Figs. 6–8	*N. dutertrei* type, from the Atlantic, Cape Bojador, core 15/3.
Figs. 9–13	*Neogloboquadrina atlantica,* Monte Sante Nicola, sample CP 3780.

All magnifications X 80.

Plate 5

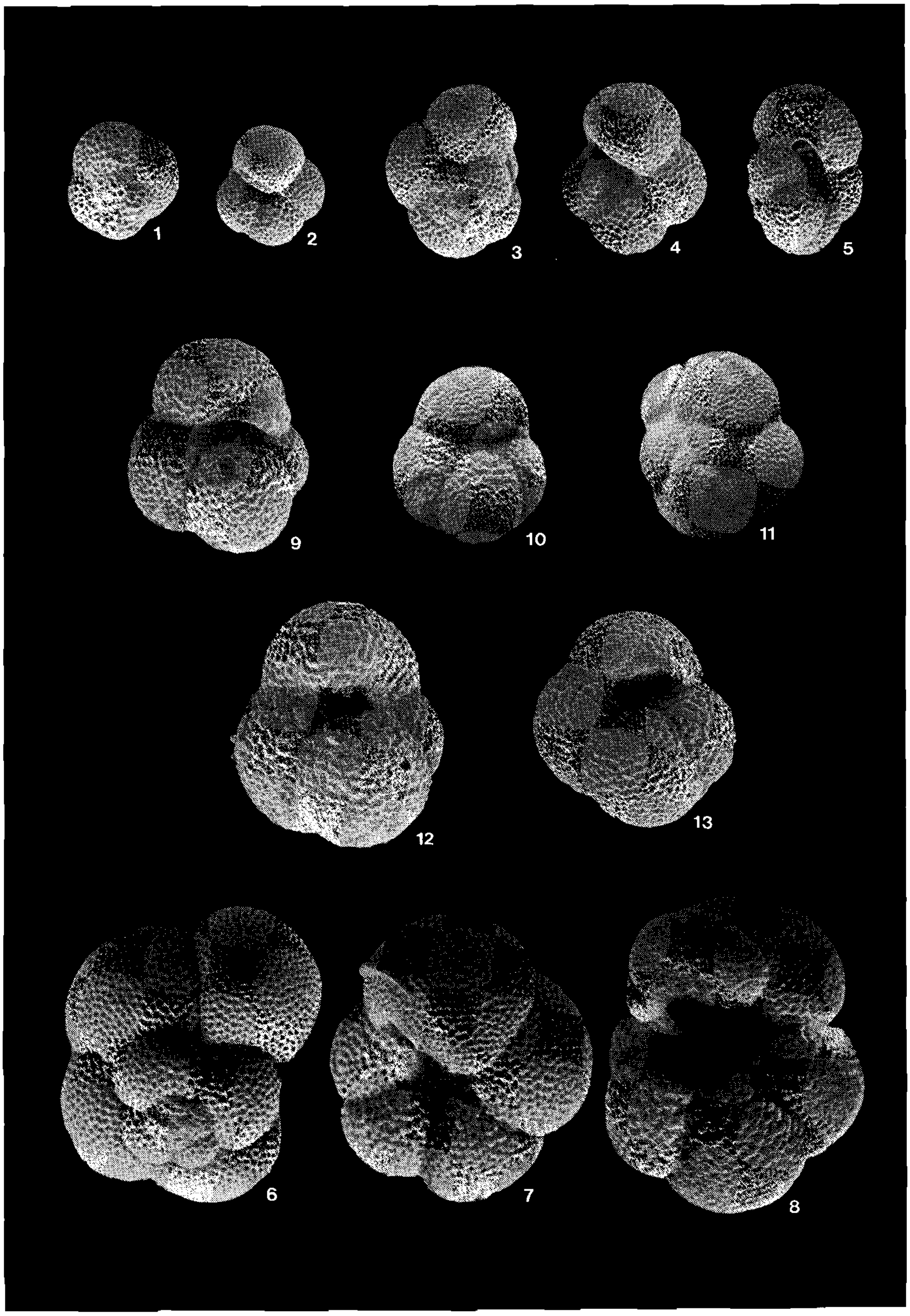


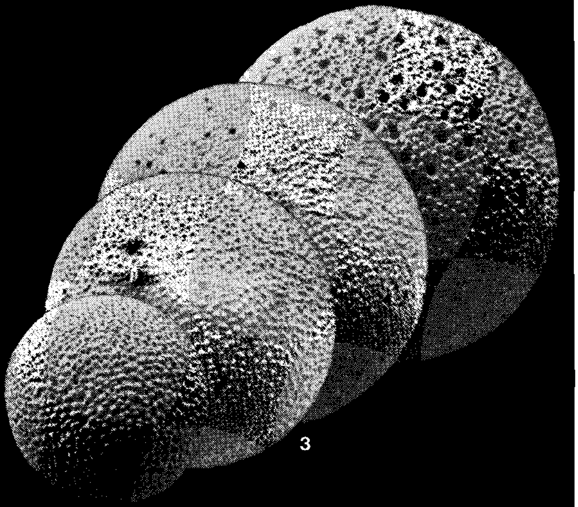
Plate 6

Figs. 1, 2	*Sphaeroidinella dehiscens,* Semaforo, sample JT 6232.
Fig. 3	*Orbulina universa,* with various diameter values; the two smallest specimen from Kalithea, sample 2667; the two largest ones from Lido Rossello, sample CP 4215.
Figs. 4–6	*Globorotalia scitula,* fig. 4: Cape Bojador, core 15/5, such large specimens were found in our Atlantic material only; figs. 4, 5 show the average size of *G. scitula* in the Mediterranean, Capo Rossello, sample CP 4009.

All magnifications × 80.

Plate 6


1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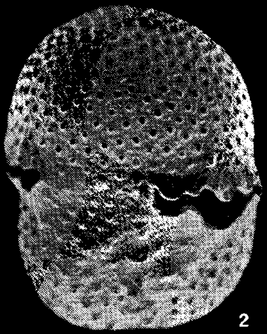
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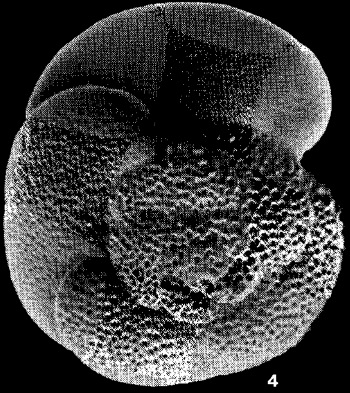
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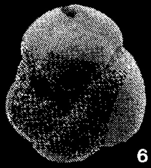
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Plate 7

	Globorotalia inflata group
Figs. 1, 2	*Globorotalia puncticulata,* Kalithea, sample GR 2246.
Figs. 3–5	*Globorotalia bononiensis,* Punta Piccola, sample JT 5708.
Figs. 6–8	*Globorotalia inflata,* Vrica, sample JT 6280.
Figs. 9, 10	*Globorotalia inflata,* from laminated sediments (*G. oscitans* type) Vrica, sample JT 6272.

All magnifications × 80.

