

**UTRECHT  
MICROPALAEONTOLOGICAL  
BULLETINS**

E. F. J. DE MULDER

MICROFAUNA AND SEDIMENTARY-TECTONIC  
HISTORY OF THE OLIGO-MIOCENE OF THE  
IONIAN ISLANDS AND WESTERN EPIRUS (GREECE)

**13**

## UTRECHT MICROPALAEONTOLOGICAL BULLETINS

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MICROFAUNA AND SEDIMENTARY-TECTONIC HISTORY OF THE  
OLIGO-MIOCENE OF THE IONIAN ISLANDS AND WESTERN  
EPIRUS (GREECE)

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## ABSTRACT

Detailed lithostratigraphic and biostratigraphic investigations were carried out in Oligocene-Miocene sediments on the Ionian islands Ithaki, Levkas, Kerkira and Kefallinia and in the western part of Epirus (Greece). Zonations based on planktonic organisms and on the foraminiferal families *Miogypsini*-*dae* and *Lepidocyclinidae* are applied to unravel the complex sedimentary and tectonic history of this part of the eastern Mediterranean. In spite of several inaccuracy factors, a tentative correlation was established of the larger and planktonic foraminiferal zones with the international chronostratigraphic scale.

The detrital sedimentation was strongly controlled by tectonics, which have caused more intense deformation of the Oligocene-Early Miocene on the islands of Ithaki, Levkas and Kefallinia, than of contemporaneous deposits on Kerkira and in western Epirus. These tectonics are considered to fit best in a tensional stress pattern, causing horst and graben structures, vertical block movements and strike-slip displacements along old, deep-seated fracture systems. In Middle Miocene time, thrust-faulting, most active in the west, seems to have variously affected the area.

The phylogenetic development of the *Miogypsina* assemblages in NW Greece seems to confirm the evolutionary trends known from other areas in the Mediterranean. The absence of retardation in the successive Greek *Miogypsinoidea* assemblages might suggest another bioprovince than nearby Sicily or Egypt, during the Burdigalian.

A classification of the European *Nephrolepidina* lineage, consisting of the successive species *praemarginata-morgani-tournoueri*, based on biometric criteria of assemblages, is proposed.

## Chapter I

### INTRODUCTION

#### I.1 THE SCOPE OF THE INVESTIGATION

The Oligocene and Lower Miocene successions of the Ionian islands and Epirus are interesting both from the stratigraphic-paleontological and the structural point of view. Detailed biostratigraphical data and interpretations of the sedimentary features are required to understand the tectonic history of the area.

In this paper, special attention will be paid to biometrical investigations on representatives of the foraminiferal families Miogypsinidae and Lepidocyclinidae, to the correlation of zones defined by larger foraminifera and planktonic foraminifera, and to the reconstruction of Oligocene – Middle Miocene paleogeographic configurations. Detailed studies were made of the sedimentary and faunistic features in selected sections on the islands of Kefallinia, Ithaki, Levkas and Kerkira (Corfou) and in the western part of Epirus.

The methods of investigation will be briefly discussed in chapter II. Chapter III deals with data of localities and contains a tentative reconstruction of the Oligocene – Miocene sedimentary history for the separate smaller areas. Biostratigraphic conclusions will be presented in chapter IV, together with some general conclusions regarding the Late Eocene to Miocene development of western Epirus and the Ionian islands.

#### I.2 GEOLOGICAL FRAMEWORK

The Oligocene and Miocene sedimentation area of western Epirus and the Ionian islands is situated in the external part of today's Hellenides, a NNW-SSE trending orogenic belt. In the concept of Aubouin (1959, 1965) the area belongs to the Ionian and Preapulian tectonic zones, which form the most western units recognized in the Hellenides. The Preapulian zone would represent the eastern slope of the foreland block, the Apulian platform (Apulian ridge). According to the literature, the Preapulian zone may be separated from the Ionian zone by a major thrust fault, crossing the islands

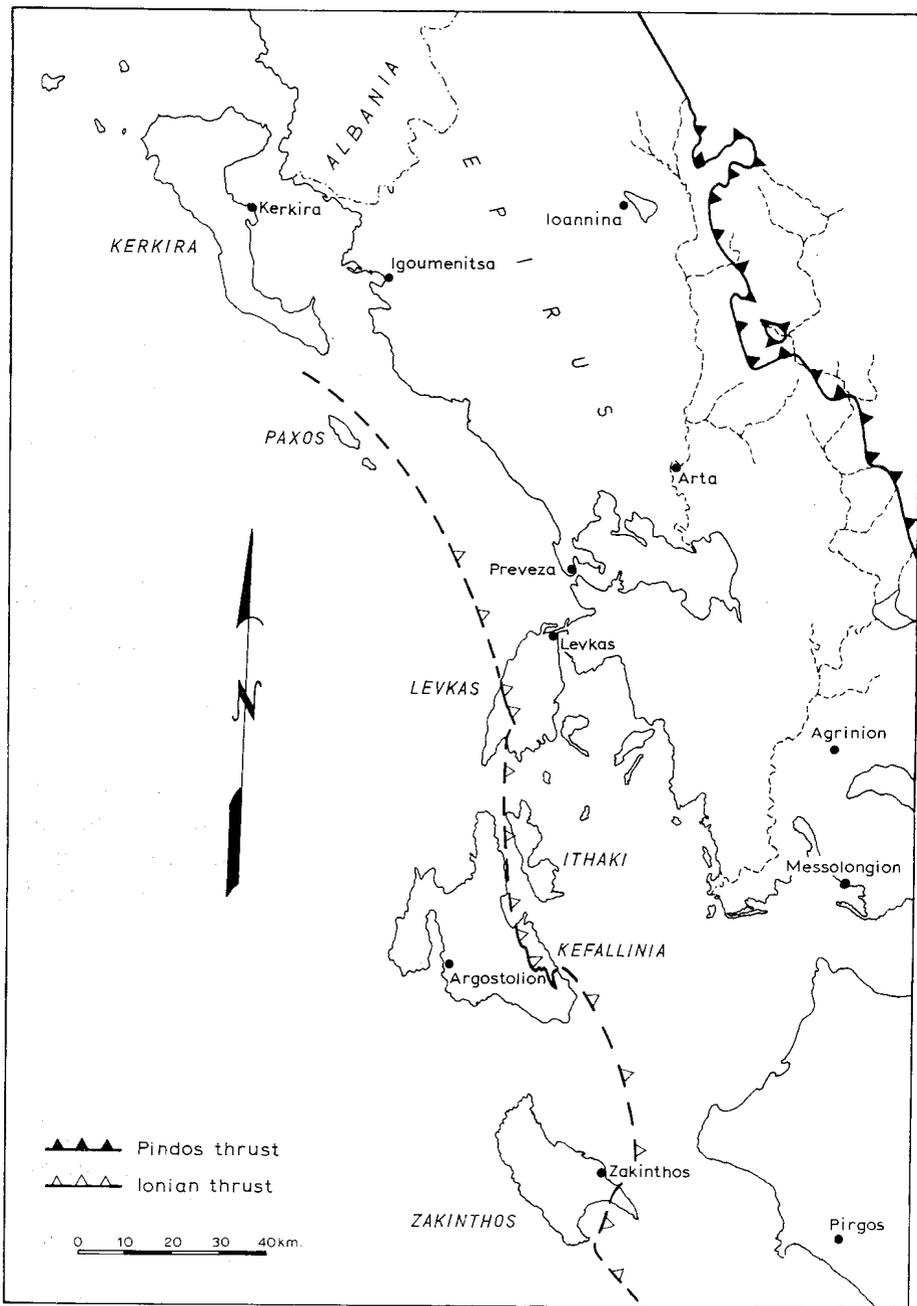


Fig. 1 Schematic map of NW Greece. The position of the major thrusts is approximate (after Bizon, 1967).

of Zakynthos, Kefallinia and Levkas (fig. 1).

After the accumulation of predominantly calcareous sediments during the Late Mesozoic and the Paleocene – Eocene, larger quantities of terrigenous clastics were deposited, first in elongated basins, separated by emerging ridges. Tectonics caused a highly variable pattern in the nature and distribution of the Oligocene – Miocene sediments. During the Miocene, part of the sediments was folded, and overthrust towards the west.

### 1.3 LITERATURE

Amongst the papers on the Oligo-Miocene of Western Greece, that by the Institut Français du Pétrole (1966) presents the most detailed information on the stratigraphy and structural development of the investigated area. The French authors follow Aubouin's (1959, 1965) concept and nomenclature of the Preapulian and Ionian zones. These zones were folded and uplifted in Miocene time. Detailed information was given on the sediments of Epirus and the island of Kerkira, less information on the islands of Levkas and Kefallinia.

The authors of the I.F.P. concluded to a close relation between the nature and thickness of the Oligo-Miocene successions and their geographic position in the Ionian and Preapulian zones. At the end of the Eocene and during the Oligocene and Early Miocene, thick successions of turbiditic, terrigenous clastics accumulated in the Ionian zone, originating from the emerging Pindos cordillera in the east. In general, the thickness of these deposits decreases from east to west, i.e. from the internal to the external part of the Ionian zone.

The terrigenous clastics were trapped in the Ionian furrow, which acted as a "barrière-en-creux", bordered to the west by the eastern slope of the Apulian ridge. In this Preapulian zone of present nomenclature, calcareous sedimentation continued throughout the Oligocene, followed by deposition of predominantly marls and clays during the Early, Middle and part of the Late Miocene.

In the Burdigalian, a major tectonic phase resulted in folding and upheaval of the sediments in the Ionian furrow. These movements did not affect the Preapulian zone, which remained free of flysch-type deposits. A new, transgressive sequence in the Ionian zone would have started earlier on Levkas than on Kerkira and in Epirus.

According to Aubouin (1965), the uplift of the Ionian zone was followed by subsidence of smaller troughs, in which Middle Miocene detrital sedi-

ments accumulated. The Apulian ridge would have emerged during the Middle Miocene, but subsided again in the Late Miocene, when it became part of a rapidly subsiding basin, the so-called Molise trough.

In his monograph on the geology of Levkas, Bornovas (1964) assigned the western part of the island to the Paxos zone (= Preapulian zone). He included the eastern part in the Ionian zone. Calcareous sedimentation in western Levkas started in the Jurassic and continued until the Aquitanian; in the east, the transition into flysch-type sedimentation took place during the Late Eocene already. Accumulation of the flysch deposits came to an end in the Aquitanian, when the eastern part of Levkas emerged. The emergence was followed by renewed subsidence, as marine, Middle Miocene sediments are found unconformably overlying the flysch of the Ionian zone.

Dremel (1968) studied the southern part of Kefallinia. He assumed two successive transgressions in the Early Miocene. The first transgression took place in the Aquitanian; marine sedimentation would have ended during an orogenic phase in the Early Burdigalian. The second transgression took place later in the Burdigalian and marine sedimentation continued throughout the Middle and Late Miocene. Dremel concluded that Kefallinia emerged during the Oligocene, but the authors of the I.F.P. (1966) reported calcareous Oligocene deposits from the northern part of the island.

A general review of the Miocene sediments of Kefallinia, Ithaki and Levkas was given in the paper on the geology of mid-western Greece by the British Petroleum Company (1971). The report contains geological maps, published in 1967. Oligocene sediments were not recognized by the authors.

A limited number of recent papers has been published on faunas of the Oligo-Miocene sediments on the Ionian islands and in western Epirus. Extensive lists of planktonic and larger foraminifera were presented in the paper by the authors of the I.F.P. (1966). Mrs. G. Bizon, in her micropaleontological studies on the planktonic foraminifera from western Greece, included data from various other areas in the Mediterranean. This resulted in her monograph on the planktonic foraminiferal biostratigraphy of the Oligocene to Pliocene of Greece, published in 1967.

In 1958, Hagn described the co-occurrence of *Miogypsina* and *Orbulina* from a section in southeast Kefallinia. He concluded to an overlap in the ranges of both genera, which was rejected by Drooger (1958), who considered the larger foraminifera in this assemblage to be reworked. As part of his investigation on Kefallinia, Dremel (1968) established a planktonic foraminiferal zonation, which he correlated with the *Miogypsina* zones. He confirmed Hagn's conclusions regarding the overlap of *Miogypsina* and *Orbulina* and, as a consequence, he placed the *Orbulina* datum at the Aquitanian –

Burdigalian boundary.

From the Afales-bay section (N. Ithaki), Lange (1968) studied the larger foraminifera and Bischoff (1968) the planktonic foraminifera and the sedimentary features. On the basis of biometrical data, Lange concluded to a polyphyletical development of the Lepidocyclinidae. Bischoff proposed four planktonic foraminiferal zones for the Afales-bay section. More recently, Matsumaru (1971) studied the Lepidocyclinids from two levels in the same section.

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## Chapter II

### METHODS OF INVESTIGATION

#### II.1 INTRODUCTION

For a biometrical analysis of *Miogypsinid* and *Lepidocyclinid* assemblages, it was attempted to collect at least 25 free specimens for each of these groups in each sample. Free specimens were obtained from unconsolidated, relatively coarse sediments and, after treatment with Quaternary-O, also from some of the coarse, more indurated, calcareous layers. Notwithstanding the large samples (approximately 1½ kg), the number of free, megalospheric specimens, especially of the *Miogypsinidae*, proved to be much less than 25 in several samples.

The larger foraminifera were sectioned under the microscope and their equatorial chamber arrangement was reproduced by camera lucida drawings, in which counts and measurements were made. The quantitative analyses of biometrical data were made with the Cyber computer of the Utrecht State University and the Friden-132 electronic calculator of the Department of Stratigraphy and Paleontology.

Planktonic foraminifera were studied from clayey and marly deposits directly below or above the strata with larger foraminifera and from beds containing both groups of microfossils. It has not been the purpose to describe the planktonic assemblages in detail, or to establish an independent planktonic foraminiferal zonation for the Oligo-Miocene. Instead, all efforts were concentrated in recognizing index species, which allow a correlation with Blow's (1969) standard planktonic foraminiferal zonation.

#### II.2 PARAMETERS OF MIOGYPSINA AND LEPIDOCYCLINA

Counts and measurements on the early chambers of *Miogypsina* and *Lepidocyclina* were performed according to the procedures described by Drooger (1952), Drooger & Freudenthal (1964), van der Vlerk & Gloor (1968), Meulenkamp & Amato (1972) and Raju (1974). The parameters used by these authors will be briefly reviewed and their stratigraphic value discussed. An additional parameter will be introduced for the *Lepidocyclinidae*.

## II.2.1 Miogypsina

Schematic drawings of the early chamber arrangement of primitive and more highly developed *Miogypsina* specimens are given in figure 2.

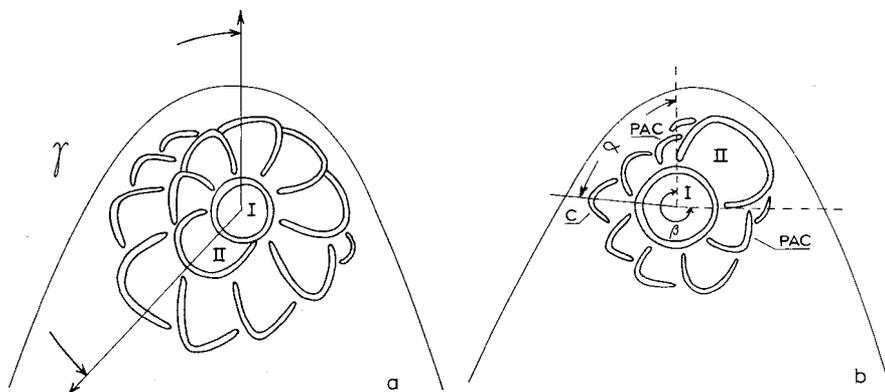


Fig. 2. *Miogypsina* parameters: a) primitive, single-spiralled form:  $X = 12$ ,  $Y = 5$ ,  $\gamma = 137^\circ$ ; b) more advanced form with two principal auxiliary chambers (PAC) resulting in four nepionic spirals:  $X = 4\frac{1}{2}$ ,  $Y = 0$ ,  $\gamma = +45^\circ$ ,  $\alpha = 82^\circ$ ,  $\beta = 278^\circ$ ; c = closing chamber.

**X:** total number of spiral chambers of the primary spiral around the protoconch and deuterococonch (I and II respectively). In specimens with two principal auxiliary chambers (PAC), only the chambers in the longer spiral around the protoconch are counted; a closing chamber (in the case of two PAC) is counted as half. The two embryonic chambers are not included in the X values.

**Y:** number of spiral chambers with one stolon only, not including I and II.

**$\gamma$ :** the angle between the apical-frontal line and the medio-embryonic line. The apical-frontal line runs through the centre of the protoconch towards the apex and the middle of the frontal margin. It divides the test into two approximately equal parts. The medio-embryonic line runs through the centres of proto and deuterococonch. The value of the angle  $\gamma$  is dependent on the length of the nepionic spiral, it may be positive or negative.  $\gamma$  is positive whenever the length of the spiral is less than one whorl, as generally found in specimens with two PAC.  $\gamma$  values are negative when the length of the primary nepionic spiral exceeds one whorl. In such cases  $\gamma$  is measured from the apical-frontal line in the direction opposite to the spiral direction. In primitive specimens with more than two whorls,  $\gamma$  is less than  $-360^\circ$ .

V: a measure of the degree of symmetry of the protoconchal spirals in specimens with two PAC. V is calculated from the formula  $200 \alpha/\beta$ . In this equation the angle  $\alpha$  corresponds to the shorter spiral,  $\beta$  is the arc length of both protoconchal spirals together.

DI: diameter of the protoconch, measured at right angles to the line connecting the centres of the first two chambers. In measurements of DI, half the thickness of the wall is included.

The means of X and V have been proved to show the most reliable sustained changes in the *Miogypsina* lineages, and correlations of assemblages from different localities are primarily based upon such values. In some cases, however, as in thin sections of hard rock and in broken specimens; only minimum values of X will be obtained. In such cases,  $\bar{\gamma}$  values are a useful tool to define the relative stratigraphic position of the sample, because  $\bar{X}$  and  $\bar{\gamma}$  show intense negative correlation (Drooger, 1963).

$\gamma$  values can fairly easily be estimated, because the direction of the apical-frontal and medio-embryonic lines may be fairly accurately established in many broken specimens and in thin sections which are not exactly parallel to the equatorial plane.

## II.2.2 Lepidocyclus

Figure 3 shows the internal features counted and measured in *Lepidocyclus* of the subgenus *Nephrolepidina*.

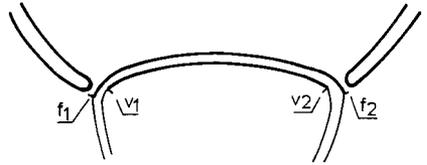
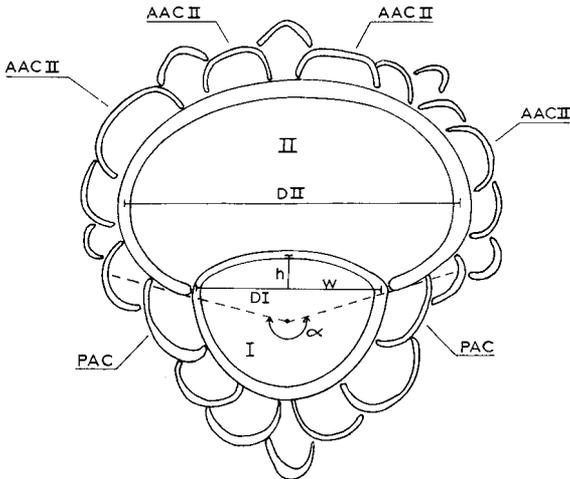


Fig. 3 Schematic drawing showing the methods of counting and measuring the internal features in *Nephrolepidina*.

Fig. 4 Methods of measuring the degree of embracement in the embryonic chambers of *Nephrolepidina*. For  $A_j$ , the length of the common wall is measured from  $v_1$  to  $v_2$ , for  $A_0$  from  $f_1$  to  $f_2$ .

A: reflects the degree of embracement of the protoconch (I) by the deuterococonch (II).

$$A = 100 \frac{\text{length of common wall between I and II}}{\text{total circumference of the protoconch}}$$

$A_0$  is calculated from measurements along the outer wall of the protoconch (fig. 4,  $f_1 - f_2$ );  $A_i$  from measurements along the inner wall (fig. 4,  $v_1 - v_2$ ). Wall lengths were measured with a curvimeter from camera lucida drawings.

C: number of accessory auxiliary chambers on the deuterococonch (AACII).

DI: maximum diameter of the protoconch, measured at right angles to a line connecting the centres of I and II. Half of the thickness of the wall is included.

DII: maximum diameter of the deuterococonch, measured at right angles to the connection line between the centres of I and II. Also in DII values, half of the thickness of the wall is included.

$\frac{DII}{DI}$ : reflects the relative size of both embryonic chambers.

R: degree of curvature, calculated from the formula  $R = 100 \frac{h}{w}$ . In this equation  $w$  is taken along the line connecting the attachment points of the deuterococonch to the protoconch. Generally,  $w$  and DI are measured along the same line. The wall thickness is not included in the values of  $w$ .  $h$  represents the maximum height of the protoconch that is enclosed by the deuterococonch, measured at right angles to  $w$ .

$\alpha$ : introduced here. It reflects the degree of embracement of the protoconch by the deuterococonch, expressed by the protoconchal angle formed by two hypothetical lines from the centre of the protoconch through the outer attachment points of the deuterococonchal walls to the protoconch (fig. 4,  $f_1$  and  $f_2$ ).  $\alpha$  can be measured easier than  $A$ , but in not well-rounded protoconches the position of the centre is rather arbitrary.

The mean number of accessory auxiliary chambers and the average degree of embracement show sustained changes towards higher values from older to younger deposits. Therefore, these parameters have been used to define the stage of phylogenetic development and the relative age of Lepidocylinid assemblages.

The means of DI and DII form a staggered pattern of increasing values. As a consequence, they cannot be used for detailed correlations. The average degree of curvature ( $\bar{R}$ ) may offer a possibility for biostratigraphic correlation, but the standard deviations for  $R$  appear to be considerably higher than those calculated for  $A$ . The same holds for parameter  $\alpha$ , which is another

form to express the degree of embracement of the protoconch by the deuteroconch.

In order to compare our results with those mentioned in the literature, our species assignments were primarily based upon  $\bar{C}$  and  $\bar{A}$  values. The  $A_i$  and  $A_o$  values were both calculated, because of conflicting opinions in literature whether the most accurate results are obtained by measuring the length of the common wall along the inner or along the outer side of the protoconch. Van der Vlerk (1964) preferred  $A_i$ , whereas Drooger & Freudenthal (1964) used  $A_o$ . In practice, both methods produced consistent results.

