UTRECHT MICROPALEONTOLOGICAL BULLETINS

H. A. JONKERS

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PLIOCENE BENTHONIC FORAMINIFERA FROM HOMOGENEOUS AND LAMINATED MARLS ON CRETE

31

UTRECHT MICROPALEONTOLOGICAL BULLETINS

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PLIOCENE BENTHONIC FORAMINIFERA FROM HOMOGENEOUS AND LAMINATED MARLS ON CRETE

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ABSTRACT

In the Pliocene, the paleogeography of central Crete consisted of a number of basins which were filled by predominantly marly sediments. In the sedimentary sequence numerous laminated sapropelic intercalations can be observed. At a higher stratigraphic level diatomaceous laminites appear. From field data and sediment analyses we have inferred a shallowing for this sequence.

Correlation of the individual strata shows that sapropelic laminites and diatomites were formed simultaneously. Turbidity-controlled differences in primary production are considered to be responsible for the simultaneous formation of both lithology types. Thickness of the sapropels is determined primarily by the amount of clastic input; in diatomites thickness depends on different rates of production of siliceous micro-organisms.

The benthonic foraminifera from the sediment successions were subjected to a quantitative study. On the basis of R-mode statistical analyses we can divide the benthonic fauna into a group with preference for the homogeneous sediments, a laminite-bound group and a group with an intermediate position. The statistical analyses suggest the existence of a stagnation gradient for the depositional environments of the successive laminites. At the extreme end of this gradient the autochthonous fauna is replaced by allochthonous benthonic elements. It can be demonstrated that the degree of stagnation during each period of laminite formation differed from basin to basin and was at its maximum in relatively shallow environments.

A stagnation gradient seems to be of little value for the homogeneous sediments. Here, minor faunal changes can be attributed to shallowing and the development of better nutrient conditions.

From distributional, sedimentary and faunistic evidence it is concluded that the Pliocene periods of stagnation are best expressed in a marginal setting. Periodically increased run-off seems to provide the most likely explanation for the origin of the Pliocene laminated sediments. Low saline land-derived waters caused the termination of the vertical circulation. In addition, such waters brought nutrients into the marine realm, giving rise to enhanced production in surface waters.

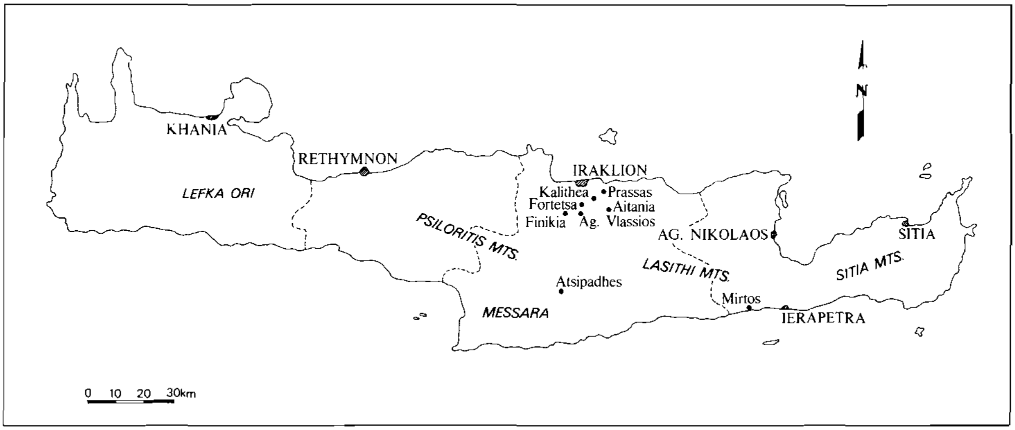

Fig. 1 Map of Crete with location of the sections.

Chapter I

INTRODUCTION

I.1. CHOICE OF THE SUBJECT

In the Mediterranean region, marine sequences of Neogene age and younger have always been of great interest to micropaleontologists. The designation of stratotypes on the Italian mainland and on Sicily initiated great activity in micropaleontology, primarily in the field of biostratigraphy. Various groups of fossil organisms have been studied for the purpose of intra-Mediterranean and Mediterranean – Atlantic correlations, with different degrees of success.

Our knowledge about the geological history of the Mediterranean and particularly about the younger Neogene, has been greatly extended by data provided by deep-sea drilling. The youngest history of the marine realm is documented by the sediments obtained from piston cores.

One of the most salient lithological features observed in the Neogene deposits is the repeated occurrence of finely laminated layers, which proved to be especially numerous in the eastern part of the Mediterranean. Much attention has been paid to the laminated sediments of the Messinian, formed prior to the salinity-crisis and to the Pleistocene and Holocene laminated layers, rich in organic material, found below the sea-floor.

In addition to micropaleontological investigations and sedimentological studies, research methods have been applied to stable isotopes, clay minerals and organic geochemistry in attempts to reconstruct the depositional environments of the laminites. A number of models have been proposed to explain the repeated formation of these laminated sediments.

The laminated layers of Pliocene age, as encountered in many land-sections, have not yet been subject to extensive research. On Crete – and especially in the Iraklion province (fig. 1) – laminated intervals can be studied at numerous locations. Two types of laminated sediments are found here, which can be easily distinguished on colour, either brown or white. Moreover, the two types were found to occupy specific stratigraphical positions. Samples derived from both types of lithology yielded benthonic foraminiferal associations which strongly deviate in composition from those in the non-laminated deposits. It was for this reason that we decided to investigate the interrelation between the environmental development and the changes in the composition of the benthonic faunas.

In addition to quantitative micropaleontological studies, we performed analyses of the sediment-compounds and of the stable oxygen and carbon isotopes in foraminiferal tests. By combining the results obtained from our investigations with literature data we tried to present a general model for the deposition of the Pliocene laminated sediments.

I.2. METHODS OF INVESTIGATION

Provenance of the samples and sampling procedure

Eight Cretan sections (Finikia, Aghios Vlassios, Fortetsa, Kalithea 1, Kalithea 2, Prassas, Aitania and Mirtos) were chosen for quantitative analyses of their benthonic foraminiferal contents. They had been selected in the first place for investigations within the framework of I.G.C.P. project No. 74/I/1 "Accuracy in time". All but one (section Mirtos) are located in the Iraklion province.

A more or less regularly spaced set of samples was obtained from each section. Sample spacing depended mainly on the vertical distribution of lithological features (e.g. laminites). Before we started the sampling procedure, rubble and incidental vegetation were removed from the outcrops so that the sediment collected would be fresh.

In addition to these sets of samples, two almost continuous sequences of samples were obtained across three successive homogeneous and laminated beds.

The sampling and measuring of all the sections were performed during the summer months of 1977–1981 by different sampling-teams.

Preparation of the samples

In the laboratory a part of each lithological sample was washed over three sieves with mesh-widths of 595, 125 and 63 μ. The residues were oven-dried and stored in glass tubes.

Quantitative fauna analyses

For the quantitative analyses of the benthonic foraminiferal faunas we commonly used the size-fraction 125–595 μ. This fraction was chosen so that we could compare our counts with those of earlier studies on similar subjects performed in the Utrecht Micropaleontological Department. For one section (Kalithea 2), the 63–125 μ and the 200–595 μ fractions were included in the investigation as well.

Countings on the 125–595 μ size-fractions were performed on small splits from the original residue, obtained with an Otto micro-splitter. The residues of the 63–125 μ fraction were not reduced by using the micro-splitter. The splitting of small portions of the residues of this size-fraction appeared to result in a considerable loss of material. Furthermore, it proved difficult to remove the splits from their storage tubes. Instead of making a split, a small quantity – roughly the amount contained in a split – was directly strewn on the picking tray.

Each split contained at least 200 individuals. It was strewn on a large picking tray with 45 fields. Care was taken to avoid size-sorting effects. All specimens encountered on the middle horizontal row were identified and counted and the procedure was continued along vertical rows starting in the middle of the tray, until the number of 200 benthonic foraminifera was reached. As a routine the number of accompanying planktonic specimens were counted as well.

Most of the individuals encountered could be identified at species level, but in some cases species were lumped from the onset in higher categories and listed as *Lenticulina* spp., *Fissurina* spp., etc. For the taxonomic concept, the reader is referred to our last chapter.

Broken specimens were counted as one if more than half of the test was preserved. Exceptions were made for very large uniserial species which were always broken, such as *Orthomorphina longiscata.* In such cases three fragments were counted as one specimen. These taxa were, however, never so abundant as to make this procedure seriously bias the 200-counts.

For all samples the required number of 200 specimens could be counted. It is assumed that differences in preservation did not seriously influence the species proportions. The number of indeterminable individuals was always small, in general not exceeding two per cent of the total fauna. In the 63–125 μ size-fraction this percentage was, on average, twice as high, due to the presence of very small-sized specimens which could not be assigned to any species.

For every section, the faunal content of each laminated bed was determined, whereas in four sections the homogeneous sediments were analyzed as well. We had to make a selection from the vast amount of samples available to us. For the laminated beds this selection was done by choosing the lowermost sample from each bed. We also took one sample from the homogeneous strata, but from the upper part. Furthermore, we studied three sets of samples quantitatively from laminated/homogeneous sequences sampled in detail.

Graphical representation of the counting results

The results of the countings are figured in such a way that samples are placed at equal distances, notwithstanding the fact that the actual distances between samples usually differed considerably. In general, only those species are figured which reach percentages of ten or more. Groups of species belonging to one genus or to one family, or which have a presumedly identical way of living, e.g. epiphytes, were lumped and subjected to the same criterion. The individual species in such groups commonly display comparable frequency patterns. The remaining low-frequency species were all put together into the "rest"-group. This method implies that in one section a particular species may be figured separately, whereas in another section it is part of the rest-group. Finally, a graphical reproduction is given of the percentage of benthonics in the entire foraminiferal fauna.

Mathematical analyses

An R-mode analysis (comparison of species and groups of species) was performed on the quantitative data obtained from four of the sections. Firstly, we analyzed the counting results from the homogeneous and laminated sediments together. Thereupon the data-sets from the two lithology types were analyzed separately.

Seventeen faunal categories were made for every section, each consisting of one or more species. One additional category consisted of the percentage of benthonic foraminifera and two more categories of the lithology types (homogeneous and laminated) and of the thicknesses of the homogeneous and laminated strata, each bed being represented by one sample.

Possible correlations between the faunal categories were analyzed using the BALANC and DISTUR programs of M. M. Drooger (1982). The comparison of the faunal categories with the other three was performed with the aid of his MATRIX program. Correlations at the levels $P < 0.01$ and $P < 0.05$ are considered significant and included in the figures.

Sediment analyses

Forty-seven rock-samples taken from five of the sections were analyzed for their carbonate, pelite and organic content.

The carbonate content was determined by treating about 5 g of sediment with 100 ml 1N HCl and titrating 20 ml of the remaining liquid with NaOH.

The pelite content considered here, is the proportion of non-carbonatic material in the size-fraction smaller than 16 microns (clay and fine silt). It was calculated from the residue that precipitated in 15 minutes after the organic material had been removed with concentrated H_2O_2 and the carbonatic material had been removed with 6N HCl from a weighed quantity of sediment. Before the settling-procedure was started, a peptisation agent (Na_2CO_3 and $Na_4P_2O_7$) was added to de-flocculate the clay particles.

The percentage total organic matter was calculated from the weight-loss after the reaction of a known quantity of sediment with concentrated H_2O_2. A disadvantage of this method is that all the organic matter may not have been oxidized during the reaction. Hence, the values we obtained for organic matter may actually be too low.

Stable isotope analyses

Oxygen isotope analyses were performed on a selection of twenty-one samples, all from section Kalithea 2. This selection consists of samples derived from homogeneous and from laminated deposits. As a routine, carbon isotope measurements were performed. An attempt was made to analyze from each sample both benthonic and planktonic foraminifera. Only monospecific assemblages were analyzed.

The benthonic foraminifer *Bolivina spathulata* was chosen, being the most abundant faunal representative in the laminated sediments.

The planktonic *Globigerinoides obliquus* was selected because it is a common species in both types of sediment, although in some of the twenty-one samples it is very scarce. If it is correct that the depth distribution of this species and its recent relative *G. ruber* is the same, *G. obliquus* may be regarded as a shallow-living species.

B. spathulata was picked from the 125–595 μ size-fraction. Some hundreds of individuals of this light-weighted species had to be collected per sample. *G. obliquus* was picked from the 200–595 μ fraction to avoid identification problems with juveniles belonging to either the nominate species or *Globigerina apertura.*

The foraminiferal tests were crushed and afterwards heated at 470°C in a He-flow for half an hour in order to destroy the organic matter. Thereupon, the carbonate was made to react under vacuum with 100% H_3PO_4 at 25°C. After four hours of reaction time, the formed CO_2-gas was collected in a liquid nitrogen-cooled trap, after passing through a trap cooled by melting acetone to remove water. Analyses were performed on a Micromass 602C mass-spectrometer.

The results are given as δ-values (per mil deviations from the international PDB standard).

I.3. ACKNOWLEDGEMENTS

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Chapter II

STRATIGRAPHY OF THE PLIOCENE OF THE IRAKLION AREA

II.1. GENERAL LITHOSTRATIGRAPHY

The stratigraphy of the Neogene rocks on Crete was outlined by Meulenkamp (1979a). He presented composite lithostratigraphical columns for the Iraklion province to illustrate the complex sedimentary and tectonic history of this part of the island. The Late Miocene to Early Pliocene development of the area which we are dealing with was described by Meulenkamp et al. (1979b). The Pliocene stratigraphy will be repeated here, and we give some additional information.

The Neogene sequence in the Iraklion province is strongly faulted, especially in the northern part. Major faults are drawn on the simplified geological map of figure 2. The fault-systems already existed during the sedimentation and they delimited a number of small basins, which were separated by shoals and small islands. For ease of reference, we call the basins used in our study Finikia – Aghios Vlassios Basin, Kalithea Basin, Prassas Basin and Aitania Basin.

In all these basins the sequences of the Lower Pliocene consist of marine sediments which unconformably overlie Messinian deposits. In the area studied, the latter are bioclastic limestones, homogeneous and laminated marls, gypsum and gypsum conglomerates. The lowermost Pliocene unit on top of such Messinian sediments is the so-called marl-breccia, a chaotic mixture of limestones, white marls and a minor admixture of other rock types. In the Finikia – Aghios Vlassios and Kalithea Basins, the contact between the marl-breccia and the underlying deposits is highly irregular and in these basins it overlies all mentioned Messinian lithotypes. In the more eastern Aitania and Prassas Basins, this contact is more regular and here the marl-breccia lies on top of bioclastic limestones. The marl-breccia was formed shortly after the flooding of the Early Pliocene as a consequence of tectonic movements along the aforementioned older fault-systems (Meulenkamp et al., op. cit.).

The next higher unit consists of white, homogeneous, ooze-like marls, which show some resemblance to the Sicilian Trubi. In the lithological columns of Meulenkamp (1979a) this unit is indicated as Kourtes facies. Alternations of marl-breccia and Kourtes marls may be seen near the boundary of the two units. Malacofaunistic features of the Kourtes marls are pycnodont oysters and pectinids. This type of lithology can be observed all over Crete.

At a higher stratigraphic level thin brown coloured laminated layers appear. Here the colour of the homogeneous marls changes gradually from white to grey; the thickness of the individual laminated beds increases upwards (Finikia facies). In the grey marls, small molluscs may be encountered, whereas in the brown laminites plant and fish remains and – occasionally – sponge spicules may be found in great numbers. Burrows can be seen, filled with light-coloured marl. Each transition from homogeneous to laminated marls occurs within one or a few centimetres and only a little mixing of brown and grey sediment is observed. The upper boundaries of the laminated beds, however, are less clearly defined. Intense bioturbation causes the top parts of the laminated beds to be mixed with overlying grey marl, with an upward increase in the amount of grey sediment. Mottling with brown marl can be observed as a common phenomenon in the homogeneous marls, probably as a result of burrowing.

In the province of Iraklion, the distribution of the Finikia facies is restricted almost entirely to the basins mentioned above. It can furthermore be observed that this unit rapidly decreases in thickness in the western part of the province, and ultimately it is absent in the area adjoining the Psiloritis mountains. The only other occurrence of alternations of grey marls and brown laminites is found in the north-eastern foothills of the Messara plain, from which area we investigated one section (Atsipadhes, fig. 1).

The next higher Stavromenos facies-unit is an alternation of generally yellow, homogeneous marls and grey or white laminated marls. A close inspection of these laminated intercalations reveals that they consist of alternating lighter and darker laminae. Some of the laminite partings show perfectly preserved fish or plant leaves (figs. 3 and 4). Sponge needles are usually abundant. Occasionally, large burrows can be seen parallel to the bedding-planes or penetrating the beds. Just as for the brown laminated beds of the Finikia facies, lower boundaries of the laminated beds are sharp, or an interval of no more than one or two cm thickness with faint lamination is present. The upper parts again show an intensely bioturbated transition to the overlying sediments. Rare examples of such laminated beds are seen to be internally broken-up or to display synsedimentary faulting.

In the Prassas Basin, where the Stavromenos succession is complete, this unit passes upwards into calcareous sandstones. In the Finikia – Aghios Vlassios Basin, in the vicinity of Fortetsa (fig. 2), yet another succession of brown laminated marls and homogeneous marls is found, but with sands on top.

The homogeneous intervals of the Stavromenos facies – and especially in the upper part of the unit – contain a rich and diverse macrofauna. The Stavromenos facies is found all over the Iraklion province.

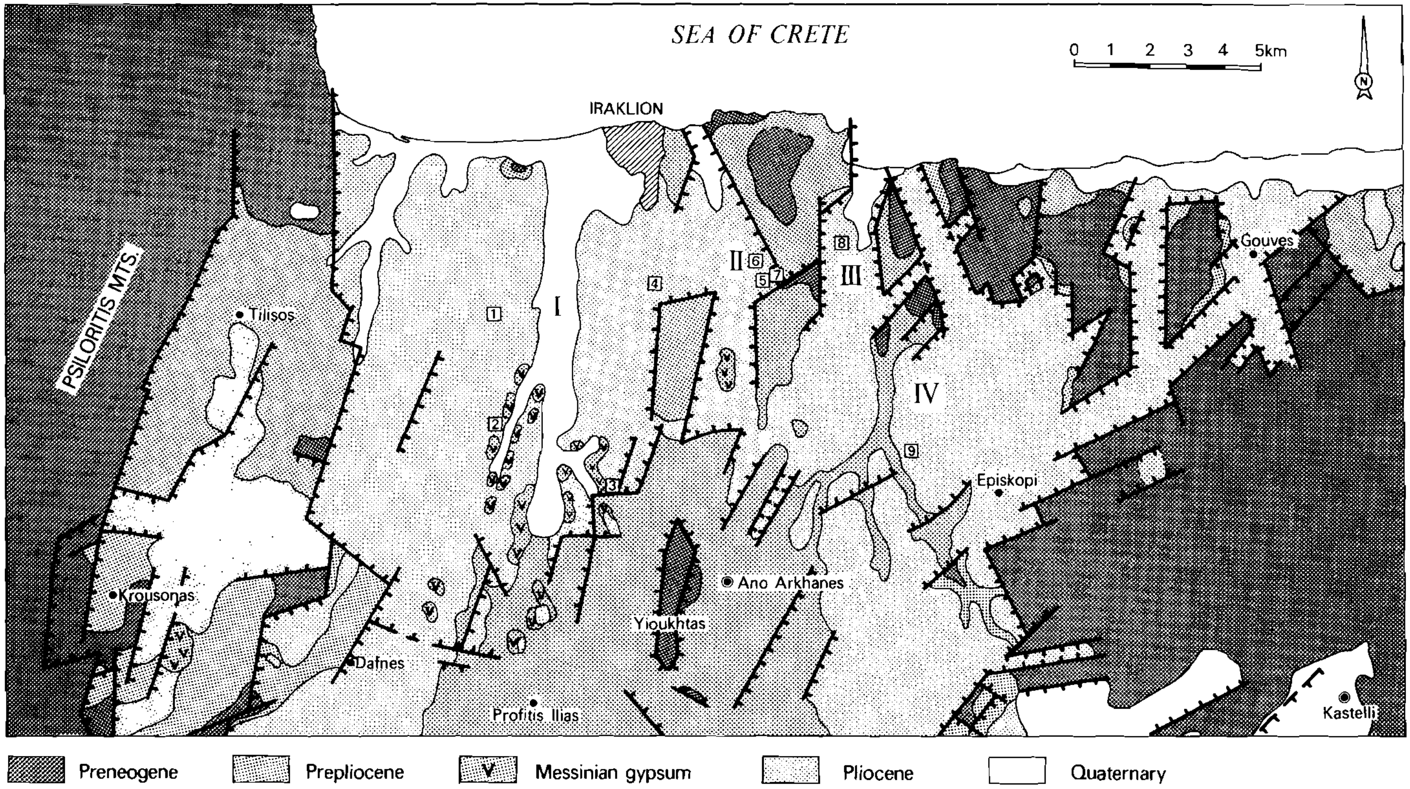


Fig. 2 Simplified geological map of the northern part of the Iraklion province. Basins: I. Finikia – Aghios Vlassios Basin; II. Kalithea Basin; III. Prassas Basin; IV. Aitania Basin. Sections: 1. Gournes; 2. Finikia; 3. Aghios Vlassios; 4. Fortetsa; 5. Kalithea 1; 6. Kalithea 2; 7. Kalithea 3; 8. Prassas; 9. Aitania.

No higher Pliocene rock-units are known from the Iraklion area. Pleistocene terrace deposits in the vicinity of the town of Iraklion have been described by Sissingh (1972). Scree deposits are present in the valleys of the rivers. Deviations from the general pattern outlined above are rare; they will be dealt with in the discussion of the sections.

II.2. BIOSTRATIGRAPHIC CONTROL

The biostratigraphy of the Pliocene deposits in the Iraklion province is well known, which allows for a good correlation of the sections. After the initial studies of Schmidt (1973) and Zachariasse (1975) on calcareous nannoplankton and planktonic foraminifera, respectively, our knowledge of the age relations of the different facies types was greatly improved by the studies of Driever (1981) and Spaak (1983).

Driever subdivided the Pliocene sequence into five units based on the relative frequencies of *Discoaster* species. In the zonal scheme of Martini and Worsley (1970), these five intervals cover NN 13 to part of NN 16.

In the Iraklion area, Spaak recognized six intervals, based on the entry and exit levels of planktonic foraminiferal species. The lowermost one corresponds to the *Sphaeroidinellopsis* Acme-zone (MPL 1 of Cita, 1975a), whereas his sixth interval is in the lower part of the *Globorotalia crassaformis* Zone of Bizon and Bizon (1972).

Planktonic foraminiferal faunas from the marl-breccia and from the Kourtes marls point to the *Sphaeroidinellopsis* Acme-zone, which indicates that the lowermost Pliocene is present on central Crete. Just below the *Globorotalia margaritae* Zone, the first brown laminated layers are found. The first appearance of white laminated beds – which mark the boundary between the Finikia and Stavromenos facies types – is highly diachronous, as shown by detailed correlation of the laminites (II.5).

The topmost strata of the Pliocene succession in the Kalithea Basin belong to the upper part of the *Globorotalia puncticulata* Zone (sensu Spaak, 1983). Marine sedimentation in the Aitania Basin came to an end somewhere in Spaak's Interval 5 (lower part of *G. crassaformis* Zone). The youngest Pliocene sediments are found in the Finikia – Aghios Vlassios Basin and in the Prassas Basin and can be assigned to the lower part of Interval 6 of Spaak (1983).

II.3. THE SECTIONS

Section Finikia

Section Finikia is located SW of the village of Finikia (figs. 5 and 6). Its

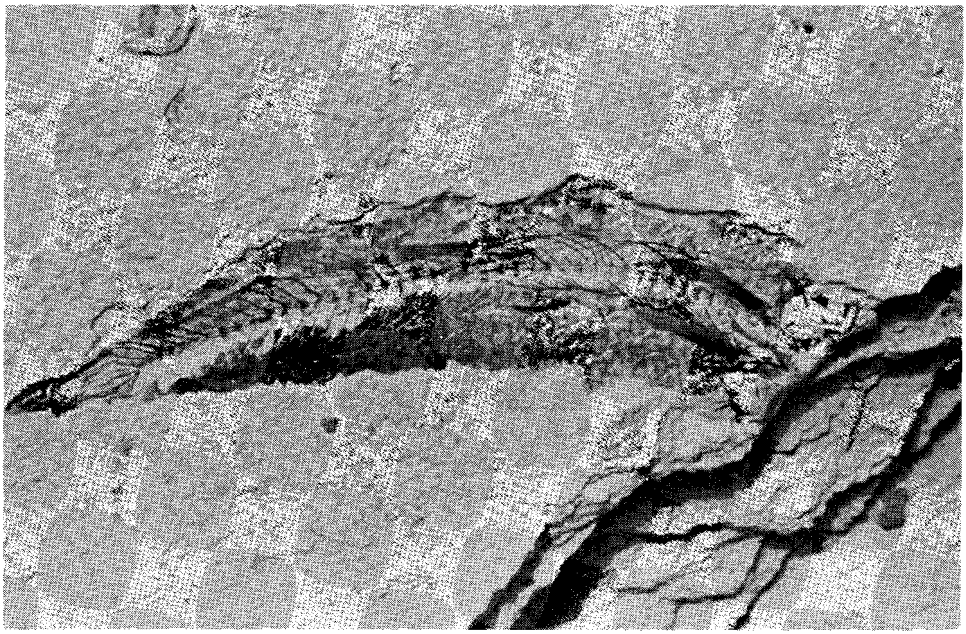


Fig. 3 Laminite parting with fossilized fish, section Prassas.

Fig. 4 Plant-remains in a laminated interval of section Prassas.

exposures face east. The section is the same as the one used by Thomas (1980) for her *Uvigerina* studies. Van der Zwaan and Thomas (1980) included a number of samples from this section in their study on stable isotopes. Associations of *Discoaster* were described by Driever (1981). Spaak (1983) gave a detailed account of the planktonic foraminiferal content of the section. In addition to the section they used, we sampled a new exposure in a stratigraphically lower interval. The stratigraphic distance between this and the main part of the section is some 10–15 m. The total thickness of the interval covered by our samples is 140 m.

The lithological column (fig. 7) displays an alternation of grey homogeneous marls and brown laminated beds as described in the previous section II.1. In the lower part, the minimum thickness of the laminated beds is 20 cm. Higher up, thicknesses become much greater and a maximum of 1.75 m was mea-

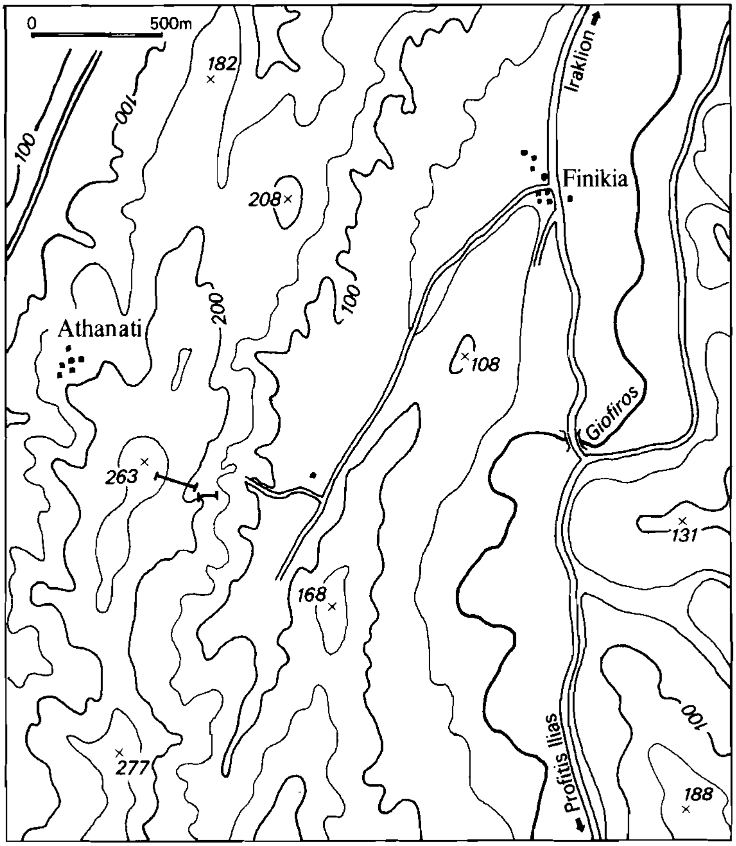


Fig. 5 Location of section Finikia.

Fig. 6 Section Finikia, looking to the south-west. The lower part of the section is exposed along the far end of the newly made vineyard.

sured. In figure 7 a total of twenty-nine brown laminites can be counted. In the top part of the section, three white laminated beds are intercalated, which measure from 40 cm to more than 1.5 m. Homogeneous intervals up to 10 m can be seen in between.

One decimetre above the base of the topmost laminated bed, a 1 cm thick volcanic ash-layer occurs (Bianchi et al., in prep.).

Altogether 189 samples were taken, mostly with a spacing of 75 cm: CP 5323 – CP 5335 and CP 2000 – CP 2175. At the level of CP 2138 two additional samples, GR 3456 and GR 3457, were taken, one of which is used in our fauna analysis. In addition, 50 samples were taken from the interval between CP 2017 and CP 2029. This series, GR 3351 – GR 3400, was obtained at 10 cm intervals, which means continuous sampling; only between GR 3365 and GR 3371 and between GR 3384 and GR 3387 was the spacing 25 cm.

Section Aghios Vlassios

This continuously exposed section is found NW of the village of Aghios Vlassios (figs. 8, 9 and 10). Section Aghios Vlassios was described briefly by

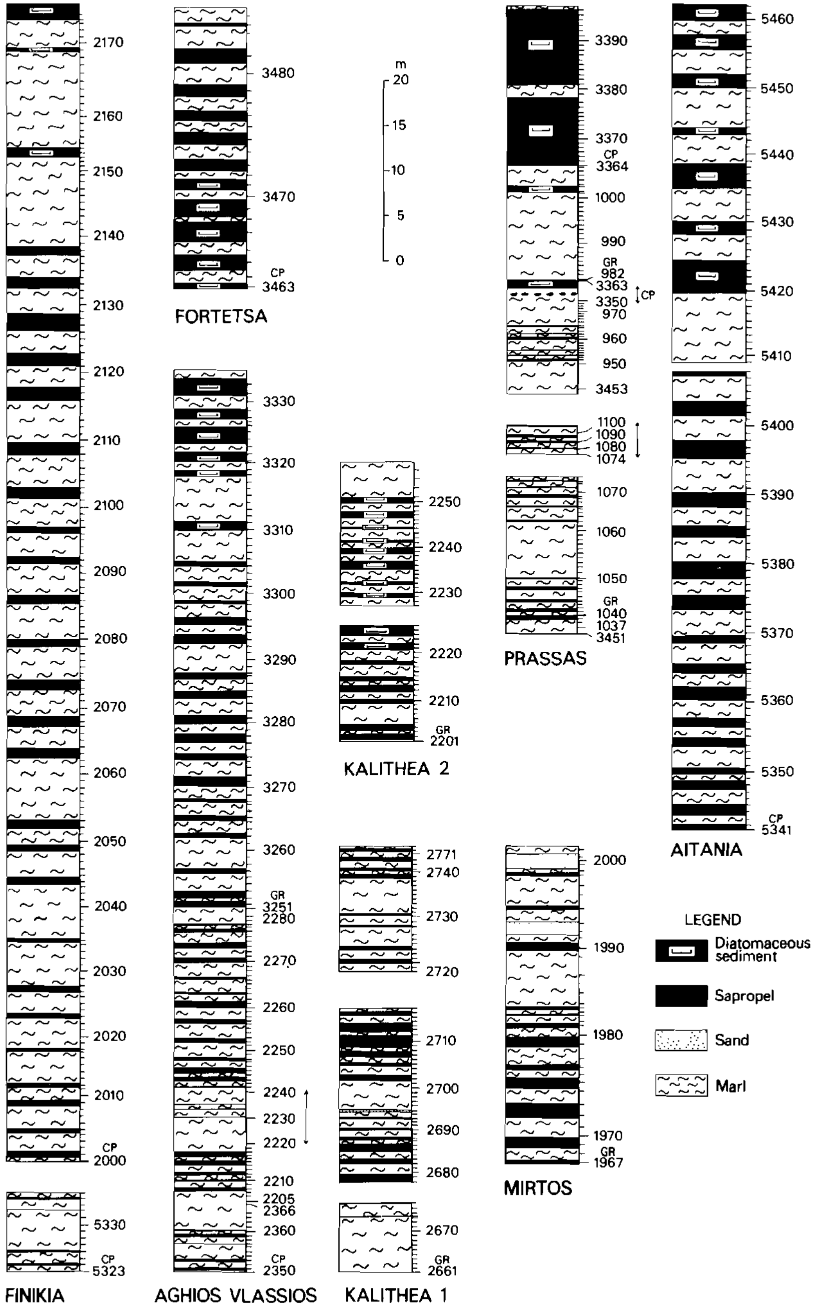


Fig. 7 Lithological columns of the sections.

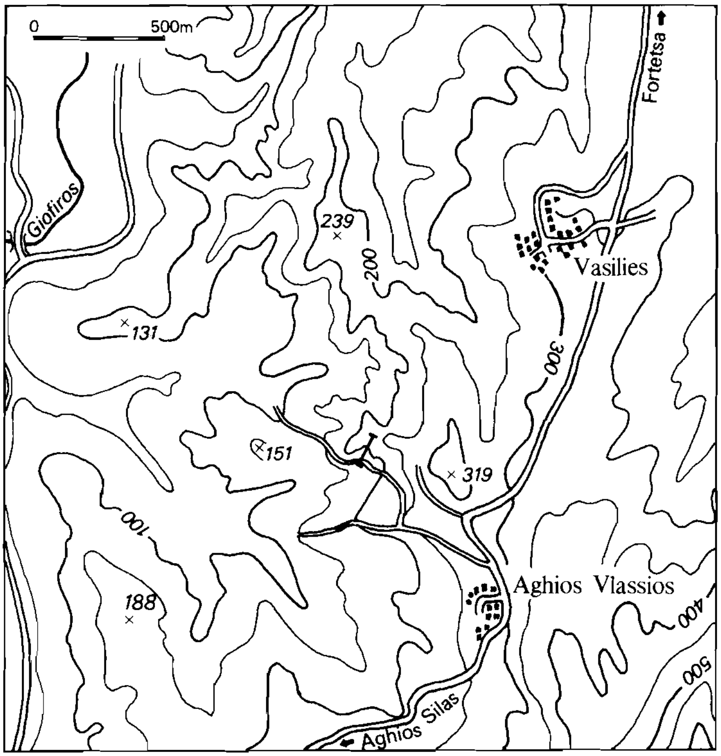


Fig. 8 Location of section Aghios Vlassios.

Fig. 9 Section Aghios Vlassios and its environs seen from the south-east. This picture was taken from the Yioukhtas Mt. at an altitude of 800 m. From this point the section lies at a distance of 3.5 km.

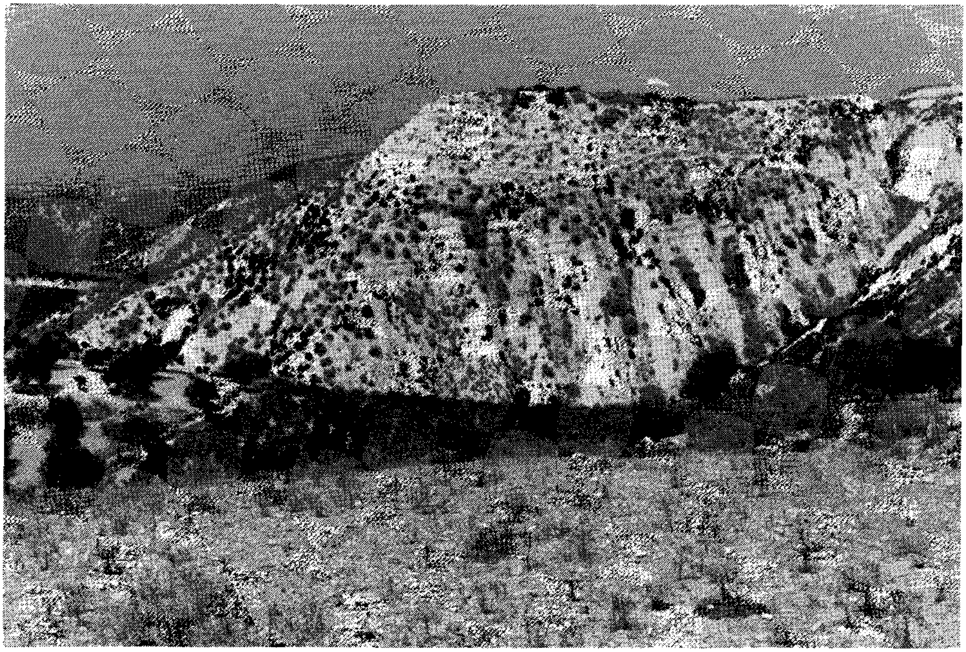


Fig. 10 Section Aghios Vlassios, looking to the north. The lowermost one of the clearly visible layers in the upper half of the section corresponds to the sample level of GR 2375.

Meulenkamp (1979a) and was studied by Thomas (1980), Van der Zwaan and Thomas (1980), Driever (1981) and Spaak (1983). Its stratigraphic thickness is 100 m. In the larger part of the lithological column, again grey homogeneous marls are found with 44 brown laminated marly layers (fig. 7). In the lower part, laminites are 10 cm thick, whereas higher up they may be as thick as 95–100 cm. In the homogeneous marls, mottling with brown sediment is a normal feature. Thick homogeneous beds between thin laminites may be devoid of such mottling.

The overlying Stavromenos facies-unit displays six white laminated beds. At 1 dm above the base of the third white laminated interval, a 1 cm thick tephra-layer is present (Bianchi et al., in prep.). The sediments of the two relatively thick homogeneous intervals in this unit (fig. 7) consist of light-grey indurated marls containing pycnodont oysters. The other homogeneous strata are essentially yellowish in colour.

In total 175 samples were taken, consisting of three sets: CP 2350 – CP 2366 and CP 2205 – CP 2280, with a sample spacing of mostly 50 cm and GR 3251 – GR 3332 with a spacing of 75 cm. The sets are superimposed without overlap or gap in the record. The interval of approximately CP 2227 to CP 2245 was also sampled in a parallel section. From this set, CP 2308 was used in our studies. GR 3318 was substituted by a new sample: GR 3458.

Section Fortetsa

In a number of exposures west of the village of Fortetsa (fig. 11) the sediments show essentially the same sequence as in section Aghios Vlassios. Zachariasse (1975) most probably refers to these sediments when describing his section Fortetsa. This sequence was partly measured, but was not sampled in detail (see II.4). To the west this succession is bordered by a fault.

In the downfaulted block, further to the NW, the upper strata of the sequence are exposed (fig. 11). In the lower part they consist of an alternation of homogeneous marls and white laminated beds, up to 2.10 m thick, whereas in the upper part we again find reddish-brown laminites (fig. 7). To our knowledge, this is the only place where the latter type of laminites can be observed above the diatomites. At the top of the section indurated burrows are

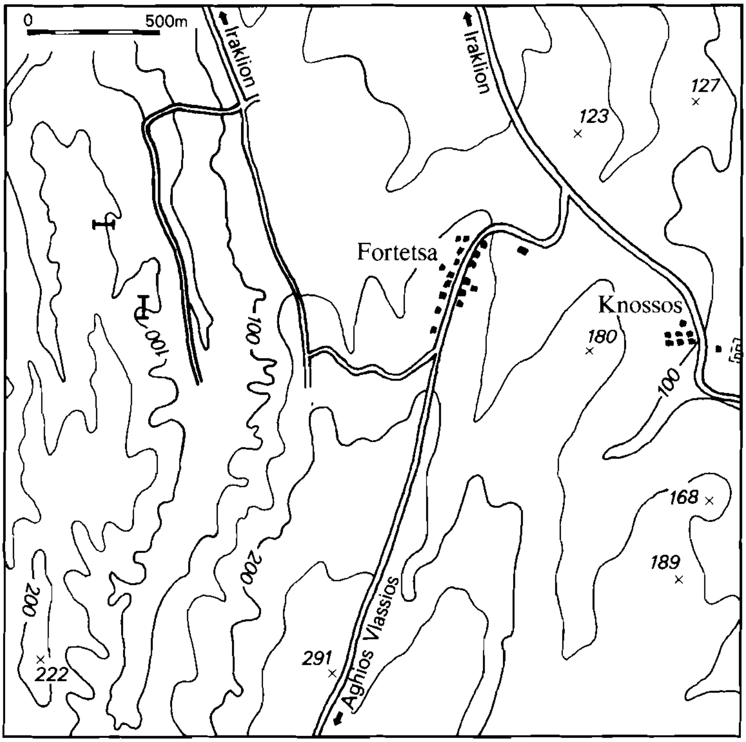


Fig. 11 Location of section Fortetsa.

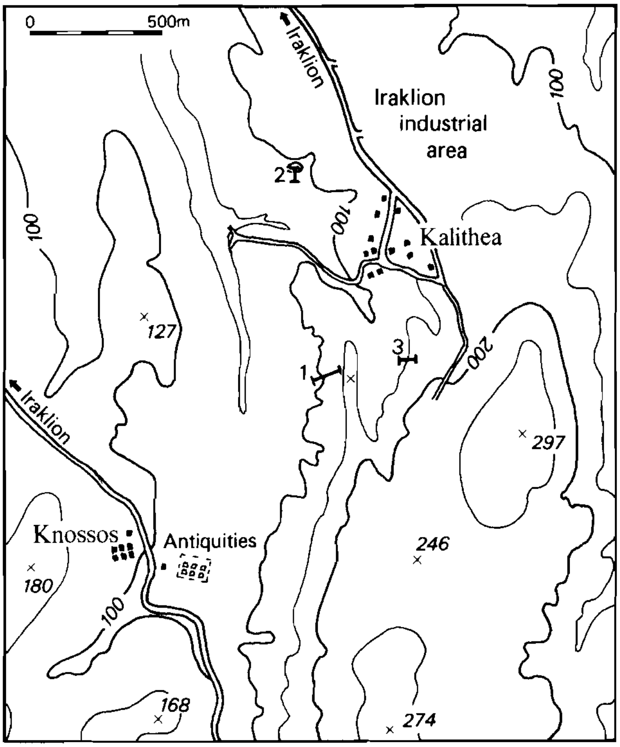


Fig. 12 Location of sections Kalithea 1, 2 and 3.

Fig. 13 Section Kalithea 1, looking to the north-east.

abundant. Still higher in the stratigraphy, sands are intercalated in the homogeneous marls; these sands probably announce the end of the marine sedimentation in this area.

Twenty-two samples, GR 3463 – GR 3484, were obtained from this locality, alternately from homogeneous and laminated layers.

Section Kalithea 1

This section is located SW of the village of Kalithea (figs. 12 and 13). It was studied by Spaak (1983) for the evaluation of planktonic foraminiferal datum levels.

The measured thickness of the sampled interval is 40 m. In the lower part, 6 m of Kourtes facies are present: white, indurated homogeneous marls (fig. 7). At one level pycnodont oysters were found. After the first thin laminated intercalations, a few metres are unexposed. In the main gully, brown laminites up to 1 m thick occur. Lithological boundaries are ill-defined because of strong bioturbation. One sand-layer of 10 cm thickness displays graded bedding. The top part of the section is separated from the middle part by an unexposed interval of again a few metres. The lithology of the thick homogeneous bed resembles that of the Kourtes facies. Here too the indurated whitish marls contain *Pycnodonta.* In total, twenty-two brown laminated beds were encountered.

Eighty-six samples, GR 2661 – GR 2743 and GR 2771 – GR 2773, cover this section; they were generally taken at 50 cm intervals. The three topmost samples are from a parallel section, which contains one higher laminated bed.

Section Kalithea 2

Section Kalithea 2 is located a few hundred metres north of section Kalithea 1 (figs. 12 and 14). The section was mentioned by Driever (1981) in his study on associations of *Discoaster;* Spaak (1983) reported on the planktonic foraminifera from this section. Correlation of the two sections in the field is not possible because of faulting in the area in between.

The total thickness of exposed sediments is 28 m (fig. 7). In the lower part, six brown laminites, up to 70 cm thick, were sampled. In the upper part, one encounters grey to yellow, sometimes silty marls with intercalated white laminites. These laminated levels may be as thick as 1 m.

Fifty-four samples, GR 2201 – GR 2254, were collected from this section. Sample-sites were at 75 cm intervals. Between samples GR 2226 and GR 2227 an unexposed part has a stratigraphical thickness of about 2 m.

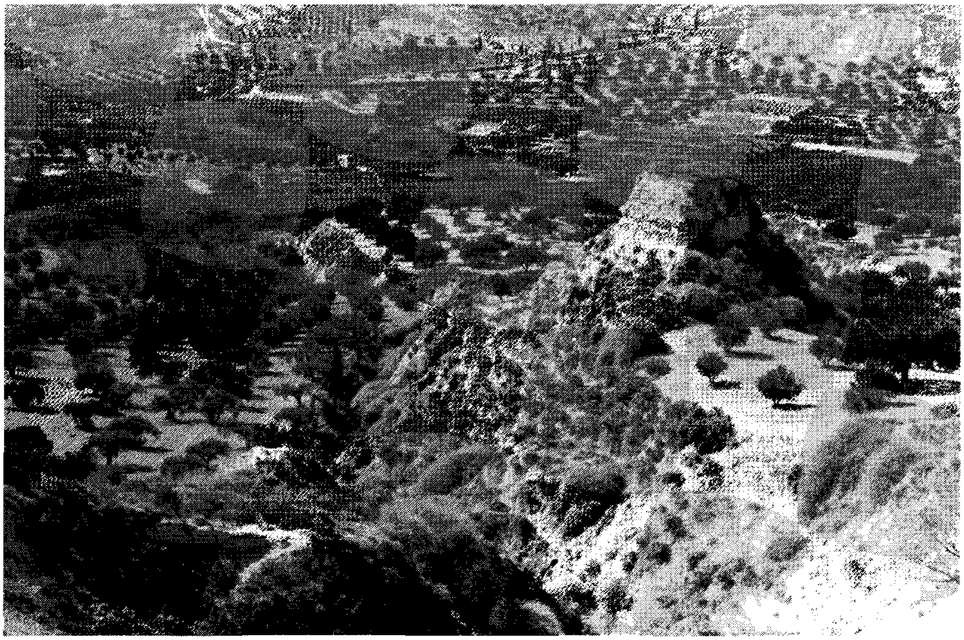


Fig. 14 Section Kalithea 2, seen from the east. The degree of exposure looks considerably worse than it actually was, owing to the oblique view. Note the indurated parts at the top of the section.

Section Prassas

In exposures along the road leading up to the village of Prassas (for location see fig. 15), four stratigraphically successive intervals can be sampled. This section was mentioned by Meulenkamp (1979a); it was used by Thomas (1980) for her study on uniserial uvigerinids and by Spaak (1983), who investigated the planktonic foraminiferal content. The section should not be confused with the one described by Tsapralis (1976) and Meulenkamp et al. (1978) along the main road from Iraklion to Aghios Nikolaos. From field evidence it is concluded that their section has a higher statigraphic position.

The marl-breccia and Kourtes marls are exposed in the lowermost interval. In the present study, this basal part is not considered. The stratigraphic gap between this and the following interval cannot be measured exactly; there are small faults between the two. The two following parts of the section display Kourtes-like marls and thin brown laminites, which commonly measure 20 to 30 cm (fig. 7). In its lower part the topmost exposure shows greyish marls and thin brown beds. An abrupt change from greyish marl to yellow silty marl can be noticed about 1 m below the first white laminated bed. Irregular-shaped concretions and shells of molluscs are present at the transition, and strong bioturbation can be observed. Biostratigraphic evidence reveals the presence of a major hiatus (see section II.4). The first white laminite is internally strongly deformed and broken-up. The very thick (± 8 m) laminated intervals at the top of the section exhibit small-scale synsedimentary faults. The lower of the two contains a thin volcanic ash intercalation; this occurs at about one metre above its base (Bianchi et al., in prep.).

A total of 154 samples was collected: GR 1037 – GR 1073 were taken at 50 cm intervals, GR 1074 – GR 1100 at 10 cm (continuous sampling), GR 950 – GR 973 at 30 cm, CP 3350 – CP 3363 at 15 cm and GR 982 – GR 1008 and CP 3364 – CP 3396 again at 50 cm intervals.

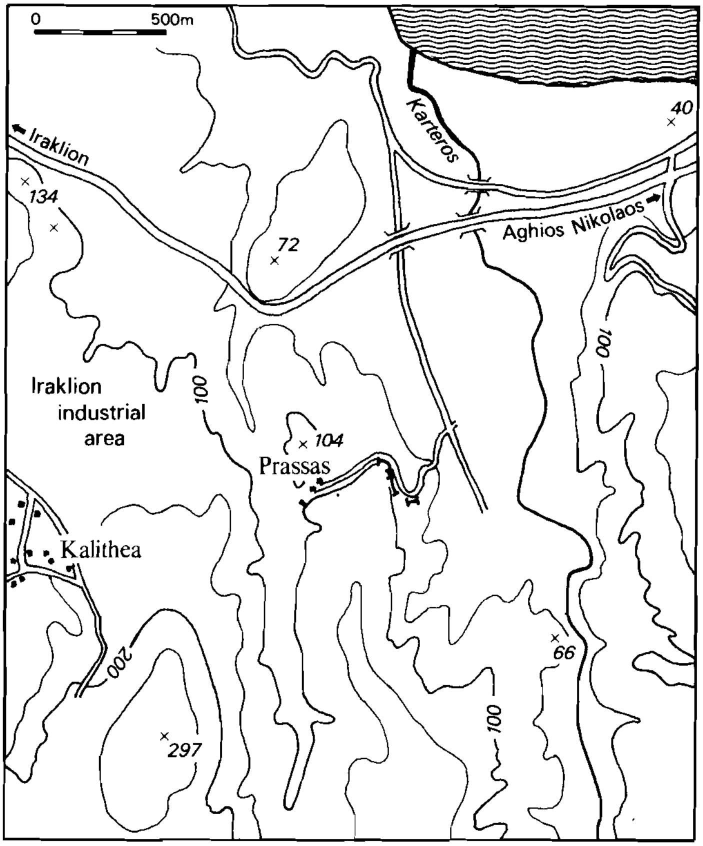


Fig. 15 Location of section Prassas.

Section Aitania

This section is exposed in a number of steep gullies west of the village of Aitania (figs. 16 and 17). The section forms part of the one studied by Zachariasse (1975) for planktonic foraminifera.

Thick brown laminites, up to 190 cm thick, are seen to alternate with homogeneous grey beds (fig. 7). In the upper part, the homogeneous marls become yellow to beige in colour and alternate with white laminated beds the thickest of which measures 3.5 m. Within the homogeneous intervals, discontinuous indurated levels may be present.

The 122 samples, CP 5341 – CP 5462, were spaced at 75 cm. Sampling of the upper part – from the level of CP 5447 onwards – was possible after a

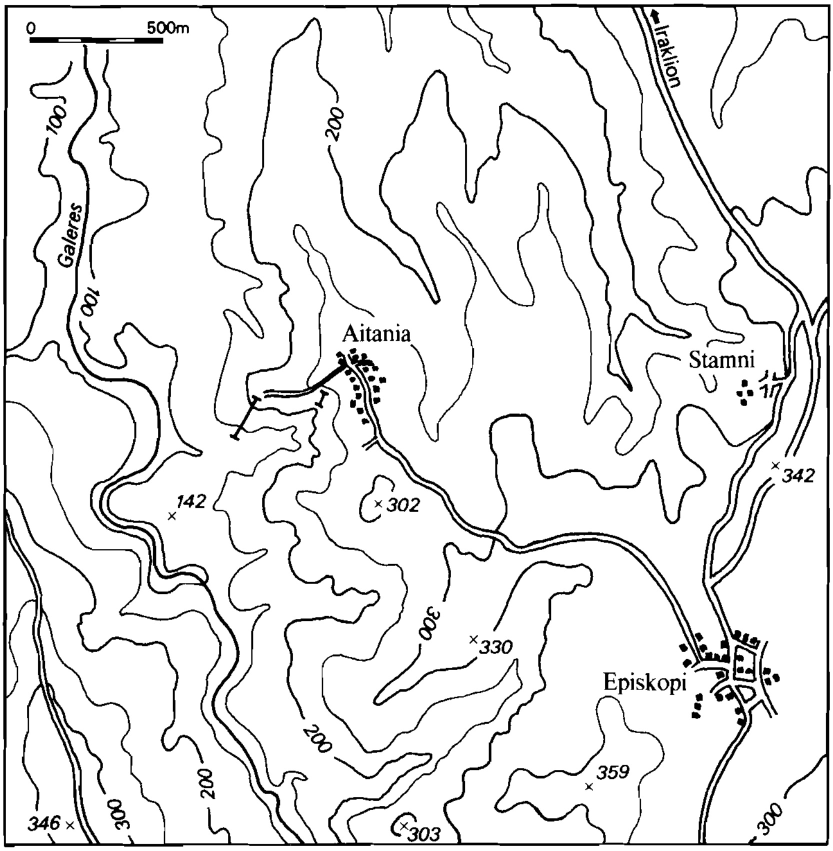


Fig. 16 Location of section Aitania.