Plate 7

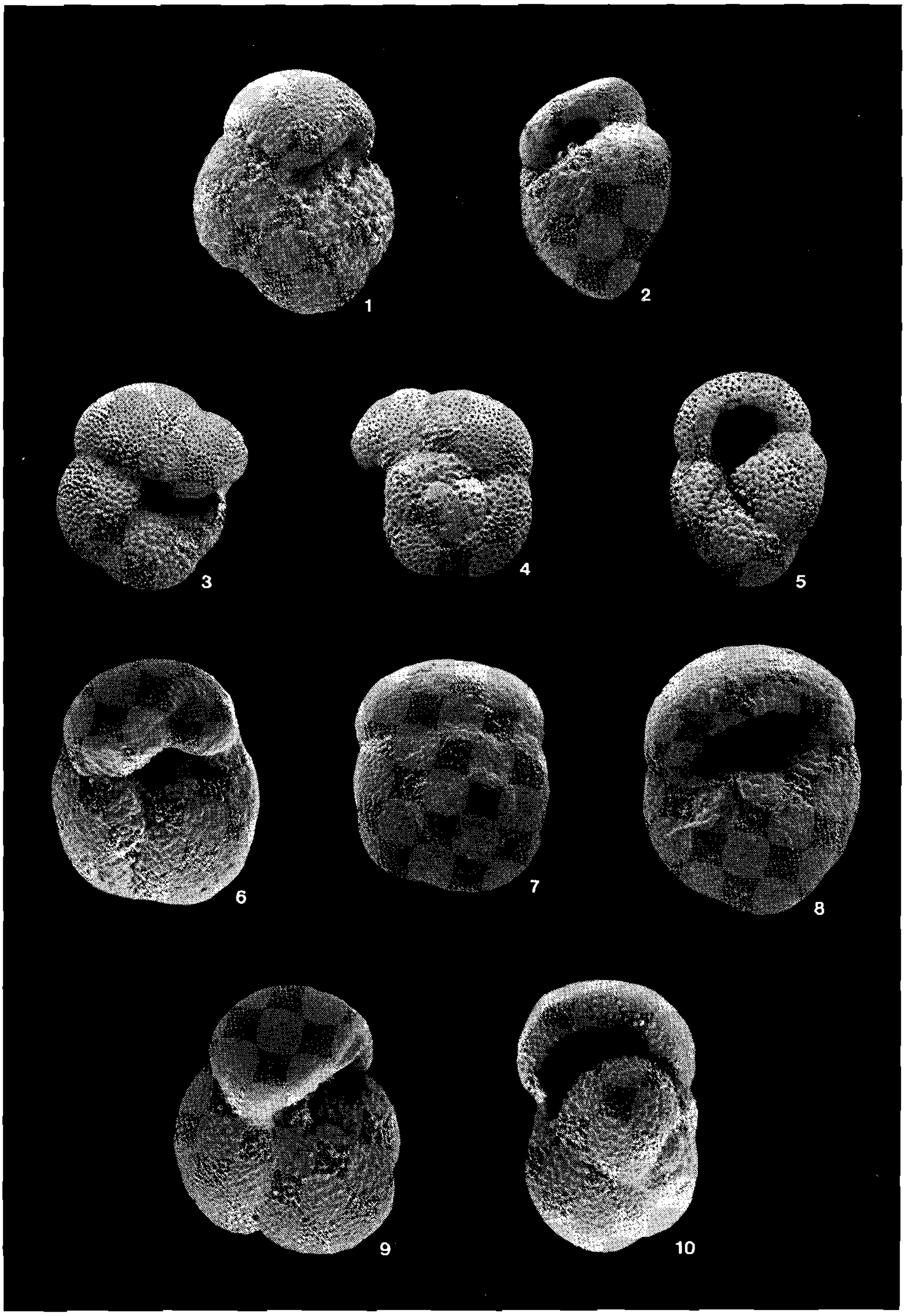


Plate 8

Globorotalia crassaformis

Figs. 1–3	specimens from diatomaceous sediments, Prassas, sample CP 3379.
Figs. 4, 6, 11, 12	Aghios Vlassios, sample GR 3318.