### II.3 STATISTICS

Mean values were calculated for each of the parameters reflecting the early chamber arrangements in either *Lepidocyclina* or *Miogypsina*. These values are given in tables, together with the ranges and the standard errors of the means. N, referring to the number of observations, may be different for each parameter in the same sample, because of the impossibility of obtaining reliable data on all parameters for some specimens. For instance, the number of observations on A in the Lepidocyclinids will generally be higher than that on C. In assemblages with a relatively large number of broken specimens, the number of observations on  $\gamma$  in the Miogypsinae will be higher than that on X.

For all combinations of parameters, the correlation coefficients (r) were calculated:

$$r = \frac{\sum (p-\bar{p})(q-\bar{q})}{\sqrt{\sum (p-\bar{p})^2 \sum (q-\bar{q})^2}}$$

in which p and q represent the parameters involved.

The difference between the frequency distributions of some parameters in different samples was tested by means of the Wilcoxon test, according to the formula:

$$u = \frac{Q}{\sqrt{N_1 \cdot N_2 \cdot \frac{(N_1 + N_2 + 1)}{3}}}$$

in which Q is the degree of difference between two assemblages and N1 and N2 refer to the numbers of observations. No significant difference is assumed when  $U \leq 1.96$ , which means that the probability that the two samples could have been derived from the same population exceeds 5% (two-sided).



## II.4 THE SEDIMENTS IN THE CHRONOSTRATIGRAPHIC SCALE

In order to translate the biostratigraphic results in terms of chronostratigraphy, we relied primarily upon the recent interpretation by Berggren and Van Couvering (1974) for the planktonic foraminifera. As to the larger foraminifera (Miogypsinidae), the interpretation by Drooger (1963) was followed, which is mainly based on first order correlations with the strato-type sections.

Based on these two methods, a correlation table was constructed for the position of planktonic foraminiferal and Miogypsinid biozones in relation to the Oligocene and Miocene stages (fig. 5). The scheme of Berggren and Van Couvering was slightly modified with respect to the base of the Langhian (here placed at the *Praeorbulina* datum) and the base of the Aquitanian (here placed within Blow's *Globigerinoides quadrilobatus primordius*/*Globorotalia kugleri* Concurrent-range zone (N4).

Correlations of Miogypsinid and Lepidocyclinid species with the planktonic foraminifera in the biozonation of Blow (1969) will be discussed in the paragraph on biostratigraphic conclusions in chapter IV.

## Chapter III

### REGIONAL STRATIGRAPHY AND PALEONTOLOGY

This chapter deals with the lithostratigraphic data and structural setting of various Oligocene and Lower Miocene successions in the Ionian islands and Epirus. The biostratigraphic evaluation of the *Lepidocyclina* and *Miogypsina* assemblages and of the planktonic foraminiferal faunas will be used to date the major changes in the sedimentation pattern and to relate the successions to the international chronostratigraphic scale.

For practical reasons, attention will be focussed on restricted areas in which the Oligocene – Lower Miocene deposits are relatively well exposed and contain rich faunas of larger foraminifera. In the following paragraphs successions of Ithaki and Levkas will be discussed in detail, and additional remarks will be made on exposures on the islands of Kefallinia and Kerkira and in parts of the mainland of Epirus.

#### III.1 ITHAKI

##### III.1.1 Sediments of the Afales-bay section

###### III.1.1.1 Introduction

Outcrops of the Oligocene – Lower Miocene of Ithaki are practically restricted to the northern part of the island. Some poor isolated exposures are found in the narrow central part.

The Oligocene and Lower Miocene sediments can best be studied in the long coastal strip of Afales-bay in the northern part of the island (fig. 6). Calcareous and terrigenous detrital sediments are found in a narrow depression between the Karamalicha mountains in the east and the Kavellares mountains in the west (fig. 7). In the east, Oligocene deposits are conformably overlying the Upper Mesozoic – Eocene limestones of the Karamalicha mountains. The contact of the Oligo-Miocene with the Mesozoic limestones of the Kavellares mountains in the west is tectonic. On the west coast, the Mesozoic limestones are separated from Middle Miocene marls by a conspicuous fault.

The coastal cliffs along the beach of Afales-bay show several non-connected successions of steeply inclined and partly overturned detrital limestones, calcareous conglomerates, marls and sandstones. The limestones and sandstones are generally rich in larger foraminifera.

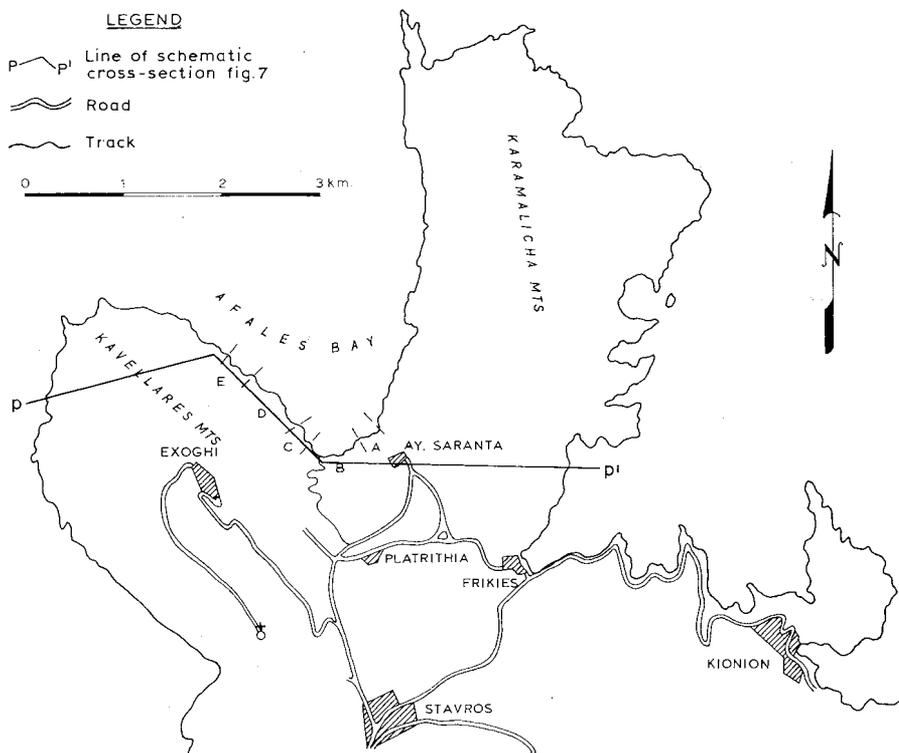


Fig. 6 Schematic topographic map of northern Ithaki. A – E refer to the position of the divisions of the Afales-bay section in fig. 8. The location of this part of Ithaki is indicated in fig. 37.

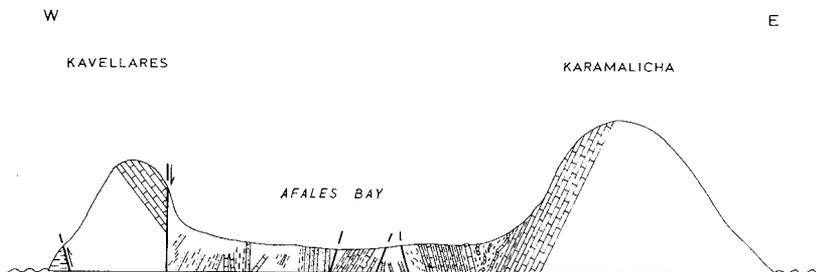


Fig. 7. Schematic cross-section of northern Ithaki along line  $p - p^1$  of fig. 6. The dimensions of the central part of the section have been exaggerated.

Some parts of the section are more or less continuously exposed, others are overgrown or covered by scree. Owing to the strongly disturbed nature of the strata, a reliable stratigraphic column cannot be established on field data only. Geographic, lithostratigraphic and tectonic data on the sediments exposed in the Afales-bay section are shown in the detailed cross-section of figure 8.

The various parts of the Afales section will be arranged in a stratigraphic order by means of biostratigraphic data. As a result, a composite stratigraphic column will be presented, based on a combination of field data and biostratigraphic evidence. Conclusions concerning the major features of Oligocene – Lower Miocene sedimentation in the area will be drawn from this composite column.

Foraminifera and sediments of the Afales-bay section have previously been studied by Lange (1968) and Bischoff (1968). The results of Lange will be compared to our final conclusions.

The sediments of Ithaki have been assigned to various tectonic “zones” on the basis of tectonic interpretations. Lange (1968) and Bischoff (1968) included the Oligocene – Lower Miocene deposits of Ithaki in their “Adriatisch-Ionische Zone”, whereas Bizon (1967) and the authors of the Institut Français du Pétrole (1966) placed them in their “Zone ionienne externe occidentale”.

Sediments in isolated exposures along the NW coast of the island have been assigned to the Middle Miocene by authors of the British Petroleum report (1971) and incorporated in the “Paxos zone”. These authors considered the fault bordering the Kavellares mountains to the west as the continuation of the Sami-Kalamitsi thrust, separating the “Ionian zone” from the “Paxos zone” (= Preapulian zone).

### III.1.1.2 *Review of the divisions of the Afales-bay section*

For the sake of convenience, the section has been subdivided into five geographically adjoining divisions (A – E), which are separated by easily recognizable beds (fig. 6).

The major facies change from dense carbonates to detrital limestones, which is placed in division A, cannot be observed in the beach succession proper. The transition must be studied higher up, just below the houses of the village Ay. Saranta. It is characterized by the appearance of detrital limestones and greenish, calcareous marls in the well-bedded pelagic limestones.

On the beach division A begins at the easternmost, well-bedded detrital limestone beds (unit A1). These beds show positive grading and nearly all of

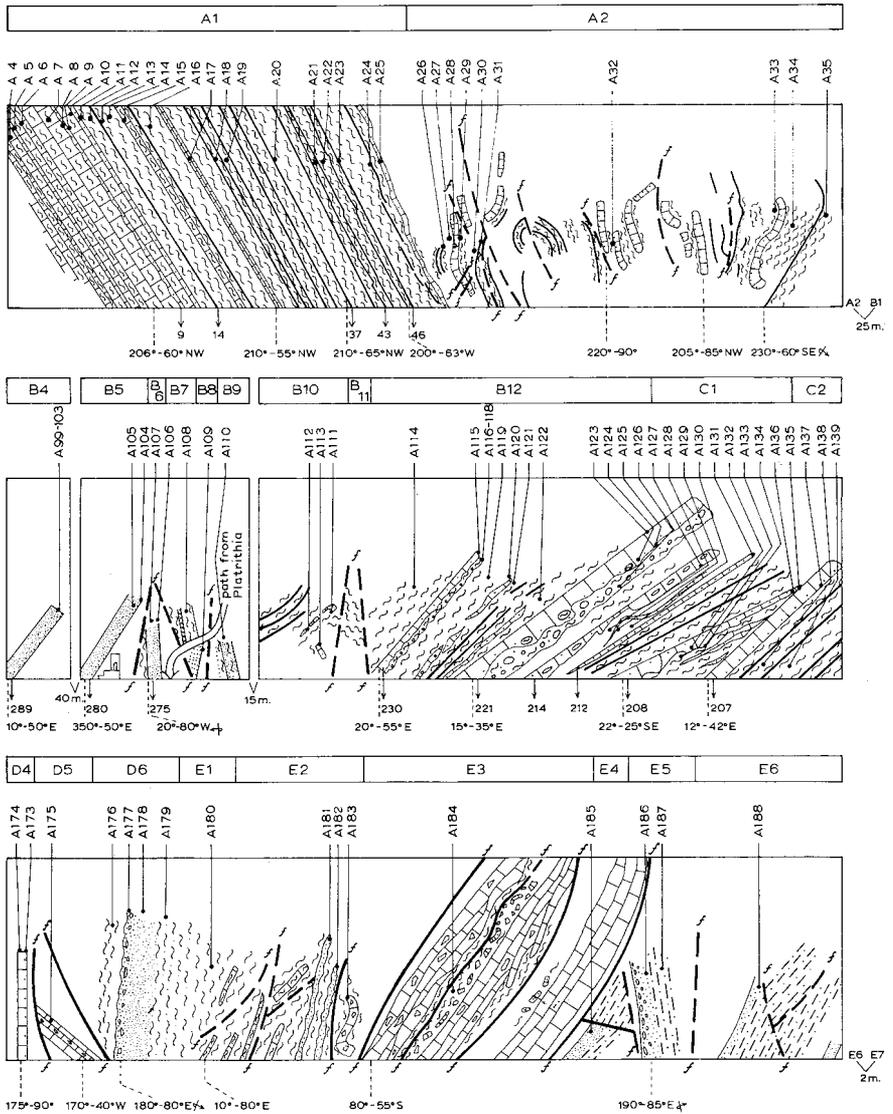
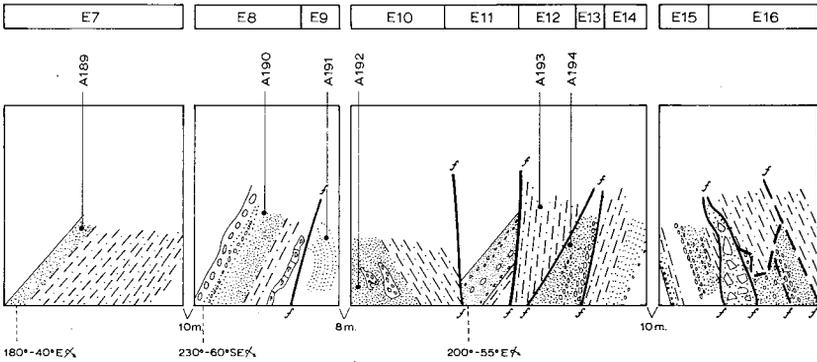
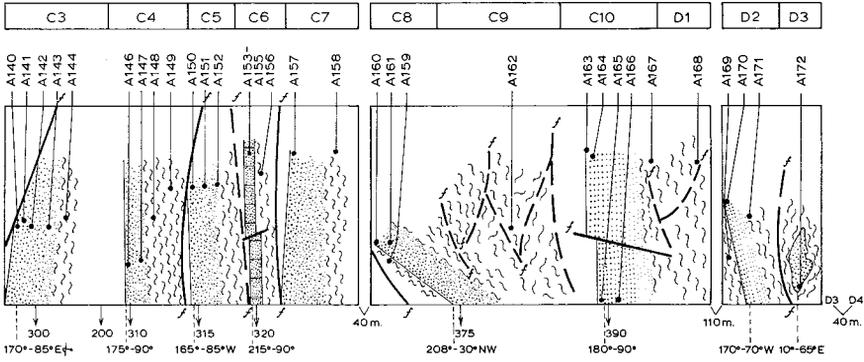
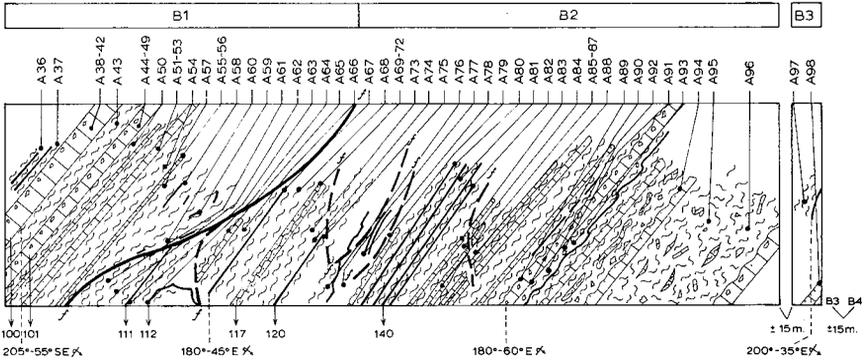
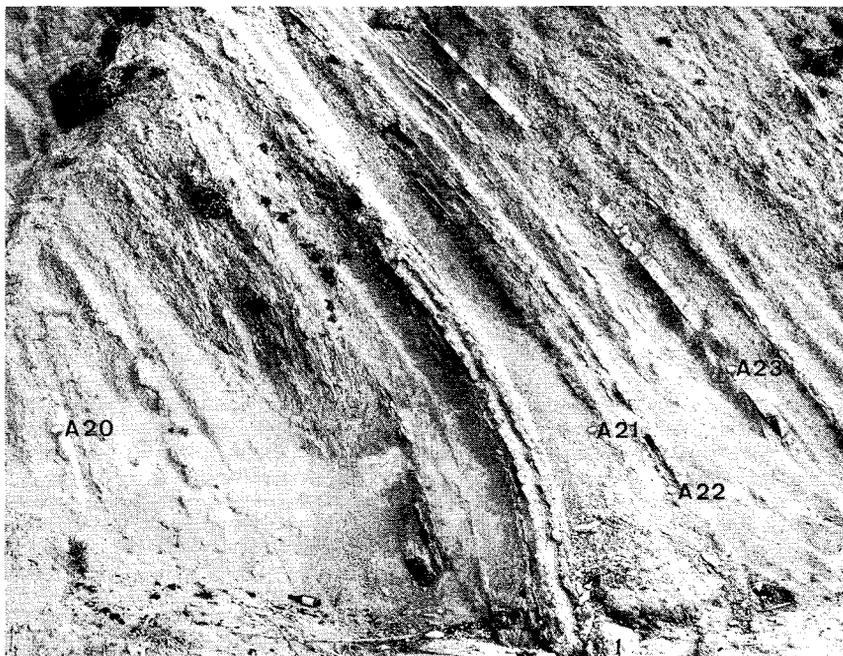


Fig. 8 Detailed cross-section of the Afales-bay sediments, Ithaki.



LEGEND

- |  |                              |  |                                 |
|--|------------------------------|--|---------------------------------|
|  | Limestone                    |  | Sandstone                       |
|  | Detrital limestone           |  | Conglomerate                    |
|  | Thin, detrital limestone bed |  | Fault ascertained               |
|  | Breccious limestone          |  | Fault assumed                   |
|  | Marly limestone              |  | Unit B3                         |
|  | Silty marl                   |  | Unexposed interval of 40m.      |
|  | Silty clay                   |  | Sample number                   |
|  | Calcareous sandstone         |  | Refers to Bischoff's „Bank 207“ |



10



9

Fig. 9

These well-bedded, detrital limestones alternating with green-gray calcareous marls of unit A1 are characteristic of the second type of sediment succession in Afales-bay, Ithaki. Note the increasing thickness of the marls to the right (i.e. to the west).

Fig. 10

Predominant marls and detrital limestone beds in the upper part of unit A1, second type of sediment succession in Afales-bay, Ithaki.

them are merging into indurated calcareous marls; they are steeply dipping to the west. In some beds, Discocylinids and Nummulitids are common. Upwards (i.e. to the west), the intercalated marls become less calcareous and less indurated, and the thickness gradually increases (figs. 9 and 10).

Farther to the west, such detrital limestone beds are folded and faulted (unit A2) and some of the beds are overturned (fig. 11). The intercalated marl beds are crumbly.

A distance of 25 meters without exposures separates unit A2 from a succession of positively graded, conglomeratic limestones and marls. The easternmost of the limestone beds reaches a thickness of about 2.50 meters. This bed is protruding several meters into the sea and forms a distinct identification bed ("Bank 100" of Bischoff, 1968), used as the basis of division B.

Division B begins with an overturned succession of approximately 100 meters (units B1, 2), consisting of detrital and conglomeratic limestones, alternating with crumbly marls. The marls are predominant. All limestone beds are positively graded; they are merging into marls from east to west (i.e. upwards), and an increasing number of features are indicative of resedimentation. The westernmost 10 meters of B2 consist almost entirely of a chaotic complex of conglomeratic marls and calcareous debris. The sediments in the upper part of the succession are rich in *Lepidocylinids*.

After passing 15 meters without exposures, but with a suspected major fault, the section contains some isolated outcrops only (units B3 – 9). Near the entrance of the track, leading uphill to Platrithia, strongly faulted, slightly indurated and positively graded sandstones are exposed, grading into and alternating with silty marls or clays. They are steeply dipping to the west or the east, and some of the beds are overturned.

Another assumed major fault in an unexposed interval, separates these units from a much better exposed part of the section, with some 45 meters of predominantly marls with intercalations of detrital and positively graded limestone beds of variable thickness. These beds (units B10 – B12, C1, 2) are hardly affected by faulting, except in the uppermost part. They are dipping about 30 degrees to the east. Four meters above the basis of this succession an internal unconformity of approximately 15 degrees may be observed. Several limestone beds have coarse, conglomeratic basal parts, which are composed of organic debris, marl pebbles and recrystallized limestone boulders with a diameter up to 1 meter (fig. 12). The limestone beds contain numerous *Lepidocylinids*.

The thickest bed of this succession ("Bank 221" of Bischoff) protrudes several meters into the sea; it serves as the boundary between divisions B and C.



11



12

Fig. 11 Strongly folded and faulted sediments of unit A2, second type of sediment succession in Afales-bay, Ithaki. The thicker, protruding layers are part of the same detrital limestone bed.

Fig. 12 Example of the coarse, conglomeratic intercalations of the third type of sediment succession (unit B12, "Bank 230" of Bischoff) in Afales-bay, Ithaki. The lower part of the bed is composed of an ill-sorted conglomerate with calcareous components floating in a marly matrix. The upper, indurated part consists of positively graded limestone with marl pebbles diminishing in size upwards.

To the NW and after passing a major fault, a nearly vertical succession consists of several sedimentary sequences, separated by steep faults or unexposed intervals (units C3 – C10). The relatively coarse basal sediments of each sequence consist of positively graded, slightly calcareous sandstone with some lignite seams or flakes. The sandstones merge gradually into thick beds of silty marls, which are generally crumbly in their upper parts. The basal parts of the sandstone beds are locally rich in *Lepidocylinids* and *Miogyssinids*. The westernmost sandstone-marl sequence forms a steep cliff and protrudes some 6 meters into the sea (“Bank 390” of Bischoff); it marks the boundary between divisions C and D.