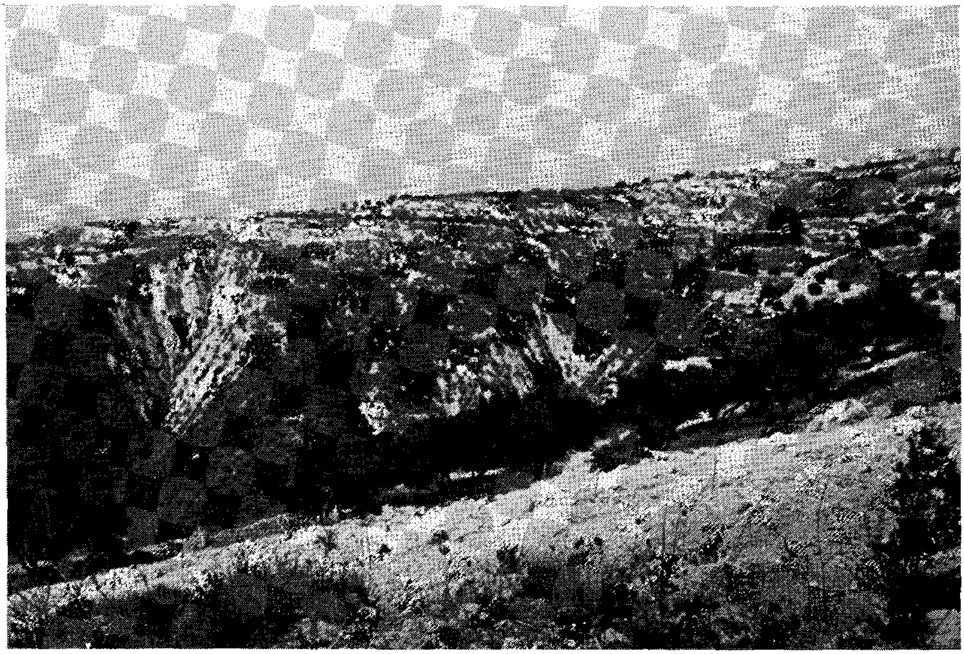


Fig. 17 Section Aitania, looking to the north.

lateral shift of about 200 m. The total stratigraphic thickness of the sampled section is 90 m.

Section Mirtos

Section Mirtos on the south-coast of Crete, was also included in our investigations. This section is located in the Lasithi province, near the hamlet of Nea Mirtos (fig. 1). It is the type-section of the Mirtos Formation of Fortuin (1977). For the exact location, the reader is referred to his paper. Driever (1981) mentioned the section in his study on calcareous nannofossils.

The lower part shows laminites up to 1.5 m thick (fig. 7). A thick homogeneous bed higher up in the section contains pycnodont oysters. Near the top, two sand-layers are intercalated, each about 1.5 m thick and rich in mollusc-debris.

Thirty-six samples, GR 1967 – GR 2002, were taken at distances of 40 cm to 2 m. The sampled section measures 35 metres in total.

Other sections

Not figured are three sections which were not studied in detail for benthonic foraminifera but which are of great interest for paleogeographical reconstructions. Two of them, section Gournes and section Kalithea 3, lie in the northern part of the Iraklion province (fig. 2). The third, section Atsipadhes, is located in the northern foothills of the Messara-plain (S-Iraklion) (fig. 1).

Section Gournes measures 55 m. In the lowermost part, Kourtes-like marls are followed by grey marls with intercalated brown laminated strata. In the top part, three white laminated beds alternate with yellow-beige homogeneous silty marls. Locally, concretionary indurations occur. Eighteen samples, irregularly spaced along the section, were obtained: GR 2255 – GR 2265 and GR 3344 – GR 3350, of which the latter series overlaps GR 2263 – GR 2265.

Section Kalithea 3 is situated just south of the village and a few hundred metres east of section Kalithea 1 (fig. 12). This location is close to the basin margin. The thickness of the section is only 27.5 m. White, indurated Kourtes marls are followed by Kourtes marls with brown laminated layers, up to 15 cm thick. In the upper part, after an unexposed stratigraphic interval of six metres, the colour changes from light grey to brown-yellow and the sediment becomes silty to sandy in texture. Here, indurated burrows are abundant. No laminated sediments are found in this part of the section, which covers more than 10 m. In a parallel section, channelling phenomena occur in sandy sediments. Twelve samples, GR 3401 – GR 3412, with 2 m spacing, were derived from Kalithea 3.

Section Atsipadhes shows 110 m of roadside exposed sediments. In its lower part, again grey marls alternate with brown beds. The middle part comprises two white, laminated levels, imbedded in yellow silt with *Dentalium* and *Amussium*. The upper 80 metres are essentially sandy in texture. Carbonate-cemented levels parallel to the bedding-planes are present and a 6.5 m thick body, containing cemented molluscan shell-debris, miliolids and *Elphidium*, shows large-scale foresetting. A very rich malacofauna of *Dentalium*, *Amussium*, *Pecten*, *Cardium*, *Arca*, oysters, *Natica*, *Vermetus*, *Aporrhais* and many other genera is encountered; the individuals are sometimes fossilized in life-position. Brachiopods and corals also form part of the macrofauna. This marine sequence is followed by red conglomerates and sands of the Aghia Galini Formation, which is of non-marine origin (Meulenkamp, 1979a).

Of special interest to us are the brown laminated beds in the lower part. They consist of an alternation of thin layers of brown-coloured marl and fine sand or silt, occasionally yielding shell-debris. The latter layers may be of mm- to cm-thickness and rarely reach 10 cm. They display parallel lamination, graded bedding or cross-bedding. The laminated beds are up to 2.5 m thick.

II.4. SEDIMENT ANALYSES

Introduction

From sections Finikia, Aghios Vlassios, Kalithea 1, Kalithea 2 and Prassas, 47 rock-samples of different lithology were selected for determination of their carbonate, pelite and organic contents. The samples were subdivided into seven categories. The first one is composed of five samples from the white, homogeneous Kourtes marls. White marls with intercalated brown laminated beds are tentatively called "transitional facies". We selected six samples from the white marls of this facies type, whereas we took five samples from the brown laminites. It is difficult to distinguish between this transitional facies type and the Finikia facies because of the gradual character of the colour change. The Finikia facies – grey marls and brown laminites – is represented by eighteen samples, nine from each lithology type. The last two categories are from the Stavromenos facies: six from yellow homogeneous marls and seven from white, laminated beds.

In order to get an idea of the proportions of the amount of material in our different sieve-fractions, we weighed the residues in the fractions of 63–125 μ, 125–200 μ and 200–595 μ. This was done for 23 samples from section Kalithea 2, in which sediments of the Finikia facies and Stavromenos facies were sampled.

Composition of the different rock types

The carbonate, pelite and organic contents of our samples are shown in percentage values in table I. The remaining constituent, the insoluble residue > 16 μ, which is the coarse silt and sand fraction, is also indicated.

From table I it is evident that carbonate and pelite together make up the largest part (80–90%) of the sediments. Coarse non-carbonate silt and sand are present in relatively small quantities (10–20%). Organic matter is only an accessory constituent in all samples.

The results of the analyses are plotted in the scatter diagrams of fig. 18. No scatter diagrams are presented for carbonate, pelite and organic material versus the residue > 16 μ, because they do not add much to our knowledge. It can be seen that the samples fall into two distinct clusters, one composed of homogeneous, the other of laminated sediments. The homogeneous samples have a carbonate content of more than 50% – the laminated less than 50% – and their pelite content is less than 35% – the laminated have more –. The strong negative correlation of pelite and carbonate percentages shows their compositional interdependence.

	Section	Sample	Carbonate content	Pelite content	Organic content	Residue > 16μ
Kourtes facies	Finikia	CP 5301	54.9	29.0	0.4	15.7
	Aghios Vlassios	CP 2338	65.8	23.4	0.1	10.7
	Kalithea 1	GR 2661	72.5	17.7	2.3	7.5
	Kalithea 1	GR 2666	77.9	16.0	-	-
	Prassas	GR 1021	61.7	25.2	1.0	12.1
	mean		66.6	22.3	1.0	11.5
transitional f. homogeneous marls	Finikia	CP 5318	60.0	25.8	0.4	13.8
	Aghios Vlassios	CP 2355	68.9	18.7	0.4	12.0
	Aghios Vlassios	CP 2364	62.3	23.8	2.0	11.9
	Kalithea 1	GR 2733	58.4	24.9	0.9	15.8
	Kalithea 1	GR 2736	58.7	27.6	1.1	12.6
	Prassas	GR 1077	62.0	21.8	0.3	15.9
	mean		61.7	23.8	0.9	13.7
transitional f. laminated marls	Finikia	CP 5319	44.7	32.1	1.0	22.2
	Aghios Vlassios	CP 2353	40.3	36.7	2.4	20.6
	Aghios Vlassios	CP 2210	26.5	51.8	3.5	18.2
	Kalithea 1	GR 2741	33.2	51.1	1.4	14.3
	Prassas	GR 1081	35.4	47.8	3.3	13.5
	mean		36.0	43.9	2.3	17.8
Finikia facies homogeneous marls	Finikia	CP 2021	56.0	30.1	3.5	10.4
	Finikia	CP 2060	54.2	33.1	1.4	11.3
	Finikia	CP 2107	56.0	30.9	1.4	11.7
	Aghios Vlassios	CP 2250	56.8	30.0	2.4	10.8
	Aghios Vlassios	CP 2268	58.6	28.0	2.3	11.1
	Kalithea 1	GR 2680	64.1	19.8	1.2	14.9
	Kalithea 1	GR 2703	57.2	20.3	4.4	18.1
	Kalithea 1	GR 2706	55.0	26.4	3.3	15.3
	Kalithea 2	GR 2208	61.7	21.9	2.0	14.4
	mean		57.7	26.7	2.4	13.1

Table I: Sediment-compounds of 47 selected samples (in %).

	Section	Sample	Carbonate content	Pelite content	Organic content	Residue > 16μ
Finikia facies laminated marls	Finikia	CP 2027	45.1	37.0	1.6	16.3
	Finikia	CP 2073	37.6	44.4	2.4	15.6
	Finikia	CP 2122	45.2	39.8	1.4	13.6
	Aghios Vlassios	CP 2252	46.6	38.4	3.8	11.2
	Aghios Vlassios	CP 2273	37.3	43.3	1.8	17.6
	Kalithea 1	GR 2679	46.2	37.8	3.4	12.6
	Kalithea 1	GR 2702	37.1	40.6	4.4	17.9
	Kalithea 1	GR 2720	41.2	39.6	0.9	18.3
	Kalithea 2	GR 2212	43.3	39.3	4.5	12.9
	mean		42.2	40.0	2.7	15.1
Stavromenos facies homogeneous marls	Finikia	CP 2162	62.3	25.0	3.1	9.6
	Kalithea 2	GR 2228	55.5	25.1	1.2	18.2
	Kalithea 2	GR 2234	54.8	27.3	1.1	16.8
	Prassas	CP 3359	55.5	19.9	3.6	21.0
	Prassas	GR 993	55.8	22.1	4.1	18.0
	Prassas	GR 1007	56.1	12.7	0.9	30.3
	mean		56.7	22.0	2.3	19.0
Stavromenos facies laminated marls	Finikia	CP 2153	27.6	55.5	3.2	13.7
	Finikia	CP 2174	21.3	58.7	3.9	16.1
	Kalithea 2	GR 2236	37.9	48.0	2.8	11.3
	Kalithea 2	GR 2247	45.8	40.4	2.1	11.7
	Prassas	CP 3361	31.7	48.6	7.3	12.4
	Prassas	GR 1002	43.5	40.2	4.9	11.4
	Prassas	CP 3364	25.8	63.9	2.4	7.9
	mean		33.4	50.8	3.8	13.1

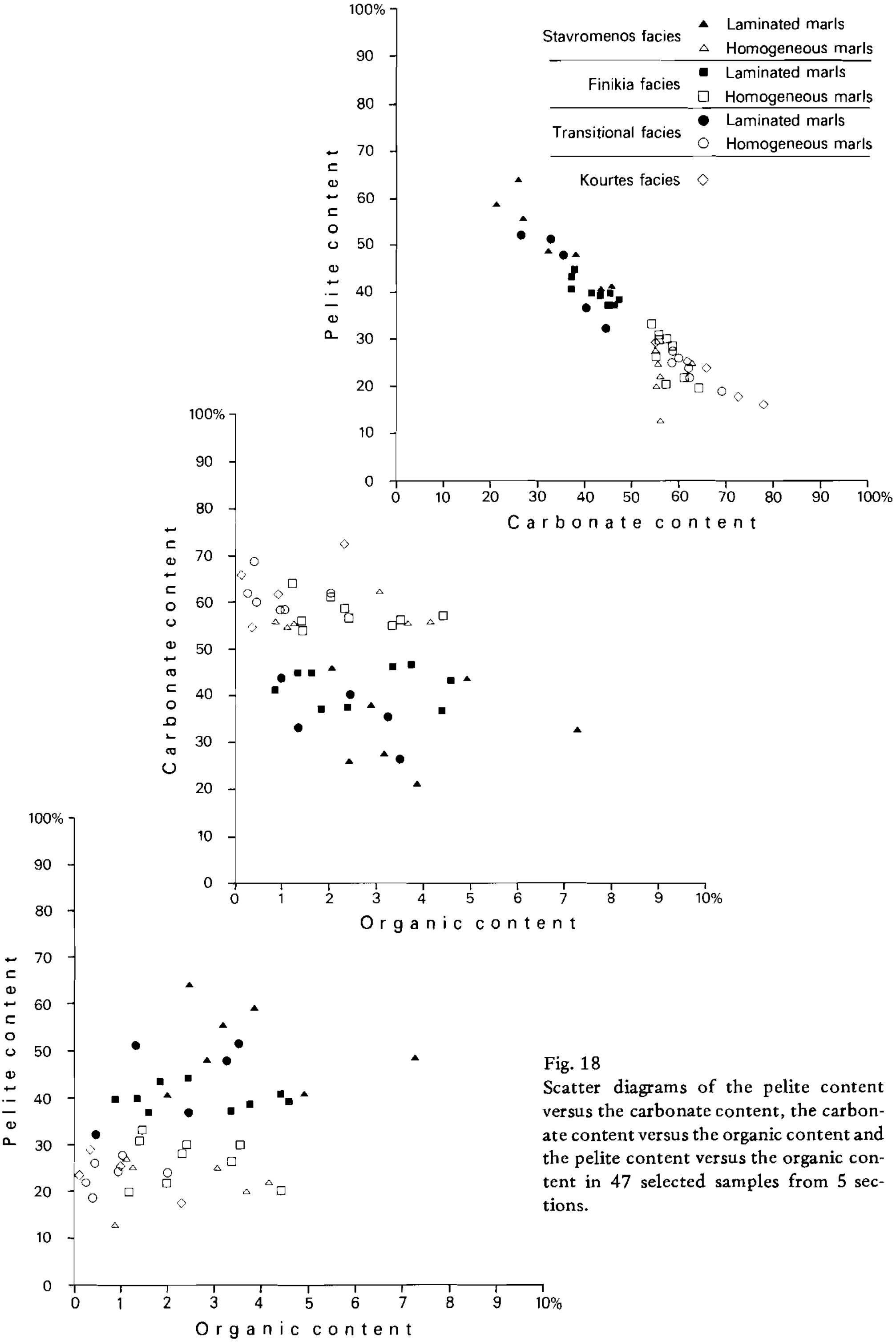


Fig. 18
Scatter diagrams of the pelite content versus the carbonate content, the carbonate content versus the organic content and the pelite content versus the organic content in 47 selected samples from 5 sections.

Inspection of the cluster of homogeneous sediments suggests that the highest carbonate values are found in samples from the Kourtes and "transitional" facies. Slightly lower carbonate contents are found in the Finikia and Stavromenos marls. The average pelite content in the Finikia marls is somewhat higher than in the other three homogeneous sediment types (table I). The relatively low pelite content in the Stavromenos marls is compensated by an aberrantly high percentage of coarser silt and sand (19%).

If we look at the cluster of laminated samples, we get the impression that the white laminites of the Stavromenos facies have the highest pelite content. Lower values are found in the "transitional" and Finikia laminites.

The organic content in the homogeneous samples ranges from almost zero to about 4.5%. Lowest values are found in the white Kourtes and "transitional" marls (table I, fig. 18). The laminated samples reveal organic material percentages of slightly less than 1% to 7.3%. Here, the highest percentages are again found in the samples of the Stavromenos facies. In fig. 18, there seems to be, at least visually, a relation between the percentage of organic matter and the pelite content: the higher the pelite content, the higher the amount of organic matter. An opposite relation exists between the organic content and the carbonate content.

Origin of the lithological components

The laminated sediments are characterized by a higher pelite content. In most of the white laminites of the Stavromenos facies this may be due to the abundance of diatom-frustules, as can be deduced from microscopical observations on smear-slides. A similar explanation was given by Van der Zwaan (1982) for white, diatom-rich sediments of Messinian Age from Crete and Sicily. The brown beds of the Finikia facies may also contain large quantities of siliceous microfossils (as do the uppermost beds in sections Aghios Vlassios and Finikia), but more often diatoms and silicoflagellates are absent. Here, the high amount of pelite is thought to be caused by a greater input of terrigenous clastic material. Examination of the 63–125 μ wash-residues from samples derived from these brown laminated sediments often shows a relatively high amount of quartz grains and phyllitic material.

It should be realized that in theory carbonate dissolution may result in sediment types which are similar to laminated ones in some respects. These are: low carbonate content, relatively large amounts of siliceous organisms and higher percentages of benthonic foraminifera – which is also true in our samples derived from laminites, see chapter III – (cf. Berger, 1973; Gardner and Hays, 1976). However, sediments affected by dissolution contain large numbers of fragmented planktonic foraminifera, are not necessarily laminated and in general do not show differences in colour. In our laminites, dissolution-susceptible planktonic foraminiferal taxa do not show abnormally low numbers (Spaak, 1983), which rules out the possibility that the low carbonate content is due to dissolution. From the benthonic foraminiferal record it is also shown that severe dissolution did not affect the fauna and hence, the carbonate content (see III.1).

The high carbonate content values of the Kourtes and homogeneous "transitional" marls are comparable to those obtained from the Sicilian Trubi at Capo Rossello (Cita, 1975b; Brolsma and Broekman, 1978). Microscopical inspection of samples from these lithology types suggests that they can be attributed to the abundance of calcareous nannofossils and foraminiferal shells (mainly planktonic foraminifera). A possible explanation for this abundance is that there was a large production of the above-mentioned calcareous organisms. If this was the case, it did not result in large quantities of organic matter. The high carbonate content of the white marls may equally well be the result of a low pelite supply. This is, for instance, also seen to be the case in today's eastern Mediterranean. Large areas are covered by sediments with carbonate percentages ranging between 50 and 70% (Venkatarathnam et al., 1972); in these areas the carbonate consists predominantly of foraminifera, coccoliths and pteropods (Emelyanov, 1972). The nutrient level – and hence, production – in the eastern Mediterranean Sea is low (McGill, 1960). Thus, low terrigenous input is responsible for the relatively high carbonate percentages.

The lower carbonate content in the homogeneous marls from the Finikia and Stavromenos facies can then be explained by a greater admixture of clastic material, which in the Finikia marls was mostly clay and in the Stavromenos facies generally coarser material. Evidence that the carbonatic part of the Stavromenos facies also consists of a relatively greater amount of coarse particles is given below. This higher pelite content may be the reflection of the shallowing of the basins in the course of the Pliocene.

The highest percentages of organic matter are found in samples in which the pelite content is also highest. One can argue that the organic matter is largely of continental origin and that it was brought into the basins as a result of adsorption onto clay particles. In the white laminites of the Stavromenos facies, in which diatom-frustules are thought to be responsible for the high pelite percentages, the organic matter may well be of marine origin.

The low values in especially the Kourtes and "transitional" marls may point either to a low supply of organic matter from continental or marine sources to the sediments or to a slow rate of deposition. In the latter case, oxidation processes were able to destroy the organic substances more thoroughly.

Weights of the sieve-fractions

The results of the weighing of the residues we obtained from the washing procedure are shown in fig. 19. The fraction > 595 μ is ignored, because in almost all samples no such residue remained from 50 g of sediment.

We can see that the weight of the size-fraction of 63–595 μ varies from about 1 to 8 g, which is only 2–16 per cent of the weight of the total sample. It is furthermore observed that samples obtained from laminated levels almost invariably show the lowest values, which means that they contain relatively more material in the fraction smaller than 63 μ. On the average, the weight of the total residue in samples from the homogeneous marls is more than twice that in samples from the laminated beds. Greatest differences in weight of the residues are found in samples from the Stavromenos facies. Here, the maximum weight in the homogeneous sediments is nine times the minimum weight in the laminites. The white laminated levels of GR 2224 and GR 2236 show the smallest quantity of residue. The homogeneous marls of the Stavromenos facies yield residues which are on the average 1.5 those of the Finikia facies.

Microscopical observations of the residues show that by far the largest part consists of foraminifera. In addition, samples from both brown and white laminated sediments show fish-bones. In these lithology types – and especially in the latter – sponge spicules and radiolarians can be abundant. In the laminites of the "transitional" facies, not included in the weighing procedure, pyrite-filled foraminifera and occasional (secondary) gypsum-aggregates occur. The brown laminites are seen to yield a relatively large amount of terrigenous material in the fraction of 63–125 μ. In the largest size-fraction (> 595 μ) echinoid spines may be present. In this fraction occasional samples from the homogeneous marls may be seen to contain small pelecypod and brachiopod shells.

The lower amount of residue in the laminated beds is thought to be the result of a relatively larger quantity of small-sized terrigenous particles and/or remains of siliceous organisms.

The average carbonate content in the homogeneous marls was seen to be about 57% by weight (table I), so the bulk of this carbonate – on the average 45% of the weight of the homogeneous sediments – results from foraminifera smaller than 63 μ, calcareous nannofossils and other small calcareous constituents.

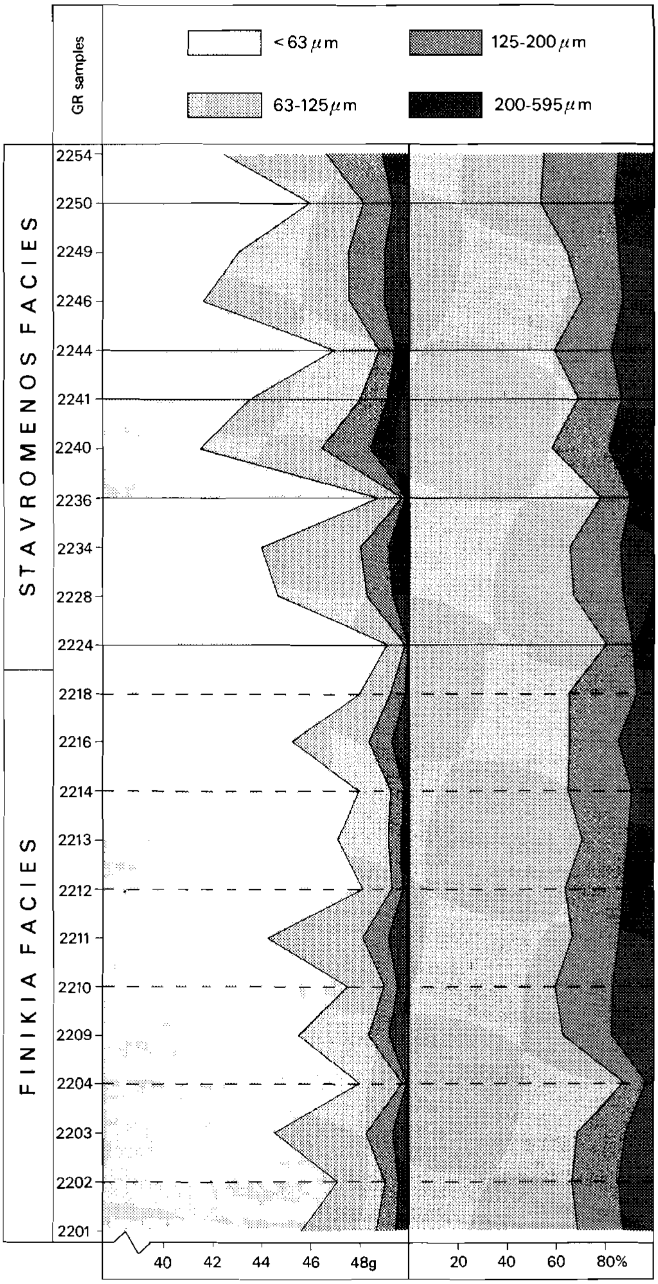


Fig. 19 Weights of four sieve-fractions in 50 g of dry sediment (left-hand side) and weight distribution of the size-fractions > 63 μ (right-hand side) in a selection of samples from section Kalithea 2. Dashed horizontal lines: brown laminated beds; solid lines: white laminites.

The larger residues in the homogeneous marls of the Stavromenos facies do not coincide with larger average carbonate contents. This leads us to the conclusion that the amount of small-sized carbonate particles in the Stavromenos marls is relatively small compared with the amount in the sediments of the other facies. As was shown above, these marls are also seen to contain a relatively small amount of very fine-grained non-carbonatic material. The "silty" appearance of the Stavromenos marls is in line with this conclusion. Such very small particles may have been removed (or were prevented from settling) by bottom-currents, which supposedly were stronger in the relatively shallow environments.

The weight distribution of the different size-fractions > 63 μ within the samples does not fluctuate strongly (fig. 19). The average weight percentage of the 63–125 μ fraction is 67%, of the 125–200 μ fraction 20% and of the 200–595 μ fraction 13%. In our routine countings of the foraminifera, we used only the 125–595 μ size-fraction, which is on average 33% of the weight of the total residue. If we take into account that one gram of the smallest size-fraction yields far more foraminifera than does one gram of the largest, the fauna in the fraction of 200–595 μ forms an entirely insignificant part of the total as far as the number of individuals is concerned.

Compared to the other samples, GR 2204, GR 2224 and GR 2236 (all from laminated layers) reveal that a relatively larger part of the residue belongs to the 63–125 μ fraction. This does not prove, however, that the foraminifera remained small in the depositional environments of the laminites, but may equally well be the result of a higher amount of radiolarians, small sponge needles or very fine sand.

Terminology for laminated sediments

In the literature, two types of laminated sediment of a "pelagic" mode of deposition – i.e. excluding high energy, shallow water sediments – are recognized, both of which are rather ill-defined. The one dominated by diatoms and with varying amounts of biogenic opal derived from other organisms is called diatom ooze, diatomaceous ooze or diatomite. Most of our white, diatom-rich laminated beds may belong here. In future this lithology type will be referred to as diatomite. The other type is known as sapropel.

Olausson (1960) described dark layers in sediment cores from the eastern Mediterranean; these layers were comparatively rich in organic matter and had either a high or a low carbonate content. He used the adjective "sapropelitic" to distinguish these layers from the bulk of the sediments not displaying these characters. In Howell (1960) a sapropel is defined as " an aquatic ooze or sludge that is rich in organic (carbonaceous or bituminous) matter". The definition given by Kidd et al. (1978) includes a quantitative appreciation of the thickness and the organic carbon content to delimit sapropels from underlying and overlying sediments and is as follows: "a discrete layer, greater than 1 cm in thickness, set in open marine pelagic sediments and containing greater than 2.0% organic carbon by weight". Similar layers with organic carbon contents between 0.5 and 2.0% were termed "sapropelic layers". The colour was not mentioned in the definition, but was reported to range from black to very dark green and brown. Colour, however, seems to offer a readily available subjective criterion for the recognition of sapropels, since it has been used by various workers. Lamination is not always reported, but is often observed in the thicker sapropels or in thin ones with the aid of X- radiographs (Maldonado and Stanley, 1976). The absence of benthonic life is also no compelling factor for the application of the term sapropel, as benthonic organisms in Late Quaternary sapropels were reported by Cita and Podenzani (1980) and Mullineaux and Lohmann (1981).

From the above, we feel justified in calling our brown laminated beds sapropels, because they fulfil most of the requirements generally accepted for such particular sediments. Some laminated beds are seen to contain abundant siliceous microfossils, but are still called sapropels on the basis of their brown colour. Occasional sapropels recovered in piston cores in the eastern Mediterranean Sea also yield abundant diatoms and silicoflagellates (Müller, 1973; Schrader and Matherne, 1981). The same holds for some Late Pliocene sapropels we know from deep-sea drilling (Kidd et al., 1978).

II.5. CORRELATION OF LAMINITES

The intense faulting and the hilly topography of the area covered by Pliocene sediments prohibit lithostratigraphic correlation of the sections in the field. In rare cases, individual laminites are traceable over distances of some 500 metres at maximum. To gain insight into the stratigraphic correlations between the sections we have to include biostratigraphic data.

In fig. 20, the vertical alternation of laminated and homogeneous strata is figured in such a way that the successive intervals of either type are at equal vertical distances. The numbers on the left-hand side of each column refer to the laminite intervals; we chose the number of the lowermost sample in each laminated bed. Horizontal bars indicate the thickness of each interval, resulting in two vertical graphs, one for each lithology type.

The entry and exit levels of the planktonic foraminifera *Globorotalia margaritae* and *G. puncticulata* and the entry levels of *G. bononiensis* and the calcareous nannofossil *Discoaster asymmetricus* put the successions in their relative stratigraphic position. In addition to the datum levels shown in this scheme, other biostratigraphic tools like the occurrences of *Globoquadrina altispira* and the ranges of left- and right-coiled *Globorotalia crassaformis* were used to establish the proper stratigraphic position. These occurrences are not indicated in fig. 20. The *Discoaster pentaradiatus* paracme-interval (Driever, 1981) confirms the correlations presented in this figure. For details concerning the planktonic foraminiferal and calcareous nannofossil biostratigraphy of the sections, the reader is referred to the studies of Spaak (1983) and Driever (op. cit. and in prep.), respectively.

Of all sections, section Aghios Vlassios covers the longest stratigraphic interval. The other sections can all be linked to this section, at least partially. Only the stratigraphically lowest – in sections Kalithea 1 and Prassas – and highest – in section Fortetsa – intervals do not have such a link. The unexposed part of section Kalithea 1, between the sapropel of GR 2716 and the one of GR 2720, is assumed to contain a maximum of four sapropels, if no anomalously thick homogeneous interval is present. The presence of a gap or an overlap between both parts of section Fortetsa cannot be substantiated; the higher of the two parts is still within the range of *Globorotalia bononiensis* and it is tentatively placed without overlap on top of the lower one. The top part of section Prassas can be correlated with sections Finikia, Aghios Vlassios and Fortetsa by means of the ranges of sinistrally and dextrally coiled *G. crassaformis*. This implies that there is a major hiatus between the sapropel of GR 965 and the diatomite of CP 3361 (see II.2). The position of the interval of GR 1074 – GR 1100 (fig. 7) in this section cannot be fixed exactly, due to the lack of sufficient biostratigraphic information.

In many cases, relatively thick homogeneous strata seem to be traceable from one section to the other at corresponding stratigraphic levels. For this reason, we placed the anomalously thick homogeneous interval in section Kalithea 1, between GR 2730 and GR 2739, at the same level as the one below sample CP 2208 in section Aghios Vlassios. The same manner of reasoning was followed in correlating the lower parts of sections Kalithea 1 and Prassas. If this kind of correlation is justified, then sections Kalithea 1 and Kalithea 2 would have an exact superposition without any gap or overlap.

However, the entry levels of *Globorotalia margaritae* and *G. puncticulata* do not appear as straight horizontal lines in fig. 20. There may be several reasons for these discrepancies. For instance, one of the sampling-teams may well have overlooked a sapropel. Furthermore, the entry levels of *G. margaritae* and of *G. puncticulata* are sometimes hard to pinpoint exactly, because of low frequencies of the nominate taxa at the beginning of their ranges (see

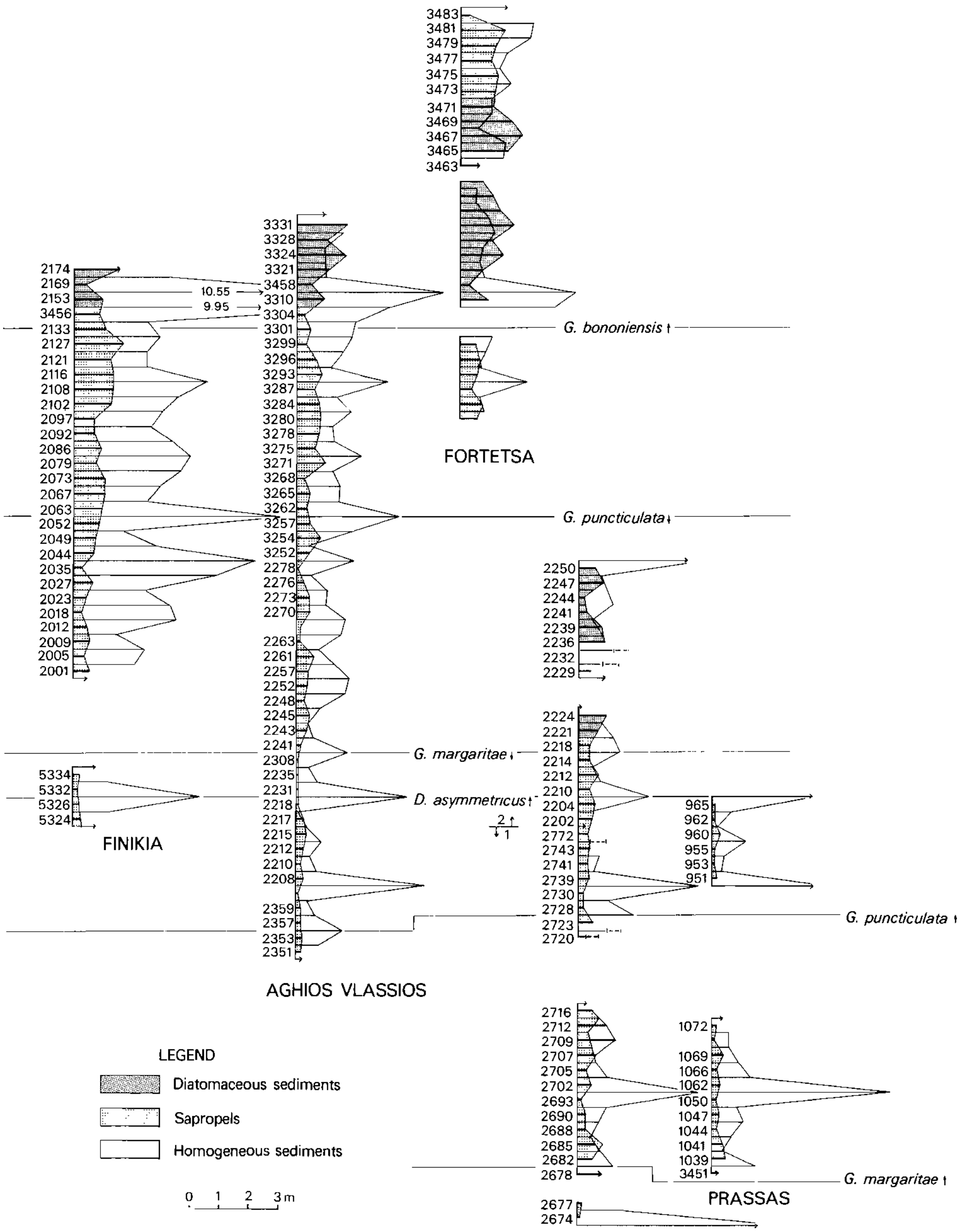
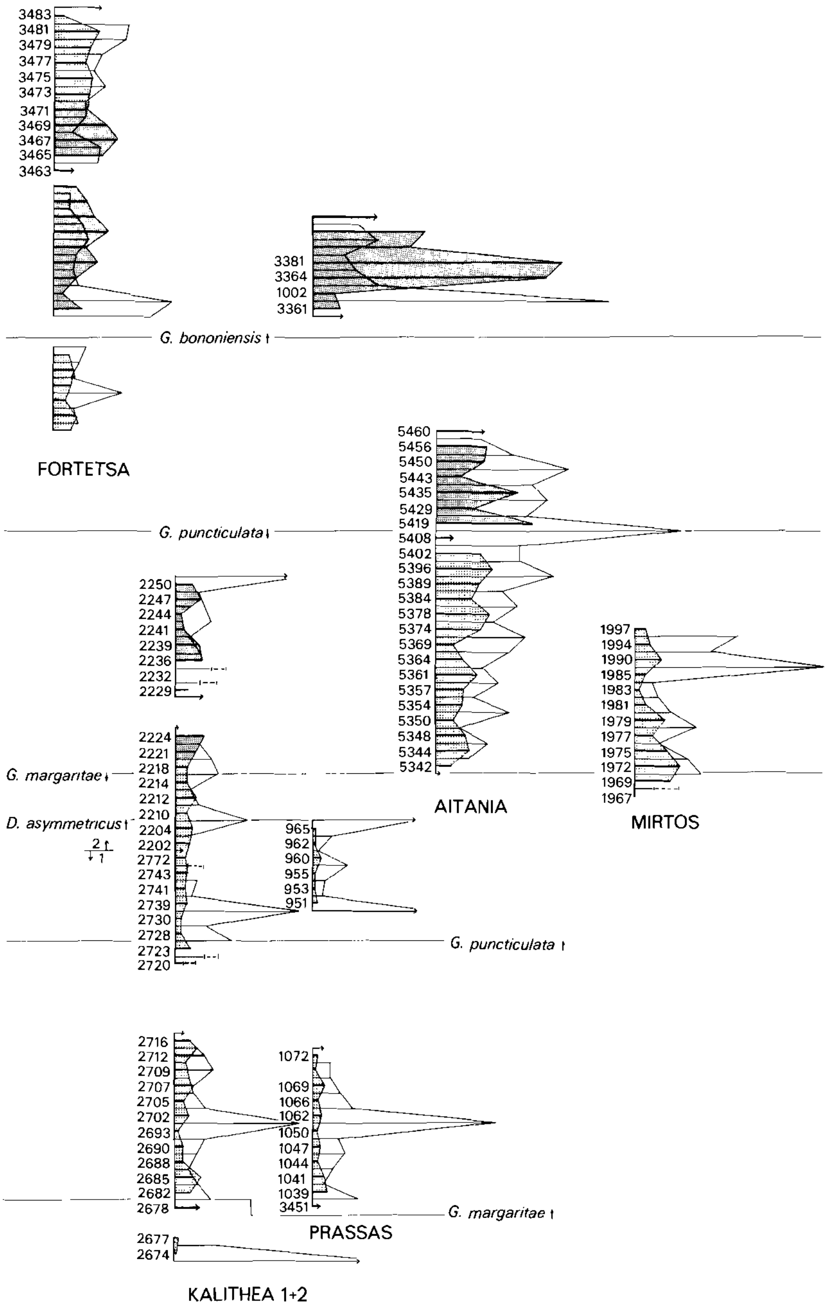


Fig. 20 Scheme showing correlations and thicknesses of individual strata in the sections.


3483
3481
3479
3477
3475
3473
3471
3469
3467
3465
3463
3381
3364
1002
3361
G. bononiensis ↑
FORTETSA
5460
5456
5450
5443
5435
5429
5419
5408
5402
5396
5389
5384
5378
5374
5369
5364
5361
5357
5354
5350
5348
5344
5342
G. puncticulata ↓
2250
2247
2244
2241
2239
2236
2232
2229
1997
1994
1990
1985
1983
1981
1979
1977
1975
1972
1969
1967
2224
2221
2218
2214
2212
2210
2204
2202
2772
2743
2741
2739
2730
2728
2723
2720
G. margaritae ↓
D. asymmetricus ↑
2 ↑
↓ 1
965
962
960
955
953
951
AITANIA
MIRTOS
G. puncticulata ↑
2716
2712
2709
2707
2705
2702
2693
2690
2688
2685
2682
2678
1072
1069
1066
1062
1050
1047
1044
1041
1039
3451
G. margaritae ↑
PRASSAS
2677
2674
KALITHEA 1+2

Spaak, 1983). Another possible reason is that the correlation of the anomalously thick homogeneous intervals is incorrect because the deposition of a thick layer of homogeneous sediment at one place did not coincide with the deposition of a thick layer elsewhere. However, in our opinion the scheme presented here offers at the moment the best possible correlation of the individual strata.

The scheme implies that the individual laminites are not locally developed phenomena, but witness to isochronous events over the entire area from which we gathered our information. Another implication is that the level at which diatomites appear is not isochronous. The diatomites of sections Finikia, Aghios Vlassios, Prassas and – partially – Fortetsa can be well correlated, but the first diatomites of sections Kalithea 2 and Aitania are much older in age. They must be correlated with sapropels in other basins. We cannot tell whether sapropel formation started simultaneously in the different basins; our record of the basal Pliocene sediments is too poor.

The conclusion one might draw from figure 20, namely that diatomite formation in one basin commenced simultaneously everywhere – as suggested by the three sections in the Finikia – Aghios Vlassios Basin – is not justified, however. This is demonstrated by section Gournes, located NW of section Finikia (fig. 2). Here, *Globorotalia puncticulata* is present throughout the lower half of the section, in which sapropels are found (II. 2). Above the extinction level of this species, a few more sapropels are found followed by diatomites. In this upper part, no *Globorotalia bononiensis* or *G. crassaformis* was found. Major sedimentary breaks were not noticed at the transition from Finikia facies to Stavromenos facies. Evidently, diatomite sedimentation started earlier in Gournes than in Finikia, despite the fact that both localities are in the same basin.

Sediments without laminated beds, but equivalent in age to the regular alternations we know from more basin-inward localities, can be found along basin margins. This is demonstrated by section Kalithea 3, which lies close to such a margin (fig. 2). In its lower half, thin sapropels are intercalated in Kourtes marls ("transitional" facies). This part of the section yields *Globorotalia margaritae.* Above an unexposed part the sediments are seen to become silty to sandy and laminated intervals are not found any more. In this part of the section *Globorotalia puncticulata* is present, initially accompanied by *G. margaritae;* this species becomes absent near the transition to the silty/sandy sediments. Thus, this transition can be correlated to section Kalithea 2 where it coincides approximately with the level at which the diatomite-layers appear.

Thicknesses of correlative strata

The laminated beds are generally thinner than the adjoining homogeneous strata (fig. 20). The section-parts with diatomites, above the *G. bononiensis* entry level show the opposite pattern, which is very pronounced especially in section Prassas.

The correlative strata in the different sections exhibit significant differences in thickness. In section Finikia, thicknesses are about twice those in section Aghios Vlassios, which lies closer to the basin margin. Though representing a longer time-interval, the entire section Aghios Vlassios is less thick than section Finikia (see also fig. 7). In the still more marginal section Fortetsa, bed-thickness is reduced even further. Thus, differences in sedimentation rates can be derived from fig. 20.

Greatest thicknesses seem to be present in the centres of the elongated basins. Because of the condensed successions at marginal localities and the calcareous character of the sediments at such places (Kalithea 3), we assume that sediment transport was in longitudinal direction. However, we know so little about the deposits along the basin margins that we cannot have a definite proof for this assumption.

According to paleogeographical reconstructions, section Aitania was close to the source area of clastics at the time of deposition. Compared with the homogeneous intervals, its sapropels have anomalously great thickness. This should be due to a relatively greater supply of clay and silt, since the sapropels invariably show high pelite contents (II. 3). Similar observations were made on very thick sapropels in section Atsipadhes, where even sandy layers are found in the sapropels. The admixture of greater quantities of terrigenous clastic material leads us to the conclusion that sedimentation rates were higher for the sapropels than for the homogeneous intervals. Combined with the fact that the sapropels are less thick than the homogeneous beds we may safely assume that periods of sapropel formation were of a much shorter duration than periods in which deposition of non-laminated sediments took place.

If aberrantly thick intervals are omitted, there are upward trends in increasing thickness of laminated and of homogeneous strata in most sections. No such a trend is clear in the combined sections Kalithea 1 and 2 and in section Prassas and a negative trend is visible in section Mirtos. If sedimentation rates remained constant from bottom to top of the sections, the trends would mean that in the upper parts of sections Finikia, Aghios Vlassios and Aitania longer time periods corresponded with the deposition of individual units of the alternations. The fact that the opposite trend is found in the time-equivalent section Mirtos precludes this conclusion. The trends can best be explained by assuming a general increase in sedimentation rates, as is corroborated by the increased pelite content in the Finikia facies.

The anomalously thick homogeneous intervals, many of which can be recognized from basin to basin, are not necessarily due to higher sedimentation rates. Here, the more calcareous character of the sediments and the presence of pycnodont oysters point to a lower rate of deposition. It seems that there was no laminite formation for a relatively long time and maybe the processes which led to the formation of the laminated beds were not active during the deposition of such intervals.

The largest differences in thickness are seen between correlative diatomites. If diatom-frustules make up the larger part of the sediment volume, then production of these organisms in the Prassas Basin was far greater than in the others. In many cases diatoms attributed so much to this kind of laminated sediment that the diatomites became thicker than the homogeneous beds.

The return to sapropel sedimentation in section Fortetsa again resulted in somewhat thinner laminites, whereas the homogeneous sediments in turn became thicker, because of an overall increased sedimentation rate.

It should be borne in mind that different rates of compaction for the various lithology types may have played a role in the resulting thicknesses, because of differences in composition and texture. However, more information is needed in order to estimate the effect of compaction.

II.6. ANALYSES OF STABLE ISOTOPES

Analytical results

The results of the oxygen and carbon isotope analyses done on a selection of samples from section Kalithea 2 are given in table II. From this table it is clear that for the oxygen isotope composition in the test of *Globigerinoides obliquus*, lower $\delta^{18}O$ values are found than in the accompanying *Bolivina spathulata.* Such a difference is commonly observed between planktonic and benthonic foraminifera (cf. Bizon et al., 1979; Kammer, 1979; Van der Zwaan and Thomas, 1980). In our samples, the opposite is true for $\delta^{13}C$.

The values of $\delta^{18}O$ and $\delta^{13}C$ of both foraminifera do not fluctuate very much throughout the investigated interval. The largest fluctuations in $\delta^{18}O$ of both taxa are up to $1.5^0/_{00}$. The largest difference in $\delta^{13}C$ of *B. spathulata* between two successive samples is $1^0/_{00}$, whereas for *G. obliquus* this is about 2 per mil. In both species a slight decrease in the values of $\delta^{18}O$ and $\delta^{13}C$ seems to be present from bottom to top.

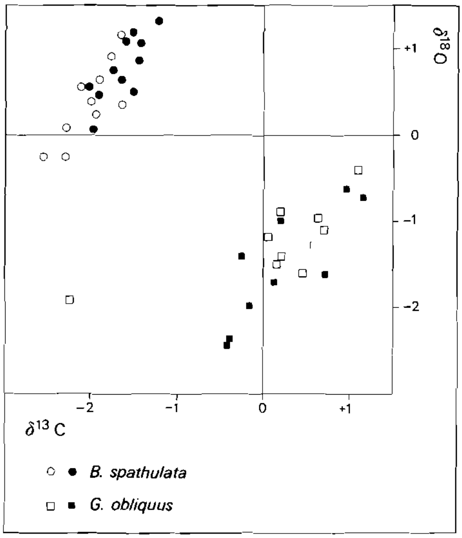


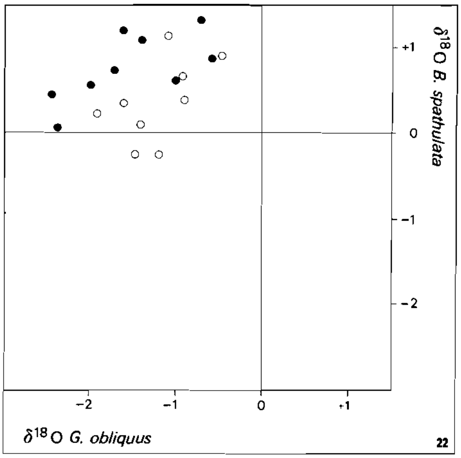
Fig. 21 Scatter diagram of $\delta^{18}O$ versus $\delta^{13}C$ of the separate species. Open symbols: homogeneous sediments; closed symbols: laminated sediments.

Table II: $\delta^{18}O$ and $\delta^{13}C$ values of *B. spathulata* and *G. obliquus* ($^0/_{00}$ relative to PDB).

sample	lithology	B. spathulata		G. obliquus	
		$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$
GR 2201	hom	+1.1	-1.7	-1.1	+0.7
GR 2202	lam	+0.9	-1.4	-0.6	+1.0
GR 2204	lam	+1.3	-1.2	-0.7	+1.1
GR 2209	hom	+0.9	-1.8	-0.4	+1.1
GR 2210	lam	+1.1	-1.4		
GR 2212	lam	+1.1	-1.6	-1.4	-0.3
GR 2213	hom	+0.6	-1.9	-1.0	+0.6
GR 2214	lam	+0.5	-1.5		
GR 2216	hom	+0.6	-2.1		
GR 2218	lam	+0.6	-1.7	-1.0	+0.2
GR 2224	lam	+0.1	-2.0	-2.4	-0.4
GR 2228	hom	+0.4	-2.0	-0.9	+0.2
GR 2234	hom	-0.3	-2.3	-1.2	0.0
GR 2236	lam	+0.5	-1.9	-2.5	-0.4
GR 2240	hom	-0.3	-2.6	-1.5	+0.2
GR 2241	lam	+1.2	-1.5	-1.6	+0.7
GR 2244	lam	+0.7	-1.7	-1.7	+0.1
GR 2246	hom	+0.3	-1.6	-1.6	+0.4
GR 2249	hom	+0.1	-2.3	-1.4	+0.2
GR 2250	lam	+0.6	-2.1	-2.0	-0.2
GR 2254	hom	+0.2	-1.9	-1.9	-2.3

In the scatter diagram of fig. 21 the relation between $\delta^{18}O$ and $\delta^{13}C$ is shown. The clusters of the planktonic and benthonic species are far apart. Moreover, it can be inferred that oxygen and carbon isotope values are positively correlated in both species.

Within the two clusters of fig. 21, no clear differentiation can be observed between samples from homogeneous and laminated marls. In *G. obliquus* there is a tendency towards lower values of $\delta^{18}O$ and $\delta^{13}C$ in the laminated sediments; in *B. spathulata* the opposite seems to be true. This may point to greater differences in $\delta^{18}O$ between plankton and benthos in the thin-bedded deposits, whereas the reverse applies to the carbon isotopes. To visualize this more clearly, the oxygen isotope values of *G. obliquus* are plotted against those of *B. spathulata* in fig. 22; the carbon isotopes are presented in a similar way in fig. 23. In these figures the two lithology types appear in different clusters. Application of a t-test showed the differences in $\delta^{18}O$ in plankton and benthos from the laminites to be significantly larger than those in the non-laminated strata ($P < 0.01$). If we leave out the anomalous sample GR 2254, the differences in $\delta^{13}C$ proved to gain statistical significance at the $P < 0.01$ level as well.