Fig. 5	Monte Sante Nicola, sample CP 3766.
Figs. 7–10, 12	Monte Sante Nicola, sample CP 3773.

All magnifications X 80.

Plate 8

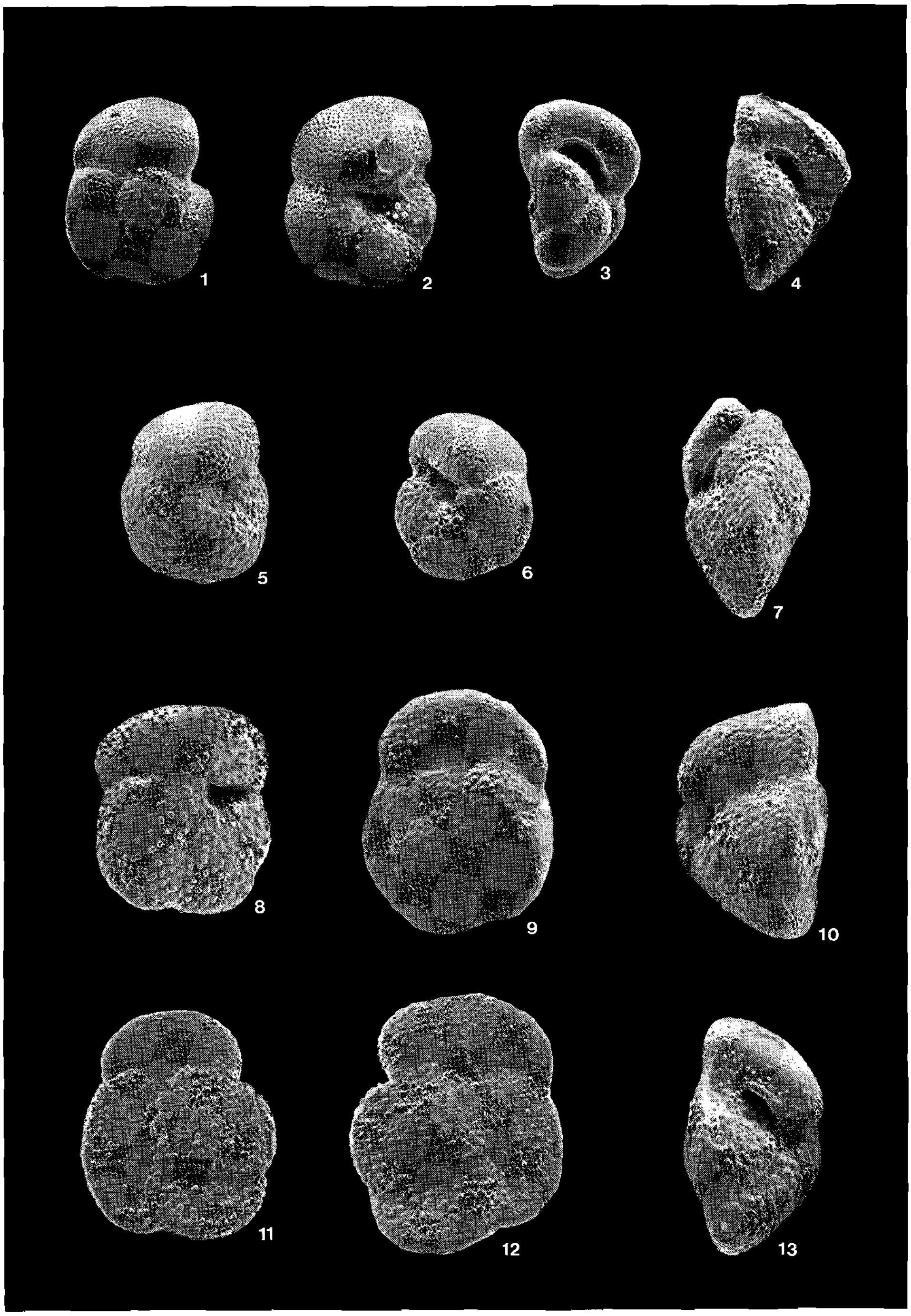
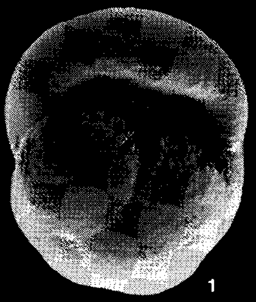