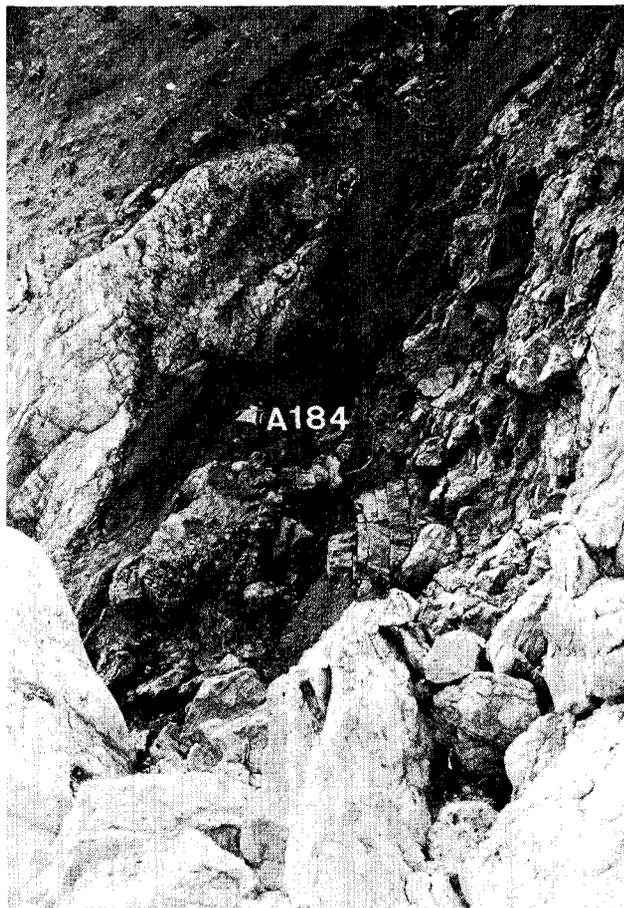
Division D extends over a distance of about 200 meters; it consists of some isolated outcrops, separated by large, unexposed intervals. In the east, some 25 meters of crumbly marls (D1) are exposed. After an unexposed interval of 110 meters, two positively graded sandstone bodies are found intercalated in silty marls. After another unexposed interval of 40 meters, a 1.50 meters thick, allochthonous, white limestone body with flintstone lenses (D5) is present in the succession. Division D is bordered in the west by a thick, positively graded, calcareous sandstone-marl sequence with a coarse, conglomeratic base. This unit D6 forms a steep coastal cliff.

From here to the NW, division E extends over some 120 meters, and can only be visited by boat. This division of the Afales-bay section consists of some isolated outcrops, separated by faults. The sediments are steep, strongly disturbed and positively graded sandstones, generally with a conglomeratic base, and merge into sandy silts or silty clays. The sandstone beds may contain rich faunas, mostly composed of *Lepidocylinids* and *Miogyssinids* (fig. 14). About 30 meters north of the coastal cliff separating the divisions D and E, three thick, allochthonous, white limestone bodies with flintstone boulders are found (E3, figs. 8 and 13). At the NW limit of division E, the sediments are covered with large, breccious boulders of unknown age.

The gently dipping marls exposed along the NW coast of the island, and those exposed between the large, breccious boulders along the NW extension of division E appear to be of Middle Miocene age; they will not be discussed in detail.

### III.1.1.3 *Types of sediment successions*

All smaller parts of the coastal section in which the stratigraphic order of the beds is clearly visible, or which are comprehensive because of comparable degrees of deformation, have been taken together as separate units. As a consequence of repeated abnormal contacts and numerous unexposed intervals, the number of units is as high as 47. The units are indicated by a letter



13



14

Fig. 13 Strongly disturbed sediments of unit E3, fifth type of sediment succession in Afales-bay, Ithaki. The large, allochthonous Eocene limestone slab to the left is intercalated in Burdigalian marls. The right part of the picture shows a coarse, chaotic breccia, being attached to another allochthonous limestone slab, of which the basal part is visible in the extreme right of the photograph.

Fig. 14 Detail of a fining upwards calcareous sandstone-marl sequence of unit E8, fifth type of sediment-succession in Afales-bay, Ithaki. The hammer is placed at the rather abrupt and irregular break between the conglomeratic basal part and the coarse-grained, horizontally laminated calcareous sandstone.

symbol, referring to the division of the section, and a number (see fig. 8).

Most of the units cannot be placed in stratigraphic order in the field. For this reason the ones with a similar type of sediment succession can be combined into five different types, either with their own characteristic lithology, or with a typical alternation of their constituents. Some of the types are found in more than one place in the coastal section. Secondary displacement of the elements of one type into strata of another is a common feature.

By using biostratigraphic data and the scarce field observations on the stratigraphic order of the various types of sediment succession, it will be attempted in the next paragraph to arrange the units into one single composite stratigraphic column.

1. The first type of sediment succession is represented by the limestones underlying the clastic sediments of Afales-bay near Ay. Saranta. These white to light grey limestones are well bedded (thickness of individual beds varying from 15 to 40 centimeters), and very rich in planktonic foraminifera. Detrital intercalations have not been observed and bioclastic elements have not been found in thin sections. Following Dunham (1962), the limestones may be classified as wackestones to mudstones. Fauna and texture of the limestones suggest deposition in a pelagic sedimentary environment.

Similar limestones were found as allochthonous boulders in units D5 and E3, and as components in the coarse, basal parts of the detrital limestone beds of divisions C, D and E.

2. The second type of sediment succession consists of calcareous clastic deposits alternating with marls. In the basal part of the Afales section, this type gradually develops from the underlying limestones of type 1 by intercalation of marly limestones and of thin, bioclastic limestone beds. In its typical form the type consists of positively graded, beige coloured, detrital limestones alternating with more or less indurated, green-grey or grey marls.

Units A1 and A2 belong to this type (fig. 8). In unit A1 there is an upward increasing thickness of the marls corresponding to a decreasing carbonate content. From bottom to top, these changes are combined with a decrease in number and thickness of the detrital limestones (fig. 10). In unit A2, the marls and limestone beds of this second type are strongly folded and faulted (fig. 11).

The sediments of unit A1 are the best example of this type of sediment succession. The unit consists of 30 meters of thinly bedded, mostly positively graded, detrital limestones of packstone texture, alternating with grey, calcareous marls. The lower bedding planes of the limestone beds are sharp, whereas the upper parts are gradually merging into the marls. The limestones

are of a beige-greyish colour; the thickness varies from 1 to 25 centimeters. They are moderately well sorted and may show horizontal lamination. Some beds are very rich in larger foraminifera: *Nummulites*, *Discocyclina*, *Alveolina*, *Chapmanina* and *Gypsina* are abundant, *Asterocyclina*, *Pellatispira*, *Planorbulinella*, *Heterostegina* and *Operculina* are subordinate. The larger foraminifera are oriented parallel to the bedding planes and most of them are found in the lower and coarsest parts of the limestone beds. Some limestone beds have an irregular lower surface; in such cases the lower part consists of organic debris and marl pebbles. The blue-grey or sometimes greenish marls contain rich and diversified planktonic foraminiferal faunas.

The sedimentation mechanism of the second type of sediment succession may be explained in terms of deposition from turbidity currents of a relatively mature character.

3. The third type of sediment succession is found in units B1 – B3, B10 – B12 and C1 – C2. The stratigraphic positions of these units relative to those of type 2 is not clear from field observations, since units A2 and B1 are separated by a fairly wide unexposed interval.

This third type is characterized by beige coloured, positively graded, coarse detrital limestones or calcareous conglomerates, alternating with greyish marls and finer grained detrital limestones. The chaotic mixture of conglomeratic marls and calcareous debris at the top of unit B2 has been included in this type. The marls and the relatively fine-grained, thinner limestone beds closely resemble those of type 2, both structurally and texturally. Most typical for this third type are the coarse conglomeratic intercalations which may attain a thickness of 2.50 meters. In addition to components of Mesozoic and Eocene rocks, the conglomerates contain mud pebbles and organic debris, mainly larger foraminifera. In the lower part of some of the beds, the components are floating in a finer grained matrix. The components may consist of conglomeratic bodies containing larger foraminifera or mud pebbles, thus suggesting repeated displacement of elements. Some of the coarsest intercalations consist of two parts, separated by an irregular boundary (see fig. 12). Such coarse conglomeratic intercalations are less abundant in the lower parts of the successions of type 3.

Larger foraminifera are numerous; they are either irregularly distributed in the fine-grained, marly matrix of coarse conglomeratic beds, or oriented parallel to the bedding planes at the basis of positively graded limestone beds. The larger foraminiferal faunas in unit B1 and in the lower part of unit B2 contain numerous *Nummulites*, *Discocyclina*, *Alveolina* and *Gypsina*, with subordinate quantities of *Asterocyclina*, *Aktinocyclina*, *Assilina*, *Chapmanina*, *Heterostegina* and *Operculina*. The upper part of unit B2 and units

B3, B10 – B12 and C1 – C2 contain predominantly *Nephrolepidina*, *Eulepidina*, *Heterostegina* and *Operculina*, fewer *Amphistegina*, *Gypsina*, *Planorbulinella*, *Alveolina* and *Nummulites* and scarce *Discocyclusina*, *Cycloclypeus*, *Linderina* and *Halkyardia*.

The conglomerate bed, which forms the top of unit C1, is representative of the coarse intercalations. It consists of two parts; its lower surface is irregular, whereas the top is formed by a straight bedding plane. The thickness varies from 2.00 to 2.40 meters. The lower part, with a thickness varying between 1.20 and 2.10 meters, consists of an ill-sorted, oligomict conglomerate. The predominant components (up to 1 meter in diameter) are well to moderately rounded, brown-grey, recrystallized limestones, and in addition, lenses and boulders, up to 60 centimeters in diameter, of green-grey marls. The matrix consists also of green-grey marl. *Nephrolepidina*, *Heterostegina*, *Alveolina* and smaller benthonic and planktonic foraminifera are common in the matrix and in some of the marly pebbles and boulders. The upper part of this intercalation consists of a more consolidated, positively graded, moderately sorted, grey limestone (packstone), with a very irregular lower bedding plane. Its conglomeratic basal part contains flat, green-grey marl lenses, decreasing in size upwards. Its top part is composed of fine-grained, detrital limestone with a straight upper bedding plane. This upper part contains *Nephrolepidina*, *Eulepidina*, *Heterostegina*, *Gypsina*, *Alveolina* and *Nummulites*.

The lower part of the conglomerate beds has been deposited from gravity induced currents, which caused secondary deposition of an immature nature. This mechanism may account for the ill-sorted components floating in a marly matrix, for the heterogeneous composition of the association of larger foraminifera, and for the large Mesozoic limestone boulders and marl pebbles. The marl pebbles are considered to have been incorporated in the water-loaded mass during transport. The positive grading in the upper part, with finer grained sediments with the particles arranged parallel to the bedding planes is consistent with this mass transport mechanism. The difference in cementation between both parts of the sequence must be attributed to the absence of marly matrix in the upper part. A rapid deposition from two successive flows, with differences in composition, seems most plausible.

4. The fourth type of sediment succession consists of brown-grey, positively graded, more or less calcareous, ill-sorted to moderately well-sorted polymict sandstones, which grade upwards into grey, silty marls or clays.

These sequences are exposed in units B4 – B9, C3 – C10 and in D1 – D3. Undisturbed parts of the successions have a maximum thickness of 20 meters. In divisions B and C the succession of strata suggests that these

sand-marl sequences belong stratigraphically above the type 3 deposits.

The grainsize of the sandstone beds never exceeds that of the coarse sand fraction in the basal parts. The sandstones show horizontal lamination and in some beds, low angle cross-stratification.

The sandstones contain abundant *Nephrolepidina*, *Eulepidina*, *Miogypsinooides*, *Miogypsina* s.s., *Heterostegina*, *Operculina*, *Amphistegina* and *Spiroclypeus* and scarce *Nummulites*, *Discocyclina*, *Alveolina*, *Chapmanina*, *Gypsina* and *Planorbulinella*. The finer sands may contain lignite flakes or thin lignite seams. Some of the marls or clays in the top part of the sequences are rich in planktonic foraminifera, whereas other marl beds are barren.

The sediments of unit C3 present a good example of the sequences characteristic of this type of succession. The basal part of the 20 meters is composed of coarse, brown-grey, moderately sorted, calcareous and glauconitic sandstone. The sandstone shows a decreasing grainsize from bottom to top and merges via fine sands and siltstones into blue-grey marls, approximately 12 meters above the base. The sandy part of the sequence contains numerous irregular veins of calcite. The relatively coarse, basal part has a limeclast packstone texture with foraminifera and algal fragments and diagenetic dolomitic replacements. Among the larger foraminifera, *Operculina*, *Miogypsina* and *Lepidocyclina* are common. The siltstones contain lignite flakes and poorly preserved benthonic and planktonic foraminifera; the marls of the upper part of the sequence are barren.

In this case we are dealing again with deposition from density currents, but the composition and possibly the source area are different from those of the earlier described types. The low angle cross-stratification in some of the sandstone beds is a well-known feature in such deposits; its origin may be due to slowing down of the current, causing the growth of ripples under conditions of relatively rapid deposition from suspension.

5. The fifth type of sediment succession shows close similarity to type 4 because of its positively graded sandstone-marl sequences. It may be distinguished by the conglomeratic, calcareous base in many units (see fig. 14), by the presence of flintstone components in the coarser beds, and by the local intercalation of large, allochthonous limestone slabs. The coarser beds contain the same genera of larger foraminifera as the sediments of type 4; in one sample *Miolepidocyclina* was found. The allochthonous limestone slabs may reach a diameter of 25 meters. The sediments surrounding these slabs may show intense folding and crumbling due to deformation during the displacement of the limestone bodies (fig. 13). Sediments of type 5 are restricted to units D4 – D6 and E1 – E16. Their position in relation to the units of the other types cannot be ascertained from field observations.

Unit D6 gives a good example of part of the clastic successions of type 5. The unit is composed of a positively graded sandstone bed, protruding several meters into the sea; it overlies blue-grey calcareous marls, of at least 2.50 meters thick. The sandstone has an undulating lower surface; it is three meters thick. The basal part consists of a coarse, ill-sorted, polymict breccia, containing flintstone, white dense limestone, strongly recrystallized limestone and marl-lenses. The texture is that of a foraminiferal limeclast-packstone with strongly indented microstylolitic grain contacts. The larger foraminifera are *Eulepidina*, *Nephrolepidina*, *Nummulites* and *Discocyclina*.

Upwards the breccia passes into well-sorted, coarse calcareous sands with a similar larger foraminiferal assemblage. The larger foraminifera are arranged with the larger dimensions parallel to the bedding planes. The calcareous sands rapidly grade into badly-sorted, brown-grey, sandy marls, rich in larger foraminifera: *Eulepidina*, *Nephrolepidina*, *Miogypsina* s.s., *Miogypsinoides*, *Miolepidocyclina* and *Asterocyclina*.

The white limestone slabs of unit E3 have a mudstone/wackestone texture, and they are very rich in planktonic foraminifera, indicating an Early Eocene age.

The sedimentation of the breccia/conglomerate-sand-marl sequences is considered to have originated also in an open marine environment with episodic supply of coarser and finer material by gravity induced currents.

Summarizing the review of the sediments of Afales-bay, it may be concluded that, except for the pelagic limestones of Ay. Saranta, all types of sediment succession show ample evidence of repeated re-sedimentation caused by gravity induced currents. Differences exist in the variation in grain-size of the redeposited material, in the nature of the transported sediment and in the degree of sorting.

The very coarse conglomerates of type three and the breccias and allochthonous blocks of type five may reflect a supply from nearby sources, whereas the detrital limestones of type 2 and the sandstones of type 4 reflect a more mature, turbiditic sedimentation.

### III.1.2 Reconstruction of the stratigraphic column of Afales-bay

The field observations enable a tentative reconstruction of the relative stratigraphic position of the five types of sediment succession. However, the section is too strongly faulted and the number of unexposed intervals is so high that not all 47 units can be arranged in stratigraphic order by use of field data only. For the same reasons we cannot expect the Afales-bay

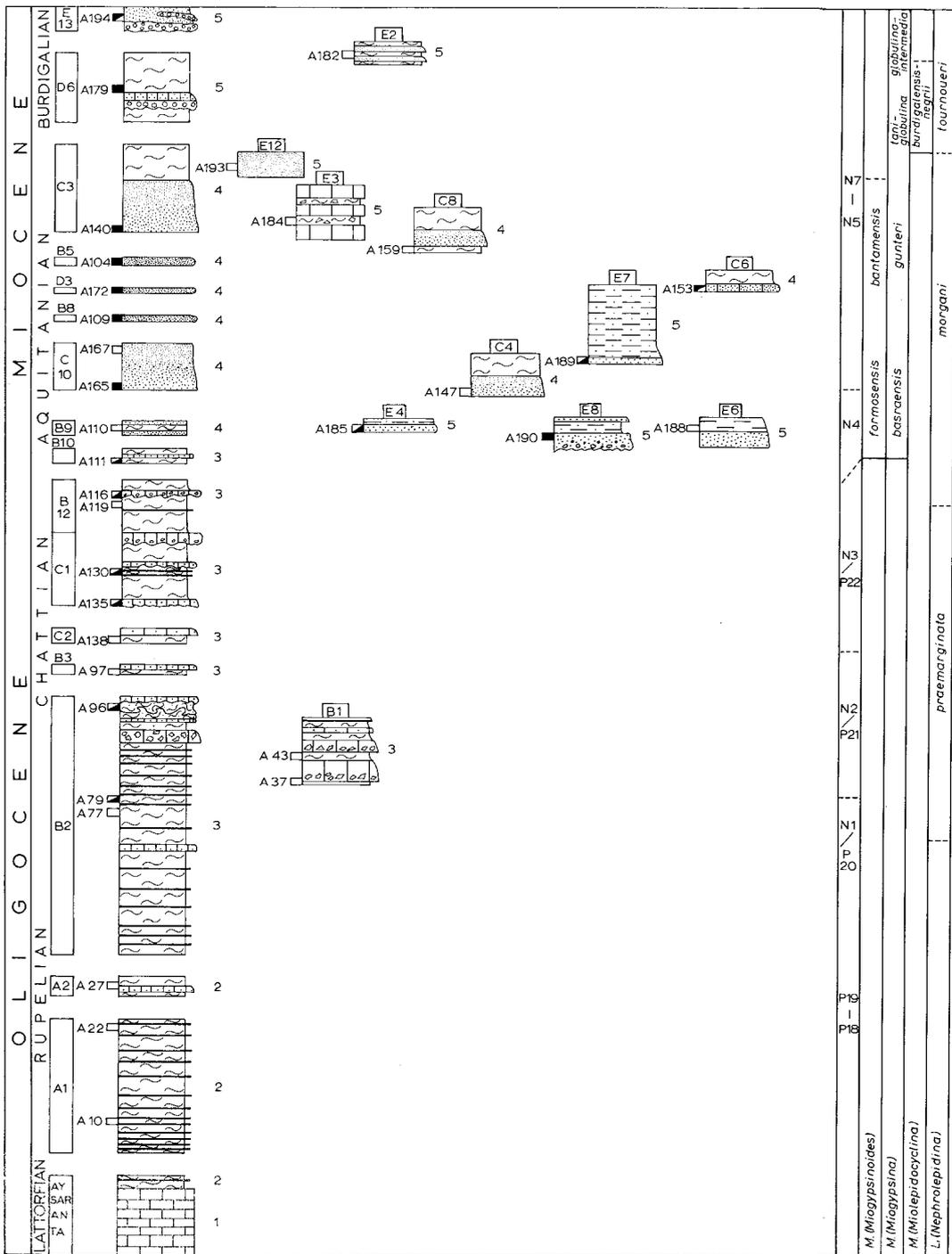


Fig. 15 Idealized stratigraphic column of the Afales-bay sediments, Ithaki. Numbers 1 – 5 refer to the types of sediment succession. The ranges of the *Miogypsina* and *Nephrolepidina* species relative to the planktonic scale may be too high because of reworking.

sediments to furnish a complete sedimentary record of the Oligocene – Early Miocene time span.

Hence, we will try to construct a composite stratigraphic column, based on the combination of field evidence and the biostratigraphic data provided by the planktonic foraminiferal associations and the representatives of the *Lepidocyclina* and *Miogypsina* lineages. This composite column is presented in fig. 15.

In the main column, at the left side of the figure, those units are shown, which either show a clear superposition in the field or which can be located fairly accurately by the presence of typical planktonic foraminiferal taxa and/or larger foraminiferal index species. The spacing between the units is not correspondent to the duration of the supposedly missing time intervals.

The succession of units B8, D3 and B5 in the main column is based on the numerical values of *Miogypsina* parameters, but the mean values of these parameters cannot be proved as significantly different. Therefore, units B8, D3 and B5 might as well be placed in a different order or considered lateral equivalents.

The faunistic data of the units placed in the central part of the figure indicate a position approximately time-equivalent with units included in the main column. For all samples containing biostratigraphic evidence for one group of microfossils only, it should be emphasized that the position of the units from which they were derived, may be slightly lower or higher in relation to the main column and to one another. This is due either to the impossibility of fixing the position of the planktonic foraminiferal associations more accurately than the range of a complete zone, or to the effect of the standard errors of the means for parameters of the larger foraminifera.

The linking between our composite column and the international chronostratigraphic scale will be attempted for each group of microfossils independently. The planktonic foraminiferal associations, present throughout the Afales-bay section, represent zones P18/P19 up to N6/N7 of the standard zonation established by Blow (1969). Following Berggren's and Van Couvering's (1974) interpretation, this means that this section covers the Lattorfian/Rupelian – Burdigalian interval (fig. 5).

The Miogypsinidae can also be used for correlation with the chronostratigraphic scale. Our *Miogypsinoidea* and *Miogypsina* s.s. assemblages include *M. ex. interc. complanata-formosensis*, *M. ex. interc. formosensis-basraensis*, *M. ex. interc. bantamensis-gunteri*, *M. ex. interc. tani-globulina* and *M. ex. interc. globulina-intermedia*. *Miolepidocyclina* is represented by *M. ex. interc. burdigalensis-negrii*.

Drooger (1963) assigned *M. complanata* and *M. formosensis* assemblages

to the Chattian, whereas circum-Mediterranean *M. bantamensis* assemblages of the main lineage have been reported from levels close to the Chattian – Aquitanian boundary, though mainly on the Oligocene side. He considered *M. basraensis* assemblages to be of Chattian Age, whereas *M. gunteri* and *M. tari* assemblages are assigned to the Aquitanian. *M. globulina*, *M. intermedia*, *M. burdigalensis* and *M. negrii* are supposed to be restricted to the Burdigalian. These age assignments are based for a part on the study of assemblages from European Oligocene and Lower Miocene stratotype sections.

The succession of the Miogypsinidae of Afales-bay seems to be in predicted order and thus allows a rather accurate age assignment of many of the units. There are several questions, however, concerning the co-occurrence of some taxa of the three subgenera in some of our samples. Details will be discussed in paragraph III.1.4.