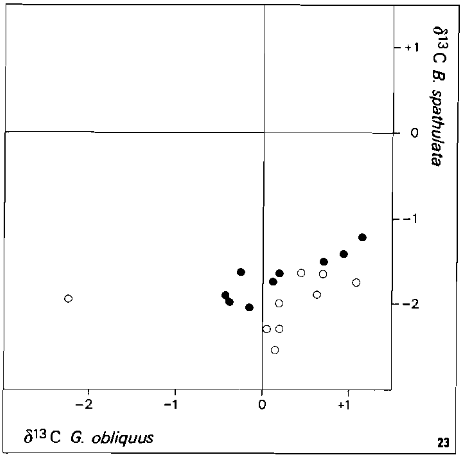


Fig. 22 Scatter diagram of the $\delta^{18}O$ values of *B. spathulata* versus the $\delta^{18}O$ values of *G. obliquus.*

Fig. 23 Scatter diagram of the $\delta^{13}C$ values of *B. spathulata* versus the $\delta^{13}C$ values of *G. obliquus.*

Discussion

Our stable isotope results imply that at a given $\delta^{18}O$ value of *G. obliquus* the value for *B. spathulata* tends to be higher in the laminites than in the homogeneous sediments. The same holds for the carbon isotopes. We can therefore conclude that the $\delta^{18}O$ gradient was stronger during laminite formation. A similar relation between $\delta^{18}O$ values in planktonic and benthonic foraminifera derived from homogeneous/laminated alternations was reported by Van der Zwaan and Thomas (1980). Their carbon isotope pattern is, however, dissimilar to ours.

Since we analyzed plankton and benthos from only 9 out of the 75 successive homogeneous/laminated alternations which we encountered in the Pliocene sequence of the Iraklion province, we shall not discuss all of our results at length. For the moment, we shall deal only with the oxygen isotope gradient in both lithology types.

The average difference between $\delta^{18}O$ of the analyzed surface- and bottom-dwelling organisms in the homogeneous sediments is about 1.6‰. If temperature is considered to be solely responsible for this difference, surface and bottom waters would differ about 7° C. This figure seems quite large for a relatively shallow basin, as compared with the differences that exist today in the deep Levantine Basin (6–7° C; Miller et al., 1970). For the laminated sediments such a difference would even be larger: more than 10° C.

Part of these large differences may be due to non-equilibrium of oxygen isotopes in foraminiferal calcite with ambient sea-water. For *Globigerinoides ruber*, a species closely related to the extinct *G. obliquus*, equilibrium is thought to be approximated (Vergnaud-Grazzini, 1976; Shackleton and Vincent, 1978), but assemblages of *Bolivina* proved to be out of equilibrium by about 0.7‰ (Hansen and Buchardt, 1977).

However, salinity may equally well be considered to account for the differences. For the Messinian, such an explanation was given to explain similar $\delta^{18}O$ patterns (Van der Zwaan and Thomas, 1980). Oxygen isotope evidence from laminated sediments in the Quaternary was also explained in terms of changes in salinity (Cita et al., 1977; Vergnaud-Grazzini et al., 1977; Williams et al., 1978).

Whatever explanation is chosen, our stronger $\delta^{18}O$ gradient in the laminites points to a better stratified water column during deposition of this sediment type. We can think of a number of factors that could have caused a better density stratification. Here, an evaluation of these possibilities is considered premature; they will be discussed later in connection with the distribution, the sedimentology and faunal record of the Pliocene laminated deposits (chapter IV).

II.7. SEDIMENTARY HISTORY

From the data presented in the preceding sections, an attempt will be made to reconstruct the sedimentary history for the Pliocene of the Iraklion area.

The base of the Kourtes facies witnesses to the Early Pliocene transgression, recognized all over the Mediterranean. The widespread occurrence and uniformity of this lithology were interpreted by Meulenkamp et al. (1979b) as a reflection of a rather deep environment, when the sea covered a vast area of land. The ooze-like character and the low organic content point to slow biogenic sedimentation. Input of terrigenous clastic material was subordinate.

Shortly after the deposition of the first Kourtes marls, movements along older fracture-systems established the delimitation of the different basins. As a consequence of these movements, Kourtes marls were removed from topographic highs, together with older strata, which resulted in the marl-breccias. Deposition of ooze-like Kourtes marls, however, still continued.

Later in the Pliocene, around the entry level of *Globorotalia margaritae*, the central part of the Iraklion province started to rise, and here Neogene and older strata were eroded. A part of the erosional products was deposited in the basins to the north and hence the relative carbonate content of the "transitional" and next higher Finikia marls gradually became less. Most of the terrigenous clastics was dumped in the central parts of the basins, resulting in greater thicknesses of the sediment column; along the margins the sediments were thinner and remained more calcareous.

From the entry level of *G. margaritae* onwards vertical circulation in the basins was repeatedly obstructed, which resulted in oxygen-deficiency at the bottom. The oxygen-poor environments were hostile to large burrowing organisms, causing the sapropelic deposits to be laminated. The presence of siliceous microfossils may point to enhanced production in the surface water layers. In such periods of poor circulation, increased quantities of terrigenous material were brought into the basins, which caused the laminated deposits to be relatively poor in carbonate. The laminated beds which were formed closest to the source area of the clastics received comparatively coarse-grained material, giving rise to a quantitatively large amount of sandy laminae. The thickness of these beds is, in general, greater than that of the beds formed at greater distances from clastic sources. The mode of deposition of the sandy laminae is thought to be mainly turbiditic, whereas in the more remote areas finer terrigenous material settled from suspension. Time and again, circulation was restored, and in these periods sedimentation of homogenized strata recurred. The periods of stagnancy were of much shorter duration than those in which "normal" circulation prevailed.

In a still early stage of the Pliocene, just after the last occurrence of *G. margaritae*, filling of the small Kalithea Basin resulted in such small depths that silty or even sandy marls were deposited. Settling of part of the smaller particles was prevented by the increased hydrodynamic energy in the shallow environments. Another possibility is that pelitic particles no longer reached the shallow areas in such quantities, resulting in sediments enriched in foraminifera. At marginal sites in the Kalithea Basin, current activity gave rise to channels in sandy deposits.

Sedimentation of the silty marls was interrupted by the formation of diatomites. In the shallower parts of the Kalithea Basin, along the basin margin, stagnant conditions did not occur and here no diatomites were formed. In the periods of diatomite formation, sapropels continued to be formed in the larger Finikia – Aghios Vlassios and Aitania Basins, to which areas predominantly small terrigenous particles were supplied.

The simultaneous formation of sapropels and diatomites implies the existence of horizontal differences in the production of diatoms and other siliceous organisms. This can be understood if we consider areas in which at present laminated diatomites are being deposited. Well-known examples are found at places in which seasonal upwelling of nutrient-rich water takes place, such as the SW African Walvis shelf (Van Andel and Calvert, 1971; Calvert and Price, 1971a, b), off the coast of northern Chile and Peru (de Vries and Schrader, 1981), the area west of Baja California (d'Anglejan, 1967), the Gulf of California (Byrne and Emery, 1960; Van Andel, 1964) and, lastly, off southern California (Emery, 1960; Hülsemann and Emery, 1961). Deposition of diatomites happens in silled basins (off California and Baja California) as well as on the shelf (Walvis shelf; off Peru) at depths varying from about 100 to 1400 metres. Bottom waters in all areas are very poor in oxygen. Mean annual precipitation in these parts of the oceans is low (see Perry and Walker, 1977), as in the adjacent land areas. Thus, erosion and sediment supply to the marine environment may generally considered to be low. Moreover, rainfall in these regions is seasonal and outside the periods in which upwelling (and diatom-blooms) occurs. One can conclude that the relative scarcity of suspended matter, which permits good light penetration, is – like nutrients – to be seen as a major prerequisite for diatom-blooms. The studies of Thomas and Simmons (1960) and Cadée (1978) on phytoplankton production in the Mississippi Delta area and the Zaire River plume, respectively, confirm the significance of the role of nutrients and the absence of strong turbid conditions for the occurrence of diatom-blooms. The importance of light and nutrients for primary production was also pointed out by Zeitzschel (1978).

From the above it appears that the paleogeographical distribution of our Pliocene sapropels and diatomites may be explained by a turbidity-controlled difference in production. The surface waters of the central parts of the basins contained relatively large quantities of suspended material and this may be the reason why production here was less than in marginal areas to which less sediment was supplied.

The Aitania Basin was the next to reach the stage of deposition of silty marls and diatomites. This occurred near the extinction level of *Globorotalia puncticulata.*

In the centre of the Finikia – Aghios Vlassios Basin sedimentation rates were still increasing, as deduced from the increasing thicknesses of the individual strata, but more to the west (Gournes) environmental conditions favoured the deposition of silty marls and diatomaceous sediments. Shortly after the entry level of *Globorotalia bononiensis,* the centre of the basin also became so shallow that favourable conditions were created for the deposition of these lithology types. Later on, increased supply of pelitic material to this basin was again the cause of sapropel formation, during periods of stagnancy. The termination of the marine sedimentation is manifested by sands, indicative of shallow deposition.

The hiatus in the Prassas Basin probably resulted from local uplift (and erosion?). The sea invaded the area again shortly after the first appearance of *Globorotalia bononiensis.*

Chapter III

FAUNA ANALYSES

III.1. INTRODUCTION

In quantitative studies, the determination of relative frequencies is one of the easiest and fastest methods of gaining insight into the faunal composition. Other methods are sometimes applied in an attempt to estimate the "absolute" abundances of the species in an association. Standing crop is used in studies on living foraminifera, whereas foraminiferal number – which is the number of forams per unit weight of dry sediment – is applied in studies on recent foraminifera as well as in studies on fossil associations. Foraminiferal numbers should be interpreted carefully, however. The total number of foraminifera in a given quantity of sediment depends on various factors, such as production (of the foraminifera), dissolution, biological destruction and dilution by biogenic, terrigenous or authigenic materials.

Zachariasse (1978) determined foraminiferal numbers in samples from the Pliocene sediments at Capo Rossello, Sicily. He found higher total numbers of planktonic foraminifera in laminated beds and ascribed these higher numbers to enhanced production. Van der Zwaan (1982) drew the same conclusion for similar patterns in the Miocene diatomites of the Falconara section on Sicily. For Miocene laminated sediments on western Crete he did not find consistent patterns of high or low total numbers.

In section II.3 we showed the existence of considerable differences in the weight of the wash-residues of samples from homogeneous and laminated lithology types. These differences were attributed to the admixture of non-foraminiferal particles during deposition of the laminated strata and it was concluded that this admixture gave rise to increased sedimentation rates. This factor together with the difficulties of making reliable splits of the residues in the fraction of 63–125 μ (see I.2), made us refrain from estimating foraminiferal numbers.

Preservation

The preservation of the foraminifera in our samples is good to excellent. In general, there has been little dissolution of foraminiferal tests in the laminated intervals. In samples from sapropels in sections Kalithea 1 and Prassas, however, calcite of the test is seen to be substituted by gypsum, which was formed as a by-product after the oxidation of pyrite. The part of the fauna displaying this feature is generally subordinate.

In order to have an idea about the state of preservation, we determined the ratio of damaged/intact individuals of *Bolivina spathulata*, after picking 50 undamaged specimens, collected for a morphological study (Jonkers, 1984). The mean ratio of damaged/intact individuals in the selected laminated sediments is 2, whereas in the homogeneous sediments the ratio is 2.3. Thus, if the damaged tests of *B. spathulata* in the laminites were the result of dissolution processes, which is to be doubted, one can say that in the homogeneous strata just as much damage was done by other processes, for instance bioturbation.

III.2. FAUNAL PATTERNS IN THREE DIFFERENT SIZE-FRACTIONS

Introduction

Theoretically, the relative frequency of a species in a given size-fraction is primarily dependent on its absolute frequency and its size frequency distribution. Hence, frequency patterns in different size-fractions need not be the same. Most quantitative foraminiferal studies are based on only one size-fraction, after which comparisons with other studies are made; very often no attention is paid to the fact that other authors may have used other size-fractions.

Table III includes all the studies on benthonic foraminifera referred to in this chapter. The selected literature shows that in most studies on recent foraminifera the fraction > ± 60 microns was used, whereas fossil foraminifera are more often studied in coarser sieve-fractions. Procedures applied in certain schools (most of the authors are from California and Utrecht) may well account for these differences.

Generally, no arguments are provided to elucidate the author's preference, but in most cases the sieve-fraction that is used will have been chosen to facilitate comparison with previous works. Our choice of the 125–595 μ fraction for routine counts was explained in I.2, the largest part of the fauna being ignored (see II. 3). In order to have some quantitative information on the small-sized specimens, however, the 63–125 μ fraction of all samples of section Kalithea 2 was included in our study. Moreover, we counted benthonic species in splits from the 200–595 μ fraction. The size-range of this fraction largely overlaps that of the fraction used for routine counts and represents on average almost 40% of the weight of the entire residue of the 125–595 μ fraction. The number of individuals in the fraction of 200–595 μ is comparatively small, however, and we shall show that large differences in composition exist between the two.

Study	Fraction examined
Recent	
Drooger and Kaasschieter (1958)	> 60 μ
Parker (1958)	> 149 μ
Zalesny (1959)	> 61 μ
Bandy (1961)	> 61 μ
Cooper (1961)	> 61 μ
Smith (1963)	> 100 μ
Harman (1964)	> 61 μ
Frerichs (1970)	> 61 μ
Pujos (1972)	not indicated
Lankford and Phleger (1973)	not indicated
Phleger and Soutar (1973)	> 62 μ
Radford (1976a, b)	not indicated
Cita and Zocchi (1978)	> 63 μ
Schnitker (1979)	> 125 μ
Ingle et al. (1980)	> 61 μ
Sejrup et al. (1981)	> 125 μ
Fossil	
Brolsma (1978)	> 63 and > 125 μ
Meulenkamp et al. (1978)	> 125 μ
Hageman (1979)	> 125 μ
Wonders and Van der Zwaan (1979)	> 125 μ
Bremer et al. (1980)	> 150 μ
Cita and Podenzani (1980)	> 63 μ
Van der Zwaan (1980)	80 – 200 and 200 – 500 μ
Van der Zwaan (1982)	> 125 μ

Table III: Sieve-fractions examined in the studies cited in chapter III.

Counting-results

In the first columns of fig. 24, *Uvigerina cylindrica* reaches the highest relative frequencies (caused by the subspecies *gaudryinoides*) in the coarsest fraction, especially in laminated sediments. Sample GR 2218 displays a remarkable peak of 58%. In the 63–125 μ fraction the species plays a subordinate role (highest value 3%), whereas the 125–595 μ fraction shows an intermediate picture.

Uvigerina bononiensis is the dominant species in the coarse fraction of almost all laminated sediments (more than 80% in GR 2210). Its near absence in sample GR 2218 is remarkable. Sample GR 2254 yields 85% *U. bononiensis*, although the lithology was classified as homogeneous marls. In the finest

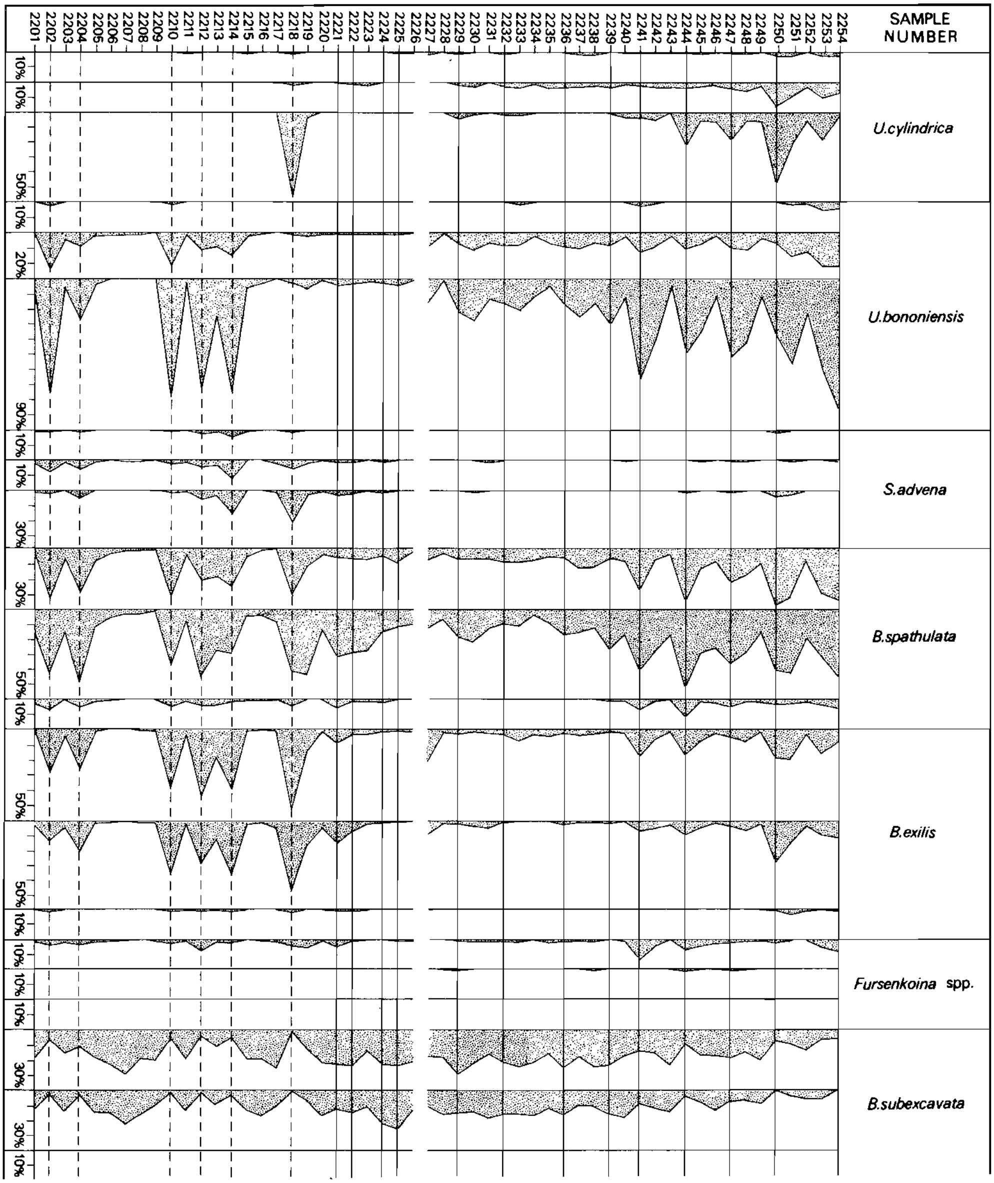
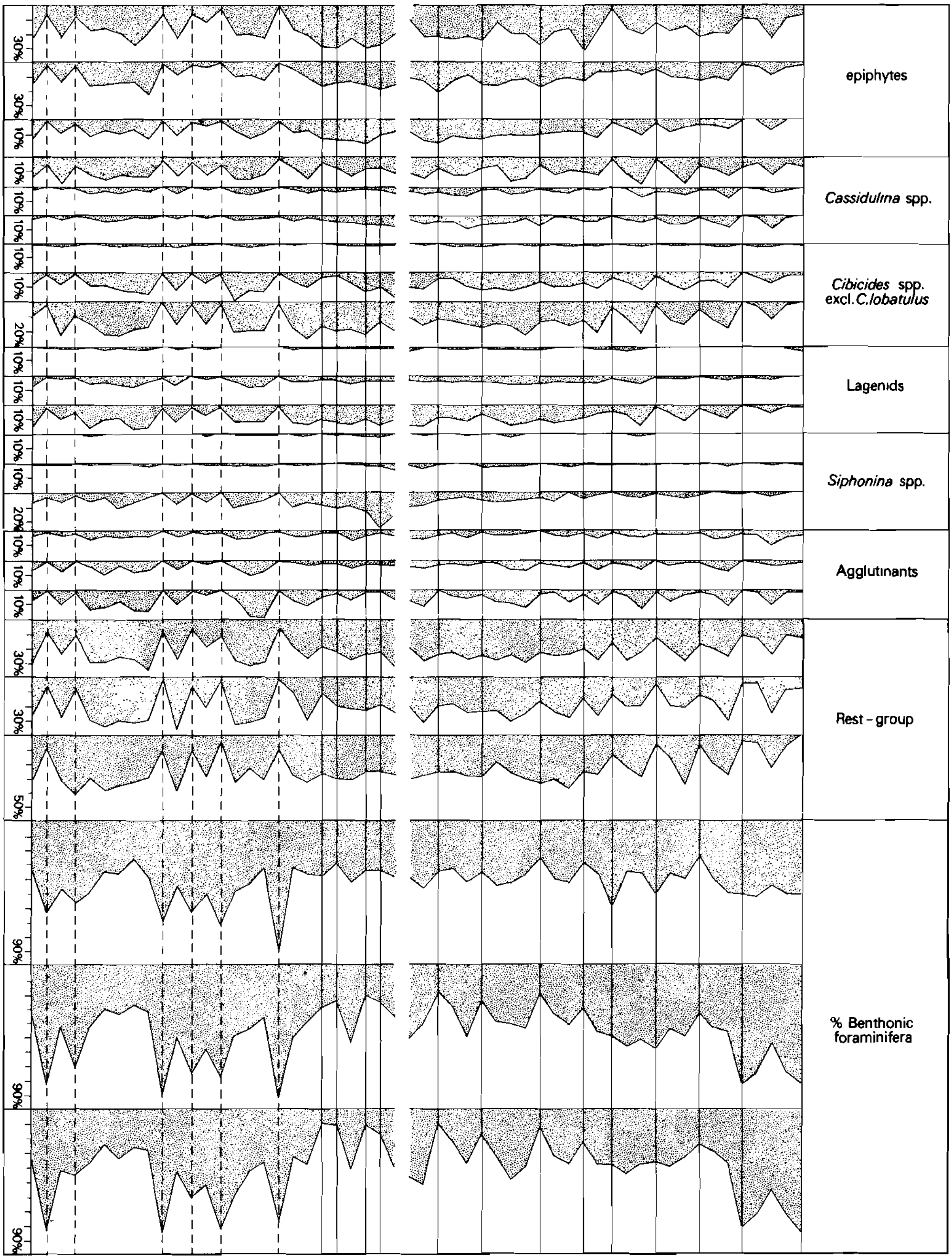


Fig. 24 Relative frequencies of the benthonic foraminifera in section Kalithea 2. Left-hand column of each category: 63–125 μ; middle column: 125–595 μ; right-hand column: 200–595 μ.


30%
30%
10%
10%
10%
10%
10%
10%
20%
10%
10%
10%
10%
10%
20%
10%
10%
10%
30%
30%
50%
90%
90%
90%
epiphytes
Cassidulina spp.
Cibicides spp. excl. C. lobatulus
Lagenids
Siphonina spp.
Agglutinants
Rest - group
% Benthonic foraminifera

fraction the species was hardly detected, whereas in the 125–595 μ fraction relative frequencies are again in between the extremes.

Stilostomella advena is also most frequent in the coarsest fraction, reaching peak values only in some of the sapropels.

Bolivina spathulata behaves differently; its highest relative frequencies are found in the 125–595 μ fraction (often over 40%) of the laminated sediments, but GR 2219 and GR 2254 (homogeneous marl) are seen to contain the species in comparably large relative numbers. In the fine fraction relative frequencies are slightly lower. The species is often absent in the coarse fraction. Here, it hardly ever exceeds 5% of the fauna.

Bulimina exilis seems to be most frequent in the finest fraction. Peak values up to 53% are found in the laminated sediments. In the 125–595 μ fraction percentages are slightly lower. *B. exilis* is almost absent in the countings on the 200–595 μ fraction.

Fursenkoina spp. (mainly the small-sized *Fursenkoina* sp., see chapter V) seems to show up almost exclusively in the 200-counts of the 63–125 μ size-fraction.

So far, we have dealt only with species which are most abundant in the sapropels and diatomites, but it can be observed that not all these levels show peaks; in the diatomites of GR 2221 to GR 2239 such peaks are absent or much less pronounced.

Bolivina subexcavata is a species most frequent in the finest fraction. It never reaches the size of 200 μ and for that reason it is absent in the coarsest fraction. The species displays highest frequencies in the homogeneous sediments, but it is equally frequent in the diatomites of GR 2221 – GR 2239.

A similar pattern can be observed for the epiphytic taxa, but they also occur in the coarsest fraction. The group is composed mainly of *Cibicides lobatulus*, *Asterigerina planorbis* and *Elphidium* species – predominantly *E. crispum*, *E. aculeatum* and *E. fichtellianum* –. It furthermore includes *Rosalina globularis*, *Discorbis* spp., *Planorbulina mediterranensis*, *Hanzawaia boueana* and *Hanzawaia* sp.

Cassidulina spp. (*C. laevigata* and *C. subglobosa*) are also most frequent in the fine fraction, but they do not show similar high relative frequencies in the aforementioned diatomites.

The next four groups all exhibit the opposite general pattern; they are most frequent in the fraction of 200 – 595 μ and all include large-growing species.

Cibicides spp. consist for the larger part of *C.* ex gr. *ungerianus*. Further species are *C. dutemplei*, *C. praecinctus*, *C. italicus* and *C. bradyi*. *C. lobatulus* is excluded from this group, as it is amongst the epiphytes. The group is almost absent in the fine fraction. Minimum values are seen in the laminites, except for the diatomites of GR 2221 – GR 2239.

The same holds for the lagenids. This group is composed of many species belonging to the genera *Lagena, Nodosaria, Orthomorphina, Mucronina, Dentalina, Amphicoryna, Marginulina, Vaginulina, Astacolus, Saracenaria, Planularia, Lenticulina* and *Plectofrondicularia.*

The combination of *Siphonina planoconvexa* and *S. reticulata* is seen to behave identically. The peak value of 25% in the coarse fraction of sample GR 2225 (diatomite) is due to *S. planoconvexa.*

The agglutinants are composed of *Karreriella bradyi, K. affinis, Dorothia gibbosa, Martinottiella communis, Bigenerina nodosaria, Sulcophax papillosus, Vulvulina pennatula, Sigmoilopsis schlumbergeri, Textularia* spp. and *Spiroplectammina* spp. Again, highest frequencies are found in the coarsest fraction, but unlike the groups of *Cibicides* spp., the lagenids and *Siphonina* spp., they are always relatively scarce in the laminites.

The rest-group includes all remaining species not dealt with so far. Large differences in percentages do not show up in the three size-fractions, but it should be noted that the rest-group in the fine fraction differs largely in composition from that in the coarsest one. In the latter fraction, *Sphaeroidina bulloides* and *Planulina ariminensis* can be relatively frequent, whereas they are inconspicuous in the former. The rest-group, in all fractions, shows low values in the laminated sediments, with the exception of again the diatomites of GR 2221 – GR 2239. The peak in the coarse fraction of sample GR 2204 is caused by high relative numbers of the two mentioned species and of *Cancris auricula.*

The percentage of benthonic foraminifera shows strongly fluctuating patterns in all size-fractions, but no large differences are observed between them. Peak values of more than 80% benthos are found in the sapropels and the uppermost laminites, though in the finest fraction these values seem to be somewhat lower than in the other two. The diatomites of GR 2221 – GR 2239 show the opposite. Here, the percentage of benthonic foraminifera has the lowest values, especially in the fraction of 200–595 μ (between 10 and 20%).

Sample GR 2254 yields a high percentage of benthonics in all three fractions. Because we also came across high proportions of species which are usually encountered in the laminated sediments, one may argue that the sediment was originally laminated, but was homogenized by subsequent burrowing.

Summary

As could be expected, largest differences are found between the fractions of 63–125 μ and 200–595 μ. In section Kalithea 2, the 63–125 μ size-fraction is dominated by an association of *Bolivina subexcavata*, epiphytes and *Cassidulina* spp. This association may constitute 60% of the benthonic fauna in this fraction. Large-growing species are entirely overruled in numbers by the small-sized species; they form only up to 15% of the benthonic fauna in the fine fraction.

In the laminated sediments *Bolivina spathulata* and *Bulimina exilis* dominate in the fine fraction, but in some laminites, the benthonic associations resemble those in the homogeneous sediments. In these cases, a slightly lower percentage of benthonic foraminifera is found.

The 200–595 μ size-fraction yields an association of *Cibicides* spp., lagenids, agglutinants, *Siphonina* spp., *Sphaeroidina bulloides* and *Planulina ariminensis*. This association may also be found in certain diatomites, but there it is accompanied by abundant planktonic foraminifera. The remaining laminites are dominated by *Uvigerina bononiensis* and, to a lesser extent, *U. cylindrica gaudryinoides* and *Stilostomella advena*.

Despite the large overlap in size-range with the fraction of 200–595 μ, the fauna in the 125–595 μ fraction, in this study used for routine countings, differs from that in the coarsest fraction. A somewhat intermediate picture is observed, with more resemblance to the fine fraction. It can be assumed that if the entire 63–595 μ fraction was investigated, the results would be nearly identical to our data for the finest fraction, due to the overwhelming presence of small-sized specimens (see II.3).

It should furthermore be emphasized that the differences observed between the fauna in the different size-fractions of one sample may be larger than the differences seen within one size-fraction in samples along a long stratigraphic series.

III.3. THE THREE DETAILED SAMPLED SECTIONS

The exercises on different residue fractions of the samples of section Kalithea 2 already showed the presence of strong dominances of a few species in most of the laminated sediments. As only one sample was taken from almost all laminites, we could not verify whether species frequencies also fluctuated within a single laminated bed. Therefore, we counted the fauna in 125–595 μ fractions in parts of sections Finikia and Prassas, sampled in detail.

Section Finikia

Fig. 25 shows the relative frequencies of the benthonic forams in a sequence of samples across three sapropels in section Finikia. The faunas in the homogeneous sediments are seen to be dominated in most samples by *Bolivina subexcavata* (up to 40% of the benthonic fauna). In these sediments other species do not reach such percentages, but all exhibit low relative numbers. In the sapropels, high frequencies of *Uvigerina cylindrica gaudryinoides*, *Bulimina exilis* and *Bolivina spathulata* are found, coinciding with high percentages of benthonic foraminifera. These species, however, do not reach high values

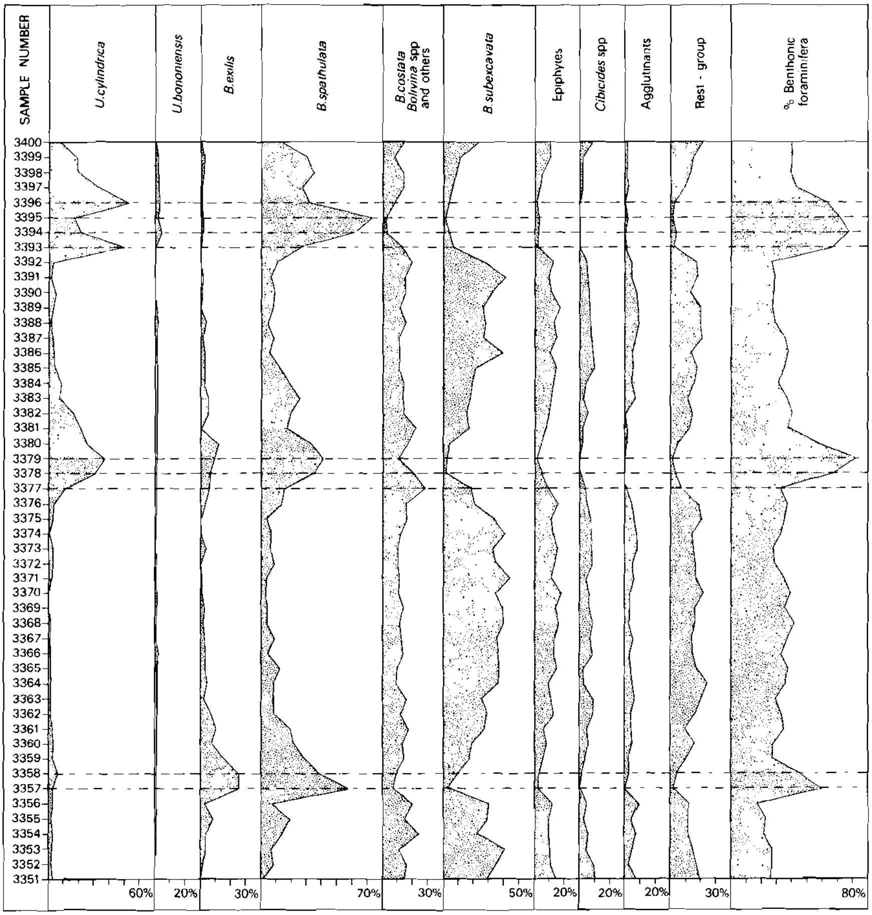


Fig. 25 Relative frequencies of the benthonic foraminifera in the detailed sampled sequence of section Finikia.

in all samples from the sapropels and within a laminated bed the fauna may fluctuate considerably. Unlike section Kalithea 2, *Uvigerina bononiensis* and *Stilostomella advena* (not figured) were not found in great numbers.

High relative numbers of the three frequent species mentioned above are met with in the lowermost samples of two of the three sapropels. No clear frequency-increase of these species is found in the samples below the sapropels, but a rather abrupt change of fauna is noticed at the transition from non-laminated to laminated marls.

Sample GR 3377, in the lower part of the middle sapropel, shows a fauna with relatively many species which are known to reach high frequencies in certain sapropels. These are *Bulimina costata, Bolivina* spp. (chiefly *B. dilatata, B. antiqua* and *B. alata*), *Uvigerina* s.s. (species with a triserial chamber arrangement in their adult stage and without triangular cross-section, mainly *U. pygmea*), the lagenids, *Cancris auricula, Valvulineria complanata, Gyroidina* spp. and *Oridorsalis* spp.

Above the laminated beds, a gradual decrease of the frequencies of the "peaking" species can be seen, corresponding to a similar increase of others (*B. subexcavata*, epiphytes, etc.) and, less clearly, a decrease in the percentage benthos. Because of the observed bioturbation (II.1), it seems most likely that the fauna above the sapropels is a mixed fauna, causing the upper half of the homogeneous beds to yield faunas most representative for such sediments.

Section Prassas

A closely sampled part of section Prassas, GR 1074 – GR 1100 (fig. 7) confirms some of the general observations made above. Here too, the homogeneous sediments are characterized by a fauna composed of relatively many species, with *Bolivina subexcavata*, epiphytes, *Cibicides* spp., lagenids and *Bulimina subulata* as the most conspicuous elements (fig. 26). The percentage of benthonic foraminifera is lower than in the laminated beds and shows decreasing values towards the upper parts of the homogeneous intervals.

In the sapropels the benthonic fauna consists of comparatively few species, some of which reach high relative frequencies. Peaks, however, are not as high as in section Finikia and, in addition to *Bolivina spathulata* and *Stilostomella advena*, some other species are encountered: *Bulimina costata, Bolivina dilatata, B. alata* and some other bolivinids. Some groups, such as *Uvigerina* s.s. and the lagenids, display neither high nor low values throughout the interval.

Finally, we investigated the two very thick diatomites in the upper part of section Prassas. Though sample distances in the diatomite-levels vary from 50

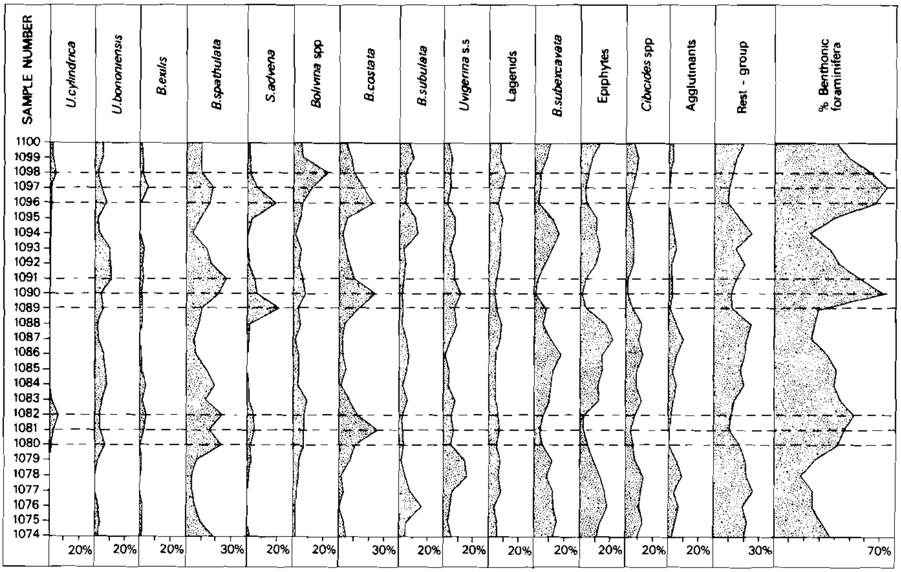


Fig. 26 Relative frequencies of the benthonic foraminifera in the detailed samples sequence of section Prassas.

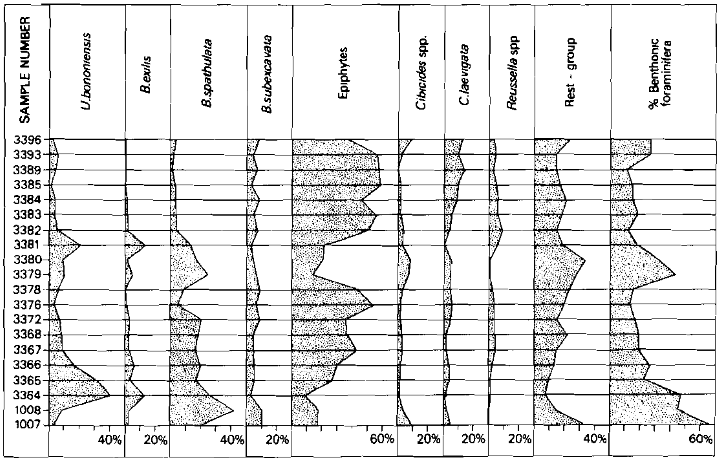


Fig. 27 Relative frequencies of the benthonic foraminifera in the thick diatomites of section Prassas.

cm in their lower parts to 2 m in the upper parts (see fig. 7), the set of samples, when compared with the sapropels in the aforegoing sections, may be considered as a detailed sequence.

The homogeneous marls contain a relatively diverse fauna, characterized by *Bolivina spathulata*, epiphytes, the rest-group and a high percentage of benthonics (fig. 27). In the laminated marls a different picture emerges. *B. spathulata* is still frequent in the lower parts, together with *Uvigerina bononiensis* and *Bulimina exilis* (in CP 3364 and CP 3381 the three make up 79 and 47% of the benthonic fauna, respectively), and the percentage of benthonic foraminifera may be relatively high. In an upward direction this fauna is gradually replaced by a fauna with abundant (almost 60%) epiphytes, while planktonic foraminifera appear in great numbers. *Cassidulina laevigata* may be common and species of *Reussella* occur as minor faunal constituents.

III.4. FAUNAL CHARACTERISTICS IN HOMOGENEOUS AND LAMINATED SEDIMENTS

From visual inspection of the counts on the samples from the three detailed sampled sections, some general faunal characteristics can be derived for both sediment-types.

The homogeneous marls were seen to contain a fauna in which none of the species or groups of species displays peak values. No large frequency fluctuations occur within a single homogeneous stratum. The percentage of benthonic foraminifera, as a rule, is relatively low.

The sapropels were found to be characterized by faunas variously dominated by species belonging to *Bolivina*, *Bulimina* and *Uvigerina* s.l. In the diatomites we found faunas dominated by epiphytes. In the first case the percentage of benthonics is high; in the second, very low relative numbers of benthonic foraminifera are found. Within one laminated bed the percentages of the separate benthonic species may fluctuate considerably.

Mixing of the faunas from laminated and homogeneous sediments is observed above the laminites and is believed to be caused by burrowing organisms. Thus, samples from the upper part of the homogeneous beds are expected to yield the faunas that tell us most about such sediments.

To find out whether our visual appreciation of the faunas in the homogeneous and laminated marls is confirmed by statistical analyses, we subjected some of our data to repeated computer-runs. For this purpose we used all data from section Aghios Vlassios and the data from sections Kalithea 1 and 2. In II.4 we concluded that sections Kalithea 1 and Kalithea 2 are stratigraphically successive. It is for this reason and the geographical proximity that we decided to regard both these sections as one.

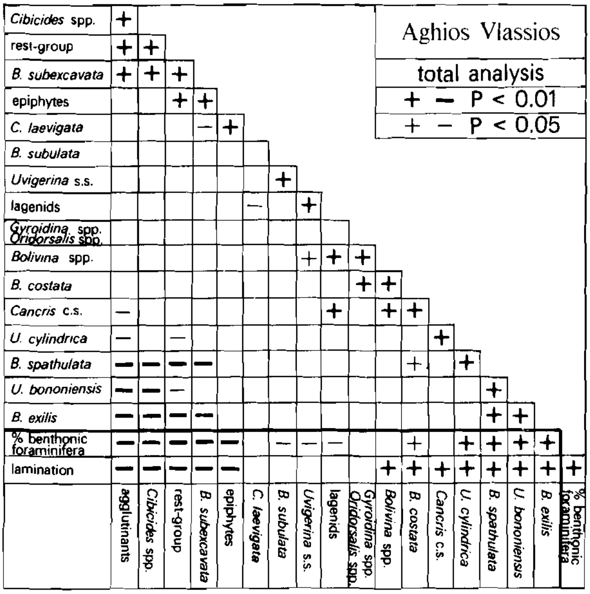


Fig. 28 Matrix of correlation coefficients of all data from section Aghios Vlassios based on the DISTUR and BALANC procedures.

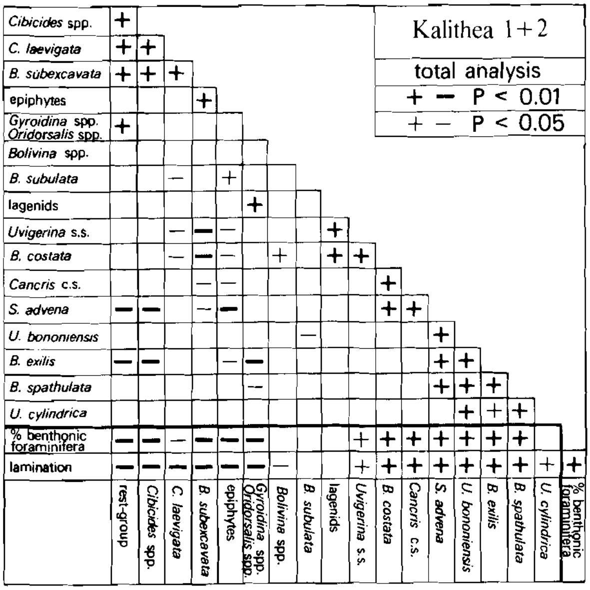


Fig. 29 Matrix of correlation coefficients of all data from section Kalithea 1 + 2 based on the DISTUR and BALANC procedures.

In the analyses, the alternating homogeneous and laminated beds are represented by one sample for each lithology type. In the two sections we chose for the computer analyses, the laminites are mainly sapropels, which may yield faunas other than those yielded by the diatomites. In these analyses trends are not considered.

The results of the analyses of the data from section Aghios Vlassios, the one which covers the longest time interval, are given in fig. 28; those of Kalithea 1 + 2 in fig. 29. In these figures only those correlations are presented which were confirmed by the use of both the DISTUR and BALANC programs. Correlations which were produced by the use of one program only are ignored. If the level of significance in one analysis was $P < 0.01$ and in the other $P < 0.05$, the latter level was chosen to be included in figures 28 and 29. Correlations with non-faunal categories were performed with the MATRIX program.

The analyses show the presence of three groups. The first one gives the taxa that have positive correlations with the laminites in both sections: *Uvigerina cylindrica, U. bononiensis, Bulimina exilis, Bolivina spathulata, Cancris* c.s. (*C. auricula, Valvulineria complanata* and *Baggina totomiensis*) and *Bulimina costata.* Such correlations we also found for the percentage of benthonic foraminifera. *Stilostomella advena* shows a positive correlation only in the combined sections Kalithea 1 and 2; the species was not included in the analysis of the data from section Aghios Vlassios.

The second group consists of the taxa with negative correlations, i.e. with preference for homogeneous sediments. These are the epiphytes, *Bolivina subexcavata, Cibicides* spp. and the rest-group. The agglutinants show a negative correlation with lamination in section Aghios Vlassios only; they were not included in the analysis of the data from section Kalithea 1 + 2.

The third group in between is variable. *Bulimina subulata* and the lagenids are the only taxa which seem to be neutral in both sections. We found a single positive correlation with laminites for *Uvigerina* s.s., whereas single negative correlations were found for the combination of *Gyroidina* spp. + *Oridorsalis* spp. and for *Cassidulina laevigata* (all in section Kalithea 1 + 2). *Bolivina* spp. (all bolivinids except *B. spathulata* and *B. subexcavata*) is the only category with opposite links with lamination in both sections; in section Aghios Vlassios a positive correlation exists between the two, whereas in section Kalithea 1 + 2 the correlation is negative.

On the basis of these computer analyses, we can compile a sequence of taxa (figs. 28 and 29) which suggests a series of habitats corresponding to a single gradient from well-aerated to extremely oxygen-poor, i.e. some kind of stagnation gradient. Relations probably were more complex because of the interaction of several environmental gradients, but our opposition of homogeneous and laminated sediment may strongly support the existence of this stagnation gradient.

At the end of "normal" marine conditions we find the association of epiphytes, *B. subexcavata*, the rest-group, *Cibicides* spp. and the agglutinants. There is a shallow marine character in this association, but although the computer analyses give no such clue, there may be environmental differences in this group, leading to the next step along the gradient which seems to consist of *C. laevigata* and *Gyroidina* spp. plus *Oridorsalis* spp. Especially the latter combination may indicate greater depth below the photic zone and/or a more muddy environment.

Such an environment seems appropriate for the association of the lagenids, *B. subulata* and, finally, *Uvigerina* spp. One may wonder whether beginning effects of oxygen depletion are already playing a role. *Bolivina* spp. has an ambiguous position, which may be due to its variable composition.

Cancris c.s. and *B. costata* seem to be a further step along the oxygen-gradient, intermediate to the more distinct group of *B. spathulata*, *B. exilis* and *U. bononiensis* to which *U. cylindrica* and *S. advena* seem to be very close.

The association of *B. spathulata* c.s. seems to be the last one along the line of increasing stagnancy of the bottom waters, possibly thriving because of a large nutrient availability.

Although not resulting from our computer analysis, there seems to be one more step along this gradient. Anticipating our discussions further down, we imagine that this last autochthonous fauna along the ladder disappears entirely to be replaced by allochthonous elements of the shallow, normal marine association, but this time combined with a low percentage of benthonic foraminifera.

The strong suggestion of a stagnation gradient, which resulted from the analyses of the data from homogeneous and laminated lithology types together, made us wonder whether elements of such a gradient can be traced in the individual lithology types as well. We therefore decided to analyse the data from each type separately. Since the gradient we inferred above is strongly reminiscent of the effect of lamination, we expect a great resemblance between the results of the analyses of the data from the laminated sediments and those of the total analyses.

III.5. TRENDS OF THE TAXA IN SECTIONS AGHIOS VLASSIOS AND KALITHEA

Before considering the details of the faunas in the individual lithology types, we shall discuss the trends of the faunal categories in the separate analyses, which may be the cause of some of the correlations which show up in these analyses.

The trends which resulted from the separate analyses are shown in table IV. Again three groups are present the first of which is composed of species with positive trends in both sections and in both lithology types. These species are *Uvigerina bononiensis*, *Bulimina exilis* and *Bolivina spathulata*, thought to be indicative of extremely stagnant bottom waters. *Uvigerina cylindrica* may also belong here, although for this taxon no such trends are found in section Aghios Vlassios.

The members of the second group of taxa mostly show negative trends in our analyses. This group consists of *Bulimina costata*, *Uvigerina* s.s., the lagenids and *Bulimina subulata*. In III.4 we concluded that these taxa indicate bottom conditions less strongly affected by oxygen deficiency.

The faunal categories of the third group, consisting of foraminifera which prefer "normal" marine conditions, are inconsistent in their trends. Of these, only *Cassidulina laevigata* shows positive trends in all analyses. The inconsistent behaviour of the members of this group may in part be explained by the

	Aghios Vlassios homogeneous marls	Aghios Vlassios laminated marls	Kalithea homogeneous marls	Kalithea laminated marls
U. bononiensis	+	⊕	⊕	⊕
B. exilis	+	⊕	+	+
B. spathulata	+	⊕	⊕	⊕
U. cylindrica			⊕	⊕
S. advena				
Cancris c.s.				–
B. costata			⊖	⊖
Uvigerina s.s.		⊖	–	⊖
Lagenids	⊖	⊖		⊖
B. subulata	–	–	⊖	–
Bolivina spp.				
Gyr./Orid.				–
Agglutinants				
Rest-group				
Cibicides spp.	⊕	–		
C. laevigata	⊕	⊕	⊕	+
Epiphytes			⊖	⊕
B. subexcavata	⊖			⊕

Table IV: Trends in the analyses of the individual lithology types (⊕⊖ symbols: + – symbols: $P < 0.05$).

inclusion of diatomites in our analyses, which may contain relatively large numbers of foraminifera of shallow origin (e.g. epiphytes, see III.6).

Thus, in all sections we are faced with positive trends of the members of the group indicating highly stagnant conditions, whereas the taxa of the group from moderately oxygen-poor environments in general exhibit negative trends. This may lead to the conclusion that stagnant conditions became more severe in the course of deposition of both sequences. The presence of similar trends in the laminated as well as in the homogeneous marls may suggest that oxygen deficiency became stronger in both lithology types. In the analyses of the individual lithology types we shall evaluate this suggestion further.

Extinction of benthonic foraminiferal taxa

Some of the trends that we found might be induced by taxa which disappear from or enter the stratigraphic record. However, in the part of the Pliocene we studied, the disappearance of only two taxa, *Uvigerina rutila* and *U. cylindrica gaudryinoides*, was observed.

In the Mediterranean, the Pliocene extinction of *U. rutila* was reported before by Barbieri (1967), Iaccarino (1967) and Wright (1978). Except in section Aghios Vlassios (fig. 39), the species is always scarce and therefore its extinction level is hard to pinpoint. Moreover, confusion with the morphologically close *U. longistriata* (syn. *U. striatissima*), a species which persists throughout our sections, might obliterate the end of its range. *U. rutila* stops entering the counts somewhat above the last occurrence of *Globorotalia margaritae* (compare figs. 39 and 20). Because of the relative scarcity of *U. rutila*, it is assumed that its extinction has no influence of any significance on the negative trends which exist for *Uvigerina* s.s. in sections Aghios Vlassios and Kalithea 1 + 2.

The disappearance level of the thick-type *Uvigerina*, *U. cylindrica gaudryinoides*, is stratigraphically just above that of *Globorotalia puncticulata* (compare figs. 30 and 20). It was mentioned before by Thomas (1980). No negative trends at all were found for *U. cylindrica*.