Plate 9

Figs. 1, 2	*Pulleniatina obliquiloculata,* Cape Bojador, core 17/3.
Fig. 3	*Candeina nitida,* Cape Bojador, core 38/4.
Figs. 4, 5	*Globoquadrina altispira,* Kalithea, sample GR 2213.
Figs. 6, 7	*Globorotalia menardii,* Cape Bojador, core 22/2.

All magnifications × 80.

Plate 9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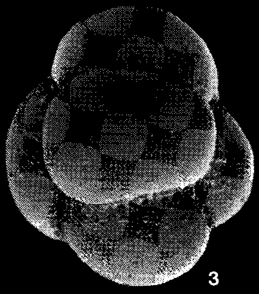
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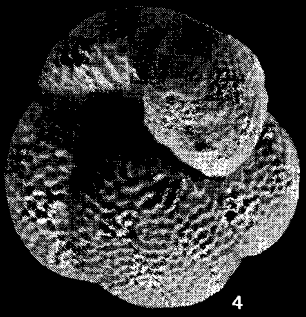
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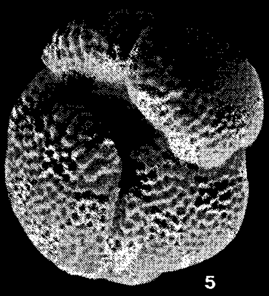
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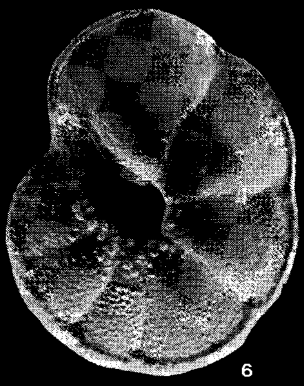
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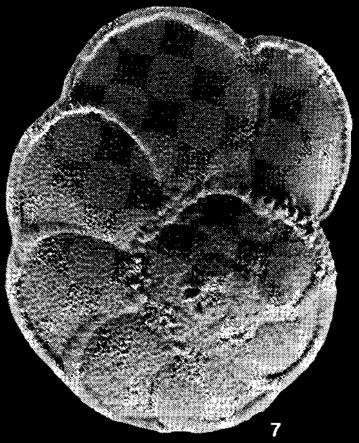
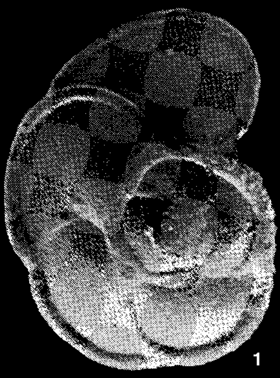

7

Plate 10

Figs. 1–6 *Globorotalia menardii,* Cape Bojador, core 41/1.

All magnifications × 80.

Plate 10



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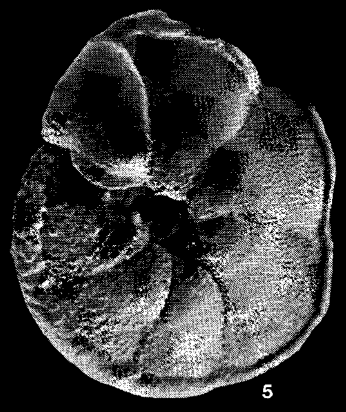

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