Less accurate results are obtained from the *Lepidocyclina* (*Nephrolepidina*) assemblages. Three successive species, *L. praemarginata*, *L. morgani* and *L. tournoueri*, are known from Europe in Oligocene and Lower Miocene strata. Vervloet (1966), who gave details on *L. praemarginata* from Costa Lupara, Italy, considered this species to be of Rupelian Age. Some of the *L. praemarginata* assemblages from Afales-bay are distinctly more primitive with respect to the embryonic-nepionic stage of development than those from Costa Lupara. In fact, the Afales-bay sediments contain the most primitive and thus the oldest representatives of the *Nephrolepidina* lineage described from Europe so far. *L. morgani* assemblages are well known from several localities in southern France and have been assigned either to the Chattian or to the Aquitanian (Drooger and Freudenthal, 1964). *L. tournoueri* assemblages are generally considered to be indicative of the Burdigalian (e.g. Drooger and Socin, 1959; Drooger and Freudenthal, 1964).

In general, the age assignments obtained from the three groups of microfossils lead approximately to the same results. It should be noted that the ranges of the *Miogypsina* and *Nephrolepidina* species relative to the planktonic scale tend to be slightly too high if compared with data from the literature. This may be explained by reworking. Reworking of larger foraminifera is also demonstrated by the presence of *Nummulites* and *Discocyclina* as far as the highest levels of the column.

However, reworking of lepidocyclinids and Miogypsinids evidently played a major part in some levels in the higher part of the column. For instance, in sample A 185 (E4), the *L. praemarginata* assemblage suggests a Late Rupelian – Chattian Age, in contrast to the planktonic foraminifera from the nearby sample A 188, which belong to zone N4, and must thus be regarded as Late Chattian – Early Aquitanian. The *M. ex. interc. formosensis*

*basraensis* assemblage of sample A 165 (C10) may point to a Late Oligocene (Chattian) age, but the planktonics found in the nearby sample A 167, are indicative of zones N5 – N7 and suggestive of a Late Aquitanian – Burdigalian Age. The position of the *M. ex. interc. complanata-formosensis* assemblage of sample A 179 (D6) is equally aberrant according to its planktonic foraminifera, which point to the Late Aquitanian – Early Burdigalian (N5 – N6). In all these cases, a reworking of the larger foraminifera may be a plausible explanation (see also III.1.4).

From the stratigraphic position of the various units it may be concluded that there is an interrelation between the types of sediment succession and their relative age. The upper part of the pelagic limestones of type 1, the alternated sequences of graded detrital limestones and marls of type 2, and the coarse conglomerates, detrital limestones and marls of type 3, appear to be successive in time. They have been deposited during the Oligocene. The sand-marl/clay sequences of type 4 and the conglomerate-sand-marl/clay sequences of type 5 with intercalated, allochthonous limestone slabs are of Early Miocene age; they cover the Aquitanian and part of the Burdigalian. The four younger units of the Afales-bay section (E12, E13, E2 and D6) all belong to type 5. Although individual units of types 4 and 5 may be time-equivalent, it is suggested that sediments belonging to the fifth type reach higher in the chronostratigraphic scale than those of type 4.

These conclusions on the composite column are based on biostratigraphic and field evidence from 28 out of the 47 units only. From field observations and faunistic data of the 19 units not included in the column of fig. 15, it may be safely assumed that the general stratigraphic relations between the various types of sediment succession and time can be applied to all sediments of the Afales-bay section.

### III.1.3 Sedimentary history

The rather abrupt change from pelagic-calcareous to detrital sedimentation is one of the most conspicuous events in the stratigraphic record of Afales-bay. The change took place some time during the Early – Middle Oligocene (Lattorfian – Rupelian). The introduction of graded detrital limestones in a depositional area of marls, followed by strong intraformational deformation of strata witnesses of an increasing clastic supply and increasing tectonic instability of the area. The accentuation of the topographic relief and the periodical supply of calcareous clastics from shallow marine and coastal areas culminated in Chattian times with the deposition of

coarse, calcareous conglomerates (top of B2, C1 and B12) which were redeposited by gravity induced currents of a proximal character, such as mudflows. The local presence in the coarser, clastic limestones of conglomerate pebbles with debris of larger foraminifera, even points to repeated displacement of the same material. The periodical influx of such coarse, ill-sorted clastics of a proximal character in an open marine environment may best be understood by assuming a pronounced relief nearby, which was constantly renewed by differential vertical movements. The intraformational unconformity in the Chattian succession of C1 – C2 also supports the idea of synsedimentary faulting. This unconformity most probably indicates downwarping of an eastern block.

Hardly any direct information can be obtained as to the source area of the clastics. Some measurements on flute casts from the lower surfaces of turbiditic beds suggest that at least part of the material came from the south or southwest.

A second major facies change, probably linked with a change in paleogeographic configuration approximately coincides with the Oligocene – Miocene boundary. The carbonate supply diminished rather suddenly and the supply of terrigenous clastics increased rapidly. In Early Miocene times, sequences of sand passing upward into marly deposits were laid down by a turbiditic sedimentation mechanism of a more distal character. Paleocurrent measurements by Bischoff (1968), based upon sole marks of the sandstone bodies, point to transport from the north. This type of sedimentation persisted upward into the Burdigalian.

During this Miocene phase the basin margins must have been very close to the Afales-bay sedimentation area, especially so for the Burdigalian. This may be deduced from the repeated intercalation of redeposited, coarse breccias and conglomerates with numerous flintstone pebbles and large, allochthonous limestone slabs of Early Eocene age, in the succession of sand-marl sequences. It is probable that the sand-marl sequences and the proximal breccias, conglomerates and allochthonous limestone bodies originated from different source areas. If true, the transport of the finer grained sands must have taken place along the longitudinal axis of the basin (from the north, whereas the breccias and conglomerates originated in nearby source areas along the borders of the supposed trough. The large limestone blocks suggest the vicinity of coastal cliffs.

The supply of coarse material from nearby sources, superimposed on the overall supply of sands, played a more important role during the Burdigalian than during the Aquitanian. This may imply that renewed, differential movements in Burdigalian times caused a conspicuously increasing relief, the

position of which may have been in the direction of today's Kavellares Mountains, i.e. to the west. This assumption is based on the coarse intercalations and allochthonous Eocene limestone blocks being restricted to the northwesternmost part of the Afales-bay section, whereas such intercalations are absent in the supposedly time-equivalent strata in the central part of the section to the southeast. The sudden supply of large amounts of flintstone may be attributed to erosion of Jurassic and Cretaceous chert formations, presently exposed in the eastern flank of the Kavellares Mountains.

The strong differential movements in the area of Afales-bay during the Late Oligocene and again during the later part of the Early Miocene caused the displacement from west to east of pre-Oligocene rocks and of Oligocene – Early Miocene calcarenitic, shallow marine clastics with larger foraminifera. The larger foraminifera are supposed to have lived in shoal areas along the tectonically instable margins of the basin to which the Afales-bay area belonged. The age of the assemblages of *Lepidocyclina* and *Miogyopsina* from the obviously displaced sediments is fairly close to that based on the planktonic foraminifera from the accompanying marls or clays; this indicates that the intermittent removal of the coarser sediments from the basin margins must have been rather continuous.

The Eocene to Early Oligocene pelagic limestones, presently exposed in the Karamalicha Mountains to the east do not contain larger foraminifera. Yet, the proximal turbidites throughout the section are rich in reworked Eocene larger foraminifera, such as *Nummulites*, *Asterocyclina*, *Discocyclina* and *Chapmanina*. They suggest the existence of flourishing larger foraminiferal populations in the vicinity of Afales-bay during the Eocene. It seems plausible to assume that a large shoal area existed to the west of today's Afales-bay also during the Eocene. After emergence, this shoal area became subjected to erosion during the Oligocene and Early Miocene. Along the eastern margins of this rising block, contemporaneous larger foraminifera and organic debris accumulated; this material was repeatedly transported by gravity induced currents towards the central part of the basin together with older eroded material. Today's Kavellares Mountains may have been part of this relatively higher block, which probably at that time was separated already by major faults from the rapidly subsiding basin.

Very few data are available to evaluate the processes governing the geological history of the Afales-bay area during the Late Burdigalian to the Early Serravallian. Remnants of Serravallian marl and clay successions indicate marine sedimentation. Serravallian deposits are exposed north of the Afales-bay section and along the northwestern coast. Sediments of Late Burdigalian or Langhian Age have not been recognized. The Serravallian

sediments along the northwestern coast are undisturbed and gently dipping inland. The folding and faulting of the Oligocene – Lower Miocene successions of Afales-bay thus seems to have taken place in pre-Serravallian time.

Evidently this tectonic phase of roughly Langhian Age was completely different from the previous Oligo – Lower Miocene disturbances with peak effects during the Chattian and Burdigalian. For these older phases, moderate relative vertical movements of individual blocks must have triggered the displacement of unconsolidated older sedimentary material to new stratified positions in the Afales depression. The Langhian phase seems to have involved larger block movements, since it is not reflected in regular sedimentary deposits. Instead, it caused major parts of the entire older sedimentary series to slide downslope, and becoming intricately folded and faulted.

The age determination of the Afales-bay sediments shows that we are not dealing with some kind of wide synclinal structure, as might at first sight be expected for these Middle Tertiary sediments lying in a depression between the culminations of Mesozoic – Eocene deposits of the Kavellares and Karamalicha Mountains. However chaotic their structure seems to be, we cannot escape from the impression of a monoclinical, though disordered, Eocene to Burdigalian sequence from east to west.

Later “sedimentary” phenomena seem to have been the irregular piling up of sheets of the earlier sediments, in which the repeated alternations of Aquitanian and Burdigalian slabs at the top of the section most clearly belong to the final Langhian phase. It is much less certain that the irregularities in the stratigraphic order of the Oligocene part of the section are of the same age, they might as well be older.

Considering that the nearby Serravallian sediments hardly deviate from the horizontal, the steep dips of the sediments up to the Burdigalian must be attributed to a next step in the Langhian tectonic phase. Particularly the overturned series of Aquitanian – Burdigalian slabs in the western part of the section require as an explanation a rapid foundering of the immediately adjoining western block, which was situated at or towards the place of the previous platform with calcareous sedimentation. Such foundering may explain the bulging of the Afales sedimentary masses towards the subsiding block. The overturned position of the higher strata and recent geodynamic theories even lead to speculating on a rapid, Langhian, underthrust phase of the Preapulian block along an eastward dipping major fault plane. If this is the case, it must be accepted that later movements along this line seem to have been vertical again, bringing part of the western foundered block high up to form the present Kavellares Mountains.

### III.1.4 Paleontology

#### III.1.4.1 Introduction

As mentioned in paragraph III.1.2, the composite stratigraphic column for the Afales-bay section has been constructed by using planktonic foraminiferal assemblages and representatives of the larger foraminiferal genera *Miogypsina* and *Lepidocyclina*. This paragraph contains a more detailed account of the planktonic foraminifera, and presents data obtained from biometrical analyses of *Miogypsina* and *Lepidocyclina*.

The Afales-bay section is of particular interest since it produces the most primitive and in one respect also the most highly developed *Lepidocyclinids* known from Europe thus far. The co-occurrence of *Miogypsina*, *Lepidocyclina* and planktonic foraminifera provides an opportunity to correlate zones of larger foraminifera and planktonic foraminiferal zones in the Oligocene – Lower Miocene. Unfortunately, the calcareous nannoplankton floras are too poorly preserved to be included in correlating the zonal systems.

#### III.1.4.2 Planktonic foraminifera

Planktonic foraminifera were found in large numbers in the marly and clayey beds of the Afales-bay section. Those observed in the coarse, basal parts of graded sequences and in thin sections of detrital limestones have not been used for biostratigraphic purposes. It has not been attempted to establish an independent zonation for the sediments of the Afales-bay section; it was tried to correlate index fossils with Blow's (1969) planktonic zonal scale. For this purpose, twenty samples were selected from various units of the types of sediment succession 2 – 5. The results are considered to provide a sufficiently sound basis for the reconstruction of their position in terms of planktonic foraminiferal biostratigraphy.

The planktonic associations in most of the samples could not be correlated with specific zones of Blow; consequently, they can only be fitted into Blow's scale by indicating the maximum ranges relative to this scale for each sample, i.e. for most samples only a range in terms of two or three successive zones. The results are represented in figure 16. Some index species are represented in plate 1 and 2.

Assigning the successive planktonic zones to the chronostratigraphic scale is primarily based on the recent interpretation by Berggren and Van Couvering (1974); their opinion on the Oligocene – Miocene boundary was not followed. According to Berggren and Van Couvering, the base of the Aquitanian coincides with the base of the *Globigerinoides primordius* – *Globoro-*

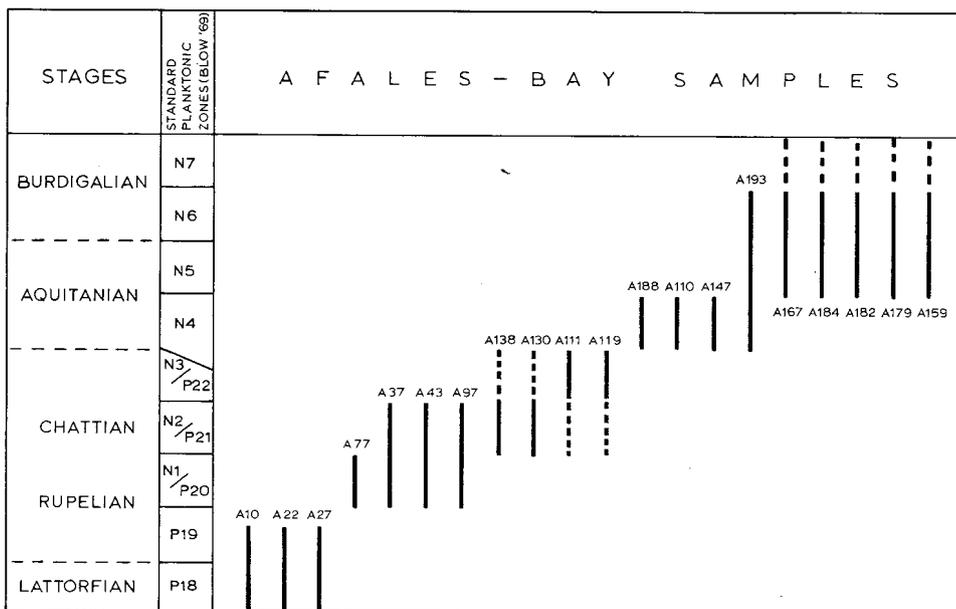


Fig. 16 Correlation of twenty planktonic associations from Ithaki with the standard zonation of Blow (1969). For each sample the maximum range is presented in relation to the zonation. The correlation with the chronostratigraphic scale after Berggren & Van Couvering (1974) is slightly modified.

*talia kugleri* Concurrent-range zone (N4). However, there is ample evidence of a diachronous character of the *Globigerinoides* "datum" and recent investigations indicate that zones N3 and N4 are partly overlapping (Meulenkamp *et al.*, 1975). For the time being, it seems better to place the Chattian – Aquitanian boundary somewhere within zone N4.

The samples A 10, A 22 and A 27, taken from marly deposits of the 2nd type of sediment succession, contain representatives of *Globigerina gortanii*, *G. ampliapertura*, *G. tripartita*, *G. ouachitaensis*, *G. venezuelana*, *Catapsydrax dissimilis* and specimens close to *Globigerina increbescens*. The observed morphotypical variation in *G. ampliapertura* includes specimens of the *G. pseudoampliapertura* type. The associations collected from these three samples are indicative of zones P18/P19 (pars), because of the presence of *Globigerina angiporoides* in A 22 and A 27, together with *Globigerina tapuriensis* in A 27. This suggests an Early – Middle Oligocene age (Lattorfian – Rupelian).

The associations from A 77, A 37, A 43 and A 97, all from exposures belonging to the third type of sediment succession, contain *G. opima nana*,

*G. ouachitaensis*, *G. galavisi* and *G. gortanii* as characteristic elements, and may be correlated with zones P20/P21 (= N1/N2). A 77 allows a more precise assignment: the fauna from this sample belongs to zone P20, because of the co-occurrence of *G. ampliapertura* and *G. opima opima*. The absence of *G. ampliapertura* in A 37, A 43 and A 97 suggests a correlation with zone P21, but this cannot be ascertained, since *G. angulisuturalis* was not found. The presence of *G. ex. interc. anguliofficinalis-angulisuturalis* in A 97 and of typical *G. ouachitaensis* in all three samples are in support of a correlation with zone P20. The P20/P21 interval may indicate (Lower) Chattian.

A second group of samples taken from deposits of the third type of sediment succession (A 138, A 130, A 119 and A 111) is characterized by the co-occurrence of *G. angulisuturalis* and *G. ciperoensis*, a combination which is indicative of zones P21/P22 (N2/N3). A 138 and A 130 still contain *G. gortanii*, which suggests that the associations from these samples belong to P21 or to the lower part of P22; the absence of this taxon in A 119 and A 111 suggests these samples to be slightly younger, i.e. belonging to zone P22 (N3), which is placed in the Upper Chattian.

Faunas in samples A 110 and A 147, taken from the fine-grained sediments of the fourth type of sediment succession may be placed in zone N4; they contain the two zonal markers *Globigerinoides primordius* and *Globorotalia kugleri*. In A 147, these index species are found together with *G. opima nana*, *G. cf. angulisuturalis* and *G. cf. ciperoensis*; in A 110, the accompanying fauna includes *G. venezuelana*, *G. tripartita*, *G. siakensis* and *G. dissimilis*. Zone N4 is considered to range from the Upper Chattian into the Aquitanian.

The assemblage collected from sample A 188 (fifth type of sediment succession) is clearly heterogeneous. It contains reworked elements such as *G. angiporoides* and specimens close to *G. increbescens*, together with *Globigerinoides primordius* and *Globigerina siakensis*, which are considered autochthonous. No decision can be made on the reworked or autochthonous nature of the co-occurring *G. venezuelana*, *G. tripartita*, *G. opima nana* and *G. cf. angulisuturalis*. These taxa are generally found in strata below the first occurrence of *Globigerinoides*, but they have also been reported from higher levels. The association of A 188 seems to fit best in zone N4, notwithstanding the fact that *G. kugleri* is absent. If this absence is considered significant, A 188 might be slightly older than A 110 and A 147.

The poor preservation in A 193 (fifth type of sediment succession) hampers the determination of the *Globigerinoides* specimens from this sample. In addition, poorly preserved *Catapsydrax dissimilis*, *G. cf. angustiumbilicata* and *Globoquadrina praedehtiscens* were observed. This association suggests

the N4 – N6 zonal interval (Uppermost Chattian – Lower Burdigalian). Five samples from the fourth and fifth types of sediment succession (A 167, A 184, A 182, A 179 and A 159) are characterized by the joint presence of *Globigerinoides trilobus* and *Catapsydrax dissimilis*. This implies that the associations of these samples belong to the interval of zones N5 and N6. However, A 179, A 182 and A 184 contain numerous reworked Oligocene elements, such as *G. ampliapertura* and *G. opima opima*; some doubt exists on the autochthonous character of *C. dissimilis* in some of these samples. If the latter species is reworked, the possible biostratigraphic range of the assemblages might extend to zone N7, but probably not higher, because of the presence of *Globigerinoides ampliapertura* in A 182 and A 184. The interval of zones N5 – N7 corresponds to the Upper Aquitanian – Burdigalian.

Summarizing the planktonic foraminiferal data, it may be concluded that the assemblages assigned to the Oligocene zones are fairly homogeneous, whereas those from the Miocene may contain a considerable admixture of reworked Oligocene elements, especially so in the samples from the highest part of the section. In terms of planktonic foraminiferal biostratigraphy the sediments of the Afales-bay section belong to the interval of zones P18/P19 to N5/N7, which may be correlated with the Lattorfian/Rupelian to the Upper Aquitanian/Burdigalian.

#### III.1.4.3 *Miogypsinidae*

##### Introduction

Representatives of the *Miogypsinidae* were found in 20 samples, all obtained from relatively coarse, sandy lower parts of the sand-marl/clay sequences exposed in units B5, B8, B10, C3, C6, C8, C10, D3, D6, E7 – E9 and E13. All these units belong to the fourth and fifth type of sediment succession. In nine of the samples the number of specimens was sufficiently large to permit a biometrical analysis of some value. For the methods applied the reader is referred to paragraph II.2.2.

##### Counts and measurements

The results of counts and measurements are presented in figure 21. Because field data on superposition are very scarce, the *Miogypsina* bearing samples were placed in stratigraphic order according to the stage of evolution of the *Miogypsina* assemblages, expressed in terms of the mean values of parameter X (number of spiral chambers) and/or parameter V, which reflects the degree of symmetry of both protoconchal spirals in more highly evolved forms.

Individuals with the subgeneric features of either *Miogypsina* s.s. or

*Miogypsinoides* were found together in seven of the samples. Their relative predominance shows a tendency to shift from *Miogypsinoides* in the supposedly older levels to *Miogypsina* s.s. in the younger samples (see fig. 17). In one sample from unit D6 (A 179), rare *Miolepidocyclina* was found together with rare *Miogypsinoides* and more frequent *Miogypsina* s.s.

Sample nr.	<i>Miogypsinoides</i>	<i>Miogypsina</i> s.s.	<i>Miolepidocyclina</i>
A194		<b>█</b>	
A179	█	<b>█</b>	█
A140	<b>█</b>		
A104	<b>█</b>		
A153		<b>█</b>	
A172	<b>█</b>		
A109	<b>█</b>		
A165			
A190			

Fig. 17 Distribution of *Miogypsinoides*, *Miogypsina* s.s. and *Miolepidocyclina* in nine selected samples from the Afales-bay section. The thicker lines refer to the prevailing taxa. The samples are arranged in the assumed stratigraphic order.

A special problem concerns the distinction between *Miogypsinoides* and *Miogypsina* s.s. in samples A 104 and A 109. Lateral chambers in these specimens were not observed in these samples during the grinding process for the equatorial sections, but transverse sections of some specimens from both samples show small cavities between the laminae of the thick wall surrounding the nucleoconch, or even small, irregularly shaped lateral chambers. This implies that part of the assemblages might be determined as *Miogypsina* s.s. It is of interest to investigate whether in mixed assemblages the difference between *Miogypsinoides* and *Miogypsina* s.s., based on absence or presence of lateral chambers, may be correlated with differences in internal characteristics. From the scatter diagrams in figures 18 and 19 it may be concluded that both subgenera in samples A 140, A 172, A 165 and A 190 are not distinguishable in separate clusters. This means that *Miogypsina* s.s. and *Miogypsinoides* specimens of these samples cannot be distinguished biometrically.