In sections Aghios Vlassios and Kalithea 1 + 2, *Bulimina subulata* is the only species which displays negative trends in both lithology types (table IV). Unlike all other taxa, a considerable drop in its relative frequencies is found at the same stratigraphic level of both sections, i.e. in between the entry level of *G. puncticulata* and the exit level of *G. margaritae* (compare figs. 30, 33, 39, 42 and 20). A similar frequency-drop as in the nominate sections was found at this level in section Prassas. The species is sporadically present above this level, but in the upper part of section Aghios Vlassios and in section For-

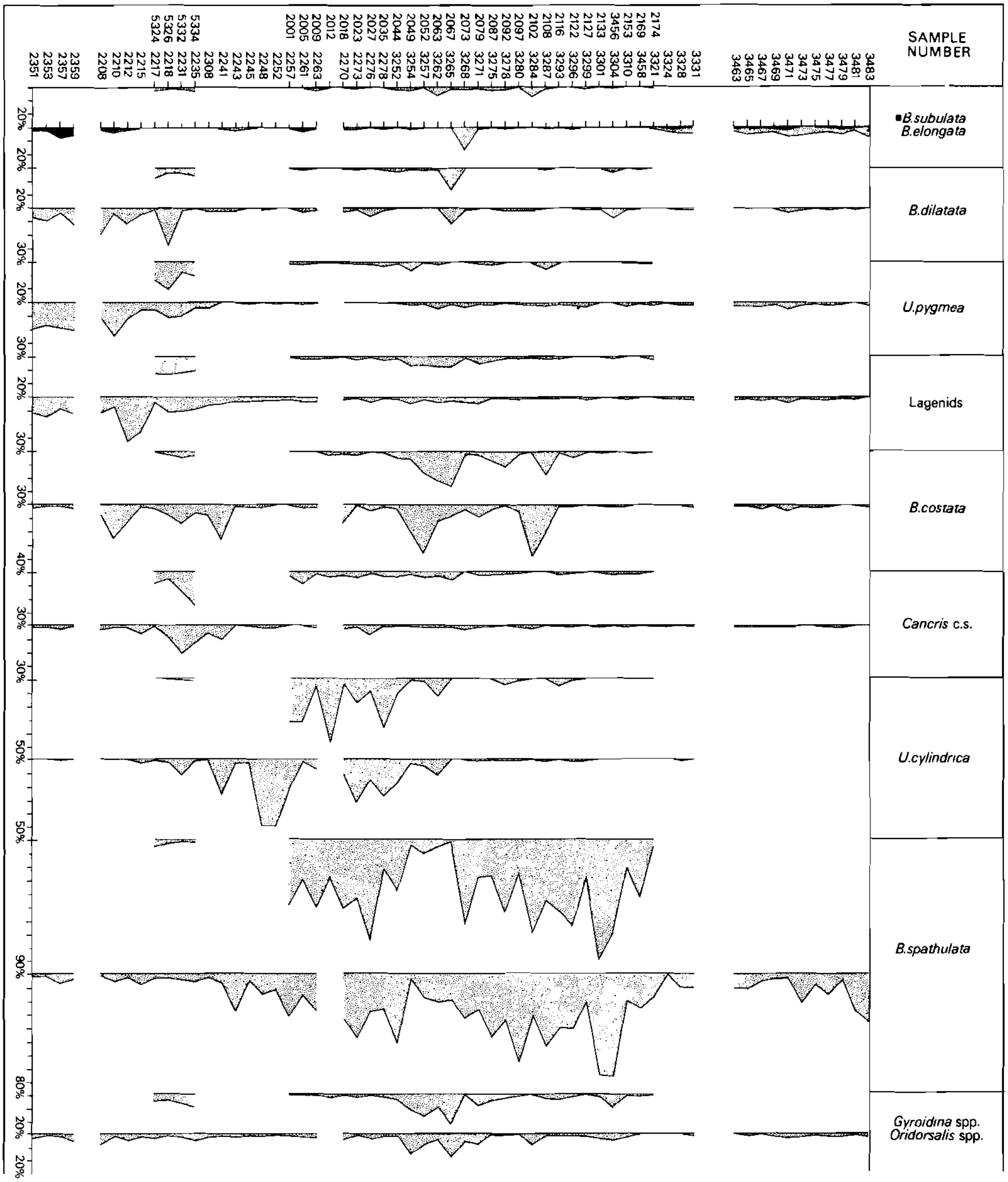
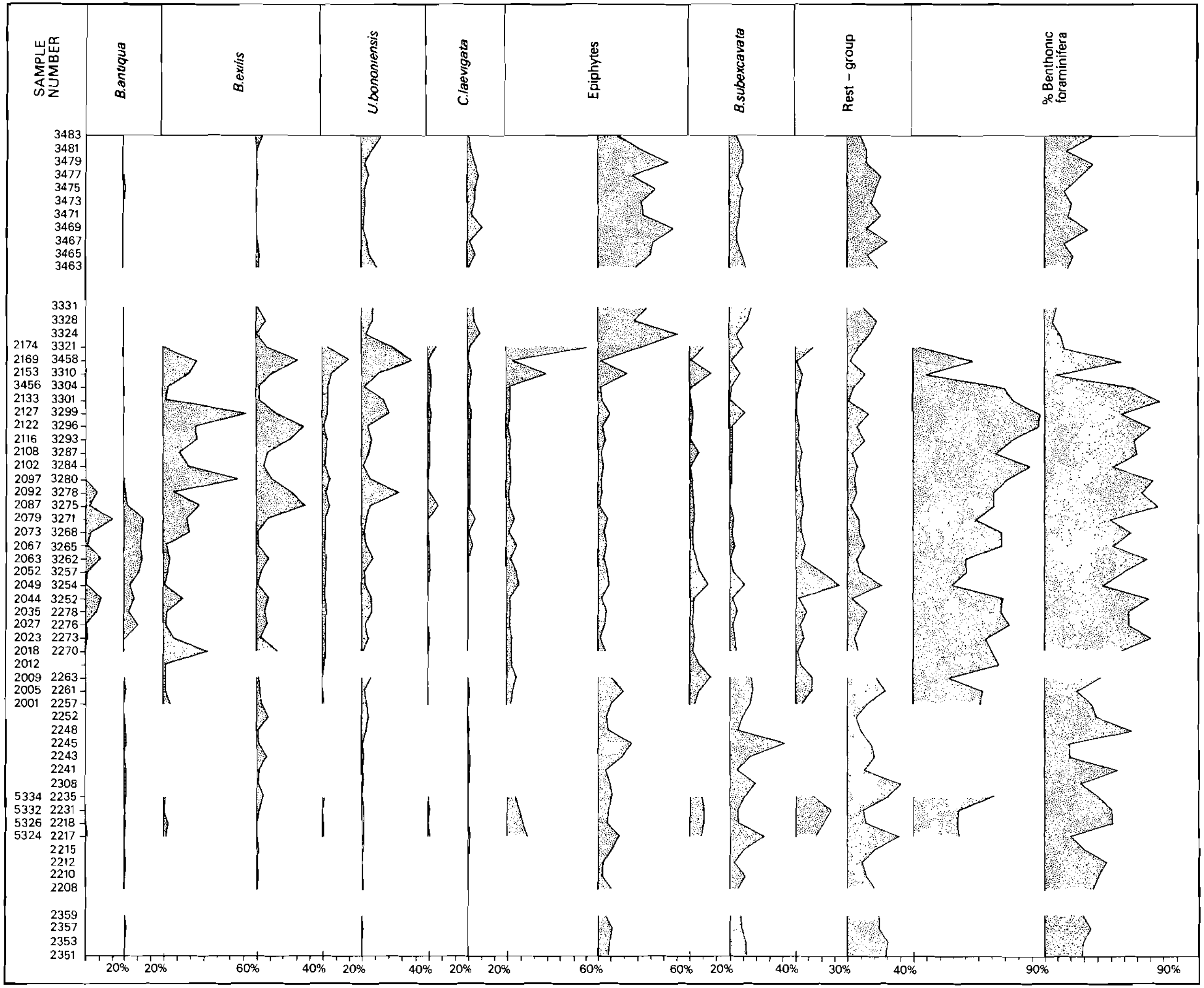


Fig. 30 Relative frequencies of the benthonic foraminifera in the laminated sediments of section Finikia (left-hand column of each category) and sections Aghios Vlassios and Fortetsa (right-hand column).


SAMPLE NUMBER
B.antiqua
B.exilis
U.bononiensis
C.laevigata
Epiphytes
B.subexcavata
Rest - group
% Benthonic foraminifera
3483
3481
3479
3477
3475
3473
3471
3469
3467
3465
3463
3331
3328
3324
2174 3321
2169 3458
2153 3310
3456 3304
2133 3301
2127 3299
2122 3296
2116 3293
2108 3287
2102 3284
2097 3280
2092 3278
2087 3275
2079 3271
2073 3268
2067 3265
2063 3262
2052 3257
2049 3254
2044 3252
2035 2278
2027 2276
2023 2273
2018 2270
2012
2009 2263
2005 2261
2001 2257
2252
2248
2245
2243
2241
2308
5334 2235
5332 2231
5326 2218
5324 2217
2215
2212
2210
2208
2359
2357
2353
2351
20%
20%
60%
40%
20%
40%
20%
20%
60%
60%
20%
40%
30%
40%
90%
90%

tetsa it is more frequent again, although with low relative numbers (fig. 30). In its stratigraphically higher range it is always accompanied – and outnumbered – by *Bulimina elongata,* so the re-introduction of the species may be the result of our taxonomic concept. In our opinion, the negative trends we found for *B. subulata* can safely be ascribed to the sudden vanishing of spinose buliminids in the Early Pliocene.

In the area and interval we studied, introductions of new benthonic species, which might be of stratigraphical importance and which might influence our statistical analyses, were not noticed. Some of the very rare taxa, recorded first in the upper part of sections Aghios Vlassios, Fortetsa and Prassas may be facies-bound and may be so infrequent in lower stratigraphic intervals that they escaped our attention (in practice: did not enter the 200-counts).

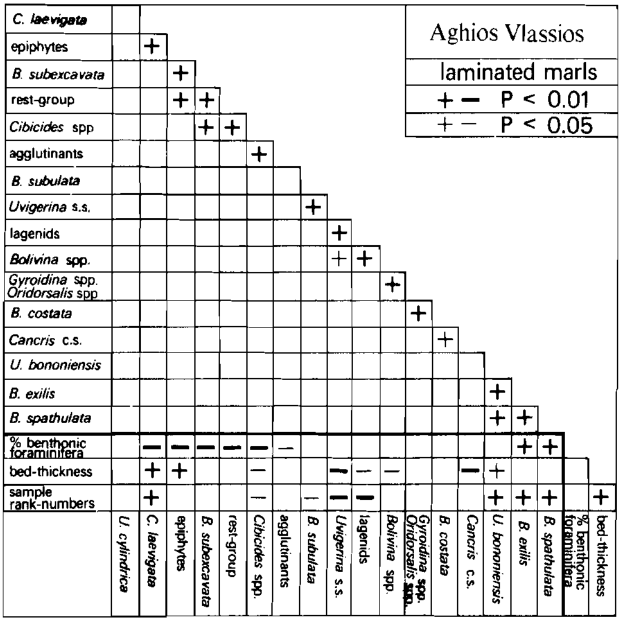
III.6. FAUNAL PATTERNS IN THE LAMINATED SEDIMENTS

Sections Finikia, Aghios Vlassios and Fortetsa

The most relevant faunal categories in the samples from the laminated sediments from sections Finikia, Aghios Vlassios and Fortetsa are shown in figure 30. Correlation of the laminated beds of sections Finikia and Aghios Vlassios was performed according to the scheme in fig. 20. The counting results for the top part of section Fortetsa have been placed above those of section Aghios Vlassios, which is situated near by.

Various species are seen to reach peak values at certain levels, which induces strong zig-zag patterns in the frequency curves. If we compare the faunas from levels which we correlated (fig. 30), it becomes clear that a peak of a particular species in section Finikia in most cases does not coincide with a similar peak of that species in section Aghios Vlassios. This is not surprising, since we learned from the studies of the detailed sets of samples that relative frequencies of a species may fluctuate considerably in a vertical sense within one laminite bed. It remains striking, however, that certain intervals of groups of laminites with high percentages of a certain species in one section correspond to intervals with similar frequencies of this species in the other. Thus, the general faunal patterns throughout both sections are essentially the same. The higher rate of sedimentation at Finikia, which was about twice that at Aghios Vlassios, did not noticeably affect benthonic life. It therefore seems reasonable to put the upper part of section Fortetsa on top of section Aghios Vlassios, even though sedimentation rates at Fortetsa were still lower.

The results of the computer analyses of the quantitative data of section Aghios Vlassios are reproduced in figs. 31 and 32. The criteria for the corre-



Aghios Vlassios

laminated marls

+ — P < 0.01

\+ – P < 0.05

	U. cylindrica	*C. laevigata*	epiphytes	*B. subexcavata*	rest-group	*Cibicides* spp.	agglutinants	*B. subulata*	*Uvigerina* s.s.	lagenids	*Bolivina* spp.	*Gyroidina* spp. *Oridorsalis* spp.	*B. costata*	*Cancris* c.s.	*U. bononiensis*	*B. exilis*	*B. spathulata*	% benthonic foraminifera	bed-thickness
C. laevigata																			
epiphytes		**+**																	
B. subexcavata			**+**																
rest-group			**+**	**+**															
Cibicides spp				**+**	**+**														
agglutinants						**+**													
B. subulata																			
Uvigerina s.s.								**+**											
lagenids									**+**										
Bolivina spp.									+	**+**									
Gyroidina spp. *Oridorsalis* spp											**+**								
B. costata												**+**							
Cancris c.s.													+						
U. bononiensis																			
B. exilis															**+**				
B. spathulata															**+**	**+**			
% benthonic foraminifera		**—**	**—**	**—**	**—**	**—**	–									**+**	**+**		
bed-thickness		**+**	**+**			–			**—**	–	–			**—**	+				
sample rank-numbers		**+**				–		–	**—**	**—**					**+**	**+**	**+**		**+**

Fig. 31 Matrix of correlation coefficients of the data from the laminated sediments of section Aghios Vlassios based on the DISTUR and BALANC procedures.

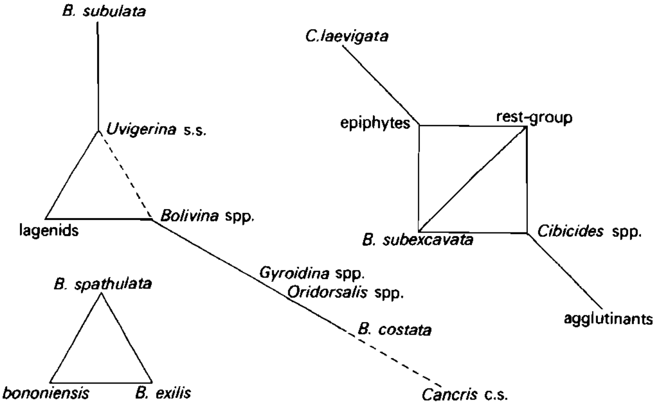


Fig. 32 Spider-web diagram for the samples from the laminated sediments of section Aghios Vlassios, showing only positive correlations. Solid lines: $P < 0.01$; dashed lines: $P < 0.05$.

lation coefficients included in these figures are the same as those for figs. 28 and 29. The analyses include some taxa which we did not figure in fig. 30 because of low frequencies. As we have already seen, these taxa play a more pronounced role in the homogeneous sediments.

First of all we observe the positive trends of *Bolivina spathulata*, *Bulimina exilis*, *Uvigerina bononiensis* and *Cassidulina laevigata* (fig. 31). The trend of increasing bed-thickness in this section, which was suggested by visual inspection of fig. 20 (II.4), proved to be significant ($P < 0.01$). The visual impression of a trend in the percentage of benthonic foraminifera (fig. 30) was not substantiated by the computer analyses, possibly due to the extremely low values in the diatomites at the top of the section. Negative trends were found for the lagenids, *Uvigerina* s.s., *Bulimina subulata* and *Cibicides* spp.

It is possible to recognize three associations. The first one is composed of three species with positive trends, *Bolivina spathulata*, *Bulimina exilis* and *Uvigerina bononiensis*. The former two species are positively correlated with the percentage of benthonic foraminifera at the $P < 0.01$ level.

The second association consists of the group of *Cancris* c.s., *Bulimina costata*, *Gyroidina* spp. with *Oridorsalis* spp., *Bolivina* spp., the lagenids, *Uvigerina* s.s. and, lastly, *Bulimina subulata*. They are tied to each other through a chain of positive correlations; the latter three have their negative trends in common. None of the mentioned categories is correlated with the percentage of benthonic foraminifera.

The central cluster of the third association is formed by *Cibicides* spp., the rest-group, *Bolivina subexcavata* and the epiphytes, which all show two or more strong positive correlations with each other. There is no significant correlation between the end members, the group of *Cibicides* spp. and the epiphytes. *Cassidulina laevigata* is tied to the side of the epiphytes, whereas the agglutinants are linked to *Cibicides* spp. All members of this association have a negative correlation with the percentage of benthonic foraminifera (for the agglutinants: $P < 0.05$; for all others: $P < 0.01$).

Uvigerina cylindrica is not found to be correlated with any other category

In figs. 31 and 32 no negative correlations between taxa are met with. The computer-runs with the aid of the DISTUR program revealed negative correlations between *B. spathulata*, *B. exilis* and *U. bononiensis*, of the first association, and members of the other two associations. With the use of the BALANC program, all such correlations proved to be below the $P < 0.05$ significance level, however.

The addition of the data from section Fortetsa in the analyses causes only a few alterations in the results. The level of significance of some correlations is changed. New introductions are the strong positive correlations ($P < 0.01$)

between *Cancris* c.s. and the lagenids, and between *Cassidulina laevigata* and the rest-group. A weak negative correlation ($P < 0.05$) appears between *Cibicides* spp. and *Bolivina spathulata.*

The results of the computer analyses of the data from the laminated sediments are similar to those of the total analyses (compare figs. 31 and 28). Hence, the stagnancy gradient, which was concluded from the total analyses, is well demonstrated by the fauna in the laminated marls.

If we look again at fig. 30, we find the lowermost sapropels in sections Finikia and Aghios Vlassios to be dominated by the members of the association of *Cancris* c.s. to *B. subulata.* The third association described above, here dominated by *B. subexcavata,* the epiphytes and the rest-group, is also relatively frequent. The environments in which these lowermost sapropels were formed must have been hospitable to a fauna composed of many species.

Except for *C. laevigata,* which is not at all frequent in this interval, all members of the *B. subexcavata* association have negative correlations with lamination in the analyses of all sediments (fig. 28). This may indicate that the presence of fair percentages of this association is the result of contamination with homogeneous sediment. If true, the laminated sediments may have become mixed by burrowing after the re-installation of normal marine conditions, or contamination was introduced during the sampling of the relatively thin sapropels in the basal parts of the sections. It is equally feasible that the members of this association are allochthonous, transported downwards from the shallower, more aerated parts of the basin.

In section Aghios Vlassios, *Bulimina subulata* is the first species to show a decrease in relative frequencies. Its disappearance level at the same stratigraphic level in other sections, both in laminated and homogeneous sediments (see III.5), may be an indication that this frequency-drop probably did not result from a decrease in the oxygen content of the bottom water; there must be another reason.

The next taxa to decrease in relative numbers are *Bolivina dilatata, Uvigerina pygmea* and the lagenids, whereas *Cancris* c.s. and *Bulimina costata* persist. In the computer analyses, *Uvigerina* s.s. and the lagenids, together with *Bolivina* spp. and *Cancris* c.s., are negatively correlated with bed-thickness of the laminites (fig. 31). If such bed-thickness has a positive relation with intensity of stagnation, the negative trends of *Uvigerina* and the lagenids are logical.

In the upward direction the benthonic associations become more and more dominated by *Bolivina spathulata, Uvigerina cylindrica gaudryinoides* and, to a lesser extent, *Bulimina exilis;* the dominance of this group of species is accompanied by an increase of the percentage of benthonic foraminifera. This shift in fauna is interrupted at the level of GR 3254. Here, *B. costata, Bolivina antiqua* and *Oridorsalis* sp. dominate, but higher up they are replaced again by *B. spathulata* and *B. exilis*, now accompanied by *Uvigerina bononiensis*. The same oscillation can be seen in section Finikia, where the sapropels of CP 2049 to 2067 contain low percentages of the *B. spathulata – U. bononiensis* association.

In both sections, *U. cylindrica gaudryinoides* has disappeared from our counts above the correlative level of CP 2063 and GR 3262. Occurrences of *U. cylindrica* at higher stratigraphic levels can be ascribed to thinner morphotypes (see Thomas, 1980).

Of the three members of the association of *B. spathulata* c.s., *U. bononiensis* is the only one which is positively correlated with bed-thickness ($P < 0.05$).

The most abrupt faunal change is observed around the level at which sapropels are replaced by diatomites (GR 3310). An association dominated by epiphytes, the rest-group and, to a lesser extent, *B. subexcavata* and *C. laevigata* replaces the *B. spathulata – U. bononiensis* association (with the exception of the level of GR 3458). Moreover, in these laminites the percentages of benthonic foraminifera are the lowest of all.

Amongst this association, *C. laevigata* and the epiphytes are strongly correlated with bed-thickness.

The recurrence of sapropels in section Fortetsa (from GR 3473 onward) is not accompanied by a faunal change of similar magnitude; only *B. spathulata* seems to have slightly higher scores than in the diatomite levels below.

Sections Kalithea 1 and Kalithea 2

The quantitative data for all laminites in sections Kalithea 1 and 2 show again strong dominances of the species or groups of species we already encountered in sections Finikia, Aghios Vlassios and Fortetsa (fig. 33). The results of the computer analyses in figures 34 and 35 show a long chain of positive correlations in which the three basic associations of the previous sections are easily discernible.

Positive trends are found for *Uvigerina cylindrica, Bolivina spathulata, Bulimina exilis* and *Uvigerina bononiensis*, and also at the other end of the chain for *Bolivina subexcavata*, the epiphytes and *Cassidulina laevigata* (fig. 34). Negative trends are seen for *Cancris* c.s., *Bulimina costata, B. subulata, Uvigerina* s.s., the lagenids and *Gyroidina* spp. plus *Oridorsalis* spp.

Again, *Bolivina spathulata, Bulimina exilis* and *Uvigerina bononiensis* are mutually correlated. *Uvigerina cylindrica* is linked to *B. spathulata* through a strong positive correlation; a similar correlation exists between *U. bononien-*

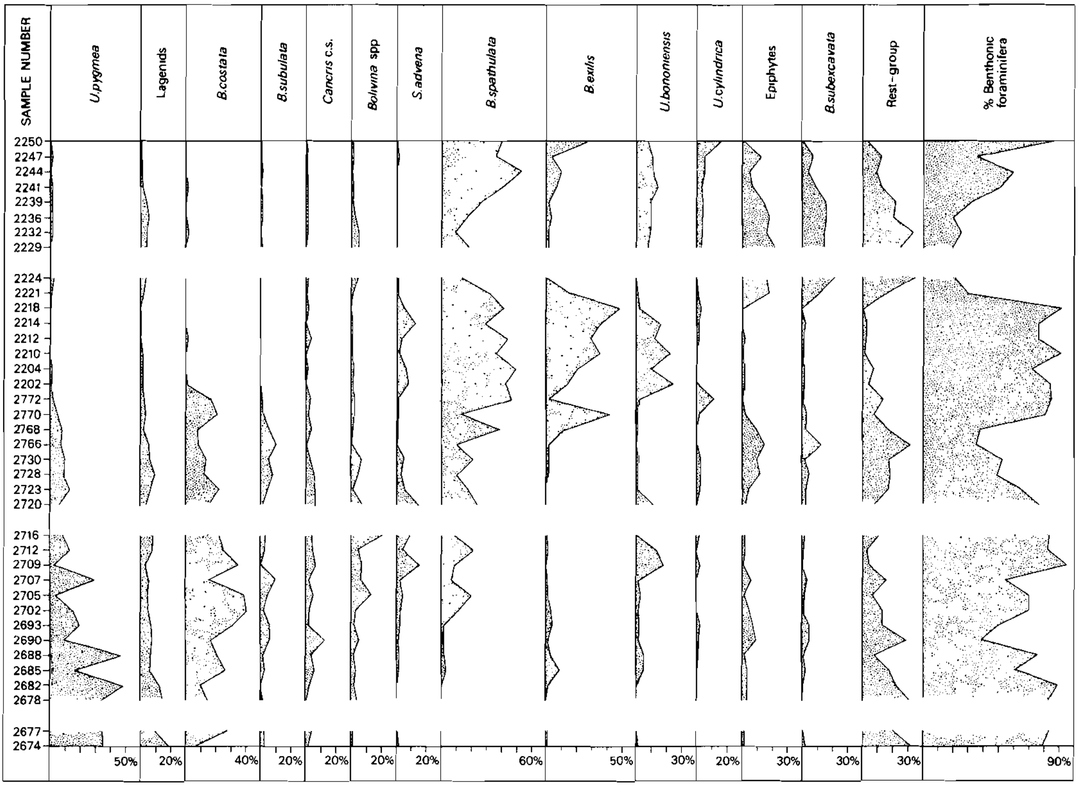


Fig. 33 Relative frequencies of the benthonic foraminifera in the laminated sediments of section Kalithea 1 + 2.

sis and *Stilostomella advena.* Of all these species, *S. advena* and *B. spathulata* are positively correlated with the percentage of benthonic foraminifera.

Via *S. advena* we encounter an association of *Bolivina* spp., *Cancris* c.s. and *Bulimina costata.* The latter species is also correlated with *Bulimina subulata* and tied to the lagenids and *Uvigerina* s.s. of the next group ($P < 0.05$ for all these correlations).

Another tightly correlated group of taxa is composed of the lagenids, *Uvigerina* s.s. and *Gyroidina* spp. + *Oridorsalis* spp. Of these, the lagenids are weakly correlated with *Cibicides* spp.; positive correlations with the rest-group are shown by the lagenids and *Gyroidina* spp. + *Oridorsalis* spp. ($P < 0.05$).

The last association of the chain comprises a group of mutually correlated taxa: *Cibicides* spp., the rest-group, the epiphytes and *Bolivina subexcavata,* the last two of which are linked to *C. laevigata.* All correlations are at the $P < 0.01$ significance level, except for the one between *Cibicides* spp. and the epiphytes (P < 0.05). All five members of this association are negatively correlated with the percentage of benthonic foraminifera (P < 0.01).

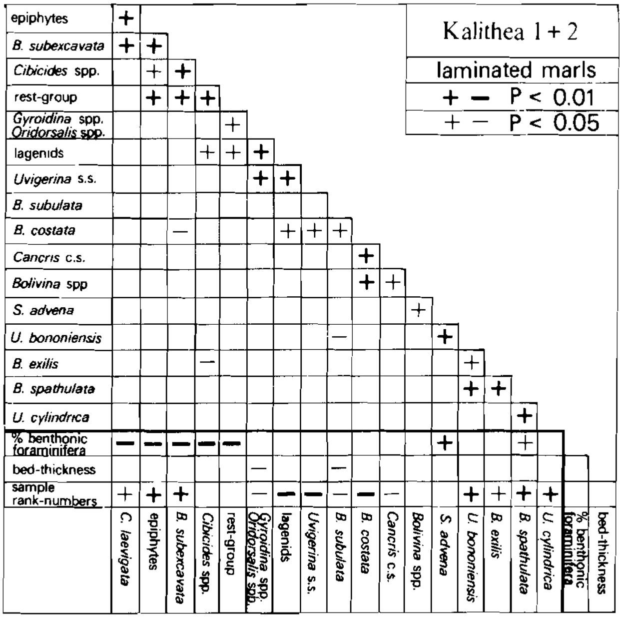
The order of the taxa in the matrix of fig. 34 is again strongly reminiscent of our stagnation gradient.

In the lowermost sapropels, dominances of *U. pygmea* are found together with fair percentages of the lagenids, *B. costata* and the rest-group (fig. 33). Percentages of benthonic foraminifera are high.

In the sapropels in the middle part of the composite section, *U. pygmea* and the lagenids play a less pronounced role. Dominances of *B. costata*, together with *Bolivina* spp., *B. subulata* and, occasionally, *Cancris* c.s. can be derived from this figure. *B. spathulata* and *S. advena* are also relatively frequent in this part of the column. *B. subulata* shows a drop in relative frequencies in both laminated and homogeneous marls.

The association of *B. spathulata, B. exilis, U. bononiensis* and, less frequent, *S. advena* entirely replaces the latter fauna in the uppermost sapropels. Percentages of benthos are extremely high (± 80%).

As in sections Finikia and Aghios Vlassios, the fauna in the first diatomite level (GR 2221) is dominated by epiphytes, the rest-group and *B. subexcava-*



	C. laevigata	epiphytes	*B. subexcavata*	*Cibicides* spp.	rest-group	*Gyroidina* spp. *Oridorsalis* spp.	lagenids	*Uvigerina* s.s.	*B. subulata*	*B. costata*	*Cancris* c.s.	*Bolivina* spp.	*S. advena*	*U. bononiensis*	*B. exilis*	*B. spathulata*	*U. cylindrica*	% benthonic foraminifera	bed-thickness
epiphytes	**+**																		
B. subexcavata	**+**	**+**																	
Cibicides spp.		+	**+**																
rest-group		**+**	**+**	**+**															
Gyroidina spp. *Oridorsalis* spp.					+														
lagenids				+	+	**+**													
Uvigerina s.s.						**+**	**+**												
B. subulata																			
B. costata			—				+	+	+										
Cancris c.s.										**+**									
Bolivina spp										**+**	+								
S. advena												+							
U. bononiensis									—				**+**						
B. exilis				—										+					
B. spathulata														**+**	**+**				
U. cylindrica																**+**			
% benthonic foraminifera	**—**	**—**	**—**	**—**	**—**								**+**			+			
bed-thickness						—			—										
sample rank-numbers	+	**+**	**+**			—	**—**	**—**	—	**—**	—			**+**	+	**+**	**+**		

Kalithea 1 + 2

laminated marls

+ — P < 0.01

\+ — P < 0.05

Fig. 34 Matrix of correlation coefficients of the data from the laminated sediments of section Kalithea 1 + 2 based on the DISTUR and BALANC procedures.

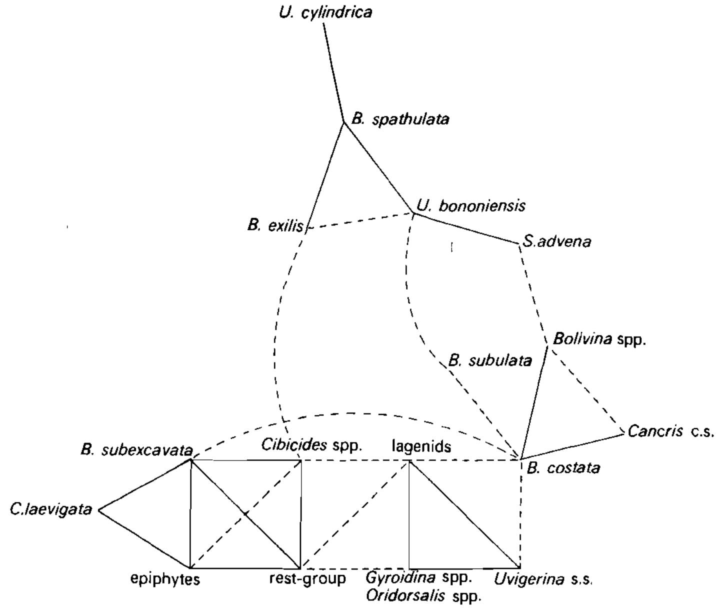


Fig. 35 Spider-web diagram for the samples from the laminated sediments of section Kalithea 1 + 2. Straight lines: positive correlations; curved lines: negative correlations. Solid lines: $P < 0.01$; dashed lines: $P < 0.05$.

ta. Here, *C. laevigata* (not figured) plays a subordinate role. The percentage of benthonic foraminifera decreases to about 20% in the lowermost diatomites.

Above the level of GR 2232, *B. spathulata, B. exilis, U. bononiensis* and *U. cylindrica* replace the more diversified fauna of the lowermost diatomites and along with this replacement the percentages of benthonic foraminifera increase again.

Summary of faunal patterns in laminated sediments

From the quantitative data of the sections so far dealt with, we showed the existence of faunal patterns which may be regarded as reflecting changes in the degree of stagnancy of the bottom waters.

The stratigraphically lowest sapropels yield faunas consisting of various species belonging to genera of the family Buliminidae, but also of other groups, such as the lagenids, species of *Cancris, Gyroidina,* etc. Such faunas were not found at all in our diatomites. Percentages of benthonic foraminifera are always higher than in the accompanying homogeneous marls (compare for instance figures 30 and 39) and sometimes display very high values. In the most basal sapropels, species of *Uvigerina* s.s. and lagenid foraminifera dominate the faunas, whereas higher up dominances of *Bulimina costata*, *Cancris* c.s. and species of *Bolivina* other than *B. spathulata* and *B. subexcavata* are found.

In the stratigraphically higher sapropels, an association of *Bolivina spathulata*, *Bulimina exilis* and *Uvigerina bononiensis* gradually replaces the former faunas. Sometimes these species are accompanied by *Uvigerina cylindrica gaudryinoides* or *Stilostomella advena*. In addition, the percentages of benthonics are always extremely high. Up to now this association has been mostly found in sapropels, but in the diatomites of section Aitania it occurs in high relative numbers as well (see below).

In the diatomites another fauna occurs in which epiphytes dominate, along with high proportions of a rest-group, *Bolivina subexcavata* and, less frequently, *Cassidulina laevigata*. Percentages of benthonic foraminifera are always extremely low. *B. spathulata* c.s. are often seen to be abruptly replaced by this epiphytes-dominated fauna. The reverse is also observed and is found to occur both abruptly and gradually.

Comparison with faunas from laminated sediments elsewhere and from recent low-oxygen environments

The most significant factors which affect the specific composition and abundance of species in benthonic foraminiferal faunas living in stagnant environments seem to be the lower amount of dissolved oxygen of the bottom waters and a relatively large nutrient availability (Van der Zwaan, 1982). Therefore, the observed changes in fauna-composition, due to increasing stagnancy conditions during the formation of our Pliocene sequence of laminites, are probably best explained by assuming an increasing impact of these factors. Such a theory finds support in the distribution patterns of many of the benthonic foraminifera in older and younger laminated sediments and in recent environments poor in oxygen or with ample food supply.

One of the dominant species in our lowermost sapropels of sections Finikia, Aghios Vlassios and Kalithea 1 is *Uvigerina pygmea* (*U. peregrina* is considered as a synonym). In the laminated deposits of the Sicilian section Punta Piccola, of Pliocene age, the species reaches higher relative frequencies (with a maximum of 16%) than it does in the accompanying homogeneous marls (Brolsma, 1978). In the present equatorial Pacific, Schnitker (1979) found the species together with *U. canariensis*, dominating assemblages in waters with moderately low oxygen levels (2.3–2.8 ml/l). Ingle et al. (1980), in a study on benthonic foraminifera in the southern Peru – Chile Trench, found up to 17% of *U. peregrina* in waters poor in dissolved oxygen between the core of the shallow O_2-minimum layer and the deeper oxygen-rich Antarctic Intermediate Water. It was also reported from the Deep Water (19%), which is oxygen-poor too. However, the species is also common in better aerated waters.

An indication for a preference of environments with ample food is provided by Seiglie (1968). He found *U. peregrina* to be correlated with sediments rich in organic matter.

A group of foraminifera which is frequently encountered in our lowermost sapropels is that of the lagenids. Lagenid foraminifera found in connection with laminated sediments are not known to us from the literature. In our samples, they seem to be able to cope with environments of lowered oxygen.

Gyroidina and *Oridorsalis* species are not reputed for being abundant in laminites. Cita and Podenzani (1979) established high relative frequencies of *"Gyroidina minima"* and *Gyroidina* spp. in the uppermost sapropel S1, below the floor of the Levantine Basin. Above the sapropel still higher percentages were recorded. Van der Zwaan (1980) provided similar data from the upper sapropel and overlying sediments from the Adriatic Sea (*G. neosoldanii* and *G. altiformis*). These species, supplemented by *G. laevigata* and an undescribed species of *Gyroidina*, dominate the benthonic foraminiferal assemblage in the present deep eastern Mediterranean Sea (Cita and Zocchi, 1978). Bottom waters here display lowest O_2-values of all larger Mediterranean basins (Miller et al., 1970), but the trophic level is also low.

Bulimina subulata shows no positive correlation with our laminated sediments, but it may be found in fair percentages in these deposits. Data from Van der Zwaan (1982) point to negative correlations of the species with lamination in Cretan Miocene sediments. Abundant spinose buliminids in Pliocene laminites are seen on Sicily (Brolsma, 1978). In sediments from the Levantine Basin, *B. aculeata* was found in very high numbers (Parker, 1958) in levels which display relatively high carbon contents, as indicated by data in Olausson (1960).

The group of *Cancris* c.s. may have distinct positive correlations with laminated sediments. *Cancris auricula* and *Valvulineria complanata* were met with in fair numbers in the laminated interval of section Potamidha, western Crete, of Miocene age (Wonders and Van der Zwaan, 1979). In recent low-oxygen environments these species do not form a major part of the fauna. According to Zalesny (1959) almost 10% of the fauna in Santa Monica Bay, California, consisted of a species of *Valvulineria* (*V. araucana*) in places at which water depth exceeded 550 metres. The deeper parts of the waters inhabited by the species are within the O_2-minimum zone (Emery, 1960). Off the mouth of the Orinoco River, *Cancris auricula* reaches its highest relative abundances, in a zone occupied by pelitic sediments (Drooger and Kaasschieter, 1958; named *C. sagra*) which zone is furthermore inhabited by *Uvigerina peregrina*. This occurrence may point to the species' preference for environments with high food supply.

Bulimina costata has strong positive correlations with our laminated sediments. Of the major association dominating the fauna in the lower sapropels, this species is the last one to show peak values before this association is replaced by the group of *Bolivina spathulata* c.s. A Miocene recording of high relative numbers is from the laminated interval of section Potamidha (Wonders and Van der Zwaan, 1979; reported as *B. striata*). On the basis of computer analyses, Van der Zwaan (1982) regarded *B. costata* to be intermediate in habitat between a group of many species indicating "normal" marine conditions and a low-diversity association, consisting of *Uvigerina cylindrica gaudryinoides*, *Bolivina spathulata* and *Bulimina elongata*; the latter association is frequent in or close to laminated sediments. He furthermore reported that the species proliferated in Miocene laminites of section Scicli, eastern Sicily.

High percentages of *B. costata* (up to 52%) were observed in samples from sapropels of Early Pliocene age on the south-coast of the island of Milos, in the Cyclades arc (author's unpublished data). The species is also seen to occur in relatively high numbers in some of the sapropels of section Punta Piccola (Brolsma, 1978; labelled *B. inflata*). M. M. Drooger (1982), when reconsidering the data from the Plio-Pleistocene boundary stratotype section at Le Castella, provided by Bremer et al. (1980), found *B. costata* to have a positive correlation with their *Bolivina attica* (= *B. spathulata*) and *Bulimina exilis*, which are abundant in laminated layers.

In modern environments, costate buliminids are not met with in high numbers, but from Ingle et al. (1980) we learn that *B. costata* (reported as *B. striata mexicana*) reaches its highest percentages (10%) in the oxygen-poor Deep Water off Chile.

Higher up in our sections species are found which are strongly correlated with lamination and which are well-known from laminated beds elsewhere in the Mediterranean region.

Uvigerina cylindrica is reputed for its quality of showing large peaks. Wonders and Van der Zwaan (1979) and Van der Zwaan (1982) confirm high relative frequencies for the Cretan Miocene. The latter author furthermore reports the species to have proliferated in Miocene laminites of the Sicilian section Scicli.

Pliocene recordings are from section Aghios Thomas on the island of Aegina, and from Milos (both unpublished).

Uvigerina bononiensis does not show up in high numbers in the Miocene. An exception is mentioned for section Aghios Ioannis, in the southern part of the Iraklion province, where it is accompanied by species indicative of low-oxygen environments (Van der Zwaan, ibid.). Pliocene Mediterranean findings of peak occurrences in laminites are, however, plentiful. On Sicily (Brolsma, 1978), but especially on Aegina and Milos the species is seen to reach extremely high values. No data on the recent distribution of the latter two *Uvigerina* species are available to us.

A species unknown from the Miocene is *Bulimina exilis*. Just like *U. bononiensis*, this species is also known from the Sicilian Pliocene (Brolsma, ibid.) and from Aegina and Milos to be able to dominate associations from sapropels and diatomites. Occurrences of the species in oxygen-minimum waters off the west-coast of the American continents are reported by various authors. Zalesny (1959) found that *B. exilis* (labelled *Buliminella tenuata*) made up 15% of the total assemblage – living and dead foraminifera – in his deepest sample from the slope of the Santa Monica Basin, California, which was taken from the zone of low oxygen. In living assemblages the species reaches values up to 60%. Harman (1964) reported the species (as *Buliminella exilis tenuata*) from the O_2-depleted floor of the nearby Santa Barbara Basin (5%). It occurred, however, in equal numbers on the better aerated slopes. Bandy (1961), in a study on foraminifera, radiolaria and diatoms in the Gulf of California, included *B. exilis tenuata* (maximum 8%) in his upper bathyal fauna, which inhabits the oxygen minimum zone. The species' behaviour off Chile is similar to that in the Santa Barbara Basin: low numbers in the (shallow) oxygen minimum as well as in the underlying oxygenated Antarctic Intermediate Water (Ingle et al., 1980; as *Buliminella tenuata)*.

High frequencies of *Bolivina spathulata* from the Upper Miocene – Holocene, reported in most of the previously mentioned studies on Mediterranean sections, coincide with or are close to laminated levels. Samples from the outer shelf off Chile, taken within the shallow O_2-minimum zone, revealed very high percentages (up to 68%) of a *Bolivina* species, morphologically similar to *B. spathulata* (Ingle et al., op. cit.; their *B. rankini*). Other species, *B. spathulata* alike, are furthermore reported in great numbers from the oxygen-poor continental slope off Central America (Smith, 1963) and from the Californian basins (Harman, 1964). Influence of the amount of food supply may be deduced from the studies of Frerichs (1970) on benthonic foraminifera in the Andaman Sea. Here, *B. spathulata* is frequent on the delta-front of the Irrawaddy River, where large amounts of terrigenous materials are being deposited.

There are no data on the recent distribution of *Stilostomella advena*. It is not known why the species remains low-frequent in the sapropels of sections Finikia and Aghios Vlassios.

Modern distribution patterns of the species met with in the laminated sediments confirm their ability to withstand lowered amounts of dissolved oxygen and/or their preference for high nutritive levels. The literature data indicate that waters with slightly lowered O_2-levels are inhabited by relatively diverse faunas, in which species of *Gyroidina*, *Valvulineria*, *Uvigerina* and costate buliminids can be numerous, whereas in the most oxygen-poor areas low-diversity faunas prevail, consisting almost entirely of *Bolivina* species. Thus, the specific compositions of benthonic faunas in moderately to extremely oxygen-poor environments seem to confirm the stagnation gradient in sections Aghios Vlassios and Kalithea 1 + 2, as concluded from our computer analyses.

Along with a decrease in oxygen content of the bottom waters, the amount of organic matter may in turn have increased, due to a lesser degree of oxidation and possibly to enhanced production in the surface waters (as, for instance, indicated by the greater abundance of siliceous microfossil-remains in the sapropels of the upper parts of sections Finikia and Aghios Vlassios).

The associations in the laminated sediments, discussed so far, were seen to show higher percentages of benthonic foraminifera than do the faunas in the homogeneous intervals. This phenomenon is also observed in the laminites of the Monte Narbone Formation on Sicily (Brolsma, 1978) and on the islands of Aegina and Milos. Such high percentages of benthonic foraminifera can be explained by assuming a strongly increased production of benthonic foraminifera, caused by relatively large quantities of available food. Increased food supply may have resulted from enlarged production in surface waters, as can be inferred from the abundance of diatom remains in some of the laminated strata. Then, if oxygen content of the water is thought responsible for the composition, nutrient supply must have controlled the abundance of the benthonic foraminifera in the stagnant environments.

In sections Aghios Vlassios and Kalithea 1 + 2, *Bolivina spathulata* is positively correlated with the percentage of benthos and may be regarded as a very productive species under low oxygen/high food conditions. *Bulimina exilis* (positive correlation in section Aghios Vlassios) and *Stilostomella advena* (positive correlation in section Kalithea 1 + 2) may also be regarded as such. In comparable recent environments, large standing stocks of benthonic foraminifera, including large numbers of *Bolivina* species, are known (Smith, 1963; Phleger and Soutar, 1973). Abundance of food, the absence of "predators" and low competition were thought to be responsible. In addition, the quality of the food-offer may also have changed. For some foraminifera, the preference for special types of food was shown in laboratory experiments (Lee, 1974).

It must be concluded that during sedimentation of most of the diatomites in sections Finikia, Aghios Vlassios, Fortetsa and Kalithea 2, benthonic life had vanished almost completely. In this respect, the faunas in these levels represent the extreme end of the stagnation gradient. High relative numbers of epiphytic forms, together with the very low percentages of benthonic foraminifera may plead for the allochthony of the former group. Meulenkamp et al. (1978) arrived at such a conclusion when interpreting similar distribution patterns in their section Prassas. Van der Zwaan (1982) considered this a possible explanation for comparable associations in Miocene laminites on Crete. The transporting mechanism for these foraminifera may have been rafting of plant-material. In this explanation, the major part of the accompanying rest-group, which consists of many species unfamiliar with low-oxygen conditions, may also be regarded as having been displaced. In most diatomites the faunas in samples right from the base indicate a rapid extermination of benthonic life, but in others a benthonic fauna proliferated initially, as in section Prassas (fig. 27).

The deterioration of benthonic life may have been due to a still further reduced quantity of dissolved oxygen near the bottom, when production in surface waters was at a maximum, as evidenced by the presence of abundant diatoms, radiolaria and other biogenic siliceous remains. The opal content is sometimes so large that the foraminiferal fauna is strongly diluted, as concluded in II.3 and confirmed by visual examination of thin sections.

The hostile environment may also have been the result of toxic conditions that arose under reducing circumstances. The generation of hydrogen sulphide, known to be formed by anaerobic bacteria in oxygen-depleted basins as for instance the Santa Barbara Basin (Emery, 1960) and the Black Sea (Emery and Hunt, 1974), cannot be substantiated for our diatomites because iron-sulphides are virtually lacking.

The returning to sapropelic sediments in section Fortetsa is not accompanied by a major change in the composition of the faunal associations. Only the somewhat higher percentages of *Bolivina spathulata* may point to slightly less adverse bottom conditions.

The extreme association of ***Bolivina spathulata*** c.s.

The high and fluctuating relative frequencies of *Bolivina spathulata, Buli-*

mina exilis, *Uvigerina bononiensis*, and in several samples of *Uvigerina cylindrica* and *Stilostomella advena*, together obscure the frequency behaviour of all other species present in the samples. They induce severe "closed sum effects" when the DISTUR program is used and these cause negative correlations between most of the above-mentioned species and other faunal categories. Such correlations largely disappear with the use of the BALANC program, which is based entirely on the open covariance concept (M. M. Drooger, 1982). In order to have an idea of the composition of the additional fauna and the relative frequencies of its species, we performed 200-counts on eight samples of section Kalithea 2, displaying extreme values for the five species mentioned above (from 84.5% of the benthonic fauna in GR 2204 to 98.5% in GR 2218). These species were not considered in the countings presented here. The samples are both from sapropels and white laminated intervals.

GR-samples	2202	2204	2210	2212	2214	2218	2250	2254
Bolivina spp.	4	7.5	5	5.5	3.5	2	7.5	13.5
Cancris c.s.	4.5	3	12.5	11	3.5	6.5	5	2
B. costata	4.5	3	14	6.5	4.5	2	0.5	3
Uvigerina s.s.	4	4.5	5	4.5	3	2.5	4.5	5.5
Lagenids	7	6.5	5.5	5.5	2.5	1.5	5.5	4.5
Gyr./Oridorsalis	2.5	4	2.5	3	2.5	2	2	4
B. subulata	0.5	0	0	0	1.5	0	2	0.5
Rest-group	24.5	27	24	21.5	26.5	53.5	24	25.5
Cibicides spp.	7	6.5	3.5	4.5	10	3	4.5	4.5
B. subexcavata	18.5	17.5	5.5	11	20	6	18.5	13.5
Epiphytes	20.5	16.5	21	25.5	19	20.5	24	21
C. laevigata	1	3	1.5	1	2.5	0.5	1.5	2
Indeterminable	1.5	1	0	0.5	1	0	0.5	0.5
Total	100	100	100	100	100	100	100	100
Nr. of cat. in rest-group	23	20	19	20	22	20	26	21
% *B. spathulata* c.s. in routine-counts	88	84.5	95	89.5	93	98.5	93.5	85

Table V: Percentages of faunal categories in 200-counts, excluding *B. spathulata, B. exilis, U. bononiensis, U. cylindrica* and *S. advena.*

One would expect the species which were the last to be replaced by the association of *B. spathulata* c.s., such as *Cancris auricula*, *Bulimina costata*, species of *Bolivina* and *Uvigerina* and lagenid foraminifera, to form the bulk of the remaining fauna. This seems to be contradicted by our results given in table V, in which the same groupings have been formed as those used in the computer-runs. Some of these taxa may incidentally reach values of over 10 per cent, however. Generally, there are no large fluctuations in the scores.

The larger part of the fauna is made up of epiphytes with frequencies around 20%, the rest-group and, with more variable frequency, *Bolivina subexcavata.* As usual, the rest-group in each sample is composed of many taxa (at least 19), which are more or less equally distributed. The only exception is sample GR 2218, in which one member of the rest-group, *Fursenkoina* sp., accounts for 31% of its total. This species is rarely met with in the routine-counts, but may be common in the 63–125 μ fraction in samples from laminated marls (see III.2).

Thus, if we exclude the five dominant species, we are faced with a rather diversified fauna, in which the most common species are found also in the relatively shallow water associations known from the homogeneous marls. Mixing of the two sediment types by burrowing organisms or during the sampling procedure may provide an explanation. However, the composition of the fauna is not quite the same as that in the homogeneous sediments in this part of the section; for instance, the percentage of epiphytes is higher (compare fig. 42). It is more likely that we are close to the extreme end of the stagnation gradient, where the association of *B. spathulata* c.s. is still capable of coping with the extreme oxygen-poor conditions, but where the less tolerant species have practically disappeared and the bulk of additional species is allochthonous. The mode of transportation may have been through rafting of plant-material (for most epiphytes) or by turbidity currents, which occurred repeatedly during sapropel formation.

Section Prassas

The fauna composition in the sapropels of section Prassas (not figured) strongly resembles that in the sapropels of section Kalithea 1; there are dominances of *Uvigerina pygmea, Bulimina costata* and, sometimes, *Stilostomella advena.* Again these dominances coincide with relatively high percentages of benthonic foraminifera. We can conclude that stagnation during deposition of these sapropels was not very intense.

The diatomites above the hiatus (see II.2 and II.4) yield a fauna characterized by high relative numbers of epiphytes, the rest-group, *Cassidulina laevigata* and planktonic foraminifera. In only a few instances do *Bolivina spathulata, Bulimina exilis* and *Uvigerina bononiensis* dominate, coinciding with low relative numbers of planktonic foraminifera (see also III.2). Here, we seem to be dealing with fluctuations to and fro across the limit of autochthonous life.

Section Aitania

A different picture arises when the data from the laminated sediments of

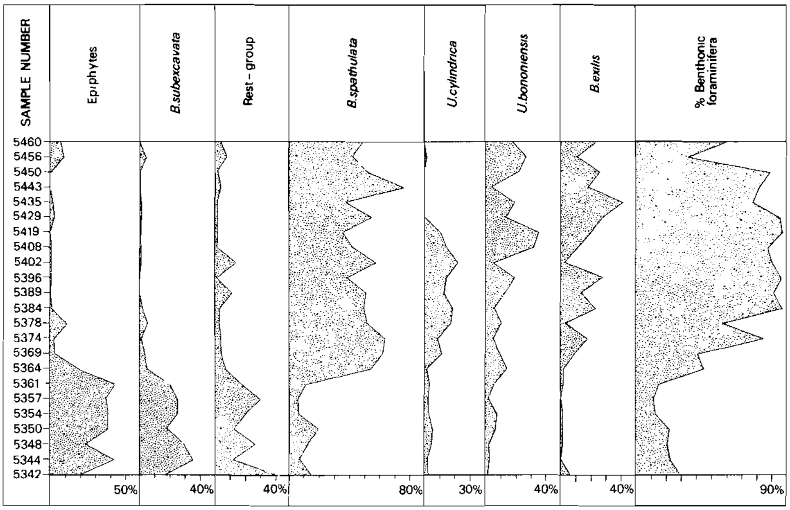


Fig. 36 Relative frequencies of the benthonic foraminifera in the laminated sediments of section Aitania.

section Aitania are considered (fig. 36). The sapropels in the lower part contain faunas known only from diatomites in all sections dealt with so far. They are dominated by the epiphytes, *Bolivina subexcavata* and the rest-group. In samples from these sapropels, the numbers of planktonic foraminifera are overwhelming. We must conclude that highly stagnant conditions which prevented benthonic life not only occurred during diatomite formation, but also existed during sapropel deposition.

An abrupt change is observed at sample level CP 5364. From here on, *Bolivina spathulata, Uvigerina cylindrica gaudryinoides, U. bononiensis* and *Bulimina exilis* make up almost the entire fauna in the remaining sapropels and diatomites, whereas the percentage of benthonic foraminifera is very high. Evidently, oxygen depletion was not complete during deposition of these levels.

In this section the replacement of sapropels by diatomites is not clearly reflected in the benthonic faunas.