Only in sample A 179 the representatives of *Miogypsina* s.s. show higher  $\gamma$  values and shorter spirals. Only in this sample there is evidence that representatives of a more primitive *Miogypsinoides* population became admixed to a *Miogypsina* s.s. assemblage. The histograms of DI classes in figure 20 also demonstrate the close similarity of the ranges of protoconch diameters for

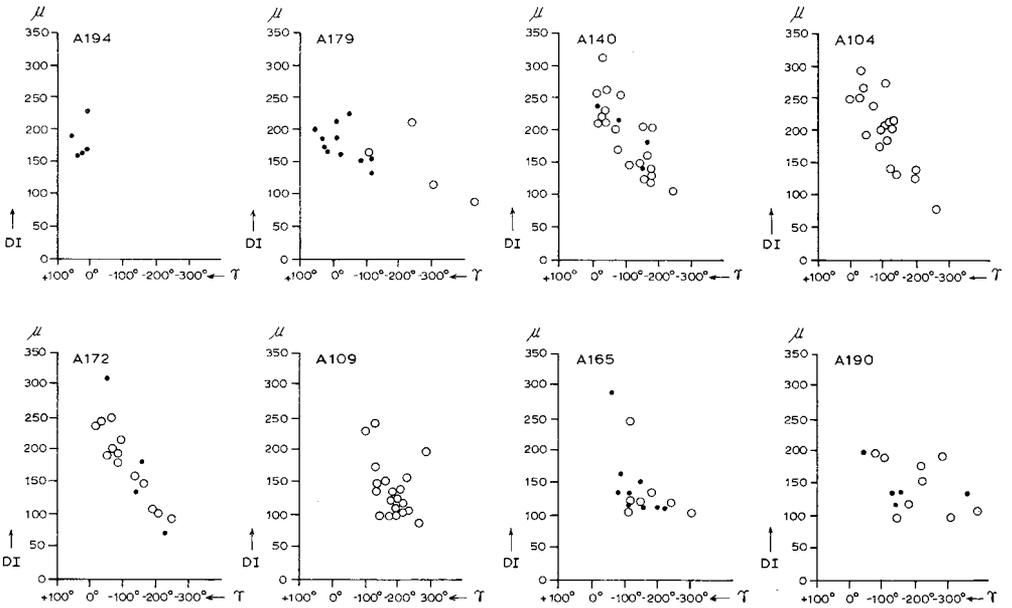


Fig. 18 Relation between  $\gamma$  and DI for specimens of *Miogypsinoidea* (open circles) and *Miogypsina* s.s. in eight selected samples from Afales-bay, Ithaki.

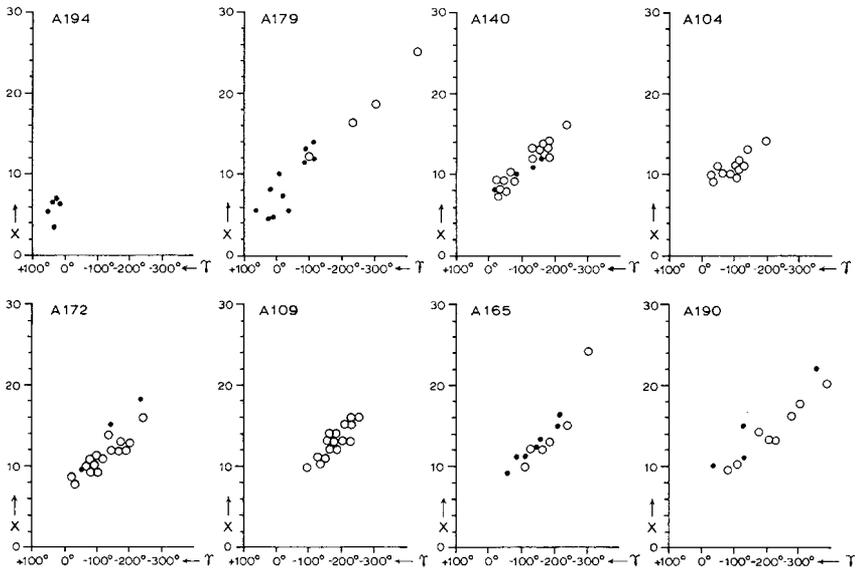


Fig. 19 Relation between  $\gamma$  and X for specimens of *Miogypsinoidea* (open circles) and *Miogypsina* s.s. in eight selected samples from Afales-bay, Ithaki.

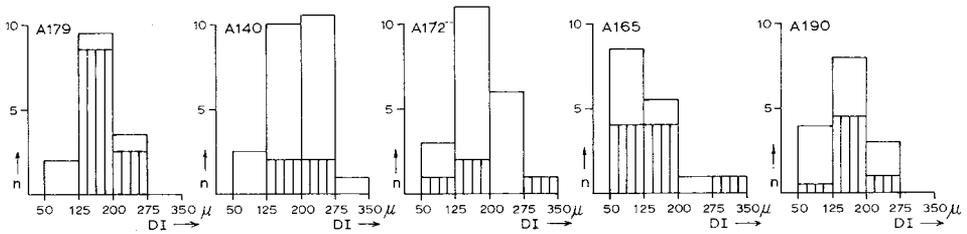


Fig. 20 Frequency distributions on DI classes of five *Miogypsina*-bearing samples of Afales-bay, containing both *Miogypsinooides* and *Miogypsina s.s.* (shaded columns) individuals.

the *Miogypsinooides* and *Miogypsina s.s.* specimens in single samples, except again for sample A 179.

Since no distinction can be made between both subgenera with respect to the numerical values of internal characteristics in samples A 140, A 172, A 165 and A 190, and since the presence of lateral chambers in specimens of samples A 104 and A 109 cannot even be observed during the grinding, the associations in these samples will be treated together and the calculations on the means will be based upon the total number of observations. Although the effect of washing together of material from different levels cannot be excluded (i.e. for A 179), the assumption of single populations with features intermediate between both subgenera is quite reasonable for most of these samples.

### Species designation

If all specimens per sample are taken together for species designation (except for A 179), intermediate notations are obtained for species names of both subgenera. An additional problem is that the calculated  $\bar{X}$  values might necessitate an intermediate notation in the species suites of the subgenera as well. A two-species exemplum intercentrale notation will be used in which the prevalent subgeneric group will be ranked first, the closest specific unit in the other as the second part of the determination.

The stratigraphic order of figure 21 is shown again in figure 22, in which the combination points of  $\bar{X}$  and  $\bar{\gamma}$  of the studied assemblages appear to be arranged along a fairly straight line. Some *Miogypsina* species are illustrated in plate 3.

The lowermost sample (A 190) with  $\bar{X}$  of 14.2 contains an assemblage of *M. ex. interc. formosensis-basraensis*. Because of the  $\bar{X}$  value of 13.2, sample A 165 is thought to be slightly younger; it also contains *M. ex. interc. formosensis-basraensis*, but this assemblage is very close to a notation *M. ex. interc. bantamensis-gunteri*. The order of the species names may be changed

sample		X	Y	$\gamma^{\circ}$	V	DI $\mu$	species
A 194	M	5.7	0	+25	48.5	183	<i>M. ex. interc.</i>
	$\sigma$ M	0.6	—	8	7.7	13	<i>globulina-intermedia</i>
	N	5	5	5	5	5	
	range	3.5–6.5	—	+4/+53	33.7–75.9	161–232	
A 179	M	8.6	0.6	–31	16.3	176	<i>M. ex. interc.</i>
	$\sigma$ M	1.2	0.5	17	5.8	8	<i>tani-globulina</i>
	N	11	11	12	10	11	
	range	4.5–14	0–5	–117/+58	0–53.4	131–223	
A 179	M	18.1	8.2	–272	0	144	<i>M. ex. interc.</i>
	$\sigma$ M	2.7	1.9	68	—	27	<i>complanata-formosensis</i>
	N	4	4	4	4	4	
	range	12–25	4–13	–435/–106	—	89–208	
A 179	M	2.5	0		50.3	155	<i>M. ex. interc.</i>
	$\sigma$ M	—	—		15.0	8	<i>burdigalensis-negrui</i>
	N	1	3		3	3	
	range	—	—		33.6–80.3	143–169	
A 140	M	11.3	2.9	–109	0.8	193	<i>M. ex. interc.</i>
	$\sigma$ M	0.5	0.4	13	0.8	11	<i>bantamensis-gunteri</i>
	N	23	26	24	24	24	
	range	8–16	0–7	–243/–20	0–19.8	101–308	
A 104	M	10.7	3.3	–104	0	201	<i>M. ex. interc.</i>
	$\sigma$ M	0.4	0.5	14	—	13	<i>bantamensis-gunteri</i>
	N	13	15	20	20	20	
	range	8–14	0–6	–260/–10	—	83–296	
A 153	M			–108	0	174	<i>M. ex. interc.</i>
	$\sigma$ M			21	—	19	<i>gunteri-bantamensis</i>
	N			7	7	7	
	range			–210/–15	—	118–278	
A 172	M	11.6	3.7	–124	0	183	<i>M. ex. interc.</i>
	$\sigma$ M	0.6	0.6	13	—	12	<i>bantamensis-gunteri</i>
	N	19	15	21	21	21	
	range	8–18	0–9	–248/–30	—	74–306	
A 109	M	13.0	3.6	–175	0	144	<i>M. ex. interc.</i>
	$\sigma$ M	0.4	0.4	10	—	9	<i>formosensis-basraensis</i>
	N	17	11	21	21	21	
	range	10–16	1–6	–267/–92	—	95–248	
A 165	M	13.2	4.1	–154	0	143	<i>M. ex. interc.</i>
	$\sigma$ M	0.9	0.6	16	—	13	<i>formosensis-basraensis</i>
	N	13	9	16	16	16	
	range	9–22	1–7	–310/–60	—	107–290	
A 190	M	14.2	5.3	–194	0	157	<i>M. ex. interc.</i>
	$\sigma$ M	1.1	0.9	27	—	10	<i>formosensis-basraensis</i>
	N	12	14	14	14	15	
	range	9–21	0–11	–384/–43	—	104–205	

Fig. 21 Results of counts and measurements on *Miogypsina* assemblages from Afales-bay, Ithaki.

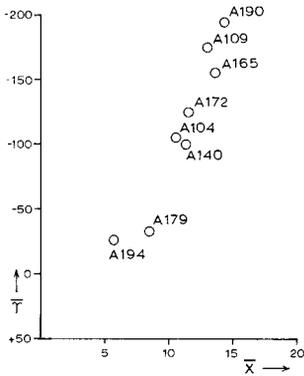


Fig. 22 Relation between  $\bar{X}$  and  $\bar{\gamma}$  values for eight *Miogypsina* assemblages from Afales-bay, Ithaki.

because the number of actual observations of both subgeneric groups is nearly the same. According to the mean of the total number of observations on  $\bar{X}$ , sample A 109 contains an assemblage which cannot be shown to be significantly different from that of A 165.

Sample A 172 was placed above A 109 because of the lower  $\bar{X}$  value (11.6) which causes the assemblage to be determined as *M. ex. interc. bantamensis-gunteri*. The *Miogypsinidae* from sample A 153 could only be studied in thin sections of hard rock. Reliable  $\bar{X}$  values were not obtained, but  $\gamma$  values could be measured for seven specimens. The mean value of  $-108^\circ$  may correspond to an  $\bar{X}$  value between 10 and 11 (Drooger, 1963, fig. 10). Since the associated *Miogypsinoides* specimens are relatively rare, the assemblage is assigned to *M. ex. interc. gunteri-bantamensis*.

In A 104, we face again the difficulty of hardly recognizable lateral chambers; the  $\bar{X}$  value suggests the determination *M. ex. interc. bantamensis-gunteri*. The *Miogypsinids* of A 140 may be given the same name as those of A 104.

A peculiar association was found in A 179, which contains *Miogypsina* s.s., *Miogypsinoides* and *Miolepidocyclina*. The few *Miogypsinoides* specimens, which show an  $\bar{X}$  value higher than those of any of the other samples, may be determined as *M. ex. interc. complanata-formosensis*. Almost half of the *Miogypsina* s.s. specimens have a second principal auxiliary chamber; the group as a whole is classified as *M. ex. interc. tani-globulina*. If we consider the  $\bar{X}$  range ( $4\frac{1}{2} - 14$ ) of this group as unusually wide, the longer spiralled forms might be reworked as well, leaving the determination *M. globulina* as the most likely one. A 179 is the only sample from Ithaki with a few representatives of the subgenus *Miolepidocyclina*; they are named *M. ex. interc. burdigalensis-negrii*.

Sample A 194 contains the most highly developed assemblage from Afa-

les-bay; it belongs to *M. ex. interc. globulina-intermedia*.

Bischoff (1968) also studied Miogypsinidae from this section; he distinguished four species: *M. complanata* (1 specimen), *M. bantamensis*, *M. dehaarti* and *M. gunteri*, but his species concept is typological. His data cannot be recalculated according to our concept.

#### Biostratigraphy and discussion

In the Afales-bay section the frequent co-occurrence of specimens with *Miogypsinoides* features and others which may be regarded as *Miogypsina* s.s. is of great interest. From the displaced character of the various components of the sediments from which the associations were obtained, a considerable reworking might be expected. In fact many of the *Miogypsina*-bearing samples contain reworked Eocene faunal elements as well, such as *Discocyclina*, *Asterocyclina* and *Nummulites*. Yet, the Miogypsinid associations of most of our samples do not show a heterogeneous character since the stage of phylogenetic development of both groups is roughly the same in all samples, except A 179. As a consequence, the explanation for the co-occurrences of both groups in terms of mixing of more highly developed and more primitive assemblages by reworking of the latter seems unnecessary. It may as well be assumed that for a longer period populations had mixed characteristics in the region. Slight differences in habitat of both variant groups, as suggested by Drooger and Raju (1974), cannot be proved or disproved.

Only in sample A 179, part of the Miogypsinid specimens are considered reworked. This sample shows *M. (ex. interc. tani-) globulina*, together with *M. ex. interc. burdigalensis-negrui* and *M. ex. interc. complanata-formosensis*. Associations of *M. burdigalensis* and *M. globulina* are quite common in Europe (SW France) and Africa (Morocco, Cameroon), but without *M. complanata* or *M. formosensis*. In the Mediterranean area *Miogypsinoides* species have been reported together with each of these species, but then we are invariably dealing with *M. bantamensis* or with slightly more primitive forms. The co-occurrences of *M. globulina* and *M. bantamensis*, closest to the Ionian region, are those reported from Sicily (Felix, 1974). For the time being, our few *Miogypsinoides* specimens in A 179 may be considered reworked, but it is surprising that no such primitive *Miogypsinoides* assemblages were found in any of the other samples. *M. complanata* is known from many localities in Europe, and is considered of Rupelian to Chattian Age. In the Afales-bay section the planktonic foraminifera do not point to any major hiatus in this time interval. Since the appearance of the Miogypsinids in the section coincides with the change toward sandy sedimentation, the absence of the oldest Miogypsinid species might be due to some paleoenvironmental factor.

However, it cannot be excluded that there is a gap in the Afales sedimentary record which may correspond to some part of the Middle-Upper Oligocene, a hiatus that is too small to be detected in the succession of planktonic foraminiferal faunas.

Considering the sequence of *Miogypsina* assemblages more closely, it is striking that there is ample evidence of Oligocene species, but that beyond the *M. bantamensis-gunteri* level of development the further Aquitanian part of the lineage is not represented and the Burdigalian part to a lesser degree only. This can again be explained either by paleoenvironmental control or by gaps in the record.

#### III.1.4.4 *Lepidocyclinidae*

##### Introduction

Representatives of *Lepidocyclina* are the most common larger foraminiferal elements in the Oligocene – Miocene sediments of Afales-bay. They are generally found in the lower parts of the graded detrital limestone and calcareous sandstone beds. Free specimens were obtained from the less indurated, coarse basal beds and from the marly matrix of the coarse, conglomeratic mixtures of organic debris, marls and limeclasts. Both the subgenera *Nephrolepidina* and *Eulepidina* are present and they are usually found together. The biometrical analysis deals with *Nephrolepidina* specimens only. The lowermost *Eulepidina* specimens are from sample A 69. The first *Nephrolepidina* specimens were found four meters higher, in sample A 73 (see figure 8).

##### Counts and measurements

More than 200 megalospheric specimens from 14 samples were studied. For the applied method of the biometrical analysis, reference is made to paragraph II.2.2. The results of counts and measurements are presented in figure 23. The samples in this figure are arranged according to observations of the superposition of units in the field (A 79 – A 96 and A 135 – A 111), the decrease of  $\bar{X}$  values in the *Miogypsinidae* and the succession of planktonic foraminiferal faunas.

For European *Nephrolepidina*, Freudenthal (1964), Drooger and Freudenthal (1964) and Drooger and Socin (1959) reported an overall but irregular increase in the average degree of embracement of the protoconch by the deutoconch ( $\bar{A}$ ) and in the average number of accessory auxiliary chambers on the deutoconch ( $\bar{C}$ ) in the course of time. A rather gradual increase of  $\bar{A}$  and  $\bar{C}$  was also observed in assemblages from the lower part of the Afales-bay section (A 79 – A 111). Here, we are dealing with comprehensive parts of

sample		A <sub>i</sub>	A <sub>o</sub>	C	DI $\mu$	DII $\mu$	DII/DI	R	$\alpha^{\circ}$	species
A 179	M	47.5	52.1	6.8	358	563	1.58	34.6	175	<i>L. tournoueri</i>
	$\sigma$ M	1.1	1.1	0.5	22	33	0.03	2.7	4	
	N	18	18	13	18	18	18	18	18	
	range	36.4–56.8	39.5–59.6	3–9	235–531	340–803	1.41–1.92	11.3–62.3	145–216	
A 140	M	44.3	48.0	4.4	283	443	1.56	27.4	190	<i>L. ex. interc.</i>
	$\sigma$ M	1.2	1.2	0.3	11	19	0.04	2.5	4	<i>morgani-tournoueri</i>
	N	16	16	16	17	17	17	17	16	
	range	35.5–57.9	40.6–59.4	2–6	210–390	345–635	1.31–1.84	10.7–54.0	148–215	
A 104	M	41.4	44.3	3.7	293	434	1.49	21.5	201	<i>L. morgani</i>
	$\sigma$ M	0.9	1.1	0.3	12	16	0.04	2.7	4	
	N	17	17	17	17	17	17	18	17	
	range	34.1–49.2	38.7–55.3	2–9	240–410	350–590	1.28–1.84	6.2–49.2	159–225	
A 172	M	43.2	46.2	5.8	330	501	1.48	25.7	193	<i>L. ex. interc.</i>
	$\sigma$ M	0.9	1.3	0.5	19	29	0.03	2.5	4	<i>morgani-tournoueri</i>
	N	12	12	11	12	11	11	12	12	
	range	40.0–50.0	40.4–56.1	2–8	213–429	338–662	1.28–1.62	13.0–45.0	167–215	
A 109	M	41.1	45.2	3.6	266	386	1.46	24.8	199	<i>L. morgani</i>
	$\sigma$ M	1.2	1.2	0.3	13	18	0.03	2.2	5	
	N	16	16	11	16	16	16	16	16	
	range	31.7–48.8	37.3–52.6	2–5	195–375	280–480	1.17–1.75	7.9–42.1	172–228	
A 165	M	44.7	47.0	5.2	354	524	1.48	29.2	191	<i>L. ex. interc.</i>
	$\sigma$ M	1.1	1.2	0.3	14	21	0.03	2.3	5	<i>morgani-tournoueri</i>
	N	18	18	16	18	18	18	18	18	
	range	38.0–52.9	38.8–54.8	3–8	250–460	400–785	1.28–1.76	12.9–49.4	162–217	
A 190	M	42.9	45.2	5.6	322	479	1.50	23.0	194	<i>L. ex. interc.</i>
	$\sigma$ M	1.5	1.7	0.6	22	33	0.04	3.4	6	<i>morgani-tournoueri</i>
	N	15	15	12	15	15	15	15	15	
	range	34.4–51.4	36.1–58.2	3–10	205–470	274–757	1.24–1.86	4.6–43.3	149–223	
A 185	M	36.4	39.3	2.3	219	292	1.33	12.4	218	<i>L. praemarginata</i>
	$\sigma$ M	0.9	1.1	0.2	8	14	0.02	2.2	3	
	N	16	16	15	16	16	16	16	16	
	range	31.6–42.8	32.3–48.6	1–4	139–361	177–375	1.16–1.45	1.0–37.9	195–241	

A 111	M	43.0	46.8	4.1	266	422	1.58	27.7	190	<i>L. morgani</i>
	$\sigma$ M	1.2	1.3	0.4	15	26	0.03	1.5	4	
	N	16	16	16	16	16	16	16	16	
	range	36.4–51.8	38.9–56.9	2–9	150–375	235–625	1.30–1.76	14.3–40.0	162–219	
A 116	M	40.5	43.1	3.1	285	416	1.43	21.8	206	<i>L. ex. interc.</i>
	$\sigma$ M	1.4	1.5	0.3	16	31	0.04	2.2	6	<i>praemarginata-morgani</i>
	N	20	20	15	20	20	20	20	20	
	range	26.6–50.9	28.1–55.0	1–5	155–480	185–720	1.05–1.81	6.0–42.7	161–255	
A 130	M	37.6	39.9	1.9	214	272	1.26	10.7	221	<i>L. praemarginata</i>
	$\sigma$ M	0.8	0.8	0.2	5	13	0.04	1.2	3	
	N	15	15	13	15	15	15	15	15	
	range	33.3–44.0	35.8–48.2	1–4	195–260	175–400	0.87–1.54	2.4–20.6	193–240	
A 135	M	36.6	38.8	2.1	213	275	1.29	12.6	225	<i>L. praemarginata</i>
	$\sigma$ M	0.9	0.8	0.2	8	12	0.02	1.0	3	
	N	18	18	17	18	18	18	18	18	
	range	28.3–44.0	33.3–44.6	1–4	160–285	205–415	1.11–1.47	5.3–21.3	205–249	
A 96	M	36.7	38.4	2.1	226	290	1.29	12.8	227	<i>L. praemarginata</i>
	$\sigma$ M	0.9	0.8	0.3	8	11	0.02	1.5	3	
	N	18	18	17	18	18	18	18	18	
	range	31.4–48.3	32.7–46.7	0–4	165–305	215–385	1.14–1.40	4.2–32.7	202–248	
A 79	M	33.4	35.7	1.6	251	306	1.22	12.0	234	<i>L. praemarginata</i>
	$\sigma$ M	0.8	0.8	0.2	8	11	0.02	1.3	3	
	N	17	17	13	17	17	17	17	17	
	range	25.0–39.1	28.3–42.5	1–3	190–320	190–385	1.00–1.37	4.5–23.5	203–252	

Fig. 23 Results of counts and measurements on 14 *Nephrolepidina* assemblages from Afales-bay, Ithaki.

the section, or with units that can be arranged in their probable stratigraphic order on the basis of field observations. Also the means of  $\alpha$ , another parameter reflecting the average degree of embracement of the embryonic chambers, show a succession of decreasing values. In contrast, the average degree of curvature of the common wall between the protoconch and deuterococonch ( $\bar{R}$ ) has a less regular pattern of increasing values. As to these lower six samples, no clear trend is observed in the average sizes of protoconch ( $\bar{DI}$ ) and deuterococonch ( $\bar{DII}$ ). An initial decrease up to level A 130 is followed by an increase. Values of  $\bar{DII}/\bar{DI}$  are not actually changing in the lower four samples, but in those obtained for A 116 and A 111 they are significantly higher. These values are very close already to the value calculated for A 179, which contains the most highly evolved assemblage of Afales-bay.