The drop in the relative frequencies of *U. cylindrica gaudryinoides* is remarkable; the subspecies is absent above the first diatomite level. This frequency-drop correlates well with the extinction level in sections Finikia and Aghios Vlassios (compare figs. 36, 30 and 20).

Section Mirtos

The two associations recognized in section Aitania are also found in the sapropels of section Mirtos in the Lasithi province (fig. 37). Again, each association dominates in a number of successive sapropels; replacement of one association by the other is abrupt. Once more, bottom waters were severely lacking in oxygen during sapropel formation.

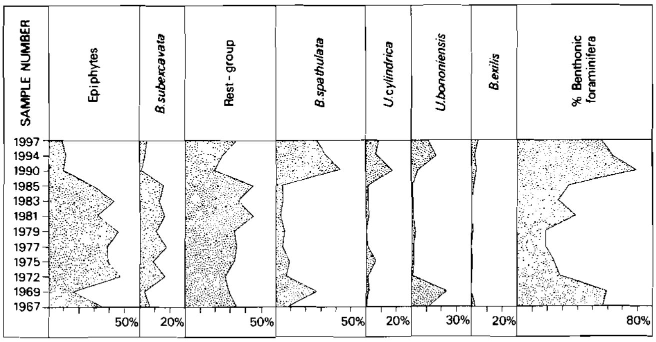


Fig. 37 Relative frequencies of the benthonic foraminifera in the laminated sediments of section Mirtos.

Stagnation in the different basins

The stagnation gradient was concluded from similar faunal changes in sections Aghios Vlassios and Kalithea 1 + 2. The extreme end of this gradient, demonstrated by the absence of benthonic life, was found to be manifest in the diatomites of these sections. The fact that the diatomites in section Kalithea 2 are older than those in sections Finikia and Aghios Vlassios implies that periods of complete oxygen depletion in the Kalithea Basin corresponded to periods of less intense stagnancy in the Finikia – Aghios Vlassios Basin. This is visualized in fig. 38, in which the relative frequencies of five major groups in the total foraminiferal fauna are depicted for each laminated bed. The sections are positioned in accordance with the scheme in fig. 20.

The figure furthermore shows that the sapropels with faunas indicative of total oxygen depletion (dominated by planktonics and epiphytes) in sections Aitania and Mirtos were formed in the same time-interval in which similarly high stagnant conditions and diatomite formation prevailed in the Kalithea Basin. Later on, the degree of stagnation in all three of these basins was slightly less, but – especially in the Kalithea and Aitania Basins – still greater than in the Finikia – Aghios Vlassios Basin, if one considers the difference in fauna-content.

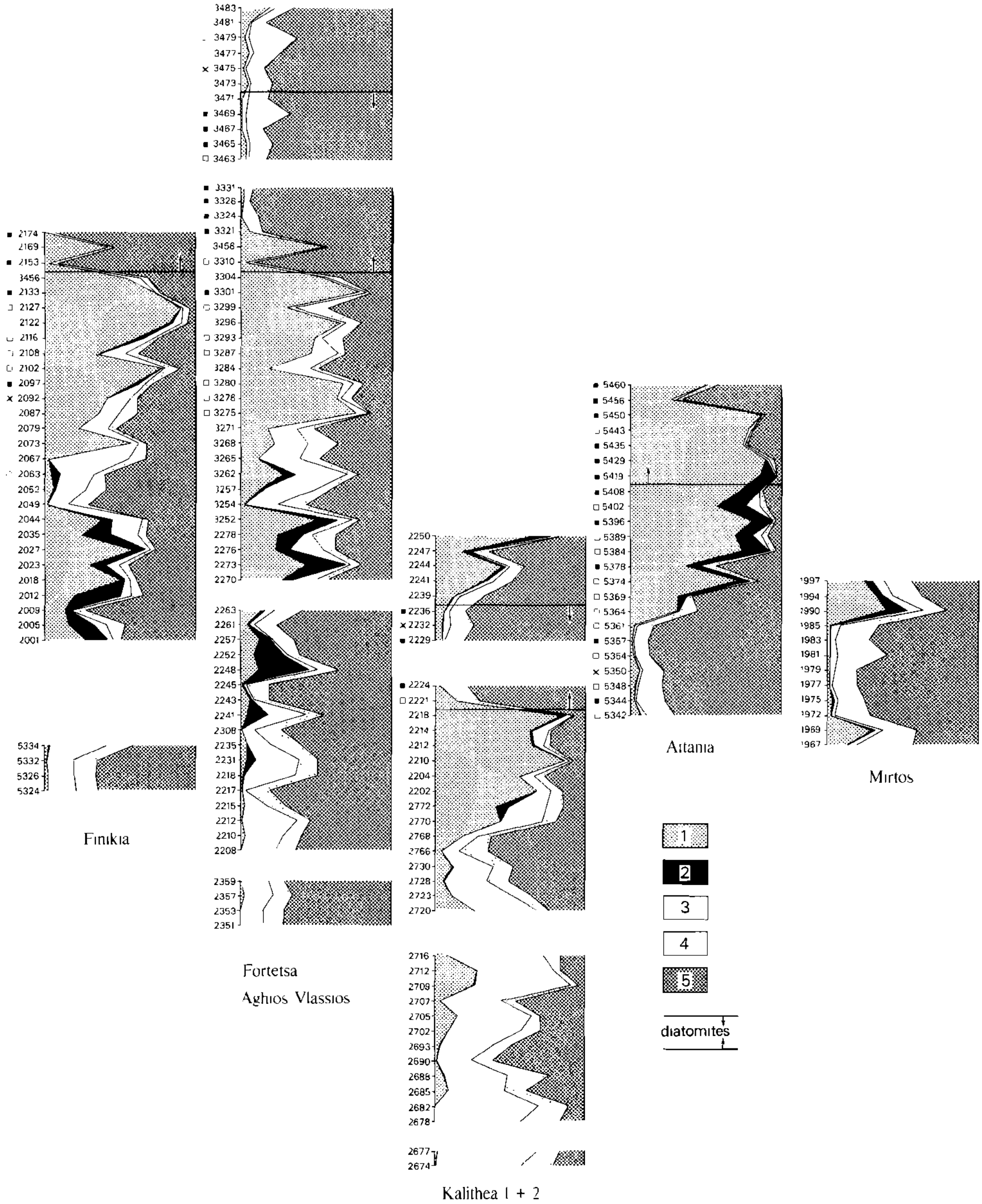


Fig. 38 Cumulative frequencies of five major foraminiferal groups in the laminated sediments of sections Finikia, Aghios Vlassios, Fortetsa, Kalithea 1 + 2, Aitania and Mirtos. 1. *B. spathulata, B. exilis, U. bononiensis;* 2. *U. cylindrica;* 3. *S. advena, Cancris* c.s., *B. costata, Bolivina* spp., *Gyroidina* spp., *Oridorsalis* spp., *Uvigerina* s.s., lagenids, *B. subulata;* 4. epiphytes, *B. subexcavata, C. laevigata, Cibicides* spp., agglutinants, rest-group; 5. planktonic foraminifera.

■ Well-preserved diatoms; □ poorly preserved diatoms; X diatom remains incidentally present.

In the Finikia – Aghios Vlassios Basin, the trend towards lower O_2-content is abruptly interrupted at the level of CP 2049/GR 3254; during this and a number of subsequent periods of sapropel formation bottom waters were less poor in oxygen than during earlier or later periods. This phenomenon is unique for the Finikia – Aghios Vlassios Basin; in the time-equivalent interval in the Aitania Basin waters remained very poor in oxygen, as demonstrated by the high percentages of *Bolivina spathulata* c.s.

In fig. 38 we indicated the presence of diatom-remains in the samples. The diatoms were searched for in smear-slides, which we prepared for all samples from the laminated sediments. In this procedure, two subjective preservation categories were distinguished, based on the general presence or absence of the apical ends of pennate forms. This is obviously no measure of their abundance; poorly preserved diatoms can be observed in high relative numbers in section Aitania. However, in the case of good preservation, diatoms are plentiful.

It is evident that in sections Finikia, Aghios Vlassios and Aitania diatoms do not occur exclusively in the sediments which were classified in the field as diatomites. It is more remarkable, however, that in many of the levels that indicate strong stagnation diatom-remains are found. The probable role of diatom production for the reduction of the oxygen-content of bottom waters is nicely demonstrated by the level of CP 2169 (Finikia)/GR 3458 (Aghios Vlassios), in which no diatom-remains were found. Here, stagnation was slightly less, indicated by large relative numbers of *B. spathulata* c.s. In section Kalithea 2 excess organic matter from diatoms may have caused near-exhaustion of oxygen in the depositional environments of the laminites of GR 2221 – GR 2236. The uppermost white laminated levels (above GR 2236) do not yield diatoms; benthonic foraminifera were again allowed to inhabit the basin-floor.

Severe stagnant conditions also occurred in the absence of diatoms, as at Mirtos. Here, the only siliceous organic remains found are sponge needles (GR 1967 and GR 1969). Maybe diatoms were not preserved at this locality. The same may apply to the topmost sapropels in section Kalithea 2.

The faunal evidence in the last laminites of section Fortetsa, which were formed in a very shallow part of the basin, indicates a severe lack of oxygen just prior to a period of well aerated waters (fig. 38). From the data provided by Meulenkamp et al. (1978) the same can be concluded for such laminites in the Prassas Basin. Here too, the overlying sediments were deposited in even shallower water and show no evidence of O_2-minimum conditions.

Sections Finikia and Aghios Vlassios

An entirely different picture emerges from the quantitative data of the faunas in the homogeneous sediments. In fig. 39, sections Finikia and Aghios Vlassios are placed parallel to each other in the same way as was done for the laminated sediments.

From fig. 39 it is clear that in the samples from the homogeneous sediments there are no strong dominances of one or a few species, as was seen in the laminated sediments. There are neither large fluctuations in the percentages of the faunal categories nor dramatic changes in the faunal composition from bottom to top. Moreover, it can be observed that the faunas in both sections display essentially the same composition. Just as in the case of the laminated intervals, the higher sedimentation rates during deposition of the homogeneous beds at Finikia did not seriously influence the composition of the benthonic fauna. Another observation is that the first appearance of diatomites – in section Finikia between samples CP 2149 and CP 2166 and in section Aghios Vlassios between GR 3308 and GR 3316 – is not associated with abrupt faunal changes in the homogeneous strata. All through the sections there is a consistent faunal composition with frequent representatives of the epiphytes, *Bolivina subexcavata*, *Cibicides* spp. and the rest-group.

The results of the computer analyses of the data from section Aghios Vlassios are given in figs. 40 and 41. For these computer analyses we used the same categories as those entered for the laminites. Some of these taxa are very rare, however, especially those of the group indicating little-to-weak stagnation (*Gyroidina* group, *Bolivina* spp., *Cancris* c.s., *B. costata*). In figure 39 they are included in the rest-group. In contrast, the group of *Nonion* s.l., which appears in fig. 39, is not included in the computer analyses. The group consists of species belonging to *Nonion*, *Nonionella*, *Nonionellina*, *Astrononion* and *Pullenia*.

We found strong positive trends for *Cibicides* spp., *Cassidulina laevigata* and the percentage of benthonic foraminifera (fig. 40). Positive trends at the $P < 0.05$ level were found for *Bolivina spathulata*, *Bulimina exilis* and *Uvigerina bononiensis*. Negative trends exist for *Bolivina subexcavata*, the lagenids (both $P < 0.01$) and *Bulimina subulata* ($P < 0.05$).

The computer analyses revealed the existence of five groupings. The first one is composed of the mutually correlated *B. spathulata*, *B. exilis* and *U. bononiensis* ($P < 0.01$). All three species are weakly correlated with the percentage of benthonic foraminifera. *B. spathulata* has a link ($P < 0.05$) with

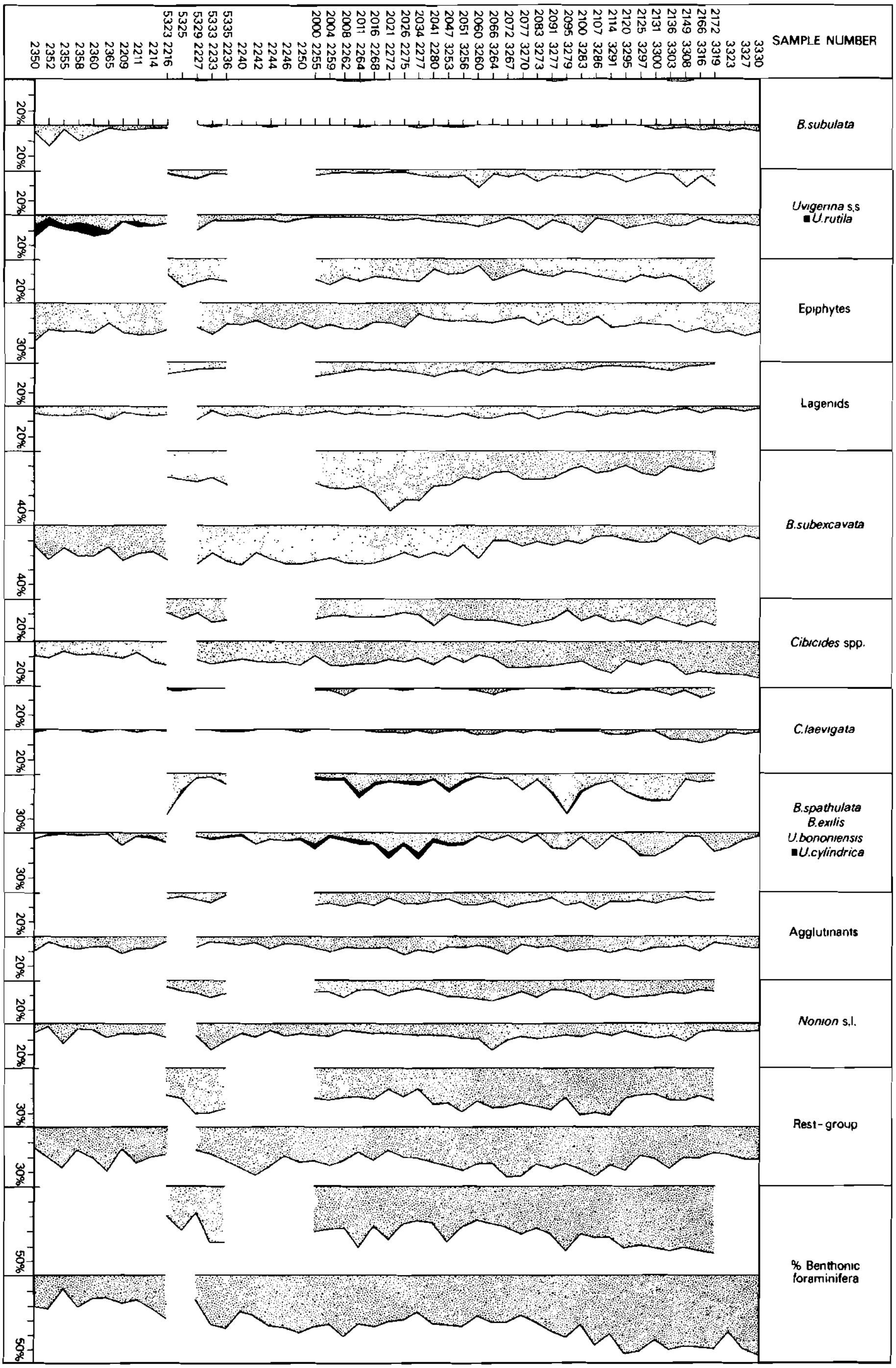
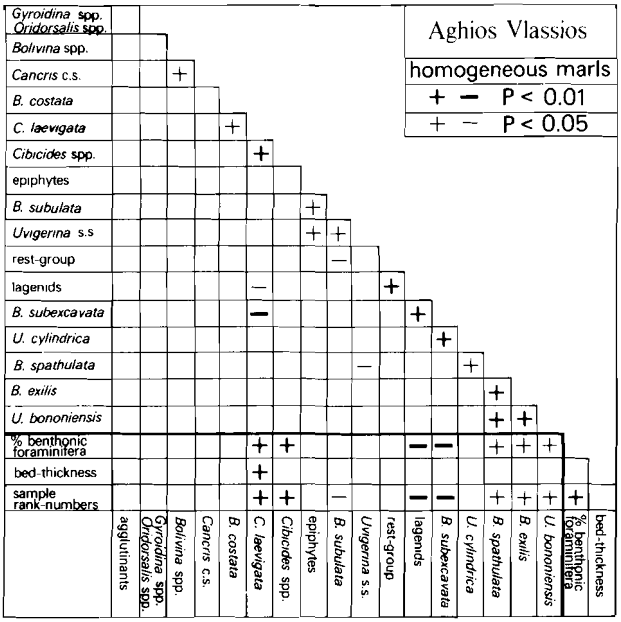


Fig. 39 Relative frequencies of the benthonic foraminifera in the homogeneous sediments of sections Finikia (left-hand column of each category) and Aghios Vlassios (right-hand column).



Aghios Vlassios

homogeneous marls

+ − P < 0.01

\+ − P < 0.05

	agglutinants	*Gyroidina* spp. *Oridorsalis* spp.	*Bolivina* spp.	*Cancris* c.s.	*B. costata*	*C. laevigata*	*Cibicides* spp.	epiphytes	*B. subulata*	*Uvigerina* s.s.	rest-group	lagenids	*B. subexcavata*	*U. cylindrica*	*B. spathulata*	*B. exilis*	*U. bononiensis*	% benthonic foraminifera	bed-thickness
Gyroidina spp. *Oridorsalis* spp.																			
Bolivina spp.																			
Cancris c.s.			+																
B. costata																			
C. laevigata					+														
Cibicides spp.						**+**													
epiphytes																			
B. subulata								+											
Uvigerina s.s								+	+										
rest-group									−										
lagenids						−					**+**								
B. subexcavata						**−**						**+**							
U. cylindrica													**+**						
B. spathulata										−				+					
B. exilis															**+**				
U. bononiensis															**+**	**+**			
% benthonic foraminifera						**+**	**+**					**−**	**−**		+	+	+		
bed-thickness						**+**													
sample rank-numbers						**+**	**+**		−			**−**	**−**		+	+	+	**+**	

Fig. 40 Matrix of correlation coefficients of the data from the homogeneous sediments of section Aghios Vlassios based on the DISTUR and BALANC procedures.

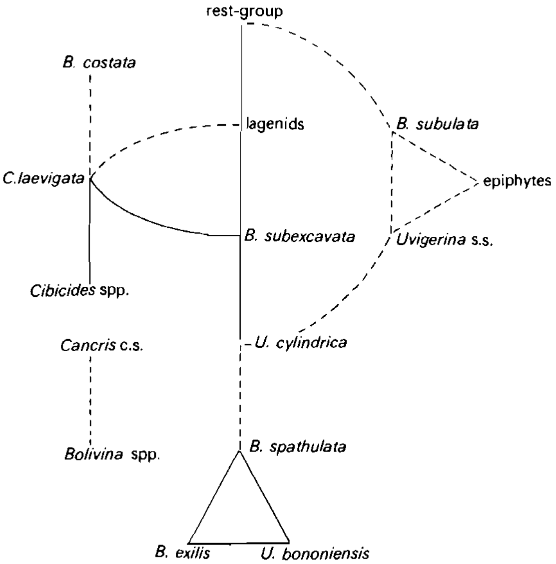


Fig. 41 Spider-web diagram for the samples from the homogeneous sediments of section Aghios Vlassios. Straight lines: positive correlations; curved lines: negative correlations. Solid lines: $P < 0.01$; dashed lines: $P < 0.05$.

U. cylindrica. These correlations are logical from the trends as well as from the picture obtained from the laminites.

The second association consists of *Uvigerina cylindrica, B. subexcavata,* the lagenids and the rest-group. The successive members of this association are linked by strong positive correlations ($P < 0.01$). Two members, *B. subexcavata* and the lagenids, exhibit strong negative correlations with the percentage of benthonic foraminifera. The correlations of the latter two categories are again logical from the trends. There may be a similar reason for the correlation of *U. cylindrica* with *B. subexcavata.* This correlation is rather meaningless, however, because the subspecies *gaudryinoides* is extinct above the level of GR 3262. The remaining subspecies enters the 200-counts only incidentally.

Uvigerina s.s., *Bulimina subulata* and the epiphytes form the third association. All are weakly correlated with each other. *Uvigerina* s.s. and *B. subulata* are negatively correlated with *U. cylindrica* and the rest-group, respectively ($P < 0.05$). According to the visual impression in fig. 39, the members of this association show a kind of bimodal distribution in the stratigraphic column of section Aghios Vlassios, being less frequent in the middle part.

The fourth association is formed by *Cibicides* spp. and *Cassidulina laevigata,* which have their positive trends in common. Loosely attached to the latter is *Bulimina costata. Cibicides* spp. and *C. laevigata* are both strongly correlated with the percentage benthos. Negative correlations are found between *C. laevigata* and *B. subexcavata* and the lagenids, members of the second association ($P < 0.01$ and $P < 0.05$, respectively).

Finally, *Cancris* c.s. are seen to be weakly correlated with species of *Bolivina,* other than *B. spathulata* and *B. subexcavata.*

No significant correlations were found for the combination of *Gyroidina* spp. plus *Oridorsalis* spp. with the other categories. The same is true for the agglutinants.

The most remarkable fact that emerges from these analyses is that the epiphytes and *B. subexcavata* appear in different groups.

The members of the association of *B. subexcavata* and the group of lagenid foraminifera are more frequent in the lower and middle part of the Aghios Vlassios section. From the level of CP 2272 onwards, *B. subexcavata* can be seen to decrease in relative numbers. The same can be noticed from the correlative level of CP 2021 onwards in section Finikia.

The association of *Cibicides* spp., *C. laevigata* and *B. costata* (not figured separately) is most frequent in the upper part of the column.

In fig. 39, the cumulative frequencies of *B. spathulata, B. exilis* and *U. bo-*

noniensis are shown. In the upper part of section Aghios Vlassios, this association is somewhat more frequent than in its lower part. In III.4, we concluded that the three species indicate extremely stagnant conditions; hence we might assume that the upward increase of adverse conditions affected the environments of both laminated and homogeneous strata. However, in this context it is peculiar that the group of taxa indicating beginning stagnancy is so infrequent. Therefore, it is quite understandable that the fair percentages of this *B. spathulata* association were caused by a contribution of material from the underlying laminites, either due to burrowing activity or to close to syn-sedimentary reworking (see III.3). The different state of preservation we sometimes observed (gypsum fill or brown staining by oxidation products of pyrite) may give weight to the latter explanations.

The agglutinants and representatives of the group of *Nonion* s.l. are low-frequent throughout the sections, hardly ever exceeding 10% of the benthonic fauna.

Lastly, the percentage of benthonic foraminifera is seen to be highest in the upper part of both sections. The frequency-increase was confirmed by the computer analyses.

Sections Kalithea 1 and Kalithea 2

When considering the quantitative data from the homogeneous marls of sections Kalithea 1 and Kalithea 2, the faunal patterns show some general characteristics already observed in sections Finikia and Aghios Vlassios, such as low frequencies of individual species and no large fluctuations of most of the faunal categories (fig. 42). Again no marked change can be deduced around the level at which diatomites start to occur (between GR 2220 and GR 2223).

The computer analyses revealed positive trends for the following species (fig. 43): *Bolivina spathulata, Uvigerina bononiensis, U. cylindrica, Cassidulina laevigata* (all $P < 0.01$) and *Bulimina exilis* ($P < 0.05$). Furthermore, a positive trend exists for the percentage of benthonic foraminifera. Negative trends were found for the epiphytes, *Bulimina subulata, B. costata* (all $P < 0.01$) and *Uvigerina* s.s. ($P < 0.05$).

The associations differ somewhat from those in section Aghios Vlassios (figs. 43 and 44). The association of *B. spathulata, B. exilis* and *U. bononiensis* is enlarged here with *Stilostomella advena* and the group of *Cancris* c.s. *U. cylindrica* is linked to this tightly correlated group of taxa through strong positive correlations with *U. bononiensis* and *B. spathulata* ($P < 0.01$). Statistical affinity to this association is shown by *C. laevigata*, being correlated with *U. cylindrica* and *B. spathulata* ($P < 0.05$). All taxa are correlated with the percentage of benthonic foraminifera at the $P < 0.01$ level, except *S. advena* and *Cancris* c.s. ($P < 0.05$). Apart from these two categories they all exhibit positive trends, which may account for part of the correlations.

Another association is formed by *Bolivina subexcavata* and *Cibicides* spp. A weak correlation of the latter group of species with *C. laevigata* exists at the $P < 0.05$ level.

A third association consists of *Uvigerina* s.s., *B. costata, B. subulata* and the epiphytes. In this association, *Uvigerina* s.s. and the epiphytes are not correlated with each other. Some members of this association show negative correlations with species of the first association. All members of the third association are negatively correlated with the percentage of benthonics. All these correlations are logical in view of the trends discussed above.

No significant correlations with other faunal categories were found for the

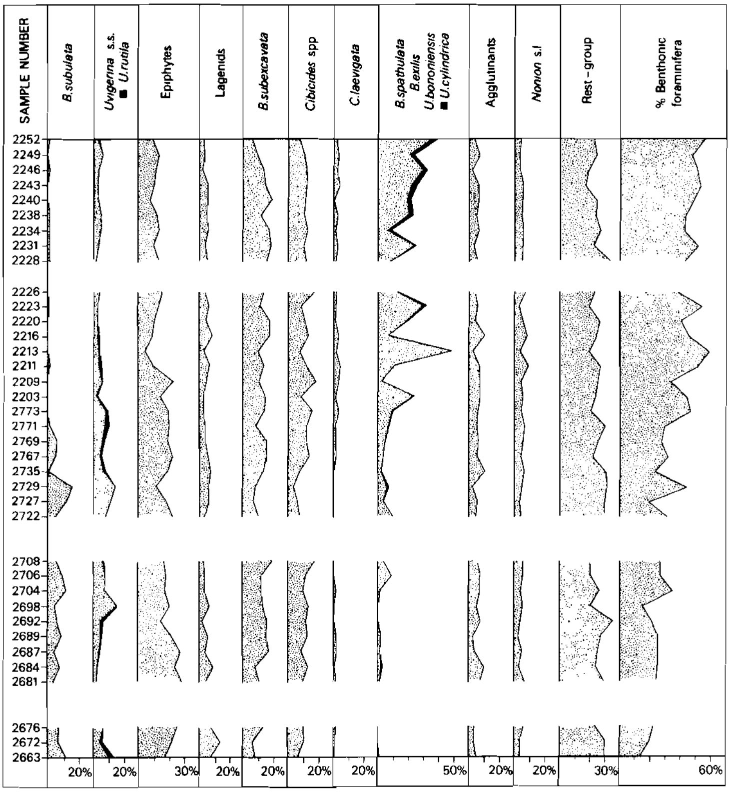
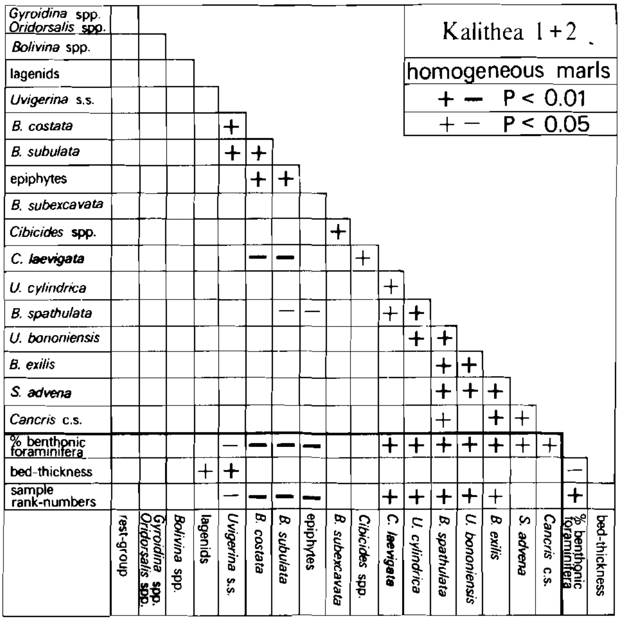


Fig. 42 Relative frequencies of the benthonic foraminifera in the homogeneous sediments of section Kalithea 1 + 2.



Kalithea 1+2

homogeneous marls

+ − P < 0.01

\+ − P < 0.05

	rest-group	*Gyroidina* spp. *Oridorsalis* spp.	*Bolivina* spp.	lagenids	*Uvigerina* s.s.	*B. costata*	*B. subulata*	epiphytes	*B. subexcavata*	*Cibicides* spp.	*C. laevigata*	*U. cylindrica*	*B. spathulata*	*U. bononiensis*	*B. exilis*	*S. advena*	*Cancris* c.s.	% benthonic foraminifera	bed-thickness
Gyroidina spp. *Oridorsalis* spp.																			
Bolivina spp.																			
lagenids																			
Uvigerina s.s.																			
B. costata					**+**														
B. subulata					**+**	**+**													
epiphytes						**+**	**+**												
B. subexcavata																			
Cibicides spp.									**+**										
C. laevigata						**−**	**−**			+									
U. cylindrica											+								
B. spathulata							−	−			+	**+**							
U. bononiensis												**+**	**+**						
B. exilis													**+**	**+**					
S. advena													**+**	**+**	**+**				
Cancris c.s.													+		**+**	+			
% benthonic foraminifera					−	**−**	**−**	**−**			**+**	**+**	**+**	**+**	**+**	+	+		
bed-thickness				+	**+**													−	
sample rank-numbers					−	**−**	**−**	**−**			**+**	**+**	**+**	**+**	+			**+**	

Fig. 43 Matrix of correlation coefficients of the data from the homogeneous sediments of section Kalithea 1 + 2 based on the DISTUR and BALANC procedures.

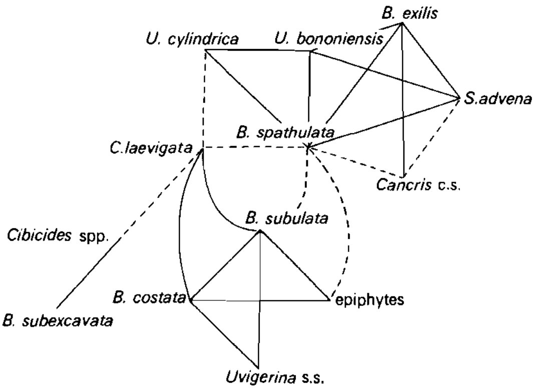


Fig. 44 Spider-web diagram for the samples from the homogeneous sediments of section Kalithea 1 + 2. Straight lines: positive correlations; curved lines: negative correlations. Solid lines: P < 0.01; dashed lines: P < 0.05.

lagenids, *Bolivina* spp., *Gyroidina* spp. + *Oridorsalis* spp. and the rest-group. Again the most remarkable feature is the lack of a positive correlation between *B. subexcavata* and the epiphytes.

The association of *Uvigerina* s.s., *B. subulata, B. costata* (not figured) and the epiphytes is, according to the visual impression, most frequent in the lower half of the composite section (fig. 42).

B. subexcavata and *Cibicides* spp. do not increase or decrease in relative frequency. *C. laevigata,* which is attached to the latter group, remains low-frequent throughout the column, though higher percentages are found in the upper part.

The cumulative percentages of the most frequent species of the association of *B. spathulata* c.s., *B. spathulata, B. exilis* and *U. bononiensis*, show that highest values are found in the upper part of the composite column. All other taxa belonging to this association are scarce in the samples from the homogeneous sediments and they do not appear in separate colums in fig. 42. As in section Aghios Vlassios, the laminated intervals in the top part of section Kalithea 1 + 2 contain high relative numbers of the three mentioned species (see III.6). Again the higher percentages in the homogeneous marls might be explained by mixing of the two sediment types caused by burrowing or redeposition.

The scores of the agglutinants and of *Nonion* s.l., which were not included in the computer analyses of the data from section Kalithea 1 + 2, as well as the scores of the rest-group do not seem to change.

The percentage of benthonic foraminifera is highest in the upper part of the column. An increase in this percentage was confirmed by the stratistical analyses (fig. 43).

Summary of benthonic faunas in the homogeneous sediments

If we disregard the infrequent taxa, the associations which resulted from the computer-runs of the data from the homogeneous marls of sections Aghios Vlassios and Kalithea 1 + 2 start to look more similar. Then, an association of *Uvigerina* s.s., *Bulimina subulata* and the epiphytes is seen to be prominent in the lower parts of both sections. In section Aghios Vlassios, this association is again frequent in the upper part.

In section Aghios Vlassios, *Bolivina subexcavata* is associated with the lagenids, both being most frequent in the lower half. The association is here completed by the rest-group, which is a rather meaningless category, because it includes many low-frequent species. In section Kalithea 1 + 2, *B. subexcavata* is correlated with *Cibicides* spp. and shows no frequency increase or decrease throughout.

Species of *Cibicides* and *Cassidulina laevigata* are strongly correlated in section Aghios Vlassios and are met with in higher percentages in the top part. In Kalithea they also show a positive link; here *C. laevigata* is the only of the two which is somewhat more frequent in the upper part.

Higher relative numbers of the association of *Bolivina spathulata, Bulimina exilis* and *Uvigerina bononiensis* are found in the stratigraphically higher parts of both sections.

Interpretation of the faunal patterns in the homogeneous sediments

The stagnancy gradient which resulted from the analyses of the laminites of both sections, seems to be of little value for the successions of homogeneous sediments, because of rather large dissimilarities of the faunal patterns in both lithology types. The positive trends for the members of the association of *Bolivina spathulata* c.s. in the homogeneous strata might be the result of a general increase of adverse conditions during the deposition of all sediments at both localities, but in our opinion they are better explained from some kind of sedimentary mixture, particularly since the association connected with weak stagnancy phenomena plays no role whatsoever. As a consequence, each of the remaining associations in the homogeneous sediments is assumed to have inhabited some particular environment in the "normal" marine realm. The succession of associations, which gradually replaced each other, is thus believed to reflect overall environmental changes that took place during the deposition of the homogeneous Pliocene sediments.

From the lithological data in chapter II, we inferred a shallowing for all sections. As most benthonic foraminifera have no narrowly defined depth habitats, this shallowing is not easily deduced from the depht ranges of individual species. Moreover, all common species, except for a very few already mentioned, are present throughout the sections. The differences in fauna composition from bottom to top are too small to conclude that there was any large depth change for our sections.

The shallowing tendency can best be concluded from the steady increase of the percentage of benthonic foraminifera as observed in all sections. This is a phenomenon commonly observed in transects from offshore to coastal environments (see for instance Drooger and Kaasschieter, 1958; Reiss et al., 1974); it is primarily due to the relative decrease in number of planktonic individuals, while the number of benthonics may remain stable. For the relatively low percentages of benthonic foraminifera in the lowermost parts of sections Aghios Vlassios and Kalithea 1, we prefer another explanation, however.

It was seen that in both sections these low percentages are accompanied by fairly high percentages of epiphytes and that also *Bolivina subexcavata* may be relatively frequent. Incorporation of the 63–125 μ fraction would show them to be still more abundant (see III.2).

In Messinian sediments of western Crete, Van der Zwaan (1982) found *B. subexcavata* (his *Bolivina plicatella*) to be positively correlated with epiphytic taxa, i.c. species of *Discorbis* and *Elphidium*, *Asterigerina planorbis* and *Cibicides lobatulus*. In this context it is remarkable that from our analyses it appears that *B. subexcavata* and the epiphytes seem to have had different habitats.

Data on the recent distribution of *B. subexcavata* indicate that the species lives in shallow environments. Cooper (1961) reported the synonymous *B. pseudoplicata* in tide-pools along the coast of California. Here it was found living on calcareous algae; beach-sand samples were devoid of the species. In the same region, Lankford and Phleger (1973) found *B. subexcavata* to be most common on a rocky bottom, its maximum frequency being 9%. Their *B. pseudoplicata*, which resembles our specimens to a lesser degree, was reported from rocky bottoms as well as from sands. Radford (1967a, b) recorded *B. subexcavata* on very fine terrigenous sand off the mouth of the Courland River (Tobago). Here, the species reaches highest frequencies (5–20%) at depths shallower than 5 metres.

Thus, the faunal patterns suggest that the deepest parts of the basins were inhabited by reputedly shallow and epiphytic species. The epiphytes and *B. subexcavata* may be allochthonous, however, their high relative frequencies being caused by the low level of autochthonous benthonic life. The low abundance of autochthonous benthonic foraminifera in the basal parts of the sections may have resulted from low nutrient supply by low production in the surface waters. This may find support in the low organic content in the Kourtes and "transitional" lithology types (see fig. 18). The poor bottom life may thus have contributed to the high percentages of planktonics, epiphytes and *B. subexcavata*.

Another species characteristic for the lower parts of section Aghios Vlassios and Kalithea 1 + 2 is *Uvigerina pygmea*. At first sight the high frequency of the uvigerinids in these stratigraphic intervals is quite puzzling.

In the analyzed sections, *Uvigerina* s.s. belongs to a chain of positive links with the epiphytes. For species of *Uvigerina*, no record of an epiphytic mode of life is known to us, however. Recent data on *U. pygmea* (*U. peregrina* is in our opinion a synonym) indicate that the species has a considerable depth range (see literature compilation in Brolsma, 1978). Schnitker (1979) reported foraminiferal assemblages from the eastern equatorial Pacific to be dominated by *Uvigerina canariensis* and *U. peregrina*. Water at the sampling site contained a low amount of dissolved oxygen. Cita and Zocchi (1978) described *U. peregrina* as a characteristic constituent of deep benthonic faunas in the western Mediterranean, whereas it is absent in such faunas in the eastern Mediterranean Sea. Higher production in the waters of the western part may be thought responsible for this pattern. Seiglie (1968) reported the species from sediments with a high organic content.

In the Kourtes and "transitional" marls, no indications of lowered oxygen levels are met with and the organic content of these sediments was seen to be low. Reworking from underlying and overlying sapropels (in which the species can be numerous, see III.6) may be considered possible, but the strong positive correlation of *Uvigerina* with bed-thickness in section Kalithea 1 + 2 pleads against this assumption.

A clue for the high percentages of *U. pygmea* in our most calcareous deposits may be found in the data provided by Drooger and Kaasschieter (1958). They reported *U. peregrina* to reach maximum frequencies in areas with highly pelitic sediments on the Trinidad – Paria shelf and off the mouth of the Orinoco River. The individuals were relatively large-sized and had costae all over the test. Forms that were usually smaller in size and often had spinose later chambers (named by them *U. peregrina* var. *parvula*) were found to dominate assemblages of uvigerinids from more sandy, calcarenitic sediments. Our specimens in the associations of *U. pygmea* from the basal Pliocene often have spinose terminal chambers and in this respect they resemble *U. peregrina* var. *parvula* as described and figured by Drooger and Kaasschieter (op. cit.). Hence, it may be true that within the Pliocene assemblages of *U. pygmea* different types lived in different habitats, with the relatively loose-coiled forms which have spinose terminal chambers more frequent in the deposits characterized by a low pelite content.

The positive correlation between *Bulimina subulata* and *Uvigerina* may indicate similar environmental requirements of both taxa in these sediments. This may also apply to the lagenids.

The recurring higher frequencies of *U. pygmea* in the Finikia marls of sections Finikia and Aghios Vlassios, which are more pelitic and which have a higher organic content, are caused by relatively close-coiled forms, which seem to have better developed costae. This change in morphology may suggest that nutrient conditions improved in an upward direction. If this explanation is correct, the low *Uvigerina*-scores in the middle part of the Aghios Vlassios section are not understood.

In the top parts of sections Finikia and Aghios Vlassios, the fauna suggests that there are again relatively more epiphytes, this time accompanied by high frequencies of species of *Cibicides* (mainly *C.* ex gr. *ungerianus*) and *Cassidulina laevigata.* These parts of the sections may have been deposited closer to the area in which epiphytes actually lived. Epiphytes are even more abundant in the shallowest deposits, e.g. the bioclastic limestones in section Prassas of Meulenkamp et al. (1978). From their data it can be concluded that *Cibicides* spp. and *C. laevigata* are less frequent in such shallowest parts. This conclusion is supported by observations on samples from the silty and sandy sediments of section Atsipadhes: epiphytes and *C. laevigata* initially occur together, but in the stratigraphically higher and coarser part of the section the latter species is virtually absent. As a consequence we are inclined to place the *Cibicides – Cassidulina* combination in a habitat deeper than that with ample vegetation, but shallower than that of the species of *Uvigerina*, *B. subulata* and of the lagenid foraminifera. The positive trends of *C. laevigata* in all analyses suggest that in the course of the Pliocene such and intermediate environment did exist in both the Finikia – Aghios Vlassios Basin and the Kalithea Basin.

From the literature we learn that the members of the *Cibicides – Cassidulina* association can be found in a variety of habitats. Evidently, depth does not seem to be a major controlling factor for the distribution of these taxa, but the role of sediment composition and texture is not very clear either.

Data from the fossil record of Plio-Pleistocene sediments on the Peloponnesus show that *C. laevigata* (reported as *C. carinata*) reaches its highest value (to 55%) in sediments which were deposited in the most marine of the shallow environments (Hageman, 1979). The muddy character of the substratum on which the species seems to have lived was stressed by this author. The species is also abundant in Holocene deep-sea calcareous muds in the Levantine Basin (Cita and Podenzani, 1979) and in the SE Adriatic (Van der Zwaan, 1980); these authors listed the species as *C. carinata*, and *C. laevigata* + *C. carinata*, respectively. It should be noted, however, that in both studies the smallest mesh-widths of the analyzed fractions are smaller than that of the fraction we used for routine counts. This may have caused an enrichment of the species in their residues (see III.2). Sejrup et al. (1981) reported maximum frequencies (over 40%) of *C. laevigata* from the Norwegian continental margin, with highest abundances where the carbonate content exceeds 30%.

Concerning *Cibicides ungerianus*, the literature furnishes more or less identical data: it is a species with a relatively large depth range, which is not confined to one special sediment type.

Assemblages dominated by *Cibicides* cf. *ungerianus* and *Cassidulina laevigata* are described from various sediment types (mud to coarse sand) on the continental shelf off the Gironde estuary (Pujos, 1972). Joint percentages of over 50% were found below 60 m water depth. In shallower assemblages the latter species is almost absent.

In the upper part of the composite column of section Kalithea 1 + 2 no marked changes in faunal composition are observed. The shallowing trend is indicated only by the increasing percentage of benthonic foraminifera. The admixture of fauna from the laminated sediments (which in this part of the section consists predominantly of benthonic foraminifera, see III.6) may have helped to reduce the percentage of planktonics. Such an admixture might also have a blurring effect on the relative frequencies of the "indigenous" taxa and partially explains the lack of increase of the epiphytes as seen, for instance, in section Aghios Vlassios. Perhaps the environment was still too deep for the development of vegetated areas. Another possible reason for this frequency pattern may be derived from the fauna in section Kalithea 3, which is located close to the basin margin. Inspection of its faunal content revealed the silt and sand samples from the upper part to be almost devoid of epiphytes. Apparently, extensive areas with vegetation on which the epiphytes could thrive were absent in this basin.

Altogether, we have the impression that if the stagnancy gradient played any role during the deposition of the homogeneous strata, it was a subordinate one. Otherwise we seem to be dealing with the development of better nutrient conditions. Our sections show little evidence of a shallowing reaching the phase of strongly vegetation-bound associations. The negative trends of the epiphytes (section Kalithea 1 + 2) and *Bolivina subexcavata* (section Aghios Vlassios) may suggest that there was no effect of an increase of displacement of such elements during the shallowing of the basins. The relative scarcity of *B. subexcavata* in the top part of the Aghios Vlassios section may be explained by the fact that this species prefers solid substrates, such as rocky bottoms (Lankford and Phleger, 1973), which were not widespread during the deposition of the Stavromenos facies in the Finikia – Aghios Vlassios Basin.

Chapter IV

LAMINATED SEDIMENTS IN THE MEDITERRANEAN

Introduction

The repeated intercalations of laminated layers in marine marl sequences of the Mediterranean Neogene have been the subject of many papers. There has been a great deal of speculation about the genesis of these layers and a variety of models have been proposed. Although all models agree on the direct cause of the laminated deposits, the absence of bioturbation through oxygen deficiency of bottom waters which resulted from restricted vertical circulation, the mechanism responsible for the slowing down of such vertical circulation is still subject of continuous discussion.

Since much attention has been paid to the laminites of Messinian and of Quaternary Age, most of the models refer to the specific geological, oceanographical and climatological circumstances of these periods of geological time. These specific circumstances are not necessarily responsible for the origin of the laminated sediments in the Pliocene.

Distribution of laminated sediments

Before dealing with the various models, it is useful first to consider the distribution in time and space of the Neogene laminated deposits in the Mediterranean.

After the break-up of the Tethys, close to the Oligocene – Miocene boundary (Drooger, 1979), the Mediterranean became more and more confined to its present configuration. In sediments from the Middle Miocene onwards, we find regular occurrences of homogeneous/laminated alternations. Laminites which antedate the Messinian are known especially from the area from Sicily to the east.

On Sicily the oldest known sapropels – in the Monte Giammoia section – were formed close to the *Orbulina* datum level (i.e. in the Langhian). Dark laminites continued to be formed on this island until the Tortonian – Messinian boundary (Van der Zwaan, 1982).

Diatomaceous limestones and bituminous laminated clay-layers from the island of Zakinthos were assigned to the Upper Burdigalian and the Lower Tortonian, respectively (Dermitzakis, 1978). The former sediment type does not seem to be part of a regular alternation with the homogeneous sediment type we commonly find.

Clayey and marly sediments of Tortonian Age on western Crete do not include laminated beds (Meulenkamp, 1979b). In section Aghios Ioannis on central Crete (unpublished), however, numerous sapropelic layers are intercalated in marls which can be attributed to the Tortonian and partly to the Messinian in the sense of d'Onofrio et al. (1975). Marls of similar (Messinian) age, exposed in the lower part of section Faneromeni (province of Lasithi; Gradstein, 1973) contain such layers as well.

South of Turkey, Miocene sapropels were recovered by deep-sea drilling (D.S.D.P. site 375) in deposits which range from the Serravallian up to the Messinian (Kidd et al., 1978).

The most widespread laminated sediments are found just below the Messinian evaporitic sequence and are generally of the diatom-rich type. They are found all over the Mediterranean, from Spain and Morocco to Cyprus (see literature compilation by Van der Zwaan, 1982).

The geographical distribution of the Pliocene sapropels and diatomites is roughly the same as that of the older Miocene laminated beds, again from Sicily to the east. The most significant occurrences are included in fig. 45.

The Trubi limestones on Sicily contain only a few local laminated intercalations (Brolsma and Broekman, 1978), but in the overlying Monte Narbone Formation numerous dark, sapropelic laminites can be observed (Brolsma, 1978; Spaak, 1983). At higher stratigraphic levels in this formation no such sediments are found any more.

In the northern part of the Caltanissetta Basin (in the area between Caltanissetta and Centuripe) the marls and clays overlying the Trubi limestones were deposited in a more marginal part of the basin and are devoid of sapropels. It should be noted, however, that the Pliocene formations are strongly diachronous: the terrigenous sediments in the north are equivalent in age to the more calcareous Trubi deposits in the south (cf. Meulenkamp et al., 1981).

In Calabria, laminite formation occurred repeatedly during the Pliocene. Marly sequences in the area between Capo Spartivento and Soverato (e.g. section San Rocca) show regularly interbedded grey to brown layers which are often laminated. They occur right from the base of the Pliocene up to somewhere in the *Globorotalia margaritae – G. puncticulata* Concurrent-range-zone.

The youngest Italian Pliocene sapropels can be observed in the Crotone Basin; the Semaforo and Vrica sections include very thick sapropelic layers (Selli et al., 1977; Spaak, 1983).

Pliocene laminated sediments can be studied at numerous localities in Greece (fig. 45). On Crete, in the Iraklion area, the first sapropels can be as-

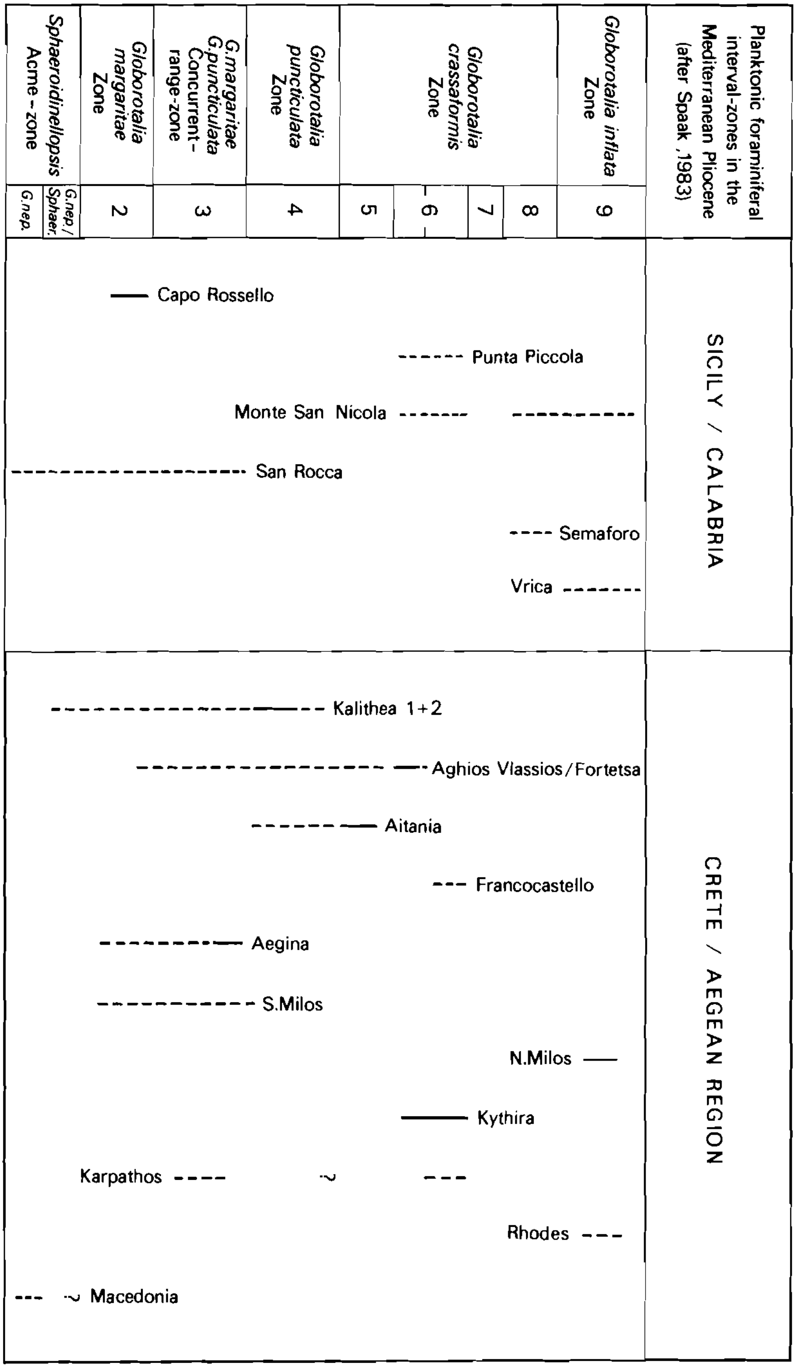


Fig. 45 Stratigraphic distribution of Pliocene laminites known from land sections. Dashed lines: sapropels; solid lines: diatomites.

signed to the *Sphaeroidinellopsis* Acme-zone. Both sapropels and diatomites are found from about the exit level of *Globorotalia margaritae* (hence in the *G. puncticulata* Zone sensu Spaak, ibid.) and continued to be formed up to some level in the *G. crassaformis* Zone. Laminated beds which can be assigned to the latter zone also exist in the provinces of Rethymnon and Khania (cf. Meulenkamp, 1979a) and on the islet of Koufonisi, eastern Crete (Dermitzakis and Theodoridis, 1978). The youngest laminites on Crete are found in section Francocastello (*G. crassaformis* Zone, upper part of Interval 6 of Spaak, 1983).

Not all Pliocene sequences on Crete include laminated beds; in the Voukoulies Basin (province of Khania), Kourtes-like marls referable to the *Sphaeroidinellopsis* Acme-zone and the *G. margaritae* Zone are without laminated layers (Spaak, 1981).