Little can be said about the relative stratigraphic position of the remaining eight samples. From field observations it may be assumed that the units from which these samples were obtained should be placed above those containing samples A 79 – A 111, but field evidence does not permit a definite conclusion as to their stratigraphic interrelation. It may be attempted to place the eight samples (A 185 – A 179) in stratigraphic order by applying the biometric data of the *Nephrolepidina* assemblages.  $\bar{A}$  and  $\bar{C}$  values are considered of primary importance to determine the relative stratigraphic position of the samples. A 185 and A 179 may be considered the lowest and highest sample respectively, but the six samples in between do not show any significant differences in their  $\bar{A}$  values (fig. 23). Such differences are actually present between the assemblages from some of the six samples on the basis of the average number of accessory auxiliary chambers; unfortunately the individual observations on  $\bar{C}$  are sometimes unreliable due to the poor preservation of the specimens. As a consequence, samples A 190, A 165, A 109, A 172, A 104 and A 140 cannot be placed in a reliable stratigraphic order, and the assemblages will be grouped together as “intermediate” between those from the samples A 185 and A 179. The conclusion is supported by the biometrical data on the *Miogypsinidae* from the same samples. These *Miogypsina* assemblages are in about the same stage of phylogenetic development (fig. 21).

If all eight samples (A 185 – A 179) are stratigraphically located above those from the lower part of the section, the numerical values obtained for the *Lepidocyclina* assemblage of A 185 are in contradiction with this assumption. The values are within the range of variation of those calculated for the lower group of samples A 79 – A 111. The assemblage of A 185 is considered reworked, however, as it contains a planktonic foraminiferal

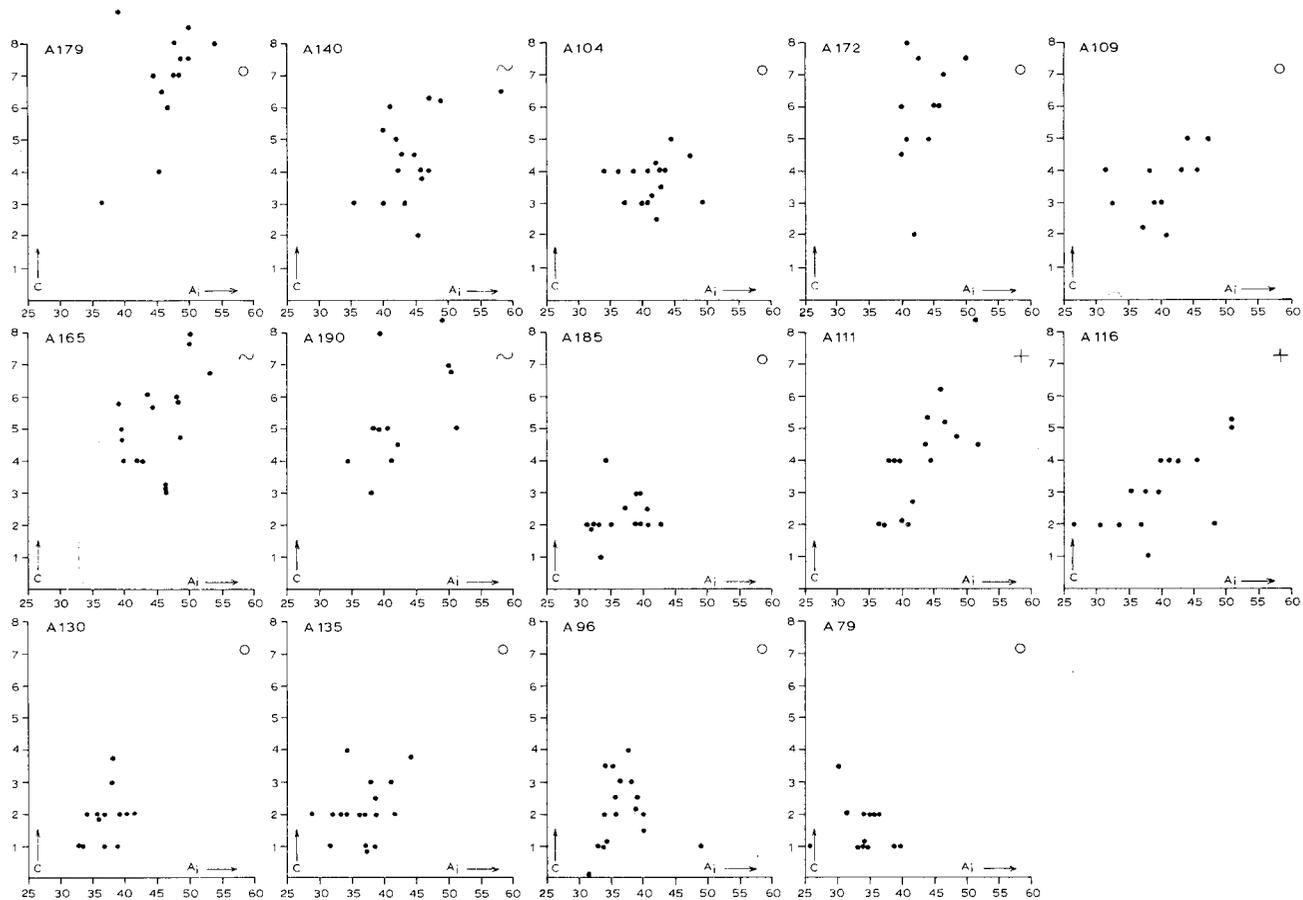


Fig. 24 Relation between C and  $A_1$  values for fourteen selected *Nephrolepidina* assemblages from Afales-bay, Ithaki.  
 + refers to a strong positive correlation with a probability of more than 99%, two sided; ~ refers to a weak positive correlation with a probability between 90% and 99%, two sided; o means no correlation.

association characteristic of zone N4, whereas the samples from the lower part of the section all belong to the range of zones P20 – P22 (= N1 – N3).

A 179 shows the highest  $\bar{A}$  and  $\bar{C}$  values. The stratigraphic level of this sample is one of the youngest in Afales-bay, a conclusion that is confirmed by the planktonic foraminifera (N5 – N7) and the Miogypsinidae.

The means of A and C show a distinct positive correlation (fig. 27). No significant setbacks occur in the lower part of the section, in which the succession of the samples is clearly established on the basis of field evidence. In contrast with the relation between  $\bar{C}$  and  $\bar{A}$ , absence or presence of significant positive correlation between A and C per sample seems to be arbitrary (fig. 24). Positive correlation with a probability of more than 99% was found for two samples only. As to the relation between the diameter of the deuteroconch and the number of accessory auxiliary chambers (fig. 25), four out of fourteen assemblages show that both parameters are positively correlated, with a probability of more than 99%. These observations suggest that the number of accessory auxiliary chambers cannot be proved to be strongly dependent either on the degree of embracement or on the diameter of the deuteroconch. This conclusion is in fair agreement with the observations by Meulenkamp and Amato (1972) on material from the Oligocene of Mollere, northern Italy. However, positive correlation between the means of C and DII is good (fig. 24a)

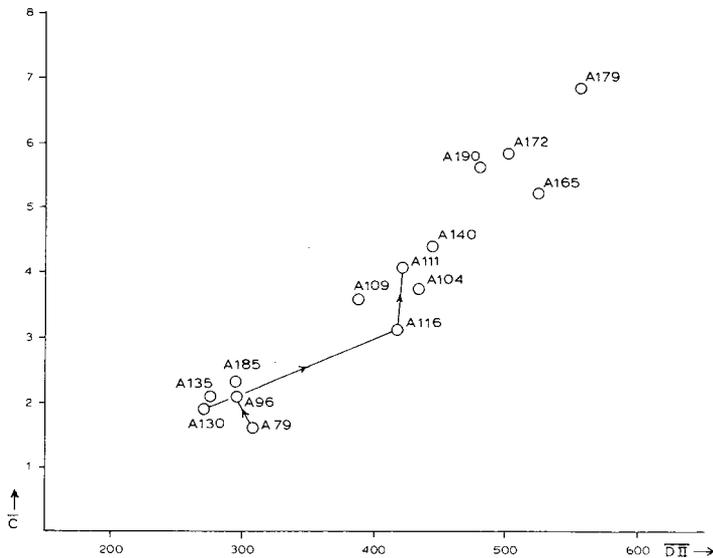


Fig. 24a Relation between  $\bar{C}$  and  $\bar{DII}$  for fourteen selected *Nephrolepidina* assemblages from Afales-bay, Ithaki.

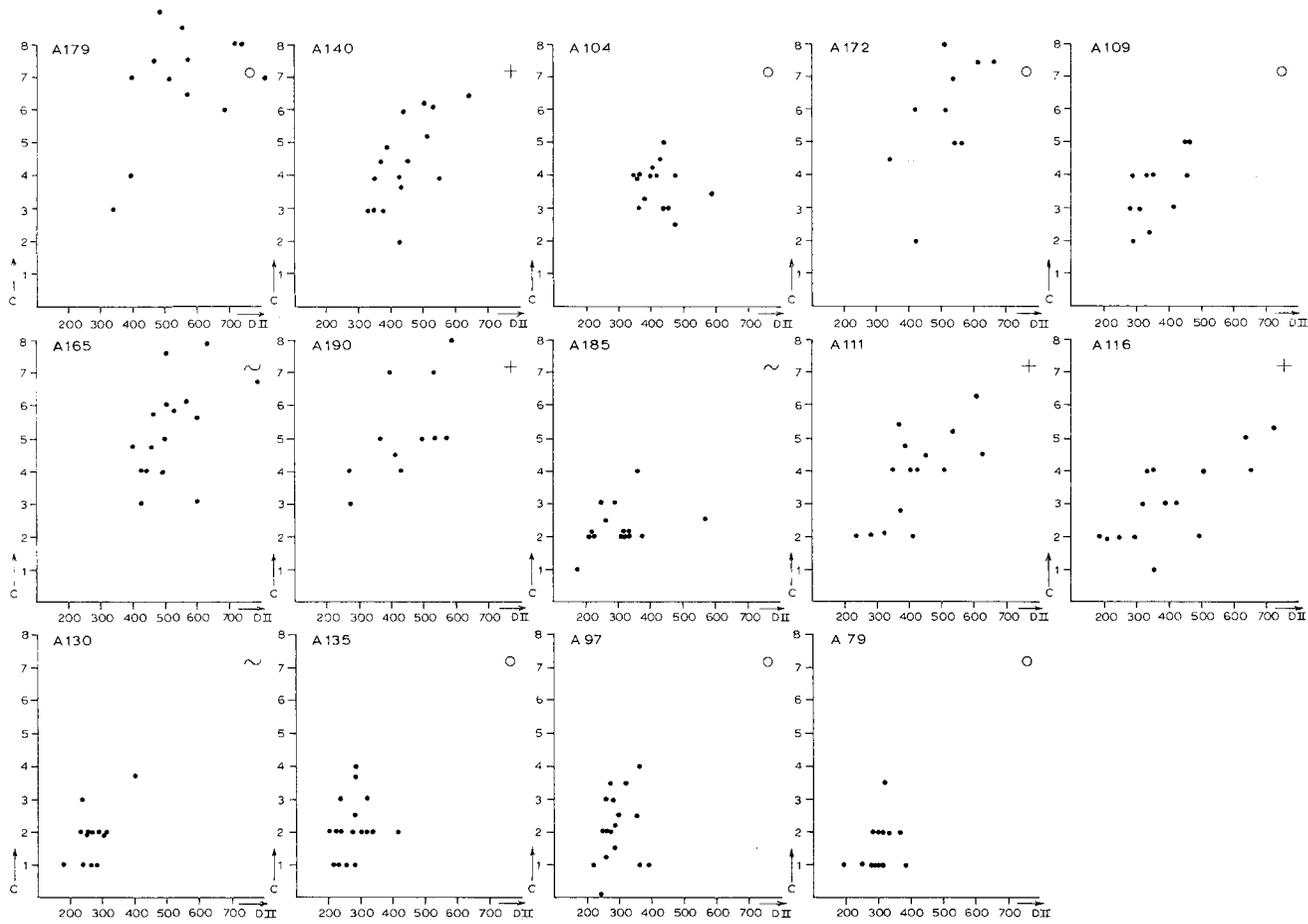


Fig. 25 Relation between C and DII values for fourteen selected *Nephrolepidina* assemblages from Afales-bay, Ithaki. For explanation of symbols, see fig. 24.

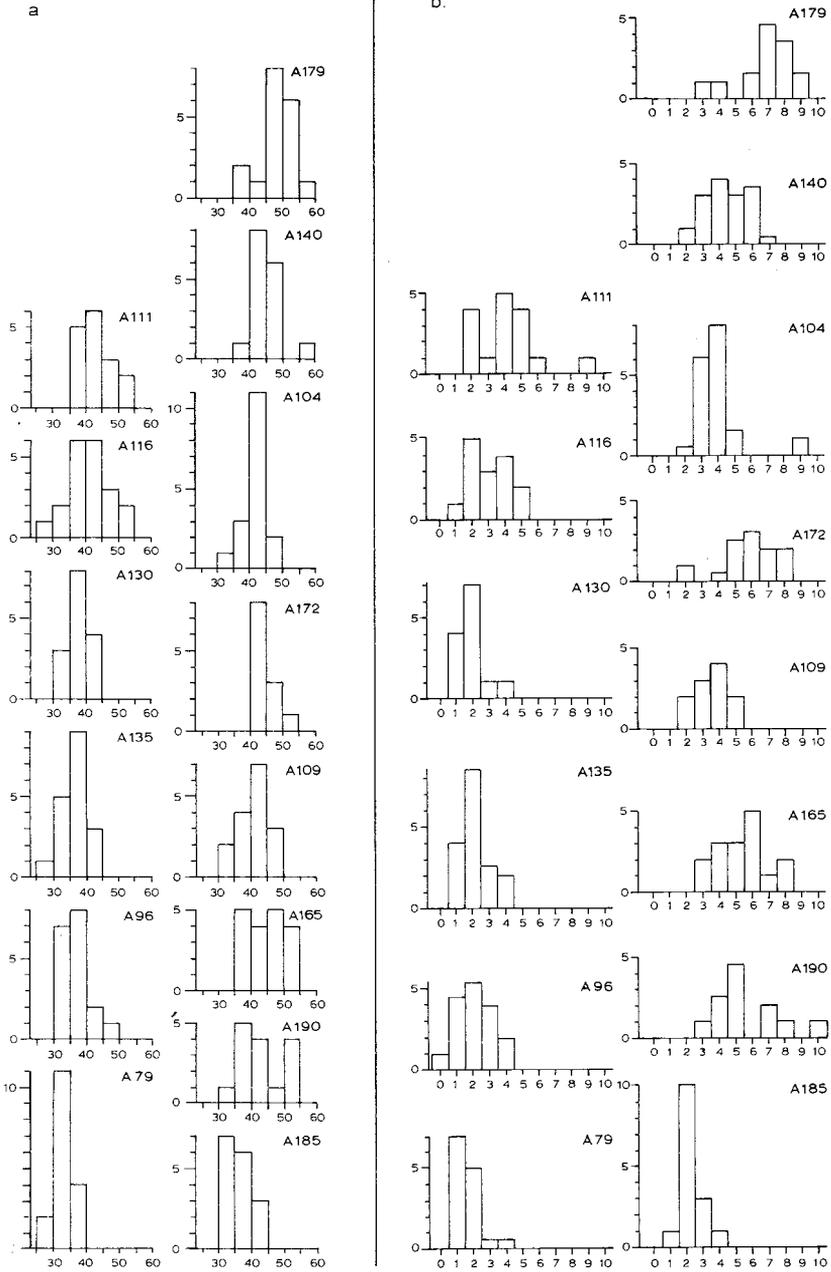


Fig. 26 Histograms of A<sub>i</sub> classes (a) and of C classes (b) of fourteen selected *Nephrolepidina* assemblages from Afales-bay, Ithaki.

The histograms of C and A classes (fig. 26) have unimodal and fairly normal distributional patterns for most of the samples. The irregularities in the C histograms (e.g. samples A 179, A 104, A 172, A 111) might be explained by the low numbers of observations in comparison to the wide variation and/or the inaccuracies in counting the number of accessory auxiliary chambers. However, the wide variation and skewed character of the C histograms of some of the samples may as well be explained by mixing of more primitive and more highly developed assemblages. This cannot be excluded, in view of the displaced nature of most of the elements in the *Lepidocyclina*-bearing beds.

### Taxonomy

Freudenthal (1970) concluded that external morphological features, such as surface ornamentation and size of the test, cannot be used for distinguishing taxonomic units that reflect the degree of phylogenetic development in *Nephrolepidina*. The external features are considered to be strongly environment-controlled.

The European *Nephrolepidina* lineage has been subdivided into three successive species, *Lepidocyclina praemarginata*, *L. morgani* and *L. tournoueri* (Freudenthal, 1964; Drooger and Freudenthal, 1964; Vervloet, 1966; Meulenkamp and Amato, 1972) on the basis of mean C and A values. A

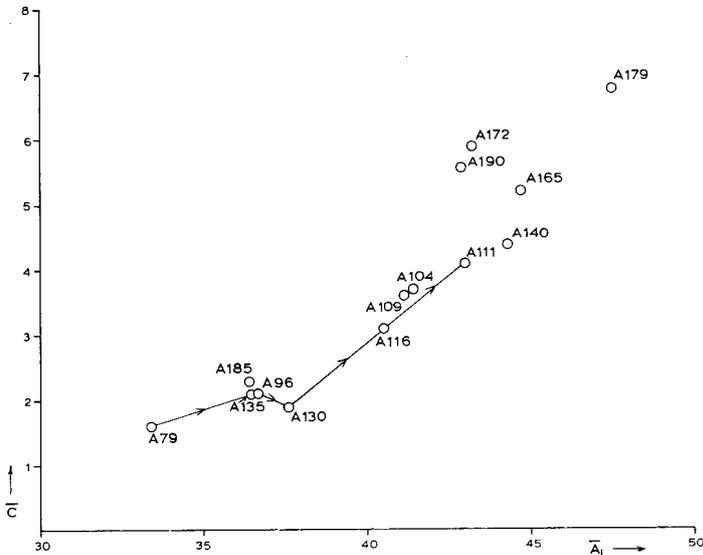


Fig. 27 Relation between  $\bar{C}$  and  $\bar{A}_i$  values for fourteen *Nephrolepidina* assemblages from Afales-bay. Samples collected from comprehensive parts of the section are connected by a line, and arrows indicate their stratigraphic order.

comparison with the data of these authors and with toptype material of the three species allows us to assign most of the Ithaki assemblages to one of the mentioned taxa. For several of the assemblages this cannot be readily done, because the species limits have not yet been defined, due to the absence of long, continuous *Nephrolepidina*-bearing successions in Europe and to the uncertainty whether priority should be given to the  $\bar{A}$  or to the  $\bar{C}$  values for the species delimitation. Drooger and Freudenthal (1964) concluded that the average degree of embracement, considered by van der Vlerk (1963) as the most reliable parameter in evolution, gives less suitable results for subdivision of the lineage than the average number of accessory auxiliary chambers. In the Afales-bay section, similar controversial results as to the  $\bar{C}$  and  $\bar{A}$  values were obtained. Several samples show significantly different  $\bar{C}$  values, whereas no significant difference was found between the corresponding values of  $\bar{A}$ . However, the degree of embracement may be measured more accurately in most samples than the number of accessory auxiliary chambers, owing to the bad preservation of the material. As a consequence, species limits based on combinations of  $\bar{A}$  and  $\bar{C}$  values seem to be appropriate.

It is proposed to define the limit between *L. praemarginata* and *L. morgani* at  $\bar{C} = 3$  and  $\bar{A}_i = 40$ , and that between *L. morgani* and *L. tournoueri* at  $\bar{C} = 5.25$  and  $\bar{A}_i = 45$ .

Several of our assemblages must be considered as intermediate between two species, because of their mean  $A_i$  and  $C$  values require an assignment to two different species.

*Lepidocyclina (Nephrolepidina) praemarginata* R. Douvillé

Pl. 3, figs. 6–8; Pl. 4, figs. 8–11

*Lepidocyclina praemarginata* R. Douvillé, 1908, Bull. Soc. Géol. France, ser. 4, vol. 8, p. 91, figs. 1, 2, 4.

*Lepidocyclina (Nephrolepidina) praemarginata* R. Douvillé, Vervloet, 1966, Strat. Pal. Data Tert. southern Piemont, p. 59, fig. 5, pl. 12, figs. 1–4.

*Nephrolepidina praetournoueri* (H. Douvillé), Lange, 1968, Thesis Univ. München, Bamberger Fotodruck, p. 57, pl. 1, fig. 1.

Lange (1968) assigned his Ithaki specimens with isolepidine embryonic apparatus to *N. praetournoueri* (H. Douvillé). According to Vervloet (1966), who studied the Lepidocyclinids from the type locality of *L. praemarginata* at Costa Lupara (N. Italy) and reappraised the *Nephrolepidina* material assigned by Bronnimann (1940) to *L. praetournoueri*, both species may be synonymous. According to Vervloet, the  $\bar{C}$  value of the toptype material of Costa Lupara is  $\bar{C} = 2.40 \pm 0.21$  and the corresponding  $\bar{A}_0 = 36.6$ .

The somewhat less primitive Italian assemblage from Mollere (N. Italy) described by Meulenkamp and Amato (1972) has also been assigned to *L. praemarginata*. In figure 28, the  $\bar{C}$  and  $\bar{A}_O$  values of the *praemarginata* assemblages from Mollere and Costa Lupara are compared with those of the most primitive *Nephrolepidina* assemblage from the Afales-bay section (A 79). It is evident from this figure that because of the distinctly lower  $\bar{C}$  value and the slightly lower  $\bar{A}_O$  value, the Afales-bay assemblage is more primitive than that of Costa Lupara. In fact, we are dealing here with the most primitive European *Nephrolepidina* assemblage known thus far. The assemblages from Costa Lupara and Mollere have been assigned to the Rupelian, mainly because of the absence of *Miogypsinoides*.

Assemblages from Senegal and Guinee-Bissao, studied by Freudenthal (1970), show much lower  $\bar{C}$  (0–0.6) and  $\bar{A}_i$  (25.3–33.3) values. Their age is close to that of the Eocene – Oligocene boundary, and they are considered to provide evidence of Lepidocyclinids having developed independently of the American lineage in the eastern hemisphere. Hence, migration of American Lepidocyclinids to Europe and Africa does not necessarily have taken place. According to Freudenthal, the African forms might well have been the ancestors of the Mediterranean assemblages.

Since as yet there is no need to distinguish a more primitive *Nephrolepidina* species than *L. praemarginata* in the Mediterranean, all our assemblages with  $\bar{C}$  values below 3 and  $\bar{A}_i$  values below 40 are assigned to this species. This means that the lower limits of *L. praemarginata* are left undecided. There seems ample opportunity to give the West African assemblages a different name, if the limit were to be suggested at  $\bar{C} = 1$  and  $\bar{A}_i = 35$ .

The *Nephrolepidina* assemblages of samples A 79, A 96, A 135, A 130 and A 185 thus belong to *L. praemarginata*. Except A 185, all samples have been taken in the lower part of the Afales-bay section. In neither of these samples specimens of *Miogypsina* were observed. The planktonic foraminiferal faunas from the same or from nearby samples point to zones N1, N2 and N3, indicating Late Rupelian to Chattian Ages. For the reworked assemblage of A 185 the N4 determination may point to a Late Chattian – Early Aquitanian Age of displacement.

	$\bar{C}$	$\bar{A}_O$
Mollere JT616	2.85 ± 0.14	42.5 ± 0.7
Costa Lupara C-L-001	2.4 ± 0.21	36.6
Afales-bay A 79	1.58 ± 0.20	35.7 ± 0.8

Fig. 28 Comparison of biometrical data from three Mediterranean *L. praemarginata* assemblages.

*Lepidocyclina (Nephrolepidina) morgani* Lemoine & R. Douvillé

Pl. 3, fig. 9; Pl. 4, figs. 4–7

*Lepidocyclina morgani* Lemoine & R. Douvillé, 1904, Mém. Soc. Géol. France, vol. 12, pt. 2, p. 17, 18, pl. 2, fig. 4; pl. 3, fig. 2.

*Lepidocyclina (Nephrolepidina) morgani* Lemoine & R. Douvillé, Drooger & Socin, 1959, Micropal., vol. 5, pt. 4.

*Lepidocyclina (Nephrolepidina) morgani* Lemoine & R. Douvillé, Drooger & Freudenthal, 1964, Ecl. Geol. Helv., vol. 57, pt. 2, p. 515.

*Nephrolepidina morgani* (Lemoine & R. Douvillé), Lange, 1968, Thesis Univ. München; Bamberger Fotodruck, p. 63, pl. 1, fig. 2.

According to the original description of Lemoine & R. Douvillé, this species is characterized internally by a distinct nephrolepidine embryo and externally by some seven or eight big pustules on the test. Many later authors neglected the external features and assigned the specific name *morgani* to all Mediterranean *Nephrolepidina* assemblages or specimens, the phylogenetic stage of which is in between that of *L. praemarginata* and *L. tournoueri*. Well-known *L. morgani* assemblages from southern France were placed in the Chattian or Aquitanian, depending on the species to which the co-occurring Miogypsinids were assigned. As long as no new data are available, there is no reason to give another delimitation of the species. Our species boundaries for *L. morgani* are:  $3 < \bar{C} < 5,25$  and  $40 < \bar{A}_i < 45$ .

The *Nephrolepidina* assemblages of samples A 111, A 109 and A 104 are thus assigned to *L. morgani*. The planktonic foraminiferal associations at or close to these levels point to zones N3, N4 and N5, and the accompanying Miogypsinid assemblages consist of *M. ex. interc. formosensis-basraensis* and *M. ex. interc. bantamensis-gunteri*. Both accompanying groups of microfossils point to Late Chattian to Aquitanian Age. Assemblages with intermediate notations with either *L. praemarginata* or *L. tournoueri* (A 116, A 190, A 165, A 172 and A 140) seem to be accompanied with comparable planktonic or Miogypsinid assemblages. Isolated *Nephrolepidina* assemblages evidently cannot lead to accurate age determinations.

*Lepidocyclina (Nephrolepidina) tournoueri* Lemoine & R. Douvillé

Pl. 3, fig. 10; Pl. 4, figs. 1–3

*Lepidocyclina tournoueri* Lemoine & R. Douvillé, 1904, Mém. Soc. Géol. France, vol. 12, pt. 2, p. 19, pl. 1, fig. 5.

*Lepidocyclina tournoueri* Lemoine & R. Douvillé, Drooger & Socin, 1959, Micropal., vol. 5, pp. 415–426.

*Lepidocyclina (Nephrolepidina) tournoueri* Lemoine & R. Douvillé, Drooger & Freudenthal, 1964, Ecl. Geol. Helv., vol. 57, pt. 2, p. 522.

*Nephrolepidina tournoueri* (Lemoine & R. Douvillé), Lange (pars), 1968, Thesis Univ. München, Bamberger Fotodruck, p. 59, pl. 1, fig. 3.

This species comprises *Nephrolepidina* assemblages with a well-developed nephrolepidine to trybliolepidine embryonic apparatus. Drooger & Freudenthal (1964) measured many specimens of *Nephrolepidina* collected in the area of the type-locality of *L. tournoueri* at Rosignano, Italy. In seven samples the  $\bar{C}$  values range from  $5.75 \pm 0.39$  to  $6.22 \pm 0.34$ ; the  $\bar{A}_0$  values range from  $49.5 \pm 1.1$  to  $53.8 \pm 1.6$ . In an earlier paper (Drooger & Socin, 1959)  $\bar{C}$  values for the same samples were mentioned to range from 5.60 to 6.11.

Lange (1968) disliked the wide range of values for the various parameters in *L. morgani*, and for this reason he extended the morphological range of *L. tournoueri*. In his typological species concept, individuals with an  $A_i$  value of more than 39 and a diameter of the deuterocoenoch exceeding  $450\mu$  already belong to *L. tournoueri*. In this respect, he somehow followed Bronnimann (1940) and Drooger and Magné (1959), disregarding the rectification Drooger published in the same year in collaboration with Socin because of his earlier mis-interpretation of the original material of Lemoine & R. Douvillé.

At its type-locality, *L. tournoueri* is associated with *Miogypsina globulina*; for this reason it is placed in the Burdigalian. Thus far, no other ages have been assigned to *L. tournoueri* assemblages by other authors. In this paper assemblages have been assigned to *L. tournoueri* if  $\bar{C}$  exceeds 5.25 and  $\bar{A}_i$  is larger than 45.

The only assemblage in the Afales-bay section completely fulfilling the above mentioned conditions is that of sample A 179. A comparison of this assemblage with those of Rosignano demonstrates a lower  $\bar{A}_0$  value, but a considerably higher  $\bar{C}$  value than that of the Italian samples. In fact, sample A 179 provides the most highly developed *Nephrolepidina* assemblage from Europe and the Mediterranean with respect to the average number of accessory auxiliary chambers. Its rather heterogeneous character already demonstrated with the Miogypsinidae, is also suggested by the histograms of C values (figure 26) and may point to an even higher  $\bar{C}$  value of the original assemblage being admixed with more primitive specimens.

The planktonic foraminifera and Miogypsinids of sample A 179 point to a Burdigalian Age.

Comparison with the results of Lange

Lange (1968) published a paper on the *Lepidocyclina* (*Eulepidina*) and *L. (Nephrolepidina)* assemblages from Afales-bay. His material appears to have

been obtained from divisions B and C of our section. Lange rejected the use of mean values and standard errors of the means because to his opinion populations may be composed of more than one species. In his concept, a normal distribution for the parameters cannot be expected.

Lange rejected a biometrical distinction of *Nephrolepidina* species, based on a statistical approach. Although he used the same species names, his typological species concept gives these names another significance than that used in this paper. In order to study the development of his *Nephrolepidina* populations in the course of time, he made use of histograms ("Variationskurven").

Lange's biometrical data are hard to compare with ours, though the observed evolutionary trends are in good accordance with our results. Only the number of accessory auxiliary chambers on the deuteroconch (C) may be compared, because his figure 14 shows histograms from which the means and standard errors of the means can be calculated. According to the description of Bischoff (1968) and Lange, five of their samples have been collected from the same levels as our samples listed in figure 23. A comparison of our  $\bar{C}$  values with those calculated from the histograms of Lange shows remarkable differences for the upper three samples. Since the frequency distributions are skewed in most of the samples, they were compared by means of the Wilcoxon test. The distribution patterns of two samples are considered to be significantly different, whenever  $u > 1.96$ , which corresponds to a probability of difference of 95% or more, two-sided. It appears from figure 29 that the  $u$  value for A 165 just exceeds this significance limit and that the value for A 116 is very close. Although differences between both sets of mean values are neither constantly positive or negative, the possibility of a different appreciation in counting the number of accessory auxiliary chambers between Lange and the present author seems to offer the most likely

LANGE sample nr.	DE MULDER sample nr.	n	LANGE $\bar{C} \pm \delta M$	n	DE MULDER $\bar{C} \pm \delta M$	WILCOXON'S test
390	A 165	17	4.05 $\pm$ 0.37	16	5.25 $\pm$ 0.31	$u = 2.00$
300	A 140	14	5.00 $\pm$ 0.40	16	4.43 $\pm$ 0.33	$u = 0.97$
230	A 116	19	4.05 $\pm$ 0.36	15	3.09 $\pm$ 0.30	$u = 1.73$
208	A 135	16	2.06 $\pm$ 0.22	17	2.13 $\pm$ 0.21	$u = 0.27$
134	A 79	9	1.34 $\pm$ 0.16	13	1.58 $\pm$ 0.20	$u = 0.50$

Fig. 29 Comparison of our  $\bar{C}$  values and the  $\bar{C}$  values calculated from the data of Lange (1968) for five corresponding samples from the same levels. The right column shows the results of the Wilcoxon test.

explanation for these discrepancies. Observations on C values by different authors are evidently subject to considerable bias, much greater than suggested by Drooger and Freudenthal (1964).

### III.2 LEVKAS AND THE PLAYIA PENINSULA

#### III.2.1 Introduction

Outcrops of Oligocene and Miocene sediments on Levkas are mainly restricted to three areas, located in the northeast, in the southeast and in the southwest. The smaller exposures in the interior of the island were not investigated. A schematic distribution pattern of the Oligo-Miocene is presented in figure 30.

The Lazarata area in the northeast and the Poros area in the southeast have been included in the Ionian Zone by Bornovas (1964), Aubouin (1965), the Institut Français du Pétrole (1966) and by authors of British Petroleum (1967, 1971). The Ay. Petros area in the southwest may belong to the Paxos (= Preapulian) Zone.

The Oligo-Miocene sediments on the Playia peninsula, which forms part of the opposite mainland, have generally been included in the Ionian Zone.

The four areas will be discussed in successive paragraphs, since they are separated by Pre-Oligocene rocks or by the sea, and because of their major sedimentary differences.

#### III.2.2 The Lazarata area

In this northeastern part of Levkas mainly calcareous, detrital deposits are exposed. The area is intersected by numerous faults. At several places outcrops of Pre-Oligocene rocks cause a discontinuous distribution of the Oligo-Miocene sediments. Only the largest of these Pre-Oligocene outcrops, forming a SSW-NNE ridge between Levkas-town and Lazarata, are indicated in figure 30.

Undisturbed stratigraphic contacts with older strata were not observed, although such contacts are shown on the geological maps of Bornovas (1964) and of B.P. (1967).

One section (section Spanokhorion) and five scattered outcrops (fig. 30, nrs. 1 – 6) give a representative picture of the Oligo-Miocene sedimentary record in the northern part of the Lazarata area. The exposures in the southern part were not investigated. According to the I.F.P. (1966), calcareous deposits are unconformably overlying "flysch" sediments near Alexandros (fig. 30).

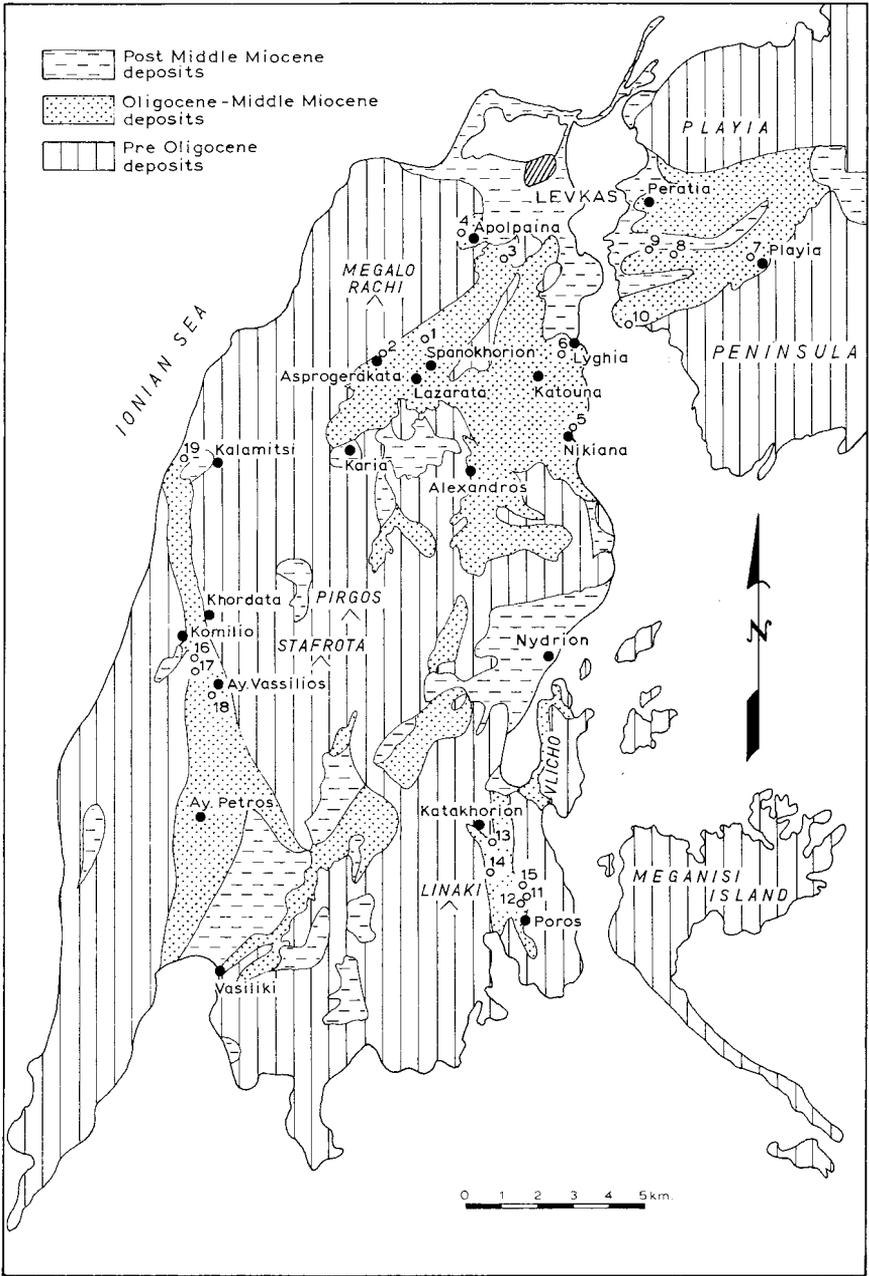


Fig. 30 Schematic geological map of Levkas and Playia, simplified after the map of B.P. (1967). The numbers refer to the Oligocene – Middle Miocene sediment successions discussed in this paper.

*Section Spanokhorion* (fig. 30, no. 1)

Section Spanokhorion (earlier referred to as section Lazarata by the authors of the I.F.P. (1966) and by Bizon (1967)), situated along the path leading in northern direction from the village of Spanokhorion down to the valley, shows a monoclinial succession of sandstones and marls, alternating with coarse, breccious beds. The dip varies between 25 and 50 degrees to the SE. According to the I.F.P., the succession is part of the western side of a syncline. A schematic stratigraphic column is given in figure 31.

The sandstone – marl succession conformably overlies white, non-detrital limestones of Late Eocene age. These limestones are separated from the lowermost coarse, detrital bed by 30 cm of white, crumbling marls. The marls (DM 636) contain a well-preserved, rich and diversified calcareous nannofossil association, including *Discoaster saipanensis*, *D. barbadiensis*, *Isthmolithus recurvus*, *Cyclococcolithus formosus*, *Ericsonia? subdisticha*, *Sphenolithus pseudoradians* and *S. predistentus?*. The association belongs to the *Sphenolithus pseudoradians* zone (NP 20), which is to be placed in the uppermost part of the Eocene. This conclusion is consistent with that based on the planktonic foraminifera; the co-occurrence of *Globorotalia centralis* and *Globigerina pseudoampliapertura* indicates zone P17, which elsewhere has been correlated with zone NP 20 (Martini, 1971).

The contact between the limestones and the white marls, and that between the marls and the lowermost coarse, clastic bed seems to be strongly disturbed. The lowermost coarse bed represents the base of the succession of 400 meters of alternating sandstones, marls and coarse breccious beds.

The grey-brown, medium to fine-grained, calcareous sandstones, predominating in the lower and middle parts of the section, are well bedded, generally ill sorted, and have a microsparitic packstone texture. The mottled or even homogenized structure of most of the sandstone beds indicates intense burrowing. From bottom to top the sandstone beds are decreasing in number and thickness. Silty and sandy, burrowed marls with some intercalations of thin, calcareous sandstone beds are prevailing in the upper part of the section.

The sandy and marly beds are alternating with thick (up to 7 meters), coarse, positively graded, polymict and ill-sorted conglomeratic breccias and with polymict and well-sorted microbreccias (component diameter not exceeding 1 cm). The coarse, breccious beds are mainly found in the lower and middle parts of the section. They are composed of a mixture of moderately rounded and angular limestone and flint components, bedded in a micritic matrix. The components have a diameter of up to 40 cm, in one bed even of 150 cm. The lower bedding planes of the breccious beds are irregular and undulating.

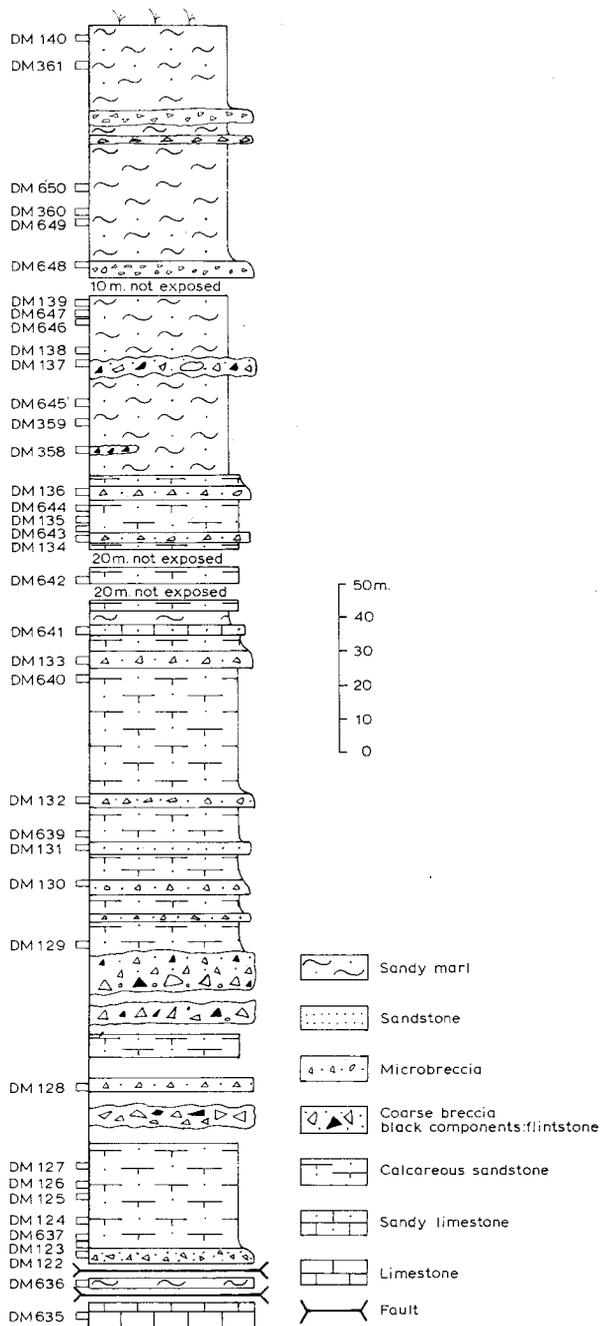


Fig. 31 Stratigraphic column of the Spanokhorion section, Levkas.

The positive grading, the ill-sorted character and the floating of the components in a micritic matrix in some of the coarse beds suggest deposition from density currents. Beds with components distinctly floating in a fine-grained matrix may best be regarded as the result of deposition by some type of mudflow. The breccias point to a periodical supply of material from a relatively nearby source area. In contrast, the positively graded microbreccias may reflect secondary deposition of a more mature character.

Bryozoa, molluscs and echinid fragments are common in the calcareous sands and in the microbreccias. Some beds are rich in larger foraminifera, including *Miogypsina* s.s., *Amphistegina*, *Gypsina*, *Operculina*, and some *Lepidocyclina*. *Nummulites* and *Discocyclina* were found only in the basal part of the section. In the upper part larger foraminifera are rare; some beds contain representatives of *Miogypsina* s.s. and *Amphistegina*.

A biometrical analysis has been carried out on two assemblages of *Miogypsina*. The results of counts and measurements are represented in figures 32 and 33. Thin sections of a microbreccia, 1 meter above the base of the section, contain numerous Miogypsinids (DM 123, figure 31). Nearly all specimens seem to have two principal auxiliary chambers, and the  $\gamma$  values are positive.  $V$  values have been estimated for seven specimens. The mean of  $V$  is 25, which allows an assignment to *M. globulina*. Sample DM 140, from the top part of the section, contains *M. intermedia* ( $\bar{V} = 63$ ). The number of Miogypsinids from other samples is too low for biometrical analysis. The same holds true for the Lepidocyclinids.

All fine-grained sediments from the section are rich in planktonic foraminifera. Sample DM 637, collected from a level approximately 3 m above the basis of the succession, contains *Globigerina siakensis*, *Globigerinoides trilobus*, *G. sicamus* (Pl. 2, fig. 12), *Globorotalia praescitula* and *G. archaeomenardii*. *Praeorbulina* or *Orbulina* were not found. This means lower N8 or N7. The higher parts of the section contain also *Globoquadrina dehiscens*, *Globigerinoides obliquus* and *Globorotalia peripheroronda*. These associations are indicative of zone N8. The presence of *Orbulina suturalis* in the top part of the section, reported by the authors of the I.F.P. (1966), may indicate that the Spanokhorion succession ranges even into zone N9, but this species was not recognized in our samples.