In other parts of Greece (see fig. 45) similar Pliocene deposits are known. Laminated sediments rich in diatoms are found on Aegina (Benda et al., 1979), Kythira (Meulenkamp et al., 1979c) and on the island of Milos. On Aegina and Milos, sapropelic deposits are exposed as well. Dark coloured laminated deposits also occur on the islands of Karpathos and Rhodes. In the thick laminated intervals on the latter island, numerous thin sand-layers are present. The non-diatomaceous laminated type of lithology is found as far as the Strimon Basin, Macedonia (Steffens et al., 1979), where it occurs in clayey deposits which can be assigned to the lower part of the *Sphaeroidinellopsis* Acme-zone (Zachariasse and Spaak, 1979). Here too, the laminated intervals contain numerous thin sand layers.

Thus, in the eastern Mediterranean we are faced with regular intercalations of laminated layers throughout the Pliocene. Moreover, in most of the planktonic foraminiferal zones sapropels as well as diatomites occur and no specific periods can be discerned in which only sapropel or diatomite formation took place. Turbidity-controlled differences in primary production are considered to be responsible for the simultaneous formation of both lithology types (see II.7).

The number of laminites found in the composite column of Crete, Sicily and Calabria totals 96. The actual number for the entire Pliocene probably exceeds one hundred. If there is any regularity in the alternation, the periodicity might be less than 30,000 years.

From deep-sea drilling we learn that Pliocene sapropels are also present in the subsurface of the eastern Mediterranean deep basins (Nesteroff, 1973; Kidd et al., 1978). Most of them are only a few centimetres thick; in rare cases they exceed one decimetre. Although occasional layers are relatively rich in diatoms, they were never classified as diatomites. Cores from the western part of the Mediterranean do not contain any such layers.

The number of Pliocene sapropels in the eastern deep basins is considerably less than the number encountered in land sections. At D.S.D.P. site 378, north of Crete, a maximum of 41 sapropels was found. This small number may be explained by poor recovery of the Pliocene sequence. Recovery was complete, however, in the interval between the entry level of *Globorotalia puncticulata* and the last occurrence of *G. margaritae.* With the use of the planktonic foraminiferal data of Bizon (in Bizon et al., 1978), we recognize 14 sapropels. A similar number is reported by Kidd et al. (1978). In section Aghios Vlassios, the *G. margaritae – G. puncticulata* Concurrent-range-zone yields 12 sapropels. Thus, in the case of more complete recovery, the number of sapropels at site 378 may not deviate much from that in land sections.

The sapropels at the offshore location are slightly thinner than those in section Aghios Vlassios, but significantly thinner than the ones in sections Kalithea 1 and 2. This difference can be attributed to reduced sedimentation rates at site 378.

In the deep Ionian Basin (at D.S.D.P. site 374), no sapropels are observed between the exit level of *G. margaritae* and the last occurrence of *G. puncticulata.* In the corresponding part of section Aghios Vlassios 16 sapropels were counted. In this interval, the sedimentation rate in the Ionian Basin was lower by a factor 3, as compared with that at Aghios Vlassios. In the biostratigraphically lower interval between the first appearance of *G. puncticulata* and the subsequent occurrence of *Globoquadrina altispira* (which is close to the entry level of *Discoaster asymmetricus*), the sedimentary record at site 374 contains only one sapropel, versus 9 on Crete. If we rule out the possibility that bioturbation completely obliterated the sapropels in the Ionian Basin, we may arrive at the conclusion that, at least for part of the Pliocene, sapropel formation was not manifest all over the eastern Mediterranean.

The distribution pattern of sapropels in the subsurface of the Mediterranean in the Quaternary concurs with that of the older Miocene and Pliocene, i.e. sapropels are restricted to the eastern part. As an exception, Olausson (1960) reported one sapropel from the Tyrrhenian Sea, so did Kidd et al. (1978).

The maximum number of sapropels in the east, observed in one piston core, is twelve (Ryan, 1972). Many of the sapropelic layers can be traced from core to core in an area from the eastern Nile cone to the northern Ionian Basin. From Ryan's data it can be inferred that the thickness of the layers ranges from less than one decimetre to one metre, but the thickness of the individual layers may fluctuate considerably from one place to another. The uppermost sapropel, for instance, measures about 1 dm south of Crete (see Ryan, op. cit.), but further to the west it attains a thickness of 1.55 m on the Mediterranean Ridge (Blechschmidt et al., 1982). This sapropel layer is also present in the Adriatic Sea (Van Straaten, 1972).

Some of the Late Quaternary sapropels are not found all over the eastern basin; some which are present in one core may be lacking in another (Cita et al., 1977). Often individual sapropels split up laterally into a number of dark layers with intercalations of "normal" sediment (see Van Straaten, 1972; Thunell et al., 1977; Cita et al., 1982). A piston core recovered from the southern Ionian Basin showed no sapropels at all (Thunell et al., ibid.). Thus, although many sapropels can be recognized all over the eastern Mediterranean, we again get the impression that sapropel formation was not always basinwide.

In land sections, sediments of Quaternary age generally do not show any evidence of stagnation, probably because of the shallow character of these deposits. However, clay sequences in the Crotone Basin, Calabria, yield thick sapropels of Early Pleistocene age (Selli et al., 1977; Spaak, 1983). Brown laminated intercalations have also been observed on the islands of Karpathos and Rhodes, in sediments containing *Hyalinea balthica* (author's observations).

From the above enumeration it is evident that almost all the Neogene sediments indicative of stagnant bottom conditions are restricted to the eastern part of the Mediterranean. An exception should be made for the laminites of the Messinian.

The vertical distribution of sapropelic and diatomaceous sediments in land sections suggests that the mechanism of laminite formation was intermittently active throughout the Pliocene. The horizontal distribution shows that the laminated strata are not developed everywhere; they may be absent in the deeper basins. The laminated levels in marginal basins may reach a considerable thickness.

Hypotheses in the literature about the origin of laminated deposits

a) *The Messinian diatomites*

Laminated sediments which were formed prior to the Late Miocene salinity-crisis have long been a field of interest, probably due to their widespread geographical distribution, their specific stratigraphical position and their remarkable fossil content consisting particularly of abundant diatoms, radiolarians and fish-remains.

Most authors agree on the stagnancy of the bottom waters during deposition of such Messinian sediments, because of the laminated character. McKenzie et al. (1980) concluded from the presence of dolomite in the accompanying homogeneous strata that stagnancy applies to this type of sediment as well. Stagnant waters are thought to have developed in basins which were provided with sills (McKenzie et al., op. cit.; Van der Zwaan, 1982). In the model of Gersonde (1980), the diatomites were deposited in relatively shallow parts of the Mediterranean.

The high abundance of siliceous microfossils in the laminated layers requires an intermittent supply of silica and nutrients. For Algerian diatomites, the silica was thought to be provided by volcanic sources, as concluded from the co-occurrence of laminated diatomites and volcanic ash layers (Van Vleck Anderson, 1933). Ash layers were also found in the underlying marl sequence without diatomaceous sediments, however. At other places, where the Messinian diatomites are not accompanied by volcanics, silica and nutrients are thought to have been supplied by upwelling (Bizon et al., 1979; Gersonde, 1980; McKenzie et al., 1980; Van der Zwaan, 1982) or to have been derived from continental sources (Bizon et al., ibid.; Van der Zwaan, 1979).

Sea-level changes resulting from climatic fluctuations play a pronounced role in the various models, but the effect of such sea-level changes is appreciated differently. According to Gersonde (1980) and McKenzie et al. (1980), upwelling of nutrient-rich water took place during periods of high sea-level. In such periods, nutrient-rich deep Atlantic waters were allowed to enter the Mediterranean (Gersonde, op. cit.).

Obstruction of the outflow of deeper Mediterranean waters by a stronger inflow of Atlantic surface waters during periods of eustatic sea-level lowering was proposed by Van der Zwaan (1982). This would have caused an increasing salinity gradient, which caused stagnation and deposition of brown, sapropelic layers. A further lowering of the sea-level would have resulted in an even stronger inflow; the ensuing upwelling of nutrient-rich deeper waters led to the deposition of diatomites. In this so-called Atlantic inflow model it is claimed that increasing vigour finally prevented the outflow of denser water, which ultimately resulted in the basin-wide accumulation of evaporites.

b) *The Pliocene laminites*

No comprehensive model has so far been proposed for the formation of all Pliocene laminated sediments, probably due to the comparatively poor and scattered information on these deposits.

The Lower Pliocene diatom-rich laminated intervals at Capo Rossello, Sicily, described by Brolsma and Broekman (1978), were thought to have originated as a consequence of upwelling (Riedel and Sanfilippo, 1978; Schrader and

Gersonde, 1978). The dark coloured, sometimes laminated layers interbedded in the overlying marls of the Monte Narbone Formation were ascribed to the influence of volcanic brines, which intermittently supplied ferromanganese oxides to the sea-floor (Brolsma, 1978).

Meulenkamp et al. (1979a) and Spaak (1983) considered the Pliocene laminites to be a reflection of periods of increased run-off. The latter author gave a detailed account of the planktonic foraminiferal associations connected with laminated sediments from Sicily, Calabria and Crete and discussed extensively the possible effects of enhanced Atlantic inflow and of increased run-off.

c) *The Quaternary sapropels*

During the last decade, a great many papers have appeared dealing with the fossil content and stable isotope record of the Late Quaternary sapropels. In these publications, stagnation of bottom waters is generally attributed to density stratification caused by an increased contribution of relatively low saline waters derived from continental sources.

The idea was first postulated by Kullenberg (1952, fide Ryan, 1972), who thought that large quantities of fresh water must have been supplied to the Mediterranean during so-called pluvial periods. The shallow sill at Gibraltar was considered helpful in restricting the water-exchange between the Atlantic Ocean and the Mediterranean during periods of maximum glaciation.

According to Olausson (1961, fide Ryan, 1972 and Van Straaten, 1972), sapropel formation took place after cold periods, as a consequence of the greater run-off of glacial melt-water, the increased precipitation and the rising temperatures. The contents of the Black Sea would rapidly spread out into the Mediterranean to form a low-salinity surface layer when the sea-level had risen to higher than -40 metres, which is the present sill depth of the Bosporus. In the western Mediterranean, no sapropels were formed owing to the inflow of deep Atlantic water which filled this basin. Extension of such bottom waters to the east was prohibited by the sill between Sicily and Tunisia.

Many later authors accepted the idea of increased run-off from either glacial melt-water (Ryan, 1972; Müller, 1973; Nesteroff, 1973; Williams et al., 1978), or from precipitation (Rossignol-Strick et al., 1982), or from a combination of both (Cita et al., 1977; Thunell et al., 1977; Vergnaud-Grazzini et al., 1977). The Black Sea is generally considered to be the source of the low-salinity waters, but contributions from other sources, such as the Adriatic (Vergnaud-Grazzini et al., op. cit.) or by excessive discharge of Nile waters (Rossignol-Strick et al., op. cit.), have been proposed as well.

A model which explains the density stratification in terms of temperature was given by Van Straaten (1972): a rapid rise of the minimum winter temperature of surface waters would prevent their sinking, which process ultimately led to oxygen deficiency of the deeper waters. Cita et al. (1982) considered stratification through warming of surface waters to be applicable for the formation of certain sapropels, whereas other sapropels would have resulted from increased run-off.

From diatom assemblages found in certain sapropels south of Turkey, Schrader and Matherne (1981) inferred high production of phytoplankton, thought to be caused by wind-driven upwelling. In their opinion, oxidation of ample organic matter in the deeper environments was responsible for the development of anoxic bottom conditions. Upwelling did not play a role in the formation of sapropels that are devoid of diatoms; such sapropels were considered to be primarily the result of low saline surface waters.

Reflections on the Pliocene laminites

In attempting to explain the origin of our Pliocene laminated sediments, we obviously should include some speculations on the Pliocene Mediterranean circulation patterns. At present, the Mediterranean is an almost enclosed basin, with a limited connection to the Atlantic Ocean. Although deep circulation is rather restricted as a consequence of the bottom topography – variously sized smaller basins separated by sills (see Carter et al., 1972; Jongsma et al., 1977) –, widespread anoxic bottom conditions do not exist. The lowest amount of oxygen in the deeper parts of today's Mediterranean is found in the eastern part (4 ml/l; Miller et al., 1970). Because of the absence of stagnant conditions, it is tempting to parallel the present situation with situations in the Pliocene periods in which well-aerated sediments were deposited.

Today evaporation exceeds precipitation and run-off, causing a constant inflow of Atlantic surface waters, which extend as far as the eastern end of the Mediterranean (Lacombe and Tchernia, 1972). In all larger basins a counter-clockwise surface circulation exists during the summer months. Eastwards surface water temperatures increase (Miller et al., 1970), leading to a better stratification of the water column in the eastern Mediterranean.

The vertical circulation is induced by regional sinking of dense waters in the winter months. In the area SW of Turkey, highly saline waters sink to form an intermediate layer. In this layer, westward flowing waters leave the eastern Mediterranean through the Straits of Sicily. After mixing processes have occurred in the western Mediterranean, the high salinity waters ultimately reach the Atlantic.

Deep water is generated by cooling during the winter (MEDOC group, 1970). The main areas in which such bottom waters are formed are located south of France and in the Adriatic Sea. The dense cold waters flow southward into the relatively deep Balearic and Ionian Basins, respectively (Miller, 1972).

Since these circulation patterns are largely governed by climate it is of interest to know whether the present type of Mediterranean climate, characterized by a seasonal rhythm of warm and relatively dry summers and of winters in which the larger part of the precipitation is supplied, might be applicable to the Pliocene as well.

From pollen analyses of NW Mediterranean Pliocene to Lower Pleistocene sequences, Suc (1982) inferred for the earlier part of the Pliocene a more humid climate than today, without pronounced seasonality. He reconstructed a climate with a seasonal rhythm, resembling that of the present Mediterranean for a subsequent period which corresponds to the larger part of the interval in which *Globorotalia crassaformis* entered the Mediterranean. In the later part of this interval, a Quaternary-style of climate with a still more pronounced seasonality came into being.

The stable oxygen isotope record of D.S.D.P. site 132, in the Tyrrhenian Sea, also indicates that relatively uniform climatic conditions prevailed during the earlier part of the Pliocene. A shift towards a cooler climate occurred in Late Pliocene times (Thunell and Williams, 1983), corresponding to the middle part of MPl 5 of Cita (1975), which is in the *G. crassaformis* Zone of Bizon and Bizon (1972).

Furthermore, it was concluded on the basis of the composition of Italian planktonic foraminiferal associations that there was a relatively uniform and stable climate of subtropical character in the larger part of the Mediterranean Pliocene (Zachariasse and Spaak, 1983). According to these authors, only minor fluctuations in climate were apparent in this period. A shift to more temperate associations was observed in the upper part of the *G. crassaformis* Zone. In the same biostratigraphic interval, Driever (1984) infers a cooling from the disappearance of *Discoaster* species.

The stratigraphic interval from which we gathered our data ranges from the *Sphaeroidinellopsis* Acme-zone to the lower part of the *G. crassaformis* Zone (lower part of Spaak's Interval 6). It covers a time-span which is about 2/3 of the duration of the Pliocene. The interval precedes the Late Pliocene cooling mentioned above, which was estimated by Zagwijn and Suc (1983) to have taken place 2.3 million years ago.

Estimates of the effect of a subtropical, humid and fairly equable climate on the circulation patterns of the Pliocene Mediterranean are of course highly speculative. Despite the clear climatic differences between the Early Pliocene and the present situation, a west – east surface current system and a gradient in temperature and salinity seem to have existed during the Pliocene as well (Spaak, 1983).

Warmer conditions may have led to a higher evaporitic loss, causing a stronger inflow of Atlantic surface waters. Concentration of such waters, leading to increased salinities, may have resulted in a vertical circulation which was primarily salinity driven. One may argue that bottom water generation by cooling, which is necessary for good ventilation of the deeper parts of the basins, was rather limited – or even had ceased – as a consequence of the absence of a pronounced seasonality combined with a warm climate.

A greater humidity would have had a negative effect on evaporation, hence on the sinking of saline waters. Higher run-off rates, resulting from increased precipitation, may however have contributed to the reduction of the vertical circulation during the earlier part of the Pliocene.

The circulation patterns may also have been influenced by the paleogeography of the Mediterranean Pliocene. In the earliest Pliocene, the marine realm was widespread. Later on, more and more parts of the land areas in and around the Mediterranean emerged, as evidenced by the shallowing sequences, examples of which are found in northern Greece (Meulenkamp, 1979c), Crete (Meulenkamp et al., 1979b; this paper) and Sicily (Meulenkamp et al., 1981). The decrease in the surface covered by the sea may have reduced the amount of evaporated water, leading to diminished quantities of Atlantic surface inflow and dense water outflow in later periods of the Pliocene.

Our speculations on the effect of the Early Pliocene climate on the circulation patterns suggest that vertical circulation was probably rather weak, due to the stable and warm climate. Under such climatic conditions, vertical water exchange may have become even more limited in the course of the Pliocene.

Replenishment of deeper waters was, however, still sufficient to prevent stagnant bottom conditions. For most of the time, vertical circulation apparently brought enough oxygen to the deeper environments, since the faunas of the homogeneous sediments do not bear evidence of any kind of stagnation.

The first prerequisite for the termination of bottom ventilation is the interruption of the downward movement of oxygenated waters. Before speculating on the mechanisms that may be thought responsible for such interruptions, we should verify whether the periodical stagnation occurred all over the – eastern – Mediterranean and whether the degree of stagnation changed with time.

To clarify this matter it is useful to consider the results of our analyses of the Cretan benthonic foraminiferal faunas. In the preceding chapter (III.6) we discussed the stagnation in the different basins on Crete. We concluded that the degree of stagnancy in the lower laminites of the Finikia – Aghios Vlassios and Kalithea Basins was rather low, whereas stagnation was most intense in the topmost laminites. The faunal trends indicate a gradual decrease in the oxygenation of bottom waters in successive Pliocene periods of stagnation. Since we inferred a shallowing for all Cretan basins, we can draw a hypothetical graph of the relative amount of oxygen in the successive stagnant environments versus depth of deposition (fig. 46).

The figure suggests that depth is one of the controlling factors for the intensity of stagnation; strongest stagnation is found in the shallow environments. Such environments were not simultaneously present in all basins. In the Kalithea Basin and Aitania Basin they existed in an earlier stage than in the Finikia – Aghios Vlassios Basin (see II.6). As we can see, severe stagnation was also reached earlier in the former basins.

The assumption that stagnation depends on depositional depth is further supported by the offshore record. For instance, in the deep Ionian Basin laminites are completely lacking in the *Globorotalia puncticulata* Zone sensu Spaak (1983). Thus, in assumedly deeper waters stagnation was absent. Apparently, even during periods of laminite formation bottom water was still generated to oxygenate the deeper environments, meaning that vertical circulation had not ceased everywhere.

In places outside Crete, strong stagnation existed in a still earlier phase of the Pliocene, as for instance is manifested by extreme dominances of *Bolivina spathulata*, *Bulimina exilis* and *Uvigerina bononiensis* in laminated sediments on the island of Aegina (Benda et al., 1979); these sediments can be assigned to the *Globorotalia margaritae* Zone and the *G. margaritae – G. puncticulata* Concurrent-range-zone (fig. 45).

Benthonic foraminiferal associations in the laminites of the Punta Piccola section on Sicily (Brolsma, 1978) indicate moderately low oxygen levels for the depositional environments of these sediments. The deposits are partially equivalent in age to those of the Cretan sections Finikia, Aghios Vlassios, Fortetsa and Prassas, at which localities waters at the bottom were periodically strongly oxygen deficient.

Altogether, it seems that the degree of stagnation varied from place to place, being at a maximum in relatively shallow environments. Severe stagnancy was already reached in early stages of the Pliocene.

Another type of observation entered in fig. 46 is the presence of diatom-remains which occur in the shallow environments. Their absence in the deeper

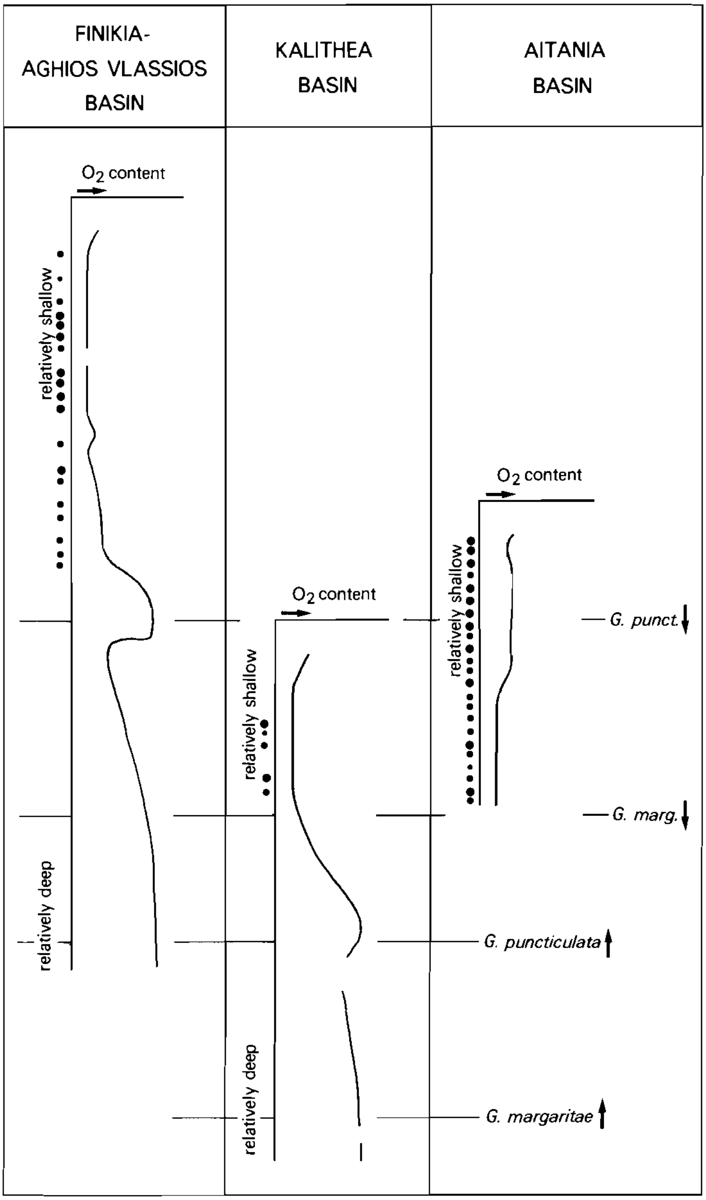


Fig. 46 Hypothetical graph of the relative amount of oxygen in bottom waters during successive periods of stagnancy versus depositional depth. ● Well preserved diatoms; • poorly preserved diatoms; • diatom-remains incidentally present.

environments may be due to dissolution during downward transport (for a discussion on opal-preservation see Gersonde, 1980), but it may also be attributed to low diatom-production in surface water layers. Anyway, diatom-remains and nearly oxygen depleted conditions often coincide, suggesting a causal relation. In this respect, the examples from Aegina and Sicily, mentioned above, are no exceptions; abundant diatom remains are observed in the laminites on Aegina, whereas they are absent in section Punta Piccola. The supply of organic matter from the surface water obviously stimulated the reduction of the amount of dissolved oxygen at the bottom. It is recalled that no specific periods of diatomite formation can be discerned; we did not find any evidence of an increase of diatomaceous deposits higher up in the Pliocene (fig. 45).

The abundance of diatoms points to enhanced production in the surface water layers in periods of laminite deposition. High fertility can furthermore be concluded from the frequency patterns of planktonic foraminifera. In Italy, periodical high fertility conditions were assumed to have existed only during the latest part of the Pliocene (*Globorotalia inflata* Zone; Zachariasse and Spaak, 1983), as deduced from peak occurrences of *Neogloboquadrina* species in connection with laminites. In the sapropels and diatomites on Crete, neogloboquadrinids are consistently found in higher percentages; this was proven by statistical analyses for sections Finikia, Aghios Vlassios and Prassas (Spaak, 1983). If one prefers to explain the high relative frequencies of this group of planktonic foraminifera in terms of raised nutrient levels, fertile conditions certainly apply to the Cretan laminites.

Another point of relevance which has to be considered in the discussion is the development of a larger density gradient, as evidenced by our analyses of stable isotopes. Oxygen isotope ratios in pre- and post-Pliocene laminated sediments also show anomalous values (Cita et al., 1977; Vergnaud-Grazzini et al., 1977; Williams et al., 1978; Van der Zwaan, 1979; Van der Zwaan and Thomas, 1979). In most of these studies, low $\delta^{18}O$ values of planktonic foraminifera correspond to deposits indicative of stagnation. Moreover, Van der Zwaan (1979) showed that such $\delta^{18}O$ anomalies were only apparent in the uppermost part of the water column. There is a consensus in the literature that the deviating oxygen isotope values represent salinity changes. Following this explanation, contribution of surface waters that are less saline is the cause of the greater density gradient. As a result, vertical circulation slowed down, favouring stagnation of deeper waters.

The low-salinity character of the surface waters may also be concluded from the frequency-behaviour of planktonic foraminifera (for the Pliocene:

Spaak, 1983; for the Quaternary: Parker, 1958; Cita et al., 1977; Thunell et al., 1977; Vergnaud-Grazzini et al., 1977).

From the above it seems that the supply of low saline surface waters can be considered responsible for the termination of vertical circulation. In addition, these waters were able to induce increased organic production. The source of waters which possess both qualities is a matter of speculation. Enhanced Atlantic inflow and increased run-off are two processes which can account for a restricted circulation.

For the Messinian diatomites, Van der Zwaan (1982) considered enhanced inflow of Atlantic waters to have been responsible for the development of an effective density stratification. The vigorous inflow caused upwelling of deeper, nutrient-rich waters in marginal areas. Diatomaceous deposits were thought to be best developed in the western Mediterranean, supporting the assumption that close to the entrance of the Mediterranean the effect of enhanced inflow was most pronounced. Inflow was strongest during glacially controlled low eustatic sea-level; in such periods outflowing deeper waters were obstructed by the inflow at the connection between the Mediterranean and the Atlantic. Progressive tectonic limitation of this connection ultimately led to the Messinian salinity crisis.

If enhanced Atlantic inflow was also the cause of the Pliocene laminites, the mechanism to account for such inflow was probably different from that in the Messinian. In Pliocene times, the Atlantic – Mediterranean connection seems to have been fairly well established. The deep-water outflow was not seriously obstructed, since the benthonic foraminiferal record does not indicate aberrant salinities. Hence, the effect of eustatic sea-level oscillations on the inflow – outflow balance is considered to be small. In the Early Pliocene, greater inflow of Atlantic water might have been achieved by greater evaporation in periods of absence of strong humidity.

For the Messinian, we find ample evidence for periodical stagnation in the western Mediterranean, the area closest to the possible source of the low-salinity waters. For the Pliocene period no such evidence is known. Bottom water formation might have prevented the deposition of such sediments, however. Another deviation from the Messinian situation is the distribution of sediments which are indicative of high fertility. In the Pliocene, diatomaceous sediments are best developed far from the entrance of the Mediterranean. The large dissimilarities to the Upper Miocene situation suggest that another process is involved in the deposition of the Pliocene laminites.

Periodically increased run-off of fresh, continentally derived waters may also inhibit the downward movement of surface waters. We do not have much direct evidence in favour of wet periods in the Pliocene; there are no detailed pollen studies, for instance. The pollen analyses from homogeneous/laminated alternations on Aegina showed the former lithology type to contain a predominance of saccate pollen types, which are susceptible to wind transport (Benda et al., 1979). In the laminated layers, higher percentages of non-arboraceous plants (Gramineae, Chenopodiaceae) were encountered, which are usually transported over shorter distances than the saccate types; they may however have been carried to the marine environment by an increased supply of water from coastal areas through run-off.

In the literature concerning the Quaternary stagnant periods, extensive run-off resulting from either glacial melt-water or increased precipitation has been proposed to account for the widespread oxygen depletion. Our Pliocene data indicate that intense stagnation only occurred in relatively shallow environments, suggesting that obstruction of the vertical circulation was only effective in a marginal setting. This may plead for a local supply of fresh water. Since climate in the earlier part of the Pliocene was already in favour of a restricted vertical water exchange, large amounts of fresh water supply are not considered to be necessary.

An indication for increased run-off may be derived from the higher proportions of pelite in the laminated beds; in thick sapropels turbiditic sand-layers may even be present. The upward thickening of individual laminites, found in some of our sections, may be the reflection of a greater terrigenous input in the shallowing environments. One may argue that this phenomenon is caused by a general increase in sedimentation rates, since the thickness of the homogeneous strata increases as well. The anomalously thick sapropels in a section close to the source of clastics (section Aitania, see II.4) may invalidate this argument.

The nutrients that were brought into the marine environment gave rise to enhanced primary production, which, as we concluded, was largest in the marginal areas. In chapter II, we stressed the absence of strongly turbid conditions as a prerequisite for high primary production. The diatom findings in sapropels do not seem to support such a statement. To explain this we need to know something about the nature of the lamination in sapropels and diatomites. So far no systematic study on this matter has been carried out, so we can – again – only speculate.

The laminae of the sapropels that are devoid of diatom-remains may be composed of predominantly clastic mud, with minor amounts of sand-sized particles. Diatom-rich sapropels are probably composed of alternating mud- and diatom-rich laminae, the former of which are assumed to be thickest.

In diatomites, laminae consisting of clastic mud are presumedly thinnest, as suggested by hand specimens and thin sections.

If one is justified in considering a couplet of diatom-poor and diatom-rich laminae to reflect a seasonal rhythm, as reported for diatom-rich laminated deposits in the Gulf of California (Schrader et al., 1980), the clastics of the diatom-poor laminae may have been supplied in months of maximum run-off; after turbidity in surface water had ceased, diatom-blooms could have developed.

The relatively short-term character (see II.4) and assumed periodicity of at most 30,000 years of laminite formation suggest a regular occurrence of relatively humid spells in a stable climate.

In a later part of the Pliocene, a cooler climate came into existence (Thunell and Williams, 1983). We cannot tell whether such a climate favoured an intensification of the processes leading to stagnation. Oxygen depletion in the deep environments occurred in the Quaternary, as can be inferred from the absence of benthonic foraminifera in sapropels from this period. At this moment it is not possible to tell when the expansion of anoxic environments took place.

Chapter V

REMARKS ON THE SPECIES

In this study, a species is defined as a homogeneous group of individuals, separated from another such group by a number of characters. From this definition it is clear that we did not choose a typological species concept. Variation within one species may be considerable; in some of our homogeneous groups a number of forms can be recognized which have been considered as different species by other authors.

In order to label our species, we chose the oldest name for the dominant morphotype (i.e. the centre of the variation) in the majority of the samples. This procedure was followed to avoid the use of different labels for a single species in cases of occasional dominances of (eco-?)phenotypes which usually form no more than a minor part of the variation of the total group of individuals.

For instance, *Bolivina antiqua*, a species with an oval cross-section and increasing but little in width during ontogeny, has coarse perforations all over the test. In some specimens the coarse pores are lacking in the upper half of their chamber walls, but they are identical in all other respects. Such forms may be assigned to *Bolivina lucidopunctata*, but we consider them to be conspecific with *B. antiqua* because they are at the end of a gradual variation, in which all forms in between can be encountered as well. However, in some of the samples from sections Finikia and Aghios Vlassios, the *lucidopunctata*-type is dominant. Yet, we preferred to label these associations as *B. antiqua*.

In this chapter we will deal with a selection of relevant species. Of the most common, we tried to demonstrate the variation in the samples. We prefer to present the species in associations, rather than in alphabetical order. Such an order does apply, however, to the species list below.

Amphicoryna scalaris (Batsch)
Pl. 6, figs. 1–3

Nautilus (Orthoceras) scalaris Batsch, 1791, Test. Aren. Mar. Tab., pl. 2, fig. 4.
Marginulina falx Jones and Parker, 1860, Quart. Jour. Geol. Soc., vol. 16, p. 302, no. 28.

In our samples, the macrospheric generation is most frequent. Together with other lagenids, this species occurs in homogeneous sediments as well as in laminites indicative of slightly lowered oxygen levels.

Asterigerina mamilla (Williamson)
Pl. 11, figs. 12a, b

Rotalia mamilla Williamson, 1858, Rec. Foram. G. B., p. 54, pl. 4, figs. 109–111.

The frequency-pattern suggests an epiphytic mode of life.

Asterigerina planorbis d'Orbigny
Pl. 11, figs. 13a, b

Asterigerina planorbis d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 205, pl. 11, figs. 1–3.

This species is found in high percentages in samples where epiphytes abound. Since literature data on its recent distribution are lacking, the suggestion of being an epiphyte is not confirmed.

Baggina totomiensis Makiyama
Pl. 8, figs. 2, 3

Baggina totomiensis Makiyama, 1931, Mem. Kyoto Imp. Univ., Coll. Sci., ser. B, vol. 7, p. 52, fig. 4.

The species may be relatively frequent in the company of *Cancris auricula* and *Valvulineria complanata,* in sediments deposited under moderate low-oxygen conditions. It is rare in "normal" marine associations.

Bigenerina nodosaria d'Orbigny
Pl. 1, figs. 1, 2

Bigenerina nodosaria d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 261, pl. 11, figs. 9–12.
Bigenerina agglutinans d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 238, pl. 14, figs. 8–10.

In our associations, variation in size and in quality of the surface of the test is observed. Thick-set forms with easily recognizable chambers and a relatively smooth surface resemble the type of *B. nodosaria.* Slender specimens with a rugose test are identical with *B. agglutinans.*

Bolivina alata (Seguenza)
Pl. 7, figs. 5, 6

Vulvulina alata Seguenza, 1862, Atti Accad. Gioenia Sci. Nat. Catania, ser. 2, vol. 18, p. 115, pl. 2, fig. 5.

This species is frequent in *Bolivina* associations from moderately low-oxygen laminites. The figured specimens may represent two species. Of the two, the relatively broad type (fig. 5) is most common in our samples; it has a more compressed test.

Bolivina antiqua d'Orbigny
Pl. 7, figs. 7–9

Bolivina antiqua d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 240, pl. 14, figs. 11–13.
Bolivina lucidopunctata Conato, 1964, Geol. Rom., vol. 3, p. 283, pl. 1, fig. 4.

The species is a common constituent of normal marine faunas, but may be relatively frequent in some of the sapropels of sections Finikia and Aghios Vlassios, where it occurs together with *Bulimina costata*, *Oridorsalis* sp. and lagenid foraminifera. The species shows very pronounced prolocular dimorphism.

Bolivina dilatata Reuss
Pl. 7, figs. 10, 11

Bolivina dilatata Reuss, 1850, Denkschr. K. Akad. Wiss. Wien, vol. 1, p. 381, pl. 48, fig. 15.

An unornamented bolivinid, of which individual specimens are distinguished from *B. spathulata* by their lower L/W ratio (1.5 in *B. dilatata* versus 2 in *B. spathulata*), thicker test and thickened chamber wall. In *B. dilatata*, the proloculus is more embraced by the first biserial chambers than in *B. spathulata*, which causes the early portion of the test of the former to be more rounded. The older part of the test of microspheric individuals is pointed. Adult specimens of *B. dilatata* are smaller than those of *B. spathulata*.

The species is common in the homogeneous sediments, but it can be relatively frequent in thin laminated deposits.

Bolivina reticulata Von Hantken
Pl. 2, fig. 9

Bolivina reticulata Von Hantken, 1875, Mitt. Jahrb. K. Ungar. Geol. Anst., vol. 4, p. 65, pl. 15, fig. 6.

A common bolivinid in normal marine associations.

Bolivina spathulata (Williamson)
Pl. 11, figs. 1–7

Textularia variabilis Williamson var. *spathulata* Williamson, 1858, Rec. Foram. G. B., p. 76, pl. 6, figs. 164, 165.

In our associations, a dentate outline can be observed in some specimens of *B. spathulata*. Non-keeled and keeled forms both occur, of which the latter may have costae on the early portion of their tests. In the literature, such forms are sometimes referred to *Brizalina aenariensis* Costa (for instance by Longinelli, 1956, Paleontogr. Ital., vol. 19; Hageman, 1979, Utr. Micr. Bull., vol. 20). A basal spine may be present in costate as well as non-costate specimens. As in *B. antiqua*, the upper part of the chamber walls may lack the normal size perforation. In some sapropelic levels, these or the costate forms may be relatively frequent, whereas they are inconspicuous elements in the underlying and overlying laminites. No trends were observed in the frequency patterns of ornamented specimens.

B. spathulata is one of the last species to disappear before oxygen deficiency inhibits benthonic life. In the suitable environment it is highly proliferant.

Bolivina subexcavata Cushman and Wickenden
Pl. 11, figs. 8–11

Bolivina subexcavata Cushman and Wickenden, 1929, Proc. U. S. Nat. Mus., no. 2780, p. 9, pl. 4, fig. 4.

Bolivina pseudo-plicata Heron-Allen and Earland, 1930, Jour. Roy. Micr. Soc., vol. 50, p. 81, pl. 3, figs. 36–40.

Bolivina plicatella Cushman, 1930, Bull. Florida State Geol. Surv., no. 4, p. 46, pl. 8, fig. 10.

Bolivina plicatella Cushman var. *mera* Cushman and Ponton, 1932, Bull. Florida State Geol. Surv., no. 9, p. 82, pl. 12, fig. 4.

The test is commonly slightly twisted; extremely tordated or flat specimens are rare. In the latter, the median furrow is least pronounced.

The species is interpreted as an epiphyte, which probably prefers an algal coated solid substrate. It seems to have lived in a normal marine environment.

Bulimina barbata Cushman
Pl. 7, fig. 1

Bulimina barbata Cushman, 1927, Bull. Scripps Inst. Oceanogr., tech. ser., vol. 1, p. 151, pl. 2, fig. 11.

A rare species, found only in sapropels.

Bulimina costata d'Orbigny
Pl. 8, figs. 6–8

Bulimina costata d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 269.

Bulimina striata d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 269.

Bulimina buchiana d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 186, pl. 11, figs. 15–18.

Bulimina inflata Seguenza, 1862, Atti Accad. Gioenia Sci. Nat. Catania, ser. 2, vol. 18, p. 109, pl. 1, fig. 10.

Bulimina inflata Seguenza var. *mexicana* Cushman, 1922, Bull. U. S. Nat. Mus., vol. 104, p. 95, pl. 21, fig. 2.

The associations of costate buliminids in our samples are considered to consist of one species; all types cited above can be recognized in our material. Considerable variation exists in L/W ratio and in length of the costae. In certain laminites, all individuals in the association may be relatively slender, whereas this is not the case in underlying and overlying intervals.

The species is more tolerant to oxygen deficiency than *Uvigerina pygmea*, *Bulimina subulata*, *Gyroidina* species and lagenid foraminifera, but is replaced by an association of *Bolivina spathulata*, *Bulimina exilis*, *Uvigerina bononiensis* and *U. cylindrica* when oxygen content becomes too low.

Bulimina elongata d'Orbigny
Pl. 9, figs. 8, 9

Bulimina elongata d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 187, pl. 11, figs. 19, 20.

The species can either cope with extremely low-oxygen conditions, or it has to be regarded as an epiphyte.

Bulimina exilis Brady
Pl. 9, figs. 10–12

Bulimina elegans d'Orbigny var. *exilis* Brady, 1884, Rep. Chall. Exp., vol. 9, p. 399, pl. 50, figs. 5, 6.
Buliminella subfusiformis Cushman var. *tenuata* Cushman, 1927, Bull. Scripps Inst. Oceanogr., tech. ser., vol. 1, p. 149, pl. 2, fig. 9.

The basal spine is not present in all specimens. The width of the aperture is subject to variation.

The species is most frequent in sapropels and diatomites deposited in nearly oxygen depleted waters.

Bulimina subulata Cushman and Parker
Pl. 5, figs. 1–3

Bulimina elongata d'Orbigny var. *subulata* Cushman and Parker, 1937, Contr. Cushm. Lab. Foram. Res., vol. 13, p. 51, pl. 7, figs. 6, 7.
Bulimina elongata d'Orbigny var. *lappa* Cushman and Parker, 1937, Contr. Cushm. Lab. Foram. Res., vol. 13, p. 51, pl. 7, fig. 8.

B. elongata var. *lappa* is commonly recognized in the *subulata*-variation. It is most frequently observed in the stratigraphically highest levels of sections Finikia, Aghios Vlassios and Prassas and in section Fortetsa. In our Cretan samples, the species shows a frequency-drop in homogeneous and laminated sediments between the successive entry and exit levels of *Globorotalia puncticulata* and *G. margaritae*.

Cancris auricula (Von Fichtel and Von Moll)
Pl. 8, figs. 4, 5a, b

Nautilus auricula Von Fichtel and Von Moll, 1798, Test. Micr. Arg. Naut., p. 108, 110, pl. 20, figs. a–f.

Rotalina (Rotalina) sagra d'Orbigny in De la Sagra, 1839, Hist. Phys. Nat. Ile Cuba, "Foraminifères", p. 77, figs. in vol. 8, pl. 5, figs. 13–15.
Valvulina oblonga d'Orbigny, 1839, Hist. Nat. Iles Can., vol. 2, p. 136, pl. 1, figs. 40–42.

The chambers may be short or elongate. In the Pliocene the species was able to thrive in oxygen-deficient waters. It is often found together with *Bulimina costata.*

Cassidulina laevigata d'Orbigny
Pl. 2, fig. 4

Cassidulina laevigata d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 282, pl. 15, figs. 4, 5.
Cassidulina laevigata d'Orbigny var. *carinata* Silvestri, 1896, Mem. Accad. Pont. Nuovi Lincei, vol. 12, p. 104, pl. 2, fig. 10.

In *C. laevigata* we included keeled forms. The species seems to have lived in a somewhat deeper environment than that occupied by abundant vegetation. In this environment it was accompanied by *Cibicides ungerianus.*

Cassidulina subglobosa Brady
Pl. 2, fig. 5

Cassidulina subglobosa Brady, 1881, Quart. Jour. Micr. Sci., vol. 21, p. 60.

Cibicides bradyi (Trauth)
Pl. 4, figs. 1a–c

Truncatulina bradyi Trauth, 1918, Denkschr. K. Akad. Wiss. Wien, vol. 95, p. 235.

Cibicides dutemplei (d'Orbigny)
Pl. 4, figs. 2, 3a, b

Rotalina dutemplei d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 157, pl. 8, figs. 19–21.

Biconvex specimens are more common than the planoconvex type figured by d'Orbigny.

Cibicides lobatulus (Walker and Jacob)
Pl. 12, figs. 1a–c

Nautilus lobatulus Walker and Jacob in Kanmacher, 1798, Adam's Ess. Micr., p. 642, pl. 14, fig. 36.

Cibicides ungerianus (d'Orbigny)
Pl. 3, figs. 1–4

Rotalina ungeriana d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 157, pl. 8, figs. 16–18.
Truncatulina pachyderma Rzehak, 1886, Verh. Naturf. Ver. Brünn, vol. 24, p. 87, pl. 1, fig. 5.

Truncatulina floridana Cushman, 1918, Bull. U. S. Geol. Surv., vol. 676, p. 62, pl. 19, fig. 2.
Cibicides kullenbergi Parker, 1953, Rep. Swed. Deep-Sea Exp., vol. 7, p. 49, pl. 11, figs. 7, 8.

Variation is most conspicuous in the degree of convexity of the spiral and umbilical sides, the curvature of the sutures and the perforation of the test. Specimens with coarse perforation on their umbilical side, in which the sutures lack the typical "hook", resemble *Truncatulina floridana.* Individuals without the large pores on the umbilical side we can refer to *Truncatulina pachyderma* or *Cibicides kullenbergi.* If we consider the adult specimens, all mentioned morphotypes can be recognized within one association; transitions from one to the other are gradual. Non of the different types was found to show a trend in relative frequencies.

Dentalina communis (d'Orbigny)
Pl. 6, fig. 4

Nodosaria (Dentaline) communis d'Orbigny, 1826, Ann. Sci. Nat., sér. 1 vol. 7, p. 254.

Dentalina filiformis (d'Orbigny)
Pl. 6, fig. 5

Nodosaria (Nodosaire) filiformis d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 253.

Dorothia gibbosa (d'Orbigny)
Pl. 1, fig. 5

Textularia gibbosa d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 262, mod. no. 28.

In general, agglutinated foraminifera are strikingly absent in samples from laminated layers, even in allochthonous associations (cf. fig. 24). It is concluded that the arenaceous foraminifera prefer oxygenated waters and that they are not susceptible to transportation. The poor preservation potential of agglutinants may be another reason for their absence in displaced associations.

Elphidium aculeatum (d'Orbigny)
Pl. 12, fig. 3

Polystomella aculeata d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 131, pl. 6, figs. 27, 28.

Elphidium crispum (Linnaeus)
Pl. 12, fig. 4

Nautilus crispus Linnaeus, 1758, Syst. Nat., vol. 1, p. 709.
Nautilus macellus Von Fichtel and Von Moll, 1798, Test. Micr. Arg. Naut., p. 66, pl. 10, figs. h–k.

The absence of an umbilical knob is not considered relevant to discriminate at the species level.

The numerous *Elphidium* species all exhibit similar frequency-patterns: they are most abundant in allochthonous associations. For this reason, they were included in the group of epiphytes.

Elphidium fichtellianum (d'Orbigny)
Pl. 12, fig. 2

Polystomella fichtelliana d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 125, pl. 6, figs. 7, 8.

Fursenkoina sp.
Pl. 9, figs. 6, 7

Test small; triserial portion much reduced, biserial part twisted; chamber-height and -width almost equal; wall opaque, but often transparent along the upper chamber-margins; aperture loop-shaped.

This species can thrive in extremely oxygen-poor environments. In the 125–595 μ size-fraction, it is outnumbered by *Bolivina spathulata, Bulimina exilis* and *Uvigerina bononiensis*, however, and hardly ever shows up in the counts.

Gyroidina soldanii d'Orbigny
Pl. 5, figs. 8, 9

Gyroidina soldanii d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 278, mod. no. 36.

G. soldanii is often found together with *Oridorsalis stellatus* and *Oridorsalis* sp. in sapropels formed under slightly stagnant conditions.

Hanzawaia boueana (d'Orbigny)
Pl. 12, figs. 5a, b

Truncatulina boueana d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 169, pl. 9, figs. 24–26.

In this study *H. boueana* is considered as having an adhering mode of life.

Heronallenia lingulata (Burrows and Holland)
Pl. 2, figs. 1a, b

Discorbina lingulata Burrows and Holland, 1895, Monogr. Foram. Crag, pt. 2, pl. 7, fig. 33.

This species was only recorded twice in the 125–595 μ fraction, but in the 60–125 μ fraction of the samples from section Kalithea 2 it was observed more often.

Karreriella affinis (Fornasini)
Pl. 1, fig. 3

Sagraina affinis Fornasini, 1883, Boll. Soc. Geol. Ital., vol. 2, p. 189, pl. 2, fig. 10.

Karreriella bradyi (Cushman)
Pl. 1, fig. 4

Gaudryina bradyi Cushman, 1911, Bull. U. S. Nat. Mus., vol. 71, p. 67, tf. 107.

Marginulina costata (Batsch)
Pl. 6, figs. 10, 11

Nautilus (Orthoceras) costatus Batsch, 1791, Test. Aren. Mar. Tab., pl. 1, fig. 1.
Marginulinopsis densicostata Thalmann, 1937, Ecl. Geol. Helv., vol. 30, p. 347, pl. 21, fig. 2.

Marginulinopsis densicostata most probably represents the microspheric generation of *M. costata.*

Marginulina hirsuta d'Orbigny
Pl. 6, fig. 12

Marginulina hirsuta d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 259.

Martinottiella communis (d'Orbigny)
Pl. 1, fig. 6

Clavulina communis d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 196, pl. 12, figs. 1, 2.

Nodosaria albatrossi Cushman
Pl. 6, fig. 6

Nodosaria vertebralis (Batsch) var. *albatrossi* Cushman, 1923, Bull. U. S. Nat. Mus., vol. 104, p. 87, pl. 15, fig. 1.

In our opinion, close affinity with *Nautilus vertebralis* cannot be proven, because the specimen figured by Batsch lacks both the initial and terminal parts.

Nodosaria catenulata Brady
Pl. 6, fig. 7

Nodosaria catenulata Brady, 1884, Rep. Chall. Exp., vol. 9, p. 515, pl. 63, figs. 32–34.

Nodosaria hispida d'Orbigny
Pl. 6, fig. 8

Nodosaria hispida d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 35, pl. 1, figs. 24, 25.

Nonion barleeanum (Williamson)
Pl. 2, figs. 2a, b

Nonionina barleeana Williamson, 1858, Rec. Foram. G. B., p. 32, pl. 3, figs. 68, 69.

Nonion pompilioides (Von Fichtel and Von Moll)
Pl. 2, figs. 3a, b

Nautilus pompilioides Von Fichtel and Von Moll, 1798, Test. Micr. Arg. Naut., p. 31, pl. 2, figs. a–c.
Nonionina soldanii d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 109, pl. 5, figs. 15, 16.

N. barleeanum and *N. pompilioides* occur in all normal marine associations.

Oridorsalis stellatus (Silvestri)
Pl. 5, figs. 4a, b

Truncatulina tenera? Brady var. *stellata* Silvestri, 1898, Mem. Accad. Pont. Nuovi Lincei, vol. 15, p. 297, pl. 6, fig. 9.
Oridorsalis westi Andersen, 1961, Bull. Geol. Surv. Louis., vol. 35, p. 107, pl. 22, fig. 3.

Oridorsalis sp.
Pl. 5, figs. 5–7

Test biconvex, periphery broadly rounded; chambers in trochoid arrangement, seven to eight in a whorl, somewhat inflated; on the spiral side, small secondary openings are present at the posterior part of the chambers, near the meeting-point of the spiral and septal sutures; aperture an interiomarginal slit.

The general characters of our species remind of *Gyroidina*, but the supplementary openings permit allocation to the genus *Oridorsalis*. *Gyroidina umbonata* Silvestri sensu Le Calvez (1974, Cah. Micr., no. 1, p. 74, fig. 2) is a similar species, but has only 5½ chambers in the last whorl.

The species is most frequent in samples from laminated sediments (maximum frequency 20%), deposited in moderately oxygen-poor waters. Here, it is accompanied by high relative numbers of *Bolivina antiqua* and *Bulimina costata*.

Planorbulina mediterranensis d'Orbigny
Pl. 12, fig. 6

Planorbulina mediterranensis d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 280, pl. 14, figs. 4–6.

Reussella spinulosa (Reuss)
Pl. 12, fig. 9

Verneuilina spinulosa Reuss, 1850, Denkschr. K. Akad. Wiss. Wien, vol. 1, p. 374, pl. 47, fig. 12.

This species is mostly found together with epiphytic taxa. In this respect, the distribution pattern of *R. spinulosa* in the Upper Miocene of Crete (Van der Zwaan, 1982) is similar to that in the Pliocene. In the computer analyses, species of *Reussella* were not included in the group of epiphytes. Since they are never found in high percentages, we assume that this omission did not seriously influence our results.

Reussella sp.
Pl. 12, fig. 10

The frequency distribution of this species is similar to that of *R. spinulosa.*

Rosalina globularis d'Orbigny
Pl. 12, figs. 7, 8

Rosalina globularis d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 271, pl. 13, figs. 1–4.

Sigmoilopsis schlumbergeri (Silvestri)
Pl. 1, fig. 8

Sigmoilina schlumbergeri Silvestri, 1904, Mem. Accad. Pont. Rom. Nuovi Lincei, vol. 22, p. 267.

Siphonina planoconvexa (Silvestri)
Pl. 2, fig. 6

Truncatulina reticulata (Czjzek) var. *plano-convexa* Silvestri, 1898, Mem. Accad. Pont. Nuovi Lincei, vol. 15, p. 300, pl. 6, fig. 12.

Siphonina reticulata (Czjzek)
Pl. 2, figs. 7, 8

Rotalina reticulata Czjzek, 1848, Nat. Abh., vol. 2, p. 145, pl. 13, figs. 7–9.
Siphonina bradyana Cushman, 1927, Proc. U. S. Nat. Mus., vol. 72, p. 11, pl. 1, fig. 4.

In the type-figure of *S. bradyana*, the pores are confined to the area adjoining the chamber sutures. In our material, such forms occur together with individuals having a more areal pore distribution. As *S. planoconvexa*, this species is most common in sediments that bear witness to a normal marine environment.

Stilostomella adolphina (d'Orbigny)
Pl. 6, fig. 13

Dentalina adolphina d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 51, pl. 2, figs. 18–20.

Stilostomella advena (Cushman and Laiming)
Pl. 9, figs. 4, 5

Nodogenerina advena Cushman and Laiming, 1931, Jour. Pal., vol. 5, p. 106, pl. 11, fig. 19.
Ellipsonodosaria oinomikadoi Ishizaki, 1943, Trans. Nat. Hist. Soc. Taiwan, vol. 33, p. 685, pl. (?), figs. 7–10.

Specimens with longitudinal striations are identical with *E. oinomikadoi.* SEM-photographs reveal that such striae are not produced on the outer test-surface.

The species is most frequent in the sapropels of sections Kalithea and Prassas.

Textularia depressula Christodoulou
Pl. 1, fig. 7

Textularia marinosi Christodoulou subsp. *depressula* Christodoulou, 1960, Palaeontogr., vol. 115, p. 82, pl. 11, figs. 6, 7.

Uvigerina angulosa Williamson
Pl. 4, fig. 5

Uvigerina angulosa Williamson, 1858, Rec. Foram. G. B., p. 67, pl. 5, fig. 140.

A triangular cross-section is not considered a suitable criterion for the separation of a different genus (i.c. *Trifarina*).

Uvigerina bononiensis Fornasini
Pl. 10, figs. 1–12

Uvigerina bononiensis Fornasini, 1888, Boll. Soc. Geol. Ital., vol. 7, p. 48, pl. 3, fig. 12.
Uvigerina parkeri Karrer, 1877, Abh. Austria K. K. Geol. Reichsanst., vol. 9, p. 385, pl. 16b, fig. 50.
Uvigerina compressa Cushman, 1925, Contr. Cushm. Lab. Foram. Res., vol. 1, p. 10, pl. 4, fig. 2.
Uvigerina parkeri Karrer subsp. *breviformis* Papp and Turnovsky, 1953, Jahrb. Geol. Bundesanst. Austria, vol. 96, p. 122, pl. 5, figs. A (3, 4).

A wide variation exists in some samples. Relatively slender types with loosely packed chambers, of which the costae end in spines, are identical with *U. compressa.* Forms with a reduced triserial part, high chambers and relatively weak ornamentation resemble – with a little imagination – *U.*

parkeri. *U. parkeri breviformis* can be recognized in thick-set, low-chambered specimens without or with slight ornamentation. All the mentioned types show intergradations with the typical *U. bononiensis*, which is dominant in all samples.

The species was able to live in waters with a severely reduced oxygen content. From recent environments, the species is unknown to us.

Uvigerina bradyi (Cushman)
Pl. 4, fig. 6

Trifarina bradyi Cushman, 1923, Bull. U. S. Nat. Mus., vol. 104, p. 99, pl. 22, figs. 3–9.

Uvigerina carinata (Cushman)
Pl. 7, fig. 4

Angulogerina carinata Cushman, 1927, Bull. Calif. Univ. Scripps Inst. Oceanogr., vol. 1, p. 159, pl. 4, fig. 3.
Angulogerina fornasinii Selli, 1948, Atti Soc. Ital. Sci. Nat., vol. 87, p. 40, fig.: p. 43, tfs. 1–4.

Variation exists in the width of the keels. The triangular cross-section becomes evident during ontogeny. Young specimens resemble *Uvigerina rutila*. The species is mostly observed in thin laminites.

Uvigerina cylindrica (d'Orbigny) subsp. cylindrica (d'Orbigny)
Pl. 9, fig. 1

Clavulina cylindrica d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 268.

U. cylindrica cylindrica is never a conspicuous faunal element.

Uvigerina cylindrica (d'Orbigny) subsp. gaudryinoides Lipparini
Pl. 9, fig. 3

Uvigerina tenuistriata Reuss var. *gaudryinoides* Lipparini, 1932, Giorn. Geol., ser. 2, vol. 7, p. 65, pl. 3, figs. 7, 8.

The subspecies *gaudryinoides* was very prolific in low-oxygen environments. It became extinct shortly after the last occurrence of *Globorotalia puncticulata*.

Uvigerina ex. interc. cylindrica – gaudryinoides
Pl. 9, fig. 2

The intermediate assemblages are mostly found in samples from laminated sediments; they are never as frequent as those of *U. cylindrica gaudryinoides*.

Uvigerina longistriata Perconig
Pl. 4, fig. 8

Uvigerina longistriata Perconig, 1955, Boll. Ital. Serv. Geol., vol. 77, p. 182, pl. 2, figs. 1–4.
Uvigerina striatissima Perconig, 1955, Boll. Ital. Serv. Geol., vol. 77, p. 187, pl. 3, figs. 1–4.

The species occurs throughout the Pliocene interval we studied. Weakly ornamented individuals may be confused with *Uvigerina rutila.*

Uvigerina proboscidea Schwager
Pl. 4, fig. 7

Uvigerina proboscidea Schwager, 1866, Novara Exp., Geol. Theil, vol. 2, p. 250, pl. 7, fig. 96.

U. proboscidea is never found in high numbers. In our sections, it is most common in the homogeneous sediments.

Uvigerina pygmea d'Orbigny
Pl. 7, figs. 2, 3

Uvigerina pigmea d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 269, pl. 12, figs. 8, 9.
Uvigerina peregrina Cushman, 1923, Bull. U. S. Nat. Mus., vol. 104, p. 166, pl. 42, figs. 7–10.

In the Kourtes marls, specimens are relatively small, loose-coiled and have spinose terminal chambers. Stouter forms occur higher up in some of our sections. The species can be numerous in thin sapropels, in the company of lagenid foraminifera and *B. subulata.* With decreasing oxygen content, these foraminifera are replaced by an association of *Bulimina costata, Cancris auricula* and allies.

Uvigerina rutila Cushman and Todd
Pl. 4, fig. 4

Uvigerina rutila Cushman and Todd, 1941, Contr. Cushm. Lab. Foram. Res., vol. 17, p. 78, pl. 20, figs. 16–22.

Above the last occurrence of *Globorotalia margaritae*, the species disappears from our record.

Vaginulina bononiensis (Fornasini)
Pl. 6, fig. 9

Marginulina bononiensis Fornasini, 1883, Boll. Soc. Geol. Ital., vol. 2, p. 187, pl. 2, fig. 7.

Valvulineria complanata (d'Orbigny)
Pl. 8, figs. 1a, b

Rosalina complanata d'Orbigny, 1846, Foram. Foss. Bass. Tert. Vienne, p. 175, pl. 10, figs. 13–15.
Discorbina bradyana Fornasini, 1900, Mem. R. Accad. Sci. Ist. Bologna, ser. 5, vol. 8, p. 393, fig. 43.

Commonly found together with *Cancris auricula.* Its environmental demands are probably quite the same.

Vulvulina pennatula (Batsch)
Pl. 1, fig. 9

Nautilus (Orthoceras) pennatula Batsch, 1791, Test. Aren. Mar. Tab., pl. 4, fig. 13.

The only agglutinant which is more frequent in the laminated sediments. However, it sporadically enters the 200-counts.

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Samples	U. cylindrica	U. bononiensis	B. exilis	B. spathulata	Bolivina spp.	B. costata	B. subulata	Uvigerina s.s.	Lagenids	Cancris c.s.	Gyr./Orid.	B. subexcavata	Epiphytes	C. laevigata	Cibicides spp.	Agglutinants	S. advena	Rest-group	Indeterminable	Total	Nr. of planktonics	Lithology
2201	0	1	3	7	9	2	0	2	1	1	2	37	49	2	1	6	1	69	7	200	380	h
2202	0	5	58	66	4	0	0	1	3	0	2	13	14	6	1	0	2	23	2	200	114	l
2203	0	0	9	13	11	0	0	0	3	0	3	30	45	13	5	5	0	58	5	200	224	h
2204	0	0	52	58	5	1	0	0	2	0	1	23	17	6	2	1	2	26	4	200	152	l
2205	0	1	4	16	12	3	0	2	0	0	9	37	36	6	18	11	0	38	7	200	213	h
2206	0	1	0	7	9	7	0	3	4	0	6	46	34	8	2	6	0	61	6	200	358	h
2207	0	0	0	3	11	4	1	3	2	0	4	59	41	4	4	8	0	50	6	200	340	h
2208	0	0	2	2	8	0	0	2	4	0	2	37	57	5	2	6	0	64	9	200	537	h
2209	0	0	2	2	10	2	1	6	3	0	11	40	40	9	4	7	0	59	4	200	316	h
2210	0	4	77	62	1	3	0	1	1	0	4	11	13	1	2	0	1	15	4	200	83	l
2211	1	0	4	7	13	1	1	4	3	1	2	38	48	7	6	8	0	51	5	200	244	h
2212	0	1	90	42	1	0	0	0	0	1	0	8	14	3	1	1	5	28	5	200	115	l
2213	0	3	37	37	5	0	2	2	1	0	5	22	24	7	1	3	2	45	4	200	195	h
2214	0	5	80	50	3	0	0	3	0	0	2	9	7	4	0	1	9	26	1	200	71	l
2215	1	0	2	9	17	2	0	2	2	0	4	38	43	9	4	9	1	50	7	200	207	h
2216	0	0	1	2	9	3	0	1	2	0	3	38	42	9	5	10	0	70	5	200	255	h
2217	0	0	3	2	6	0	0	1	1	0	8	50	47	8	2	2	0	62	8	200	416	h
2218	2	2	106	61	2	0	0	0	0	1	1	1	2	0	0	0	3	15	4	200	16	l
2219	0	0	29	23	6	0	0	2	3	0	4	25	36	6	2	6	0	51	7	200	410	h
2220	0	1	3	9	7	1	2	3	1	0	5	43	44	8	0	6	0	59	8	200	338	h
2221	0	1	18	12	6	2	0	1	2	1	3	45	60	3	0	2	0	39	5	200	320	l
2222	1	0	7	13	7	0	0	1	1	1	1	46	60	8	1	0	0	45	8	200	470	l
2223	1	0	6	14	7	2	1	1	1	2	8	27	47	13	2	12	0	50	6	200	266	h
2224	0	1	3	9	5	0	0	1	2	0	7	45	60	10	2	6	0	43	6	200	373	l
2225	1	0	2	17	10	2	0	1	1	1	4	46	57	6	3	2	0	41	6	200	363	l
2226	1	0	3	3	11	4	1	0	2	0	3	41	42	13	2	7	0	60	7	200	305	h
2227	4	3	41	15	3	1	0	1	5	2	7	34	23	6	0	9	0	43	3	200	304	h
2228	0	3	4	5	4	0	2	1	1	0	13	36	47	11	1	10	0	57	5	200	226	h
2229	2	2	6	13	7	0	1	1	1	2	4	57	45	5	0	5	0	46	3	200	358	l
2230	0	1	3	12	3	0	0	1	3	0	6	44	48	6	4	3	0	58	8	200	356	h
2231	0	1	5	12	9	2	1	5	2	1	3	32	45	13	2	9	0	51	7	200	263	h
2232	4	1	7	17	12	2	1	1	1	0	4	42	51	5	4	1	0	42	5	200	354	l
2233	1	4	15	18	9	2	1	3	2	0	6	48	26	2	2	5	0	47	9	200	241	h
2234	1	0	7	15	13	2	0	3	2	0	6	41	41	10	1	6	0	49	3	200	266	h
2235	0	0	9	10	14	2	1	4	3	0	6	31	42	8	2	3	0	58	7	200	332	h
2236	2	1	5	10	3	0	0	1	3	0	3	50	58	1	2	0	0	52	9	200	568	l
2237	3	1	8	24	7	2	0	2	1	0	5	36	38	11	1	4	0	51	6	200	298	h
2238	4	0	6	23	9	4	1	1	0	0	10	48	34	8	3	7	0	38	4	200	265	h
2239	0	0	3	12	3	2	2	2	1	0	5	46	67	9	2	2	0	38	6	200	476	l
2240	1	1	5	15	7	5	2	0	4	0	11	35	36	9	3	10	0	49	7	200	337	h
2241	1	6	36	54	10	2	0	1	2	0	2	28	6	1	0	1	0	47	3	200	129	l
2242	1	3	13	14	4	2	0	3	6	0	6	29	34	7	1	4	0	68	5	200	363	h
2243	1	0	3	6	5	2	0	3	2	0	8	46	42	14	3	8	0	51	6	200	350	h
2244	1	1	35	72	2	0	0	0	0	0	2	18	26	5	0	3	0	32	3	200	190	l
2245	2	2	15	26	4	1	4	1	0	0	3	32	38	7	2	4	0	52	7	200	338	h
2246	0	1	6	16	8	0	1	2	2	1	8	34	31	11	1	4	0	68	6	200	277	h
2247	2	4	10	44	2	0	0	1	1	0	1	37	45	4	1	2	0	43	3	200	618	l
2248	1	1	16	33	5	0	1	4	0	1	6	29	38	3	2	9	0	41	10	200	282	h
2249	0	1	3	18	7	0	0	3	2	0	3	40	41	8	4	8	0	59	3	200	196	h
2250	6	2	38	72	3	1	1	1	0	0	2	15	19	4	1	3	2	28	2	200	189	l
2251	5	4	39	62	3	0	1	3	1	0	1	20	22	2	4	4	1	26	2	200	182	h
2252	0	3	6	13	12	0	0	4	1	2	6	28	48	7	4	18	0	43	5	200	242	h
2253	7	11	32	57	4	0	1	4	2	0	4	13	19	2	1	8	0	27	8	200	194	h
2254	5	10	19	66	3	0	0	1	5	0	1	12	16	4	2	6	0	44	6	200	194	h

Table VI: Distribution chart of benthonic foraminifera in the 63–125μ size-fraction of section Kalithea 2.

Samples	*U. cylindrica*	*U. bononiensis*	*B. exilis*	*B. spathulata*	*Bolivina* spp.	*B. costata*	*B. subulata*	*Uvigerina* s.s.	Lagenids	*Cancris* c.s.	*Gyr./Orid.*	*B. subexcavata*	Epiphytes	*C. laevigata*	*Cibicides* spp.	Agglutinants	*S. advena*	Rest-group	Indeterminable	Total	Nr. of planktonics	Lithology
2201	0	4	6	29	3	1	1	5	15	2	6	24	31	2	15	11	4	37	4	200	371	h
2202	1	48	28	85	2	1	0	1	3	0	1	4	4	0	1	0	15	6	0	200	38	l
2203	0	9	9	29	9	2	0	4	5	0	5	27	28	1	16	14	2	38	2	200	258	h
2204	0	18	41	98	3	0	0	3	3	1	2	4	4	1	2	0	12	8	0	200	81	l
2205	0	3	2	23	8	4	0	1	11	4	4	27	33	4	18	7	3	47	1	200	258	h
2206	0	1	2	11	5	18	0	10	9	3	10	29	32	0	19	18	0	38	3	200	440	h
2207	0	2	0	5	9	1	0	6	12	2	10	43	29	3	25	7	2	40	4	200	365	h
2208	0	1	1	6	7	0	0	11	16	4	6	32	28	2	27	16	1	39	3	200	503	h
2209	0	0	1	2	2	4	0	10	9	1	3	19	45	5	35	14	0	47	3	200	406	h
2210	0	43	71	72	1	0	0	1	2	0	1	2	2	0	0	0	4	1	0	200	19	l
2211	0	3	3	13	17	3	1	10	13	1	7	25	18	7	23	12	2	39	3	200	190	h
2212	2	23	58	88	1	2	0	2	0	6	0	2	4	0	1	0	7	2	2	200	63	l
2213	0	18	25	53	9	3	0	7	6	5	4	18	8	2	14	4	5	18	1	200	138	h
2214	2	31	72	57	1	1	0	0	1	0	1	5	1	0	2	0	24	2	0	200	55	l
2215	1	5	4	8	6	4	1	8	7	1	2	24	20	7	40	9	0	48	5	200	199	h
2216	0	2	2	7	5	2	0	6	16	2	6	33	18	5	25	20	0	49	2	200	237	h
2217	1	0	10	16	2	5	0	2	15	2	5	20	25	1	26	15	4	49	2	200	336	h
2218	5	3	98	81	0	0	0	0	0	1	0	0	1	0	0	0	10	1	0	200	17	l
2219	2	5	33	85	6	2	0	1	7	1	1	12	10	0	12	2	4	16	1	200	188	h
2220	2	3	9	25	12	3	0	4	8	3	4	33	22	1	20	7	0	43	1	200	299	h
2221	2	2	31	63	3	0	0	2	5	0	2	24	35	2	6	3	2	18	0	200	476	l
2222	4	3	13	56	5	3	1	3	7	1	0	28	29	3	4	4	3	32	1	200	584	l
2223	5	0	3	54	12	2	1	4	12	0	4	20	27	2	16	10	0	25	3	200	171	h
2224	0	1	2	27	9	0	1	6	8	1	4	43	32	2	27	5	2	29	1	200	736	l
2225	5	1	1	22	7	2	0	2	7	0	2	50	39	1	20	5	0	34	2	200	562	l
2226	1	2	0	18	5	5	0	7	7	1	3	25	33	3	34	7	0	45	4	200	348	h
2227	8	19	19	25	3	1	1	5	6	1	5	20	22	1	21	9	0	32	2	200	183	h
2228	0	1	3	13	19	1	1	2	10	0	10	30	27	3	22	10	0	45	3	200	277	h
2229	5	15	3	36	9	1	1	1	7	0	4	29	43	2	7	5	0	31	1	200	841	l
2230	7	23	6	42	7	0	0	2	10	1	1	27	27	3	7	3	0	34	0	200	479	h
2231	1	14	9	25	10	1	1	5	7	2	2	35	18	4	19	6	1	38	2	200	190	h
2232	7	18	2	18	9	3	0	8	8	1	3	29	32	2	24	2	0	30	4	200	593	l
2233	8	16	0	22	7	3	1	5	8	0	7	31	33	0	21	3	0	31	4	200	300	h
2234	4	5	0	7	8	2	2	9	11	1	3	33	26	2	24	12	0	49	2	200	277	h
2235	9	15	1	18	5	2	1	9	12	2	3	23	24	2	20	13	0	38	3	200	248	h
2236	7	19	6	34	5	0	2	6	11	1	0	32	36	1	13	3	0	22	2	200	809	l
2237	7	21	2	30	9	4	4	6	11	1	6	19	26	4	19	5	0	23	3	200	373	h
2238	6	14	2	24	14	4	2	9	9	0	7	21	23	4	19	9	0	30	3	200	269	h
2239	8	18	3	53	2	0	1	4	8	1	4	31	28	0	15	3	0	19	2	200	452	l
2240	4	5	1	32	5	4	0	5	10	0	5	36	14	0	21	12	2	41	3	200	217	h
2241	6	28	14	82	3	2	0	6	3	1	5	17	14	0	5	2	0	10	2	200	196	l
2242	8	18	10	55	7	1	2	5	7	1	3	23	11	2	13	5	0	25	4	200	147	h
2243	7	5	6	33	6	1	0	4	11	1	4	28	19	7	23	12	0	32	1	200	179	h
2244	10	22	20	105	1	0	1	1	3	0	0	8	11	0	4	0	0	13	1	200	136	l
2245	6	15	9	57	2	0	3	13	4	0	2	15	21	4	16	7	1	24	1	200	239	h
2246	5	5	3	51	4	2	2	6	4	1	2	26	22	4	22	4	0	35	2	200	195	h
2247	10	21	7	72	7	0	0	4	2	1	1	14	26	0	12	2	1	19	1	200	378	l
2248	12	23	13	57	6	0	0	4	3	0	2	13	20	2	10	9	1	25	0	200	241	h
2249	6	8	4	29	14	1	0	12	7	3	3	17	26	5	19	14	0	32	0	200	221	h
2250	33	15	58	80	2	0	0	0	3	0	2	1	2	0	0	0	0	4	0	200	38	l
2251	18	32	31	83	2	0	0	1	3	0	0	7	6	0	5	3	1	7	1	200	65	h
2252	8	25	8	37	14	0	1	5	6	1	6	11	18	2	13	7	1	31	6	200	166	h
2253	21	45	20	62	3	0	1	2	0	0	2	12	8	1	4	5	0	13	1	200	66	h
2254	17	44	23	85	3	1	0	1	1	1	1	2	4	0	3	3	1	10	0	200	42	h

Table VII: Distribution chart of benthonic foraminifera in the 125—595μ size-fraction of section Kalithea 2.

Samples	U. cylindrica	U. bononiensis	B. exilis	B. spathulata	Bolivina spp.	B. costata	B. subulata	Uvigerina s.s.	Lagenids	Cancris c.s.	Gyr./Orid.	B. subexcavata	Epiphytes	C. laevigata	Cibicides spp.	Agglutinants	S. advena	Rest-group	Indeterminable	Total	Nr. of planktonics	Lithology
2201	0	16	0	6	0	4	0	5	30	4	2	0	26	0	20	14	3	67	3	200	360	h
2202	0	148	1	13	1	0	0	1	3	12	0	0	0	0	5	0	4	10	2	200	39	l
2203	0	12	0	0	0	0	0	11	18	1	4	0	18	0	47	19	0	67	3	200	269	h
2204	0	53	0	10	1	3	0	3	9	25	3	0	7	0	19	3	11	53	0	200	237	l
2205	0	8	0	3	0	5	0	6	31	2	5	0	22	0	30	27	0	59	2	200	327	h
2206	0	0	0	1	0	4	0	5	20	1	7	0	15	0	45	24	0	76	2	200	620	h
2207	0	1	0	0	0	2	0	8	17	1	2	0	20	0	47	15	0	87	0	200	376	h
2208	0	1	0	0	0	2	0	10	32	1	6	0	15	0	40	28	0	64	1	200	540	h
2209	0	2	0	0	0	3	0	7	31	0	2	0	27	0	37	29	0	58	4	200	481	h
2210	0	163	1	9	0	1	0	0	3	15	0	0	1	0	0	0	2	5	0	200	35	l
2211	0	4	0	2	0	2	0	13	22	0	8	0	22	0	30	19	0	76	2	200	258	h
2212	0	142	1	8	0	1	0	0	3	6	1	0	4	0	4	1	12	16	1	200	126	l
2213	2	49	1	8	0	0	0	9	12	13	1	0	9	0	31	7	7	51	0	200	178	h
2214	1	148	2	3	0	0	0	1	2	1	2	0	2	0	2	0	32	4	0	200	40	l
2215	0	11	0	1	0	4	0	11	22	1	5	0	17	0	43	11	0	73	1	200	142	h
2216	1	5	0	1	0	3	0	5	22	2	1	0	27	0	40	35	0	56	2	200	268	h
2217	1	0	0	0	0	3	0	9	21	3	7	0	19	0	40	37	2	54	4	200	345	h
2218	115	4	4	8	0	0	0	0	0	13	0	0	2	0	2	1	43	8	0	200	56	l
2219	8	12	0	0	0	3	0	5	23	7	2	0	18	0	36	15	5	66	0	200	397	h
2220	0	1	0	0	0	2	0	18	26	2	1	0	16	0	51	22	0	67	2	200	309	h
2221	2	8	1	11	0	3	0	3	18	1	4	0	28	0	34	11	7	66	3	200	1740	l
2222	2	5	1	1	0	3	0	9	22	2	5	0	28	0	41	4	4	72	1	200	1626	l
2223	1	2	0	3	0	4	0	4	24	0	4	0	29	0	39	13	0	77	0	200	277	h
2224	1	5	0	3	0	3	0	6	17	1	5	0	34	0	45	5	1	71	3	200	1504	l
2225	1	9	0	0	0	2	0	8	27	0	1	0	22	0	28	1	0	101	0	200	915	l
2226	1	3	0	0	0	1	0	3	20	1	6	0	18	0	40	13	0	92	2	200	294	h
2227	3	31	0	0	0	0	0	5	28	4	9	0	17	0	21	14	0	68	0	200	230	h
2228	1	1	0	0	0	1	0	2	28	2	3	0	29	0	33	22	0	78	0	200	175	h
2229	9	47	0	0	0	5	2	10	16	2	4	0	32	0	24	1	0	47	1	200	1705	l
2230	4	54	0	0	0	0	0	9	17	2	2	0	23	0	27	6	1	54	1	200	668	h
2231	1	26	0	1	0	7	0	6	22	0	3	0	26	0	32	11	0	65	0	200	317	h
2232	4	32	0	0	0	1	0	7	11	3	2	0	28	0	36	7	0	68	1	200	912	l
2233	5	41	0	0	0	0	0	7	19	0	3	0	22	0	31	16	0	56	0	200	393	h
2234	2	23	0	0	0	0	0	9	27	0	2	0	21	0	33	18	0	64	1	200	210	h
2235	1	18	0	0	0	1	0	6	24	3	4	0	22	0	45	23	0	61	0	200	289	h
2236	0	34	0	0	0	1	0	24	19	1	5	0	21	0	28	5	0	59	3	200	1315	l
2237	2	50	0	1	0	0	0	11	24	2	5	0	18	0	25	3	0	59	0	200	393	h
2238	2	32	0	0	0	1	0	18	21	1	5	0	17	0	33	16	0	52	2	200	314	h
2239	3	60	0	1	0	0	1	13	17	3	3	0	19	0	25	5	0	48	2	200	634	l
2240	8	24	0	2	0	1	0	10	11	2	0	0	26	0	43	19	0	53	1	200	305	h
2241	9	129	0	13	0	0	0	4	8	4	1	0	4	0	7	3	0	19	0	200	311	l
2242	12	77	0	2	0	0	0	8	12	1	3	0	12	0	22	8	0	43	0	200	237	h
2243	2	8	0	0	1	0	0	9	28	2	7	0	21	0	42	25	0	54	1	200	313	h
2244	45	98	0	23	0	1	0	2	2	2	0	0	4	0	3	3	2	14	1	200	329	l
2245	11	68	0	3	0	1	0	6	10	0	3	0	17	0	25	15	0	40	1	200	278	h
2246	13	22	0	5	0	6	1	14	21	5	2	0	11	0	31	7	0	61	1	200	370	h
2247	38	103	0	10	0	0	0	3	4	0	0	0	6	0	10	5	1	20	0	200	589	l
2248	13	81	0	3	0	0	0	12	11	2	1	0	8	1	25	7	0	35	1	200	461	h
2249	12	24	1	3	0	4	0	11	17	0	3	0	13	1	36	21	0	54	0	200	324	h
2250	98	77	1	6	0	0	0	0	0	1	0	0	0	0	0	0	8	9	0	200	44	l
2251	42	112	7	5	0	1	0	2	3	1	1	0	1	0	9	3	5	8	0	200	76	h
2252	12	45	2	3	0	1	0	12	11	0	6	0	15	0	23	20	0	50	0	200	156	h
2253	38	122	0	7	0	0	0	0	3	1	7	0	1	0	5	4	1	11	0	200	74	h
2254	10	170	1	12	0	0	0	0	2	1	0	0	1	0	0	1	0	2	0	200	37	h

Table VIII: **Distribution chart of benthonic foraminifera in the 200–595μ size-fraction of section Kalithea 2.**

Samples	U. cylindrica	U. bononiensis	B. exilis	B. spathulata	Bolivina spp.	B. costata	B. subulata	Uvigerina s.s.	Lagenids	Cancris c.s.	Gyr./Orid.	B. subexcavata	Epiphytes	C. laevigata	Cibicides spp.	Agglutinants	S. advena	Rest-group	Indeterminable	Total	Nr. of planktonics	Lithology
3351	5	0	0	2	3	1	0	4	9	1	11	57	30	0	21	16	0	40	0	200	562	h
3352	1	0	2	17	7	1	1	4	7	4	7	69	21	1	18	5	0	34	1	200	525	h
3353	3	1	8	14	1	5	0	3	6	3	3	80	21	0	10	10	0	31	1	200	554	h
3354	5	1	7	27	6	3	1	5	14	8	8	44	19	0	11	15	0	26	0	200	765	h
3355	1	1	16	38	7	0	0	4	6	6	4	58	19	1	16	8	0	15	0	200	700	h
3356	5	1	5	15	8	4	0	6	9	3	9	59	23	0	10	18	0	25	0	200	984	h
3357	5	2	50	114	1	2	0	1	1	9	0	5	5	0	1	0	0	4	0	200	135	l
3358	12	2	50	77	2	2	0	4	4	3	3	18	6	0	3	5	0	9	0	200	244	l
3359	4	0	30	57	1	0	1	8	10	5	1	34	11	1	10	4	1	22	0	200	520	h
3360	6	1	15	44	5	4	0	6	6	1	3	36	16	1	12	9	1	31	3	200	515	h
3361	4	1	21	39	8	3	0	4	9	2	5	53	12	0	10	8	0	21	0	200	367	h
3362	2	1	15	18	1	4	1	3	12	0	3	57	25	1	18	7	0	32	0	200	412	h
3363	2	2	4	18	3	1	0	3	13	5	6	48	21	0	19	12	0	41	2	200	477	h
3364	1	1	9	16	4	1	0	1	6	2	4	71	18	0	6	9	0	49	2	200	357	h
3365	1	1	5	24	4	3	0	0	6	4	2	74	29	1	5	7	0	34	0	200	337	h
3366	2	5	6	9	5	2	0	1	6	1	11	71	25	1	19	6	0	29	1	200	411	h
3367	2	2	5	17	2	3	0	1	9	1	8	69	27	2	14	11	0	27	0	200	348	h
3368	1	1	3	8	2	3	0	3	8	0	6	78	31	2	18	5	0	31	0	200	282	h
3369	0	2	5	9	4	0	1	1	5	3	12	77	28	0	13	7	0	33	0	200	367	h
3370	1	2	1	6	4	0	1	0	3	3	8	68	35	3	14	7	0	43	1	200	316	h
3371	3	2	2	7	2	1	0	1	6	3	8	86	22	1	9	13	0	34	0	200	370	h
3372	5	1	0	17	2	2	0	0	6	1	7	70	26	1	19	10	0	33	0	200	509	h
3373	5	0	7	13	1	0	1	2	8	1	6	64	29	0	16	16	0	30	1	200	518	h
3374	1	0	0	13	1	2	1	3	9	1	5	80	24	1	15	15	0	29	0	200	403	h
3375	5	1	0	7	6	2	0	6	7	2	8	66	21	3	15	11	0	39	1	200	376	h
3376	7	1	6	27	3	0	2	1	12	1	11	39	31	0	9	10	0	38	2	200	352	h
3377	21	2	11	31	11	7	0	2	8	15	9	36	18	1	7	3	1	15	2	200	419	l
3378	60	1	12	69	4	14	1	0	6	9	6	2	9	0	1	0	0	6	0	200	97	l
3379	73	1	17	81	7	5	0	0	1	3	4	4	2	0	0	0	0	2	0	200	43	l
3380	50	1	22	67	8	6	5	1	2	1	8	7	8	2	3	1	0	8	0	200	154	h
3381	43	1	0	34	5	11	0	2	7	6	7	33	15	9	4	2	0	20	1	200	326	h
3382	33	1	11	39	3	3	1	1	9	2	6	29	17	1	13	1	0	30	0	200	299	h
3383	14	1	12	51	2	2	4	1	3	4	10	34	21	1	5	13	0	22	0	200	345	h
3384	17	1	5	39	1	4	0	5	7	1	7	37	24	1	8	10	0	33	0	200	436	h
3385	9	3	5	26	5	2	0	1	9	0	4	42	29	5	19	11	0	30	0	200	370	h
3386	7	2	5	12	1	2	0	1	8	1	8	77	21	0	18	10	0	27	0	200	329	h
3387	6	1	3	17	0	1	0	5	6	2	7	52	29	2	15	13	0	40	1	200	370	h
3388	1	2	6	9	2	2	0	3	14	1	7	55	25	2	14	18	0	38	1	200	488	h
3389	5	0	0	16	3	1	0	5	10	1	2	51	34	1	14	16	0	39	2	200	552	h
3390	10	0	2	19	6	1	1	1	11	2	7	63	23	1	12	15	0	26	0	200	506	h
3391	3	0	1	13	4	2	0	4	6	3	7	80	19	0	10	9	0	39	0	200	498	h
3392	6	0	0	22	7	3	0	1	12	5	9	53	25	2	10	9	0	35	1	200	567	h
3393	99	0	0	53	4	0	0	2	7	6	6	12	4	0	0	1	0	6	0	200	100	l
3394	43	8	2	122	0	1	0	0	0	4	0	7	6	1	0	0	0	6	0	200	61	l
3395	33	3	2	147	0	0	0	1	1	1	1	1	6	0	0	2	0	1	1	200	81	l
3396	104	6	0	64	3	1	0	0	3	2	3	6	1	0	0	0	0	7	0	200	119	l
3397	66	4	1	55	2	2	0	4	9	2	8	11	7	3	4	5	0	17	0	200	261	h
3398	40	4	3	70	5	5	0	5	7	2	4	16	11	2	4	3	0	24	0	205	314	h
3399	37	4	5	59	2	2	1	2	4	1	1	21	21	3	5	3	0	29	0	200	298	h
3400	15	0	0	26	3	1	1	3	6	4	7	45	20	3	18	3	0	43	2	200	304	h

Table IX: Distribution chart of benthonic foraminifera in the detailed sampled part of section Finikia.

Samples	*U. cylindrica*	*U. bononiensis*	*B. exilis*	*B. spathulata*	*Bolivina* spp.	*B. costata*	*B. subulata*	*Uvigerina* s.s.	Lagenids	*Cancris* c.s.	*Gyr.*/Orid.	*B. subexcavata*	Epiphytes	*C. laevigata*	*Cibicides* spp.	Agglutinants	*S. advena*	Rest-group	Indeterminable	Total	Nr. of planktonics	Lithology
1074	0	4	2	36	4	9	8	11	11	1	7	25	22	0	15	5	4	32	4	200	340	h
1075	0	7	2	19	3	6	10	6	11	0	6	30	27	1	22	9	0	37	4	200	452	h
1076	0	4	3	11	4	0	29	9	7	0	9	25	37	0	17	13	0	30	2	200	598	h
1077	0	0	0	8	5	6	14	12	16	2	5	25	32	0	20	7	1	45	2	200	596	h
1078	0	1	0	7	7	3	8	31	13	1	1	16	26	0	23	18	2	42	1	200	914	h
1079	0	4	1	14	8	15	1	28	16	1	4	23	18	1	12	11	5	37	1	200	561	h
1080	2	13	0	47	14	21	6	10	10	1	2	11	10	2	10	0	4	31	6	200	273	l
1081	5	7	5	31	14	51	5	13	15	2	4	7	5	0	7	2	10	25	2	200	232	l
1082	12	6	7	47	14	24	3	9	14	2	1	11	5	1	12	3	8	18	3	200	176	l
1083	2	8	2	25	17	13	10	15	9	3	5	19	25	0	20	6	2	19	0	200	256	h
1084	0	15	7	37	6	2	4	6	10	0	4	22	24	0	14	9	2	36	2	200	306	h
1085	1	13	1	27	7	9	10	7	10	1	4	25	30	0	15	5	0	31	4	200	294	h
1086	0	10	1	13	7	5	12	2	9	1	5	35	30	0	22	10	0	36	2	200	373	h
1087	1	3	0	10	2	4	9	10	15	2	5	22	43	2	17	18	1	34	2	200	613	h
1088	1	2	1	16	9	7	4	17	16	5	5	11	33	0	21	9	3	39	1	200	531	h
1089	1	10	2	20	6	25	4	14	10	4	0	16	9	0	9	2	44	21	3	200	202	l
1090	0	7	1	43	16	48	3	23	7	6	1	2	3	0	2	5	12	17	4	200	72	l
1091	2	21	3	53	13	20	5	14	9	5	6	4	8	1	3	4	9	18	2	200	152	l
1092	1	19	1	33	7	14	7	14	14	0	6	13	21	1	10	4	1	34	0	200	274	h
1093	1	18	4	27	10	8	5	9	15	1	2	23	27	1	11	10	0	26	2	200	341	h
1094	1	5	0	8	3	4	24	15	14	1	9	32	22	0	10	7	0	41	4	200	639	h
1095	1	4	0	19	10	10	20	15	17	2	7	24	22	0	8	4	6	27	4	200	306	h
1096	2	15	0	31	12	44	7	4	11	5	3	5	9	0	3	0	37	12	0	200	95	l
1097	1	8	8	35	25	31	9	10	16	6	2	7	6	0	8	0	12	13	3	200	67	l
1098	8	4	2	20	46	19	8	8	21	0	3	7	12	0	15	1	3	23	0	200	110	l
1099	4	11	3	19	13	16	18	11	15	1	7	15	16	0	17	7	3	23	1	200	201	h
1100	3	11	1	21	11	9	12	6	15	2	10	20	27	1	12	6	2	27	4	200	279	h

Table X: Distribution chart of benthonic foraminifera in the detailed sampled part of section Prassas.

Samples	*U. cylindrica*	*U. bononiensis*	*B. exilis*	*B. spathulata*	*Bolivina* spp.	*B. costata*	*B. subulata*	*Uvigerina* s.s.	Lagenids	*Cancris* c.s.	*Gyr.*/Orid.	*B. subexcavata*	Epiphytes	*C. laevigata*	*Cibicides* spp.	Agglutinants	*S. advena*	Rest-group	Indeterminable	Total	Nr. of planktonics	Lithology
1007	0	5	4	38	2	0	4	9	2	1	4	19	35	9	20	12	0	34	2	200	108	h
1008	0	16	5	84	3	0	0	3	5	0	4	20	35	4	7	1	0	13	0	200	243	h
3364	0	81	25	52	0	0	0	2	0	3	3	5	16	2	1	0	0	8	2	200	218	l
3365	0	63	6	34	0	0	0	1	3	0	1	10	54	7	4	1	0	15	1	200	666	l
3366	0	33	12	40	0	0	0	1	3	1	3	10	60	7	4	2	0	20	4	200	548	l
3367	0	18	5	33	0	1	0	6	2	0	1	9	85	4	6	0	0	28	2	200	858	l
3368	0	16	5	37	4	0	1	5	4	1	5	7	73	3	6	0	0	31	2	200	832	l
3372	0	14	6	40	2	0	0	4	2	0	3	16	70	9	4	0	0	26	4	200	962	l
3376	0	6	1	10	1	0	3	4	4	0	1	12	108	11	3	1	0	32	3	200	1284	l
3378	0	11	0	16	4	0	1	3	5	4	1	16	88	9	6	2	0	31	3	200	1013	l
3379	0	20	9	49	0	3	2	14	2	0	14	12	27	9	14	2	0	20	3	200	254	h
3380	1	17	2	34	5	5	1	13	3	3	8	8	40	10	17	5	0	26	2	200	403	h
3381	0	40	26	27	3	0	1	5	2	2	5	6	42	1	6	0	0	30	4	200	867	l
3382	0	11	3	8	1	1	2	3	3	0	3	13	100	8	8	0	0	34	2	200	1373	l
3383	0	6	2	8	1	2	1	3	2	1	2	9	111	10	5	0	0	36	1	200	845	l
3384	0	8	2	6	1	1	2	1	6	2	3	16	91	18	5	0	0	38	0	200	1104	l
3385	0	2	1	6	1	0	1	1	3	2	0	5	117	19	6	0	0	36	0	200	1071	l
3389	0	8	1	2	2	0	6	1	0	2	1	13	114	28	0	0	0	22	0	200	1512	l
3393	0	11	0	4	2	1	1	0	2	0	1	8	113	20	4	0	0	30	3	200	538	l
3396	0	5	1	6	1	2	4	9	4	2	5	15	76	25	17	0	0	26	2	200	528	l

Table XI: Distribution chart of benthonic foraminifera in the thick diatomites of section Prassas.

Samples	U. cylindrica	U. bononiensis	B. exilis	B. spathulata	Bolivina spp.	B. costata	B. subulata	Uvigerina s.s.	Lagenids	Cancris c.s.	Gyr./Orid.	B. subexcavata	Epiphytes	C. laevigata	Cibicides spp.	Agglutinants	S. advena	Rest-group	Indeterminable	Total	Nr. of planktonics	Lithology
5323	0	10	16	30	1	2	0	3	14	0	3	35	20	1	18	7	0	37	3	200	812	h
5324	0	3	2	12	18	1	0	27	26	17	12	17	30	1	5	1	0	26	2	200	363	l
5325	1	6	3	14	5	1	0	5	11	2	8	38	38	2	26	4	0	36	0	200	486	h
5326	0	2	6	7	7	5	0	44	26	10	9	20	23	0	10	2	0	27	2	200	386	l
5329	0	1	0	5	4	5	1	9	8	1	10	40	30	1	18	8	0	57	2	200	933	h
5332	1	0	0	4	7	9	1	15	24	31	13	21	19	1	20	4	0	28	2	200	375	l
5333	0	1	1	2	8	4	0	2	7	1	7	35	26	0	31	13	0	62	0	200	325	h
5334	2	2	2	5	13	4	0	22	21	51	19	16	11	0	10	0	0	17	5	200	135	l
5335	0	4	1	8	4	0	0	3	7	3	8	44	29	0	29	4	0	56	0	200	328	h
2000	4	0	0	2	6	3	0	5	18	2	3	43	28	3	27	15	0	40	1	200	461	h
2001	62	1	9	96	1	1	0	1	2	6	1	7	6	0	2	2	0	3	0	200	195	l
2004	2	0	0	5	3	4	0	1	15	1	4	49	34	2	23	13	0	44	0	200	507	h
2005	62	0	1	60	2	0	0	2	4	19	2	13	9	0	10	2	0	13	1	200	171	l
2008	1	1	1	3	3	1	1	1	11	4	2	50	24	8	22	17	0	50	0	200	514	h
2009	10	0	1	102	0	1	2	0	5	3	1	32	14	0	9	1	0	18	1	200	559	l
2011	5	2	1	21	3	2	1	2	8	0	4	46	29	0	24	12	0	40	0	200	293	h
2012	95	2	1	57	0	5	1	0	2	9	5	12	5	0	4	0	0	2	0	200	106	l
2016	2	2	1	7	4	1	0	3	10	4	6	56	23	0	24	16	0	37	4	200	536	h
2018	7	4	63	103	1	3	0	1	0	6	0	3	6	0	0	1	0	1	1	200	129	l
2021	0	1	0	7	2	1	0	2	8	2	2	80	25	0	22	7	0	40	1	200	371	h
2023	35	4	14	86	10	5	0	1	5	10	4	6	6	1	1	1	0	11	0	200	159	l
2026	3	0	2	6	3	1	0	1	10	4	7	65	28	1	17	14	0	36	2	200	590	h
2027	27	4	1	149	0	0	0	2	1	3	1	3	2	0	3	0	0	4	0	200	72	l
2034	3	4	3	2	4	2	0	6	13	4	3	66	29	2	20	15	0	24	0	200	686	h
2035	72	7	4	44	24	1	0	6	6	10	5	3	5	0	1	1	0	10	1	200	96	l
2041	0	0	2	4	5	1	0	8	18	3	14	47	13	1	34	11	0	39	0	200	629	h
2044	21	2	28	76	28	10	0	2	3	9	9	5	3	0	0	0	0	4	0	200	88	l
2047	3	1	8	10	4	2	0	8	12	0	6	45	20	0	20	7	0	54	0	200	337	h
2049	2	3	0	9	4	10	0	14	15	6	24	27	17	0	14	5	0	49	1	200	491	l
2051	3	2	0	4	7	3	0	6	11	2	10	34	18	0	27	15	0	57	1	200	516	h
2052	4	4	5	22	8	32	0	2	12	11	34	14	13	1	13	4	0	19	2	200	292	l
2060	0	1	0	0	5	3	0	22	17	2	6	38	8	1	28	15	0	52	2	200	685	h
2063	27	6	8	12	24	43	0	3	14	8	20	8	5	1	0	0	0	19	3	200	299	l
2066	0	2	0	3	10	5	0	4	8	1	10	28	28	7	29	10	1	53	1	200	597	h
2067	0	2	2	4	34	51	0	0	15	13	46	3	14	1	7	1	0	6	1	200	97	l
2072	0	2	0	2	5	3	0	7	14	1	4	27	21	2	32	19	0	58	3	200	521	h
2073	0	3	39	128	9	3	0	0	1	0	1	2	2	0	0	0	0	11	1	200	94	l
2077	0	3	4	13	12	3	0	3	13	4	5	38	14	1	36	13	0	35	3	200	426	h
2079	0	4	35	56	41	5	0	1	11	5	18	5	10	0	3	0	0	6	0	200	227	l
2083	0	0	0	6	9	0	0	13	9	4	9	39	20	0	31	11	0	49	0	200	512	h
2087	1	10	53	54	6	13	0	3	7	5	10	5	3	14	4	0	0	12	0	200	126	l
2091	2	3	5	15	9	2	1	5	10	2	9	37	23	0	26	6	0	44	1	200	427	h
2092	10	5	15	106	17	21	0	0	2	3	7	3	2	0	0	0	0	9	0	200	125	l
2095	1	7	12	33	4	3	0	7	7	2	6	27	16	2	15	17	0	36	5	200	262	h
2097	3	11	113	50	0	3	0	0	2	2	3	1	6	0	3	1	0	2	0	200	80	l
2100	1	3	5	14	10	2	0	8	10	4	3	20	18	0	28	12	0	59	3	200	420	h
2102	0	3	36	137	0	0	0	0	1	0	1	0	4	1	0	0	1	16	0	200	23	l
2107	0	1	1	10	5	4	0	2	5	4	13	29	23	2	21	21	0	58	1	200	378	h
2108	0	5	23	90	1	35	0	8	3	1	7	12	4	1	0	2	0	8	0	200	212	l
2114	0	1	2	5	5	1	0	5	4	3	7	27	27	6	31	11	0	64	1	200	381	h
2116	11	7	50	106	0	2	0	0	3	5	8	0	6	0	1	0	0	1	0	200	67	l
2120	0	5	3	15	0	1	0	15	5	0	9	18	30	6	29	12	0	51	1	200	288	h
2122	4	2	46	127	0	9	0	0	0	1	3	1	1	1	2	0	0	3	0	200	11	l
2125	1	1	7	24	1	1	0	9	5	0	6	29	22	1	35	10	0	48	0	200	307	h
2127	1	8	124	55	0	1	0	0	0	0	0	2	3	4	0	1	0	1	0	200	7	l
2131	1	3	11	21	1	1	0	3	8	5	7	33	26	3	25	14	0	38	0	200	289	h
2133	0	9	3	178	0	0	0	0	0	0	4	1	4	0	0	0	0	1	0	200	60	l
2136	0	4	0	31	5	3	1	4	11	5	11	19	23	9	32	8	0	32	2	200	272	h
3456	0	9	7	138	6	1	0	0	1	4	19	1	3	3	0	0	0	8	0	200	89	l
2149	0	1	0	5	2	3	2	23	5	3	8	26	29	3	38	6	0	44	2	200	293	h
2153	0	14	37	42	1	0	0	1	0	1	1	31	59	3	1	0	0	9	0	200	2088	l
2166	0	2	2	6	1	7	0	7	4	6	4	28	45	13	31	11	0	30	3	200	263	h
2169	0	40	49	86	2	1	0	1	0	1	2	9	7	0	0	0	0	2	0	200	230	l
2172	0	1	4	4	4	2	0	22	2	4	4	23	31	7	38	9	0	43	2	200	247	h
2174	0	6	1	7	1	0	0	2	4	0	1	20	116	11	2	0	0	26	3	200	2498	l

Table XII: Distribution chart of benthonic foraminifera in section Finikia.

Samples	U. cylindrica	U. bononiensis	B. exilis	B. spathulata	Bolivina spp.	B. costata	B. subulata	Uvigerina s.s.	Lagenids	Cancris c.s.	Gyr./Orid.	B. subexcavata	Epiphytes	C. laevigata	Cibicides spp.	Agglutinants	S. advena	Rest-group	Indeterminable	Total	Nr. of planktonics	Lithology
2350	0	3	0	5	0	0	6	28	8	0	7	25	49	1	15	19	0	34	0	200	763	h
2351	0	0	0	3	18	5	4	47	26	2	5	23	14	0	23	8	0	18	4	200	506	l
2352	1	0	0	2	6	6	26	11	10	0	5	45	34	0	20	7	0	27	0	200	675	h
2353	0	0	0	3	19	2	3	44	30	3	1	22	16	0	24	4	0	25	4	200	478	l
2355	0	1	0	0	7	3	3	17	10	0	14	29	37	0	12	12	0	55	0	200	1836	h
2357	1	2	0	14	16	2	14	47	19	6	4	17	19	0	9	0	0	22	8	200	383	l
2358	1	0	0	2	3	4	19	20	10	0	5	41	37	0	17	15	0	25	1	200	750	h
2359	0	0	0	6	25	5	10	50	25	1	10	15	9	0	17	2	0	21	4	200	494	l
2360	1	0	0	2	4	5	6	26	9	2	5	39	39	1	16	12	0	31	2	200	1074	h
2365	0	0	0	1	3	6	0	22	16	0	9	27	26	0	18	12	0	57	3	200	1150	h
2208	0	2	0	3	38	13	3	27	22	7	14	11	18	0	6	3	1	29	3	200	352	l
2209	0	4	1	11	4	2	5	6	6	0	5	46	39	0	21	21	1	27	1	200	833	h
2210	0	1	2	11	8	49	6	49	15	4	2	21	4	0	6	1	0	20	1	200	295	l
2211	0	0	1	3	1	4	3	14	8	0	5	37	42	2	14	15	0	50	1	200	1026	h
2212	0	0	1	5	25	26	2	24	67	4	9	5	6	0	5	0	2	14	5	200	224	l
2214	2	0	0	4	2	4	1	12	10	0	6	34	41	0	27	15	0	39	3	200	715	h
2215	5	2	3	16	11	3	0	14	50	13	3	20	19	1	11	1	0	24	4	200	467	l
2216	0	2	0	10	2	5	1	8	8	1	4	45	35	1	31	5	0	42	0	200	496	h
2217	1	2	0	5	1	5	0	11	8	1	6	51	30	2	21	11	0	44	1	200	840	l
2218	3	3	0	6	54	14	0	23	21	17	1	11	12	0	11	5	2	11	6	200	189	l
2227	0	0	0	4	2	3	0	17	15	2	1	50	32	0	24	13	0	37	0	200	1009	h
2231	22	4	4	9	1	27	0	22	20	41	4	11	14	0	5	2	2	12	0	200	249	l
2233	2	1	1	4	3	1	1	5	3	1	6	36	41	0	30	6	0	59	0	200	399	h
2235	1	0	9	12	4	12	0	7	17	25	9	22	19	0	28	7	1	22	5	200	296	l
2236	1	1	1	3	4	4	0	5	11	3	8	47	27	1	27	7	0	47	3	200	355	h
2308	0	2	0	5	6	15	0	10	12	12	4	37	16	1	34	2	0	41	3	200	543	l
2240	1	2	0	0	4	1	0	6	9	4	6	52	28	2	24	10	0	51	0	200	623	h
2241	50	0	3	14	6	49	0	0	10	21	2	9	9	1	8	1	0	16	1	200	161	l
2242	0	0	1	8	6	8	0	4	14	1	5	35	22	0	27	7	0	60	2	200	531	h
2243	5	1	13	54	4	0	0	1	6	0	4	29	34	3	12	4	0	27	0	200	845	l
2244	0	0	2	6	14	2	1	4	9	0	4	44	31	0	28	15	0	40	0	200	385	h
2245	5	0	1	9	3	1	1	2	7	2	2	82	49	0	11	0	0	20	5	200	878	l
2246	0	0	1	8	3	1	0	8	7	0	3	51	34	0	28	9	0	46	1	200	362	h
2248	101	6	1	30	3	2	0	0	5	6	2	11	13	1	10	1	0	7	1	200	105	l
2250	2	1	0	5	4	0	0	4	10	1	6	51	26	1	31	10	0	48	0	200	313	h
2252	100	9	17	23	0	0	0	1	5	5	0	18	10	0	3	2	0	7	0	200	316	l
2255	6	1	1	12	7	0	0	1	8	1	2	46	34	0	18	14	0	48	1	200	372	h
2257	41	5	5	62	0	0	0	0	4	2	2	30	18	0	13	2	0	15	1	200	368	l
2259	2	0	0	3	11	2	0	2	5	1	7	43	28	0	32	19	0	45	0	200	406	h
2261	3	2	4	31	9	4	3	5	7	0	4	34	36	1	27	3	0	26	1	200	632	l
2262	2	0	0	7	5	5	0	1	9	2	1	50	34	0	32	13	0	39	0	200	289	h
2263	14	13	2	53	6	3	0	1	7	3	5	32	18	0	13	4	0	24	2	200	276	l
2264	4	3	1	7	6	0	2	1	7	0	3	52	34	0	30	14	0	34	2	200	411	h
2268	1	2	2	9	2	4	0	3	10	0	11	50	24	1	29	14	0	38	0	200	384	h
2270	20	1	30	66	11	25	0	0	4	8	7	9	8	0	1	0	2	8	0	200	149	l
2272	7	1	5	20	4	4	0	6	10	0	4	44	25	2	24	14	0	29	1	200	442	h
2273	66	9	5	95	1	0	0	0	1	3	1	6	1	0	3	1	0	8	0	200	49	l
2275	2	0	2	12	4	0	0	5	8	1	5	36	31	3	27	23	0	40	1	200	448	h

Table XIII: Distribution chart of benthonic foraminifera in section Aghios Vlassios.

Samples	*U. cylindrica*	*U. bononiensis*	*B. exilis*	*B. spathulata*	*Bolivina* spp.	*B. costata*	*B. subulata*	*Uvigerina* s.s.	Lagenids	*Cancris* c.s.	*Gyr.*/Orid.	*B. subexcavata*	Epiphytes	*C. laevigata*	*Cibicides* spp.	Agglutinants	*S. advena*	Rest-group	Indeterminable	Total	Nr. of planktonics	Lithology
2276	29	4	15	55	34	8	0	0	8	14	7	4	9	0	3	0	0	10	0	200	116	l
2277	7	4	5	19	10	2	2	4	9	1	4	43	13	1	22	17	0	36	1	200	588	h
2278	54	14	12	53	8	1	0	0	2	3	2	11	10	1	8	2	1	16	2	200	116	l
2280	4	2	3	2	4	5	0	7	11	2	9	36	20	5	30	20	0	39	1	200	420	h
3252	34	14	17	100	12	5	0	0	3	1	2	4	3	0	2	0	1	2	0	200	54	l
3253	2	4	4	6	2	3	1	9	12	3	6	41	23	1	18	13	1	50	1	200	403	h
2254	5	5	0	7	7	38	0	6	11	2	31	21	14	1	12	4	0	33	3	200	257	l
3256	3	2	1	10	5	6	1	11	8	1	8	25	23	1	27	14	0	54	0	200	381	h
3257	9	2	6	36	20	70	0	1	4	3	15	4	11	0	3	2	0	14	0	200	140	l
3260	1	0	0	3	4	2	0	15	14	3	3	44	24	5	17	11	0	54	0	200	525	h
3262	22	16	17	42	26	24	0	11	10	4	9	0	7	0	1	0	1	9	1	200	56	l
3264	0	2	1	7	8	3	0	9	14	2	3	20	25	5	21	15	0	65	0	200	442	h
3265	0	6	2	38	46	16	0	2	5	2	35	7	11	7	4	1	0	18	0	200	184	l
3267	0	0	0	3	9	8	0	2	9	2	6	19	21	0	34	23	0	62	2	200	435	h
3268	0	3	1	65	28	6	0	7	8	8	12	3	7	0	5	0	2	43	2	200	108	l
3270	0	2	0	11	13	15	0	7	8	3	4	27	18	3	34	10	0	45	0	200	555	h
3271	1	6	17	52	27	18	0	2	11	4	16	5	12	11	6	0	1	10	1	200	210	l
3273	0	0	0	2	9	6	0	18	16	2	5	21	28	0	33	14	0	46	0	200	434	h
3275	1	11	73	93	4	7	0	3	1	2	1	0	0	0	0	0	1	3	0	200	33	l
3277	0	2	7	11	16	2	0	5	11	4	5	26	20	2	32	12	1	43	1	200	334	h
3278	2	52	53	68	3	0	0	0	1	0	1	1	4	2	4	2	3	4	0	200	73	l
3279	0	6	1	14	12	3	0	10	6	3	3	20	29	1	28	19	0	42	3	200	277	h
3280	1	12	23	130	1	8	0	1	3	4	0	2	4	1	2	1	2	5	0	200	44	l
3283	0	2	2	1	12	5	0	21	7	0	7	24	28	1	25	17	0	48	0	200	416	h
3284	0	1	11	61	1	76	0	3	2	6	16	1	6	2	2	1	4	6	1	200	188	l
3286	0	2	3	16	13	6	1	3	12	5	5	15	17	2	35	16	0	48	1	200	223	h
3287	1	11	16	108	0	41	0	5	1	0	3	3	3	1	1	1	0	5	0	200	86	l
3291	0	0	0	4	4	2	0	7	8	5	4	14	33	7	40	20	1	50	1	200	307	h
3293	0	15	51	80	0	2	0	2	3	1	4	3	9	1	7	2	0	16	4	200	94	l
3295	0	1	5	6	4	2	0	17	9	2	8	18	30	7	24	15	0	50	2	200	177	h
3296	4	8	71	82	0	1	1	4	2	1	2	3	5	1	7	0	0	8	0	200	50	l
3297	1	5	7	18	0	6	0	13	5	0	5	22	26	1	29	19	0	52	1	200	192	h
3299	1	41	28	40	1	0	0	6	4	0	4	22	16	4	16	1	0	19	2	200	148	l
3300	0	3	8	19	5	0	3	9	9	1	5	21	28	1	24	14	1	46	3	200	261	h
3301	0	33	3	149	0	1	0	0	0	1	7	1	4	0	1	0	0	0	0	200	32	l
3303	0	0	0	20	5	12	1	14	4	6	7	9	29	12	28	13	1	37	2	200	200	h
3304	0	4	4	153	12	1	0	0	0	0	10	2	1	3	3	4	0	3	0	200	102	l
3308	0	0	0	4	3	5	0	13	1	0	5	15	39	13	43	11	0	48	0	200	218	h
3310	0	25	24	41	1	2	0	6	3	1	5	16	43	5	6	1	0	19	2	200	2172	l
3316	0	2	0	1	1	13	4	4	8	0	4	25	33	15	38	19	0	31	2	200	210	h
3458	0	78	63	51	0	0	0	1	0	0	0	2	1	0	0	0	0	4	0	200	141	l
3319	0	8	1	15	2	3	1	9	2	2	7	16	40	14	41	8	0	27	4	200	200	h
3321	0	46	15	34	2	0	0	3	1	1	1	20	58	3	3	1	0	11	1	200	1141	l
3323	0	3	3	13	8	1	5	11	3	0	7	21	38	4	42	10	0	30	1	200	312	h
3324	0	7	0	0	1	0	1	1	3	1	0	10	119	19	4	1	0	31	2	200	1418	l
3327	0	2	3	3	0	7	2	11	6	0	7	14	44	6	43	14	0	37	1	200	206	h
3328	1	17	13	21	2	0	3	2	3	0	1	26	53	10	12	0	0	35	1	200	2994	l
3330	0	0	0	4	2	2	6	14	2	0	12	17	38	4	48	15	0	35	1	200	172	h
3331	0	17	1	21	1	2	0	2	4	1	3	33	73	8	3	2	0	27	2	200	2015	l

Table XIII: continued.

Samples	U. cylindrica	U. bononiensis	B. exilis	B. spathulata	Bolivina spp.	B. costata	B. subulata	Uvigerina s.s.	Lagenids	Cancris c.s.	Gyr./Orid.	B. subexcavata	Epiphytes	C. laevigata	Cibicides spp.	Agglutinants	S. advena	Rest-group	Indeterminable	Total	Nr. of planktonics	Lithology
3463	0	22	3	21	3	2	4	7	3	1	1	24	54	1	9	2	0	42	1	200	952	1
3465	0	11	5	22	4	1	1	6	1	2	3	19	77	11	9	1	0	25	2	200	717	1
3467	0	8	1	10	6	6	3	12	4	1	0	10	83	3	18	2	0	32	1	200	1117	1
3469	0	1	1	6	0	2	3	5	1	1	4	10	113	22	7	0	0	23	1	200	411	1
3471	0	2	1	7	4	9	5	13	8	2	5	15	69	5	27	3	0	25	0	200	912	1
3473	0	5	1	42	1	2	1	7	1	0	4	15	65	10	11	3	0	30	2	200	762	1
3475	0	5	0	16	4	3	1	3	3	0	1	20	87	11	11	0	0	35	0	200	1076	1
3477	0	11	1	31	1	3	2	7	4	2	4	12	51	17	16	2	0	34	2	200	562	1
3479	0	5	0	7	1	0	3	2	1	3	4	20	107	10	5	0	0	31	1	200	334	1
3481	0	16	2	54	1	0	1	1	3	0	1	19	64	5	3	1	0	27	2	200	1012	1
3483	0	29	11	70	0	2	1	8	0	0	5	10	31	3	8	1	0	20	1	200	366	1

Table XIV: Distribution chart of benthonic foraminifera in the laminated beds of section Fortetsa.

Samples	*U. cylindrica*	*U. bononiensis*	*B. exilis*	*B. spathulata*	*Bolivina* spp.	*B. costata*	*B. subulata*	*Uvigerina* s.s.	Lagenids	*Cancris* c.s.	*Gyr./Orid.*	*B. subexcavata*	Epiphytes	*C. laevigata*	*Cibicides* spp.	Agglutinants	*S. advena*	Rest-group	Indeterminable	Total	Nr. of planktonics	Lithology
2663	0	1	0	0	12	5	22	26	14	0	6	15	34	0	12	9	0	43	1	200	1230	h
2672	0	0	0	0	14	4	13	11	26	0	6	12	43	1	20	6	0	43	1	200	804	h
2674	0	1	1	0	1	12	5	75	37	2	11	2	3	0	10	9	1	29	1	200	54	l
2676	0	0	0	0	4	10	13	12	14	1	3	26	50	2	19	6	0	39	1	200	712	h
2677	0	0	3	0	1	54	4	72	18	7	2	0	1	0	8	1	0	27	2	200	40	l
2678	0	0	0	0	7	28	2	67	28	0	6	1	6	0	28	1	0	25	1	200	42	l
2681	0	0	2	0	8	5	6	3	8	0	5	20	56	2	18	14	0	51	2	200	628	h
2682	0	0	1	0	3	19	0	96	24	4	7	1	6	0	19	1	0	15	4	200	25	l
2684	1	1	3	0	10	5	14	4	17	1	6	15	47	0	24	19	0	30	3	200	604	h
2685	1	9	16	5	5	51	4	37	12	10	4	4	7	0	6	0	1	21	7	200	132	l
2687	0	0	2	0	6	4	8	7	7	1	10	33	55	3	16	7	0	38	3	200	597	h
2688	2	9	5	2	3	40	2	93	13	6	5	2	2	0	6	0	2	4	4	200	63	l
2689	0	2	1	0	16	8	17	9	11	2	5	29	43	1	24	4	0	27	1	200	606	h
2690	3	2	1	1	9	32	11	19	15	23	6	9	17	1	16	2	1	30	2	200	326	l
2692	0	0	0	0	21	9	11	11	4	0	4	30	28	0	22	14	1	42	3	200	279	h
2693	4	3	7	3	3	61	10	39	14	1	4	10	14	0	3	3	4	15	2	200	201	l
2698	0	0	0	0	7	7	8	29	13	0	6	25	40	0	25	10	0	30	0	200	1135	h
2702	0	1	5	21	5	80	4	31	10	2	2	1	9	0	3	3	5	16	2	200	85	l
2704	0	1	0	0	12	6	23	13	7	1	3	23	34	2	19	14	0	38	4	200	381	h
2705	0	4	1	37	25	76	9	7	8	8	1	1	2	0	1	0	8	10	2	200	86	l
2706	0	3	0	10	2	9	18	14	7	0	7	23	36	0	22	14	0	34	1	200	529	h
2707	0	1	1	12	12	30	19	63	11	2	6	7	12	1	3	1	4	15	0	200	175	l
2708	0	1	0	5	4	7	9	11	6	1	6	38	34	0	35	10	0	33	0	200	531	h
2709	4	35	0	18	13	69	0	4	6	12	0	0	1	0	4	0	29	4	1	200	12	l
2712	0	25	1	42	14	49	4	25	15	8	0	1	4	0	2	0	7	3	0	200	43	l
2216	3	2	1	16	41	43	5	17	18	7	4	5	4	0	6	1	17	9	1	200	41	l
2720	0	22	0	47	14	30	2	10	7	12	2	6	6	0	4	1	29	8	0	200	62	l
2722	0	10	0	7	5	12	10	14	8	0	6	19	43	0	14	8	0	43	1	200	437	h
2723	2	0	0	35	2	43	8	26	13	11	4	6	8	0	17	1	11	11	2	200	107	l
2727	0	2	1	3	15	8	24	21	12	1	6	12	35	0	13	10	1	34	2	200	833	h
2728	5	1	1	20	9	24	14	18	20	11	10	10	23	0	6	0	6	20	2	200	208	l
2729	2	2	0	9	14	12	31	25	11	4	6	15	22	0	6	4	0	34	3	200	258	h
2730	4	2	2	41	12	26	9	23	12	5	3	4	19	2	8	0	9	18	1	200	181	l
2735	0	0	1	2	7	5	0	13	14	1	10	25	37	0	17	20	0	48	0	200	664	h
2766	0	0	3	20	0	17	19	15	10	0	4	25	29	2	14	6	0	34	2	200	363	l
2767	0	0	0	7	11	6	9	8	10	0	3	29	43	2	27	10	0	31	4	200	435	h
2768	0	2	22	76	1	15	10	8	3	6	2	5	19	2	6	0	2	21	0	200	333	l
2769	0	1	1	6	2	4	11	12	7	0	10	28	37	2	23	11	0	44	1	200	531	h
2770	1	1	81	26	4	41	2	10	7	2	1	6	4	0	5	0	1	8	0	200	49	l
2771	1	0	1	11	11	4	1	19	7	2	6	15	40	1	23	10	1	47	0	200	477	h
2772	22	2	1	92	4	33	1	6	5	5	3	2	1	0	1	1	1	20	0	200	36	l
2773	1	2	1	14	11	1	0	17	5	0	6	27	39	5	30	11	1	29	0	200	232	h

Table XV: Distribution chart of benthonic foraminifera in section Kalithea 1.

Samples	U. cylindrica	U. bononiensis	B. exilis	B. spathulata	Bolivina spp.	B. costata	B. subulata	Uvigerina s.s.	Lagenids	Cancris c.s.	Gyr./Orid.	B. subexcavata	Epiphytes	C. laevigata	Cibicides spp.	Agglutinants	S. advena	Rest-group	Indeterminable	Total	Nr. of planktonics	Lithology
5342	5	2	13	30	5	3	2	1	6	4	7	33	39	0	10	1	0	36	1	200	474	1
5344	3	5	0	14	3	1	1	0	2	1	0	70	84	0	0	1	0	13	2	200	681	1
5348	9	4	2	25	5	1	0	2	2	1	4	59	47	2	4	3	0	28	2	200	764	1
5350	10	12	2	39	1	1	0	0	1	1	0	35	77	5	0	0	0	15	1	200	709	1
5354	5	14	3	12	4	3	0	3	4	0	0	49	77	0	1	1	0	24	0	200	1358	1
5357	3	3	0	11	4	0	0	1	3	0	0	49	74	5	2	2	0	39	4	200	1491	1
5361	5	10	3	22	6	4	1	3	1	1	2	38	87	0	2	1	0	14	0	200	1075	1
5364	1	27	4	108	0	2	0	1	1	1	1	10	37	0	1	1	0	5	0	200	249	1
5369	21	18	18	123	1	1	0	1	0	1	1	6	6	0	0	0	0	2	1	200	289	1
5374	16	9	35	126	0	0	0	0	0	0	1	1	5	0	1	0	0	6	0	200	36	1
5378	33	20	5	103	0	0	0	0	0	0	0	10	23	0	0	0	0	6	0	200	151	1
5384	36	10	46	98	0	1	0	0	0	1	1	2	2	0	1	0	0	2	3	200	7	1
5389	25	25	26	101	9	3	0	0	0	1	0	0	1	0	1	0	1	7	0	200	20	1
5396	28	37	55	76	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	200	8	1
5402	43	8	3	115	4	6	0	0	2	0	7	1	2	0	0	0	0	9	0	200	22	1
5408	28	62	21	84	0	0	0	0	0	0	0	1	2	0	0	0	1	1	0	200	30	1
5419	20	69	38	70	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	200	6	1
5429	0	26	54	109	2	0	0	1	0	0	0	1	6	0	0	0	0	1	0	200	10	1
5435	0	38	81	73	0	0	0	0	1	0	0	1	4	0	0	0	0	2	0	200	58	1
5443	0	7	35	150	5	0	0	0	0	0	0	0	1	0	0	0	0	2	0	200	46	1
5450	0	44	51	102	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	200	26	1
5456	1	53	20	83	1	0	1	2	0	1	1	9	19	0	1	1	0	7	0	200	391	1
5460	0	35	46	97	0	1	0	0	0	0	0	1	15	1	0	0	0	4	0	200	143	1

Table XVI: Distribution chart of benthonic foraminifera in the laminated beds of section Aitania.

Samples	U. cylindrica	U. bononiensis	B. exilis	B. spathulata	Bolivina spp.	B. costata	B. subulata	Uvigerina s.s.	Lagenids	Cancris c.s.	Gyr./Orid.	B. subexcavata	Epiphytes	C. laevigata	Cibicides spp.	Agglutinants	S. advena	Rest-group	Indeterminable	Total	Nr. of planktonics	Lithology
1967	0	24	4	18	6	2	1	5	4	1	1	13	69	2	4	2	1	39	4	200	153	1
1969	3	47	0	55	6	2	1	1	4	3	3	6	30	5	2	0	1	30	1	200	140	1
1972	1	2	0	14	1	2	1	2	4	0	3	33	93	3	8	0	1	29	3	200	501	1
1975	12	3	1	19	5	2	0	6	6	0	1	17	77	1	11	2	0	33	5	201	618	1
1977	2	2	0	9	4	1	1	2	5	0	3	35	76	1	8	1	0	43	7	200	822	1
1979	1	4	1	12	5	3	0	4	6	3	4	21	92	1	12	2	0	25	4	200	840	1
1981	4	2	0	7	6	0	0	5	10	0	0	32	63	2	18	6	0	42	3	200	312	1
1983	3	2	0	10	7	1	1	2	9	0	2	25	85	1	20	7	0	20	5	200	519	1
1985	3	1	2	9	2	1	5	6	10	2	8	32	57	2	24	4	0	26	6	200	383	1
1990	36	8	6	86	2	1	1	1	4	10	4	2	18	0	6	1	0	9	5	200	53	1
1994	14	34	4	66	7	6	0	5	3	0	1	7	23	5	8	2	0	13	2	200	120	1
1997	18	23	9	54	9	4	2	6	3	1	4	10	16	1	15	3	0	20	2	200	158	1

Table XVII: Distribution chart of benthonic foraminifera in the laminated beds of section Mirtos.

Plate 1

Agglutinants, in the Pliocene of Crete mostly found in associations indicative of oxygenated environments:

Figs. 1, 2	*Bigenerina nodosaria* d'Orbigny, section Prassas, sample GR 985, × 60.
Fig. 3	*Karreriella affinis* (Fornasini), section Prassas, sample GR 985, × 72.
Fig. 4	*Karreriella bradyi* (Cushman), section Prassas, sample GR 985, × 72.
Fig. 5	*Dorothia gibbosa* (d'Orbigny), section Prassas, sample CP 3360, × 72.
Fig. 6	*Martinottiella communis* (d'Orbigny), section Prassas, sample GR 985, × 48.
Fig. 7	*Textularia depressula* Christodoulou, section Fortetsa, sample GR 3468, × 40.
Fig. 8	*Sigmoilopsis schlumbergeri* (Silvestri), section Prassas, sample GR 985, × 60.
Fig. 9	*Vulvulina pennatula* (Batsch), section Finikia, sample CP 2052, × 48.

Plate 1

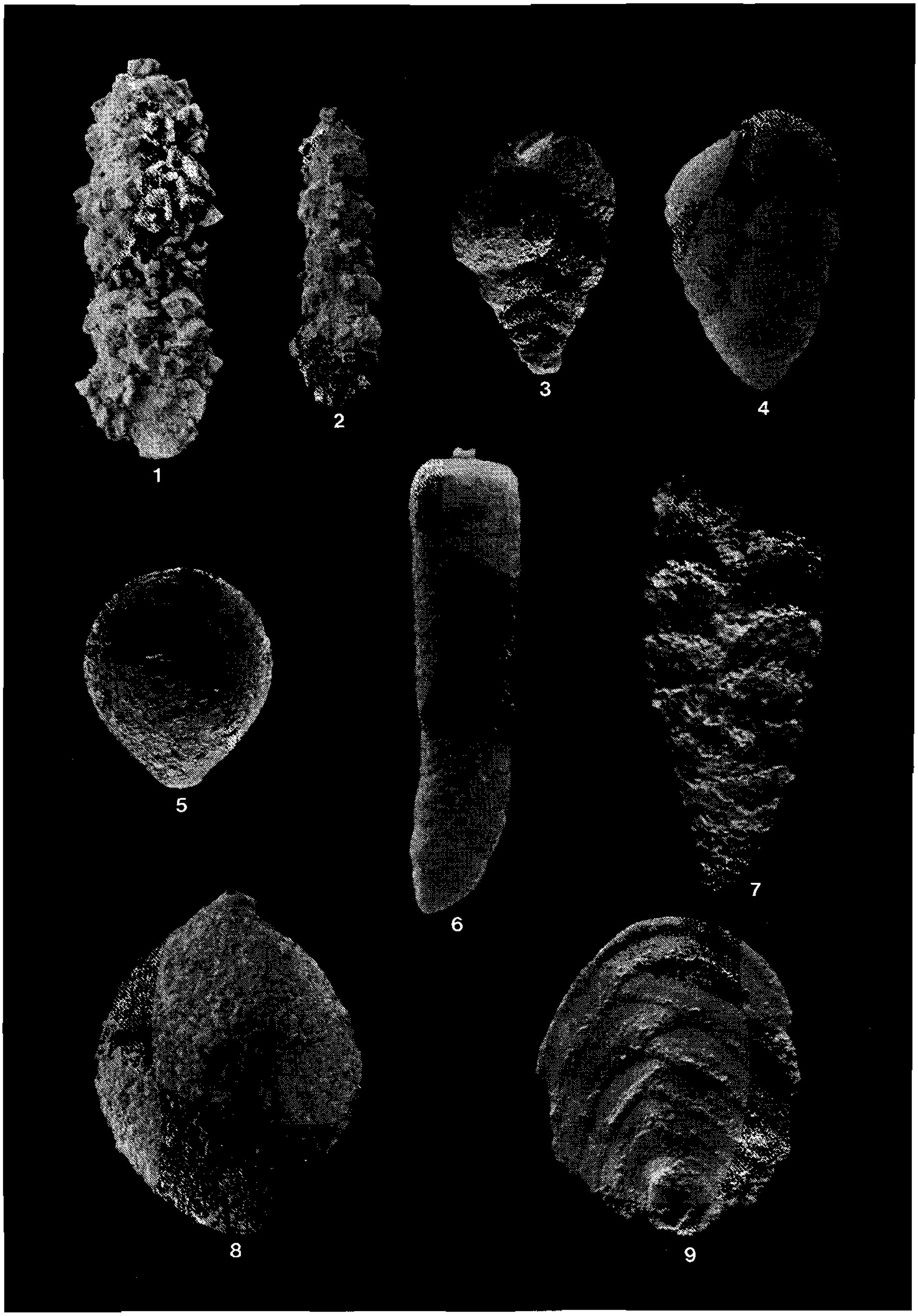


Plate 2

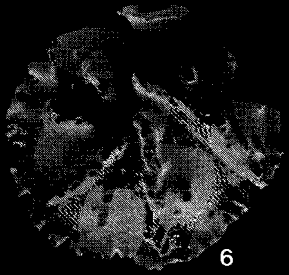
Species found in associations indicative of normal marine environments:

Figs. 1a, b	*Heronallenia lingulata* (Burrows and Holland), section Fortetsa, sample GR 3477.
Figs. 2a, b	*Nonion barleeanum* (Williamson), section Fortetsa, sample GR 3468.
Figs. 3a, b	*Nonion pompilioides* (Von Fichtel and Von Moll), section Prassas, sample GR 998.
Fig. 4	*Cassidulina laevigata* d'Orbigny, section Fortetsa, sample GR 3477.
Fig. 5	*Cassidulina subglobosa* Brady, section Fortetsa, sample GR 3468.
Fig. 6	*Siphonina planoconvexa* (Silvestri), section Kalithea 1, sample GR 2720.
Figs. 7, 8	*Siphonina reticulata* (Czjzek), 7 section Kalithea 2, sample GR 2235, 8 section Aghios Vlassios, sample GR 3283.
Fig. 9	*Bolivina reticulata* Von Hantken, section Kalithea 2, sample GR 2249.
	All magnifications X 90.

Plate 2


1a


1b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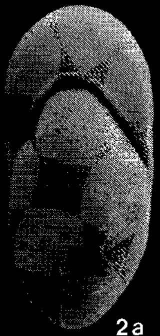
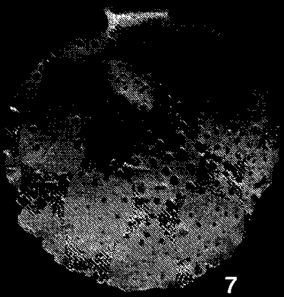

2a


2b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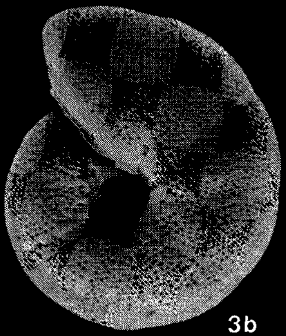
3a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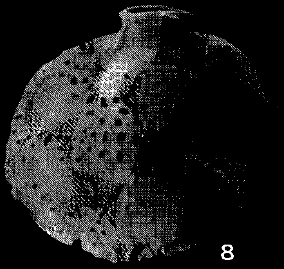
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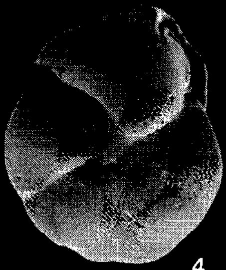
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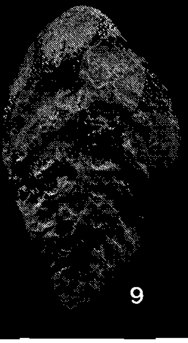
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Plate 3

Species found in associations indicative of normal marine environments:

Figs. 1–4	*Cibicides ungerianus* (d'Orbigny), 1–3 section Prassas, sample GR 999, 4 section Fortetsa, sample GR 3473. Figs. 1a–c show the typical *C. ungerianus;* the type in figs. 4a–c resembles *C. pachyderma* or *C. kullenbergi.*
	All magnifications X 72.

Plate 3

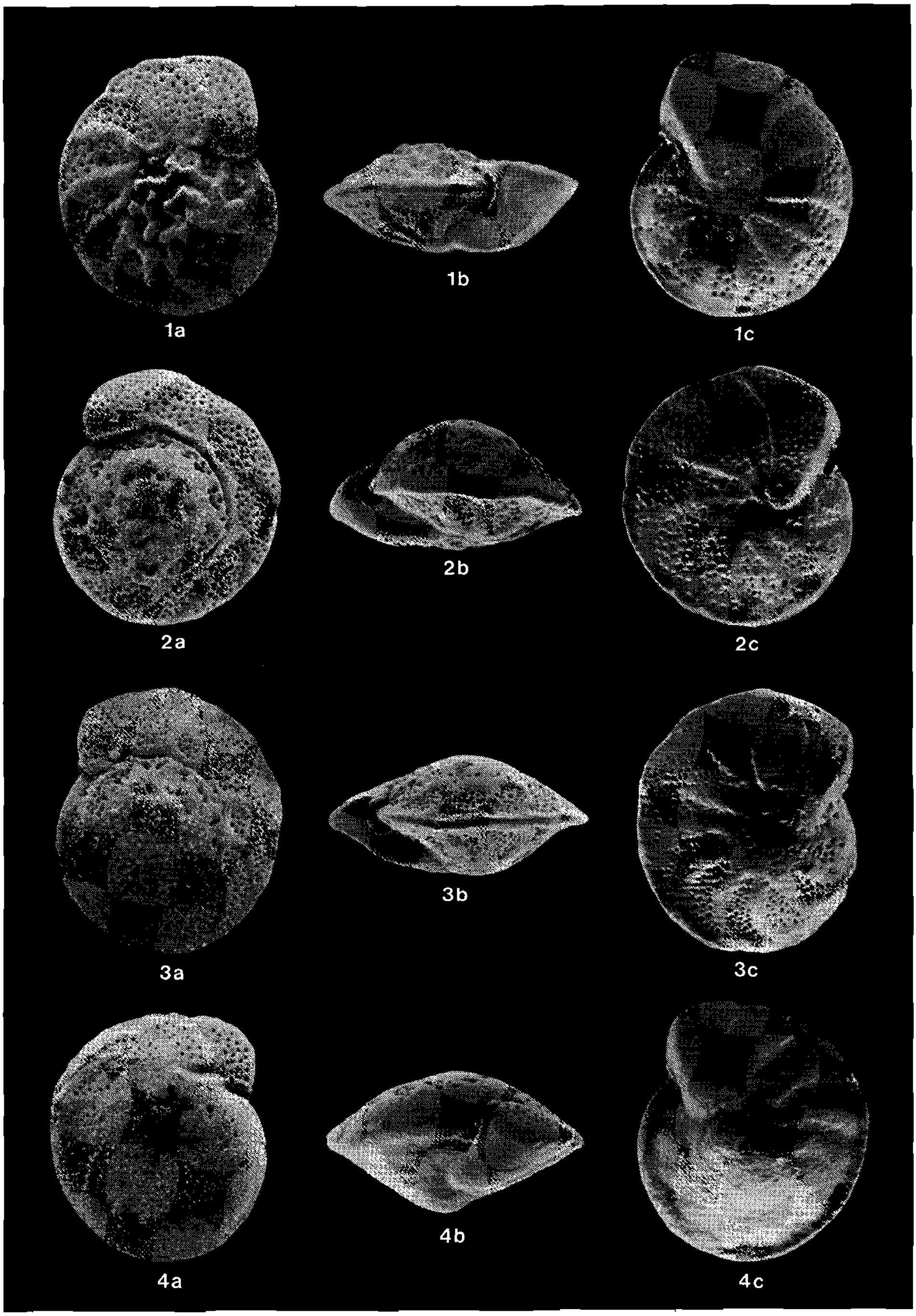


Plate 4

Species found in associations indicative of normal marine environments:

Figs. 1a–c	*Cibicides bradyi* (Trauth), section Kalithea 2, sample GR 2232.
Figs. 2, 3a, b	*Cibicides dutemplei* (d'Orbigny), 2 section Finikia, sample CP 2049, 3a, b section Prassas, sample CP 3360.
Fig. 4	*Uvigerina rutila* Cushman and Todd, section Aghios Vlassios, sample CP 2361.
Fig. 5	*Uvigerina angulosa* Williamson, section Fortetsa, sample GR 3477.
Fig. 6	*Uvigerina bradyi* (Cushman), section Fortetsa, sample GR 3473.
Fig. 7	*Uvigerina proboscidea* Schwager, section Prassas, sample GR 998.
Fig. 8	*Uvigerina longistriata* Perconig, section Kalithea 2, sample GR 2214.
	All magnifications X 90.

Plate 4

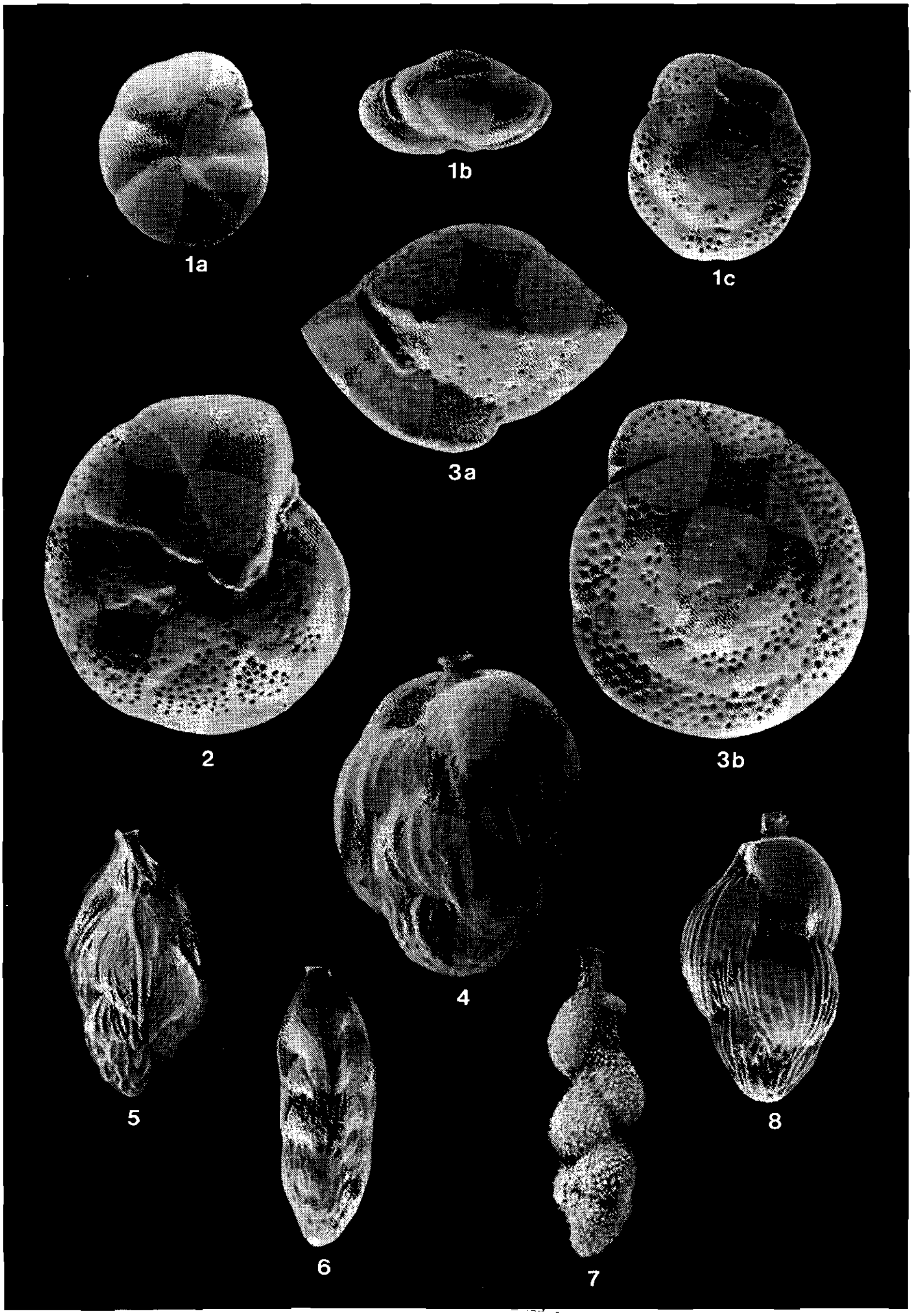


Plate 5

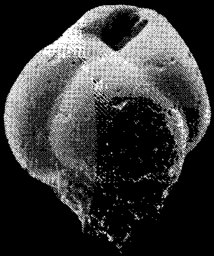
Species found in associations indicative of normal marine or slightly oxygen deficient environments:

Figs. 1–3	*Bulimina subulata* Cushman and Parker, 1, 2 *subulata* type, section Kalithea 1, sample GR 2720, 3 *lappa* type, section Prassas, sample GR 998.
Figs. 4a, b	*Oridorsalis stellatus* (Silvestri), section Kalithea 1, sample GR 2720.
Figs. 5–7	*Oridorsalis* sp., section Finikia, 5, 7 sample CP 2049, 6 sample CP 2092.
Figs. 8, 9	*Gyroidina soldanii* d'Orbigny, 8 section Aitania, sample CP 5400, 9 section Finikia, sample CP 2049.

All magnifications X 90.

Plate 5


1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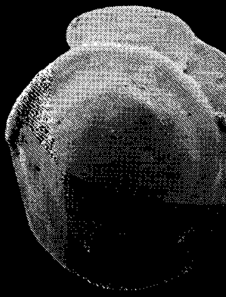
3


4a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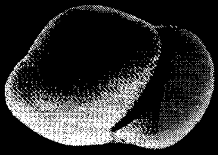
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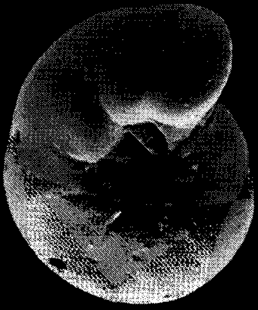
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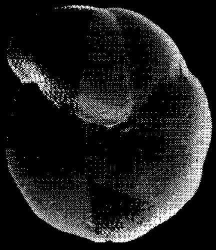
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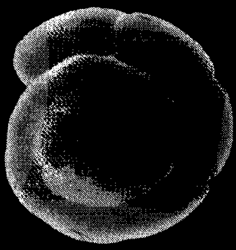
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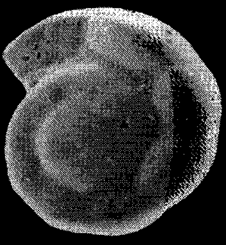
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Plate 6

Species found in associations indicative of normal marine or slightly oxygen deficient environments:

Figs. 1–3	*Amphicoryna scalaris* (Batsch), section Prassas, sample GR 998, 1, 2 microspheric specimens, 3 megalospheric specimen. All specimens × 48.
Fig. 4	*Dentalina communis* (d'Orbigny), section Finikia, sample CP 2049, × 52.
Fig. 5	*Dentalina filiformis* (d'Orbigny), section Prassas, sample GR 999, × 43.
Fig. 6	*Nodosaria albatrossi* Cushman, section Finikia, sample CP 2049, × 32.
Fig. 7	*Nodosaria catenulata* Brady, section Finikia, sample CP 2049, × 24.
Fig. 8	*Nodosaria hispida* d'Orbigny, section Finikia, sample CP 2049, × 46.
Fig. 9	*Vaginulina bononiensis* (Fornasini), section Finikia, sample CP 2049, × 24.
Figs. 10, 11	*Marginulina costata* (Batsch), 10 megalospheric specimen, section Prassas, sample GR 998, 11 microspheric specimen, section Fortetsa, sample GR 3468. Both specimens × 48.
Fig. 12	*Marginulina hirsuta* d'Orbigny, section Prassas, sample GR 998, × 38.
Fig. 13	*Stilostomella adolphina* (d'Orbigny), section Finikia, sample CP 2049, × 52.

Plate 6

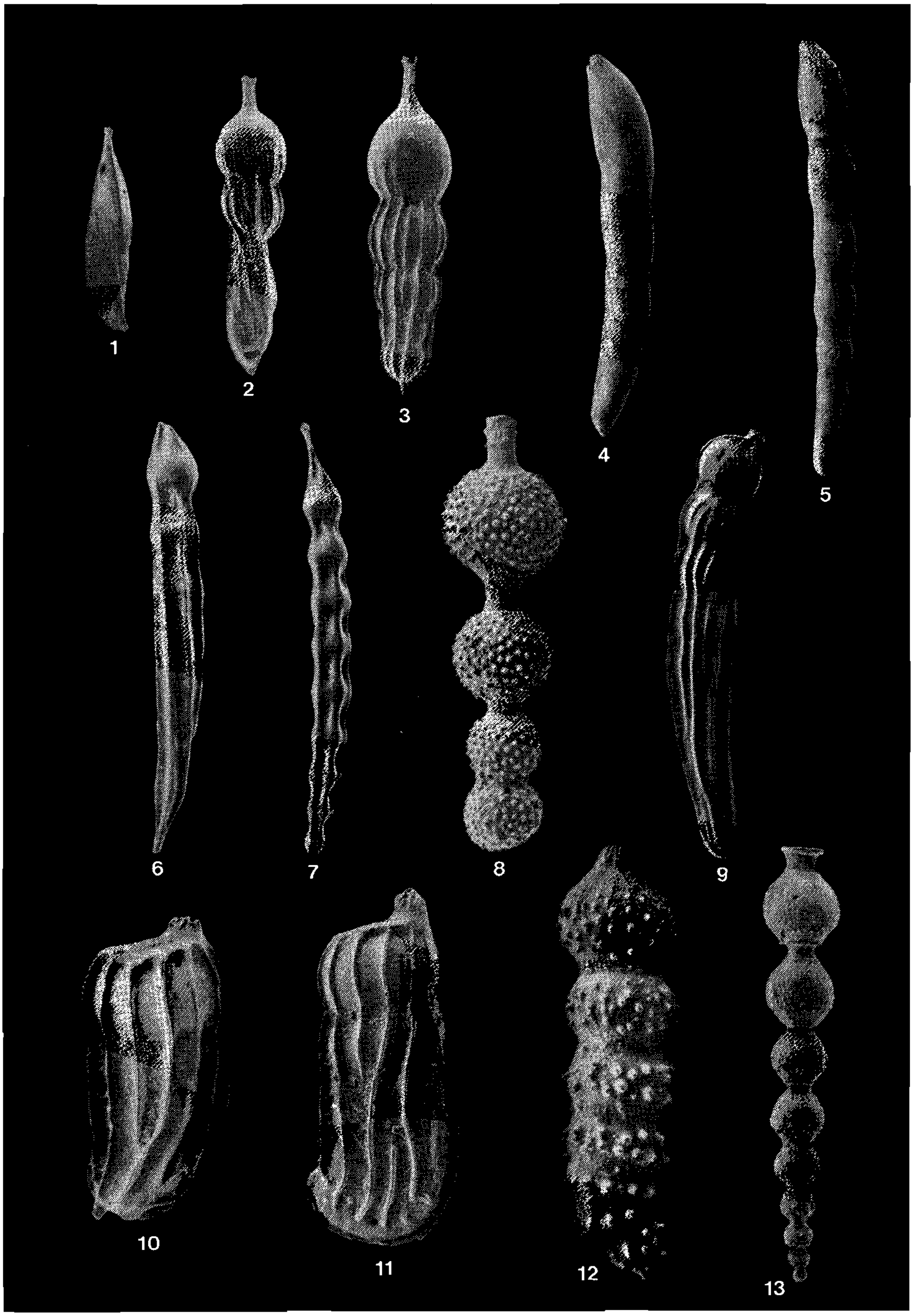


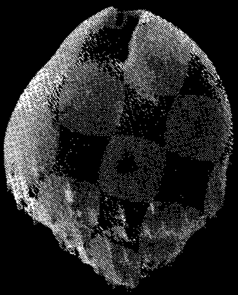
Plate 7

Species found in associations indicative of slightly oxygen deficient environments:

Fig. 1	*Bulimina barbata* Cushman, section Finikia, sample CP 2049.
Figs. 2, 3	*Uvigerina pygmea* d'Orbigny, section Prassas, sample GR 998.
Fig. 4	*Uvigerina carinata* (Cushman), section Kalithea 1, sample GR 2678.
Figs. 5, 6	*Bolivina alata* (Seguenza), section Kalithea 1, 5 sample GR 2720, 6 sample GR 2772.
Figs. 7–9	*Bolivina antiqua* d'Orbigny, 7 *antiqua* type, section Kalithea 2, sample GR 2232, 8, 9 *lucidopunctata* type, section Finikia, sample CP 2092, 7, 8 megalospheric specimens, 9 microspheric specimen.
Figs. 10, 11	*Bolivina dilatata* Reuss, section Kalithea 2, sample GR 2232, 10 megalospheric specimen, 11 microspheric specimen.

All magnifications X 90.

Plate 7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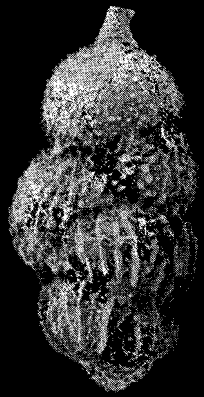
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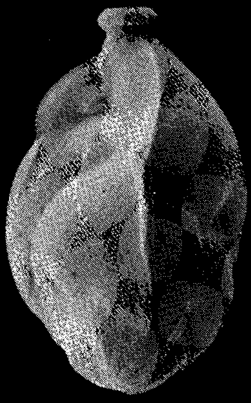
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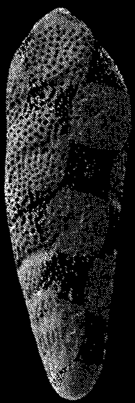
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8


9


10


11

Plate 8

Species found in associations indicative of a moderate degree of oxygen deficiency:

Figs. 1a, b	*Valvulineria complanata* (d'Orbigny), section Kalithea 1, sample GR 2720, × 90.
Figs. 2, 3	*Baggina totomiensis* Makiyama, section Aghios Vlassios, sample CP 2235, 2 × 60, 3 × 75.
Figs. 4, 5a, b	*Cancris auricula* (Von Fichtel and Von Moll), 4 section Prassas, sample GR 998, 5a, b section Fortetsa, sample GR 3473. All specimens × 50.
Figs. 6–8	*Bulimina costata* d'Orbigny, 6 section Finikia, sample CP 2092, 7 section Kalithea 1, sample GR 2720, 8 section Prassas, sample GR 998. All specimens × 90.

Plate 8

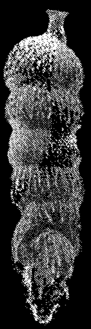
Plate 9

Species found in associations indicative of a high degree of stagnation:

Fig. 1	*Uvigerina cylindrica* (d'Orbigny) subsp. *cylindrica* (d'Orbigny), section Prassas, sample GR 998.
Fig. 2	*Uvigerina* ex. interc. *cylindrica – gaudryinoides,* section Finikia, sample CP 2092.
Fig. 3	*Uvigerina cylindrica* (d'Orbigny) subsp. *gaudryinoides* Lipparini, section Finikia, sample CP 2012.
Figs. 4, 5	*Stilostomella advena* (Cushman and Laiming), section Kalithea 2, sample GR 2204, 5 apertural view.
Figs. 6, 7	*Fursenkoina* sp., section Kalithea 2, sample GR 2218.
Figs. 8, 9	*Bulimina elongata* d'Orbigny, 8 section Finikia, sample CP 2092, 9 section Fortetsa, sample GR 3473.
Figs. 10–12	*Bulimina exilis* Brady, section Finikia, sample CP 2122.

All magnifications × 90, except 5 × 200.

Plate 9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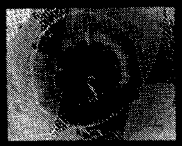
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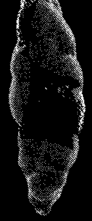
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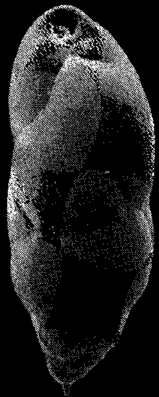
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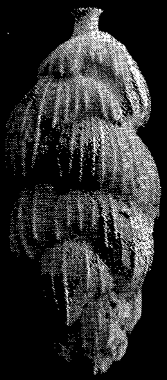
Plate 10

Species found in associations indicative of a high degree of stagnation:

Figs. 1–12	*Uvigerina bononiensis* Fornasini, 1–3 section Kalithea 2, sample GR 2202, 4 –12 section Prassas, 4–6 sample GR 998, 7–12 sample CP 3365. 1, 4, 11 *bononiensis* type, 6, 7 *compressa* type, 5, 9 *parkeri* type, 2, 3 *parkeri breviformis* type.
	All magnifications X 90.

Plate 10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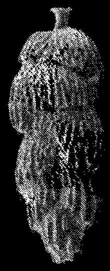
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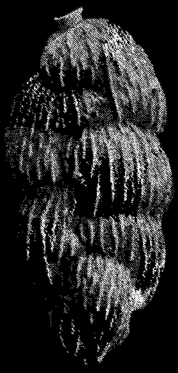
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Plate 11

Species found in associations indicative of a high degree of stagnation:

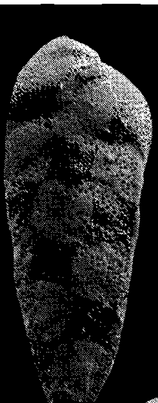
Figs. 1–7	*Bolivina spathulata* (Williamson), 1 microspheric specimen, section Kalithea 2, sample GR 2250, 2, 3, 5, 6, section Finikia, sample CP 2092, 4, 7 section Fortetsa, sample GR 3477.

Epiphytes, relatively abundant as allochthonous elements in oxygen depleted environments:

Figs. 8–11	*Bolivina subexcavata* Cushman and Wickenden, section Kalithea 2, sample GR 2232.
Figs. 12a, b	*Asterigerina mamilla* (Williamson), section Kalithea 2, sample GR 2232.
Figs. 13a, b	*Asterigerina planorbis* d'Orbigny, section Prassas, sample GR 998.

All magnifications X 90.

Plate 11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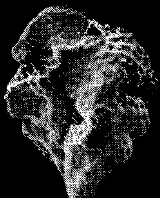
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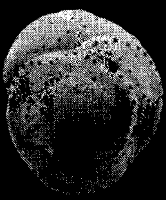
12a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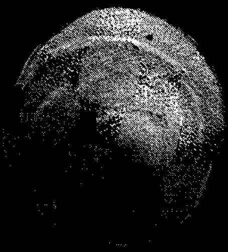

13a


13b

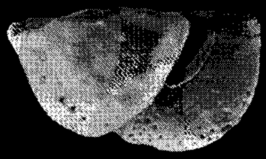
Plate 12

Epiphytes, relatively abundant as allochthonous elements in oxygen depleted environments:

Figs. 1a–c	*Cibicides lobatulus* (Walker and Jacob), section Prassas, sample GR 998.
Fig. 2	*Elphidium fichtellianum* (d'Orbigny), section Fortetsa, sample GR 3477.
Fig. 3	*Elphidium aculeatum* (d'Orbigny), section Kalithea 2, sample GR 2232.
Fig. 4	*Elphidium crispum* (Linnaeus), section Kalithea 2, sample GR 2232.
Figs. 5a, b	*Hanzawaia boueana* (d'Orbigny), section Prassas, sample GR 998.
Fig. 6	*Planorbulina mediterranensis* d'Orbigny, section Prassas, sample GR 998.
Figs. 7, 8	*Rosalina globularis* d'Orbigny, section Prassas, sample GR 998.
Fig. 9	*Reussella spinulosa* (Reuss), section Fortetsa, sample GR 3477.
Fig. 10	*Reussella* sp., section Fortetsa, sample GR 3477.
	All magnifications X 90.

Plate 12


1a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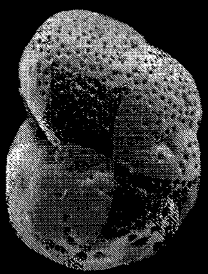
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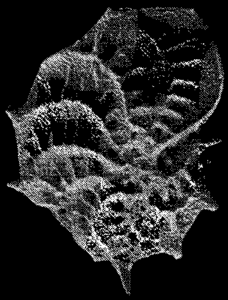
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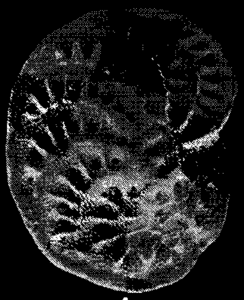
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5a


5b


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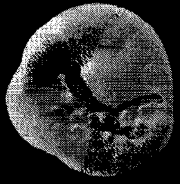
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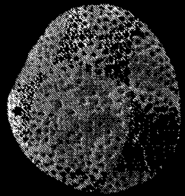
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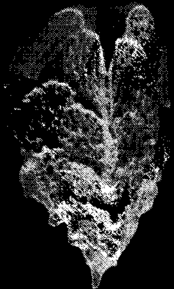
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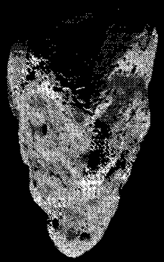
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