*Miogypsina globulina* has been reported from Burdigalian deposits in SW France and Italy, including the Burdigalian stratotype (Drooger, Kaasschieter & Keij, 1955a; Drooger & Freudenthal, 1964); *M. intermedia* appears in the uppermost part of the Burdigalian type section. The entire section thus must cover the Burdigalian.

The planktonic foraminifera indicate a somewhat different age. The N7

and lower N8 assignments may fit a Burdigalian Age, but since the Langhian is thought to start with the *Praeorbulina* datum halfway zone N8 (see Meulenkamp *et al.*, 1975), the higher part of the section seems to be of Langhian Age. It should be noted that Berggren & Van Couvering (1974) incorrectly make the base of the Langhian coincide with the base of zone N8. If *Praeorbulina* starts its range in the middle of N8, it is this middle of N8 which must be placed at the base of the type Langhian (Vervloet, 1966).

The Miogypsiniidae, present over the entire Spanokhorion section, thus suggest this section to be slightly older than is suggested on the basis of the planktonic foraminifera. This discrepancy may be explained by the displaced nature of the elements of the *Miogypsina*-bearing beds.

#### *Asprogerakata* (fig. 30, no. 2)

In a roadcut just south of the village of Asprogerakata, about 300 meters west of the bifurcation to Vasiliki, a conspicuous steep fault separates white, non-detrital limestones from approximately 100 meters of grey marls and intensively burrowed, medium to fine-grained, calcareous sands. These sediments resemble the fine-grained deposits of section Spanokhorion. Coarse intercalations were not observed in this succession, but coarse breccias were found immediately north of the village.

At some places the marls and sands are rich in planktonic foraminiferal faunas, which may be correlated with zones N6 – N7, or even N8 (Burdigalian) on account of the presence of *Globigerinoides trilobus*, *G. obliquus*, *G. subquadratus* and *Globorotalia praescitula* and the absence of *Orbulina*.

#### Road Levkas-Lazarata (fig. 30, no. 3)

Thick successions of coarse and ill-sorted, calcareous breccias with numerous flintstone components are exposed along the road from Levkas to Lazarata. The breccias strongly resemble those of section Spanokhorion; the thickness is at least 20 m. They are separated by a conspicuous fault from white, non-detrital Cretaceous-Eocene limestones. The average grain size of the breccias slightly decreases upwards. In thin sections of the matrix many specimens of *Miogypsina* s.s. were observed which could not be studied biometrically.

#### *Apolpaina* (fig. 30, no. 4)

West of the village of Apolpaina, a fragmentary section shows predominant calcareous microbreccias and some coarse conglomerates. The microbreccias, which closely resemble those described from section Spanokhorion, are separated by a fault from folded, non-detrital, white limestone beds of Eocene age. The contact is exposed along the trail leading from the large

limestone quarry to the NW.

The coarse conglomerates in the upper part of the section are exposed near a farmhouse, approximately 100 m northwest of the quarry. They show a chaotic mixture of calcareous debris, marl pebbles and different types of boulders. The matrix contains numerous algal, bryozoan and echinid fragments and larger foraminifera. *Lepidocyclina*, *Gypsina*, *Operculina*, *Heterostegina* and *Amphistegina* are common.

The planktonic foraminiferal association from intercalated (sample DM 668; Pl. 2, figs. 10, 11) marls includes *Globigerina siakensis*, *Globigerinoides trilobus*, *G. altiapertura*, *G. subquadratus*, *Globoquadrina dehiscens*, *Globorotalia praescitula* and *G. peripheroronda*; this assemblage seems to allow a correlation with the zones N6 – N7 (Burdigalian).

*Nikiana* (fig. 30, no. 5)

In the easternmost part of the Lazarata area the Post-Eocene sediments are predominantly thick successions of coarse, ill-sorted, calcareous breccias. The polymict breccias closely resemble those of the roadcut Levkas-Lazarata and those in section Spanokhorion. They may be distinguished from the latter by the minor amounts of matrix and by the absence of marly interbeds.

The breccias, best exposed along the coastal road from Levkas town to Nikiana, contain numerous pebbles and boulders of Eocene limestone with *Alveolina* and *Nummulites*.

Immediately north of the village of Nikiana, the breccias are conformably overlain by approximately 25 meters of brown-grey, silty or sandy, crumbly marls, containing thin, discontinuous seams of limestone fragments.

The marls are rich in planktonic foraminifera. The assemblage with *Globigerina siakensis*, *Globigerinoides trilobus*, *G. subquadratus*, *Globorotalia praescitula* and *Orbulina suturalis* and the absence of *Orbulina universa* seems to be comparable with assemblages of the basal part of zone N9 (Langhian).

*Katouna* (fig. 30, no. 6)

Along the road leading uphill from Lighia to Katouna, approximately 25 meters of thin-bedded, detrital limestones are exposed. The limestones are well sorted and have slightly undulating bedding planes. The texture is that of a packstone. Many of the limestone beds contain an abundance of larger foraminifera, oriented parallel to the bedding planes. Some beds are composed for more than 80% of the tests of *Miogypsina* s.s.. *Nephrolepidina*, *Amphistegina*, bryozoan and coral fragments are less abundant. The association seems to be autochthonous.

The average  $V$  value of 9 specimens of *Miogypsina* s.s. ( $\bar{V} = 63$ ), measured in thin sections (sample DM 669), shows that the assemblage belongs to *M. intermedia*, which suggests a Burdigalian Age (see fig. 32).

### *Discussion*

The data obtained from section Spanokhorion and the five scattered outcrops of the Lazarata area allow some general conclusions regarding the depositional conditions in this northern part of Levkas.

The sedimentary and faunistic features of the Burdigalian-Langhian deposits (zones N6/N7 – N9) indicate the existence of shoal areas with flourishing populations of larger foraminifera and the proximity of pronounced reliefs.

The larger-foraminiferal limestones of Katouna do not have features indicative of displacement by density currents. They may have been deposited in or very close to a shoal area in Burdigalian time. The thick, coarse, polymict breccias of Nikiana are an example of deposits laid down very close to a pronounced relief, which was subject to erosion possibly during Late Burdigalian-Early Langhian time. Similar breccias are found in the central part of the Lazarata area, e.g. in section Spanokhorion, but here they are intercalated in an open marine, sandy-marly succession. At these places they represent the result of redeposition by gravity induced currents of a very immature and proximal character.

The thick breccia successions of Nikiana are conformably overlain by marine marls of Langhian Age (N9), which closely resemble the marls of approximately the same age in the top part of the Spanokhorion section. These data suggest that during the Burdigalian the area of Spanokhorion was situated more basin inward than Katouna with its neritic limestones and Nikiana with its breccias.

Another source area for material displaced towards the deeper part of this basin may have been situated in the west. This is suggested by the thinning of coarse conglomeratic beds from west to east in the vicinity of Lazarata, as reported by the authors of the I.F.P. (1966). The assumption is supported by the presence of coarse intercalations of a very proximal character along the present western margin of the area, as for instance near Apolpaina and north of Asprogerakata.

Altogether, the observations on the Burdigalian-Langhian deposits point to the presence of a relatively narrow, rapidly subsiding basin, which was bordered to the east and to the west by pronounced reliefs and shoals. Material from the larger-foraminiferal limestones and from fans of eroded older rocks, accumulated along the margins, was periodically transported by

density currents to the central part of the depression. The regular vertical distribution of the coarse beds and the presence of two successive *Miogypsina* species in the displaced sediments of section Spanokhorion support the idea of repeated though somewhat retarded cleaning of the shoal and coastal areas. These processes may best be understood by assuming repeated differential, vertical movements along faults bordering the depression.

In the course of the Langhian, the supply of coarse clastics rapidly decreased and sedimentation of marine marls became predominant. Evidently, the eastern part of the area became submerged as well. It seems plausible to postulate that the Burdigalian-Early Langhian process of strong differential movements and rapid basin-infill was followed by an overall subsidence of the area.

### III.2.3. The Playia area

The Paleogene and Lower Miocene deposits of the Playia peninsula, situated just opposite the northern part of Levkas island, are exposed in a broad depression, bordered by Pre-Oligocene limestones in the north, east and south (fig. 30). The deposits are separated by the narrow Strait of Levkas from the Miocene in the Lazarata area to the west. In the east, lacustrine beds of probably Pliocene/Pleistocene age cover the Oligo-Miocene deposits. The faults bordering the Oligo-Miocene to the north and to the south are regarded as thrust faults and tear faults respectively by the authors of B.P. (1967, 1971). Scattered outcrops of Eocene limestones in the distributional area of the Oligo-Miocene are not shown in fig. 30.

The sediments in this area are distinctly different from those in the Lazarata area by their generally terrigenous-clastic character. Only in the southwesternmost part, coarse, calcareous breccias are found similar to those in the Lazarata area. The Playia area is poorly exposed; the best exposures are found on the road from Peratia to Playia.

#### *Section Playia* (fig. 30, no. 7)

The section is exposed along the uphill part of the road from Peratia to Playia. It shows a fairly well exposed succession of approximately 150 m of terrigenous-clastic sediments with a few calcareous, detrital intercalations. The strata are steeply dipping SE; some beds are overturned.

The lower 30 m consist of rapidly alternating brown-green, fine sands and light-grey, silty marls, which may be strongly burrowed. Twenty-five meters above the base a thin calcareous intercalation contains numerous representatives of *Lepidocyclina* and *Miogypsina*, with an orientation parallel to the bedding plane. This succession passes upward into medium to coarse-

Fig. 32 Results of counts and measurements on *Nephololepidina* and *Miogypsina* assemblages from Levkas and the Playia peninsula.

*Lepidocyclus*

sample		A <sub>i</sub>	A <sub>o</sub>	C	DI $\mu$	DII $\mu$	DII/DI	R	$\alpha^{\circ}$	species
DM 367	M	36.0	39.7	2.3	205	277	1.35	15.7	219	<i>L. praemarginata</i>
	$\sigma$ M	1.5	1.6	0,2	6	13	0.04	2.9	6	
	N	15	15	20	19	19	19	15	15	
	range	26.5–45.2	32.4–51.2	1–4	170–255	185–410	1.09–1.86	0–35.5	182–249	
DM 368	M	42.8	45.2	4.9	331	503	1.53	27.6	196	<i>L. morgani</i>
	$\sigma$ M	1.0	1.2	0.3	12	18	0.04	2.0	4	
	N	22	22	15	23	23	23	22	23	
	range	33.9–53.6	33.8–55.3	2–7	235–465	375–740	1.21–1.98	8.2–38.5	160–237	
DM 363	M	43.8	47.1	4.0	284	452	1.57	29.9	191	<i>L. ex. interc. morgani-tournoueri</i>
	$\sigma$ M	1.7	1.8	0.7	18	36	0.05	2.9	6	
	N	22	22	13	22	22	22	22	22	
	range	32.2–56.4	34.2–61.9	1–9	137–466	229–807	1.15–2.06	6.4–62.5	136–235	

*Miogypsina*

sample		X	Y	$\gamma^{\circ}$	V	DI $\mu$	species
DM 123	M			positive	25		<i>M. globulina</i>
	$\sigma$ M				6		
	N				7		
	range				0–50		
DM 140	M	5.0	0	+20	63.0	201	<i>M. intermedia</i>
	$\sigma$ M	0.3	–	6	5.0	8	
	N	14	15	15	15	14	
	range	3.5–7	–	–34/+55	26.2–95.1	148–249	
DM 669	M			positive	63		<i>M. intermedia</i>
	$\sigma$ M				8		
	N				9		
	range				30–100		
DM 368	M	11.8	4.2	–120	0	147	<i>M. gunteri</i>
	$\sigma$ M	0.5	0.2	8	–	6	
	N	11	11	12	12	12	
	range	10–15	3–6	–172/–72	–	113–172	
DM 363	M	8.6	0.9	–47	16.0	184	<i>M. ex. interc. tani-globulina</i>
	$\sigma$ M	1.2	0.5	17	5.8	12	
	N	8	10	11	10	11	
	range	4.5–14	0–4	–154/+16	0–44.6	130–260	
DM 363	M	4.3	0		74.9	189	<i>M. negrii</i>
	$\sigma$ M	0.2	–		7.2	8	
	N	9	9		9	9	
	range	3.5–5.5	–		32.4–100	140–230	

grained, positively graded, well-sorted, brown-green sandstone beds, rich in glauconite, alternating with silty marls. Still higher in the section, the coarse sandstones disappear and the silty marls and fine, micaceous sands contain some intercalations of detrital limestones with positive grading. The limestones have a packstone texture; they are rich in bryozoan, algal and coral fragments, and in larger foraminifera, including *Lepidocyclina*, *Miogypsinoidea*, *Miogypsina* s.s., *Spiroclypeus*, *Operculina*, *Nummulites*, *Discocyclina* and *Chapmanina*. The last three taxa are considered reworked.

The uppermost part of the section is predominantly composed of medium-grained sandstones with indistinct positive grading in some beds only. The sands may contain lignite seams or flakes.

Counts and measurements have been performed on *Lepidocyclinids* and *Miogypsiniids* from the thin, calcareous intercalation in the lower 30 meters of the section (figures 32 and 33, sample DM 368). The *Lepidocyclinids* belong to *L. morgani* and the *Miogypsiniids* to *M. gunteri* (Pl. 3 fig. 3). This association suggests an Aquitanian Age.

Planktonic foraminifera were studied from silty marls directly above the calcareous, larger-foraminiferal bed in the lower part of the section and from the fine clastics in the uppermost part. The association of *Globorotalia kugleri*, *G. venezuelana*, *Globigerinoides primordius* and *Catapsydrax dissimi-*

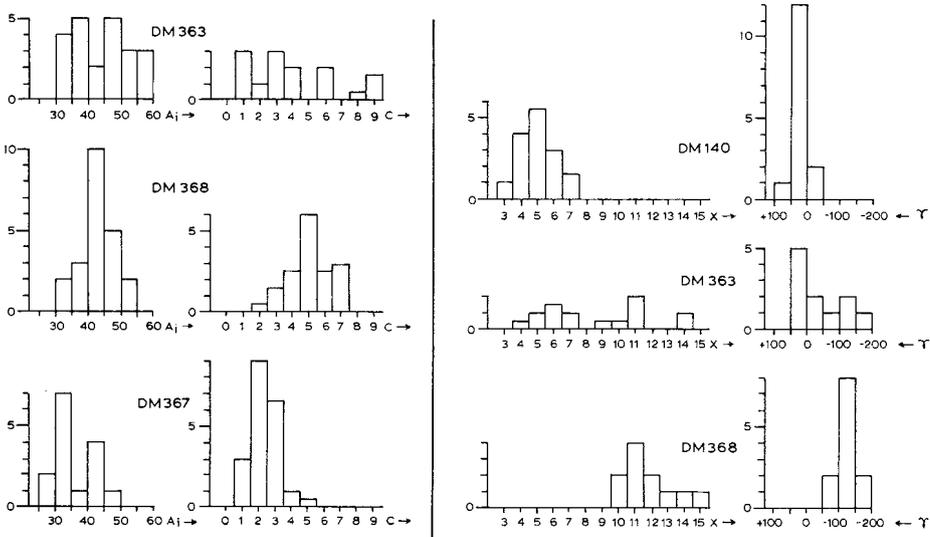


Fig. 33 Histograms of *Nephrolepidina* ( $A_i$  and C classes) and of *Miogypsina* s.s. (X and  $\gamma$  classes) assemblages from Levkas and Playia. In cases of doubt (C and X classes) specimens were counted as half an observation on either side of the limit.

lis allows a correlation with zone N4 (Late Chattian-Early Aquitanian). This is consistent with the one based on the larger foraminifera.

*Roadcuts Peratia – Playia* (fig. 30, nrs. 8 and 9)

Two other small sections are exposed along the road from Peratia to Playia. In the easternmost, 2 km W of section Playia, 12 m of steeply inclined silty marls and fine-grained sands closely resemble the sediments in the lower part of the Playia section (fig. 30, no. 8). The marls contain a planktonic foraminiferal association with *Globigerina venezuelana*, *G. tripartita*, *G. ampliapertura*, *G. galavisi*, *G. opima nana*, *G. anguliofficialis*, *G. tapuriensis* and *Catapsydrax dissimilis*, which suggests an Early to Middle Oligocene age (P18 – P19). A thin, calcareous detrital interbed in the upper part of the sequence contains *Lepidocyclina praemarginata* (figs. 32 and 33; sample DM 367). This intercalation may belong to zone P20 (Late Rupelian-Early Chattain) on account of the co-occurrence of *Globigerina ciperensis*, *G. ampliapertura* and *G. ex. interc. anguliofficialis-angulisuturalis*.

A hundred meters farther to the west, a coarse to very coarse-grained sandstone bed is overlain by some 10 meters of silty marls and fine sands (fig. 31, no. 9). The sandstone bed displays positive grading and is rich in green, probably glauconitic components. Larger foraminifera, abundant at the base of the sandstone, include *Eulepidina*, *Nephrolepidina*, *Miogypsina* s.s., *Miolepidocyclina*, *Gypsina*, *Amphistegina* and *Discocyclina*.

Results of counts and measurements on the *Nephrolepidina*, *Miogypsina* and *Miolepidocyclina* assemblages are presented in figures 32 and 33 (sample DM 363).

The C histogram of *Nephrolepidina* (fig. 33) shows a very wide range and irregular pattern; the number of accessory auxiliary chambers varies from one to nine. Both the ragged frequency distribution and the unusually wide variation suggest a mixture of primitive and more advanced specimens, which may be explained by reworking. For these reasons the “average” assignment of the assemblage to *L. ex. interc. morgani-tournoueri* is questionable.

The frequency distributions of X and  $\gamma$  for *Miogypsina* s.s. (fig. 33) also point to a heterogeneous assemblage. The average indicates *M. ex. interc. tani-globulina*. Considering the frequency distributions, a mixture of *M. gunteri* and *M. globulina* seems more likely. The co-occurring representatives of *Miolepidocyclina* may be assigned to *M. negrii*; seven out of nine values calculated for V are within the range from 79 to 100.

The presence of *M. negrii* indicates a Burdigalian Age. This agrees fairly well with the age based on the planktonic foraminifera. Although negative

evidence plays a part, the co-occurrence of *Globigerina siakensis*, *Globiquadrina dehiscens*, *Globigerinoides trilobus* and *Catapsydrax dissimilis* might point to zones N5 – N6 (Upper Aquitanian-Lower Burdigalian). Probably the sample is of Burdigalian Age containing a considerable admixture of reworked larger-foraminiferal elements.

#### *The ancient fortress* (fig. 30, no. 10)

In the vicinity of the ancient fortress, in the southwesternmost part of the Playia area, two entirely different successions may be observed. Steeply inclined and slightly folded, detrital limestones, alternating with indurated, calcareous marls, are exposed in the coastal cliff near the fortress. The detrital limestone beds are positively graded and coarse grained in their basal parts. In thin sections they have a packstone texture. From the marls, planktonic foraminifera have not been obtained. The presence of *Discocyclina* and *Asterocyclina* and the absence of any other taxon of larger foraminifera in the limestones suggest an Eocene age for these sediments.

Below and around the fortress, thick successions of coarse, ill-sorted, poorly stratified breccias are exposed. The breccias are gently dipping SE. Recrystallized limestone and flintstone components are common. The breccias are similar to those described from the opposite, eastern part of Levkas (Nikiana). In thin sections, representatives of *Miogypsina* s.s., *Gypsina*, *Amphistegina* and *Discocyclina* were observed. The age is thought to be Miocene.

Unfortunately, the contact between the Eocene succession in the coastal cliff and the Miocene breccias is not exposed. The authors of the B.P. (1967) assumed a fault, but the presence of an angular unconformity cannot be excluded.

#### *Discussion*

The biostratigraphic record of the Eocene-Lower Miocene interval in this area is far from continuous. The successions found suggest Eocene to Burdigalian marine deposition of predominantly terrigenous-clastic character.

The sedimentary features of many of these terrigenous-clastic beds point to displacement by gravity induced currents.

The coarse Eocene *Discocyclina* – *Asterocyclina* limestones in the southwest (loc. 10) reflect redeposition of a proximal character. The sandstones with positive grading and the limestone interbeds of the Oligocene and Lower Miocene successions show features of a more mature turbiditic character.

The Miocene limestone breccias in the southwest (loc. 10) bear ample evidence of the proximity of a pronounced relief, that was subject to

erosion. This relief was probably bordered by shoal areas, where larger-foraminiferal, algal and bryozoan debris accumulated. The ill-sorted, thick breccias near the ancient fortress thus may be the result of mixing of eroded older rocks and shoal material during transport towards slightly deeper places. In this respect these breccias are similar to those of the nearby coastal part of the Lazarata area, north of Nikiana (loc. 5). The age of the breccias at the fortress is thought to be roughly the same (Burdigalian-Langhian) as that of the Nikiana coarse deposits, which are conformably overlain by Langhian marls.

Probably the breccias at the fortress are younger than the terrigenous Oligocene-Lower Burdigalian finer grained detrital successions at localities 7, 8 and 9. If this is correct, the breccias reflect renewed coarse deposition resulting from a fundamental change in the paleogeographic configuration, caused by major tectonic movements in Late Burdigalian or Early Langhian.

Summarizing, the fragmentary stratigraphic record of the Playia area seems to indicate Eocene shallow bioclastic deposition, followed by deeper and more offshore conditions from Oligocene to Early Burdigalian and renewed nearby vertical movements and emerging areas in Late Burdigalian to Early Langhian time.

#### III.2.4 The Poros area

In the southeast of Levkas, Post-Eocene deposits are restricted to the N-S valley between the villages of Katakhorion and Poros and to the coastal area along the west side of the Vlichos peninsula (fig. 30). The deposits in the peninsula were not investigated; Bornovas (1964) placed them in his "Post-Aquitanian transgressive series".

The Post-Eocene sediments are part of a synclinal structure with an overturned eastern flank. In the west, they conformably overlie Eocene limestones; in the east they may be separated from Eocene limestones by thrust faults according to the geological map of Levkas, B.P. 1967. Some outcrops of supposedly allochthonous Eocene limestones in the distributional area of the Oligo-Miocene are not indicated in figure 30.

The sediments in the Poros area show a few exposures only and the stratigraphic relation between the scattered outcrops cannot be ascertained in the field. Terrigenous as well as calcareous deposits are exposed; the former are relatively well exposed in the vicinity of Poros. The calcareous deposits are restricted to a narrow strip bordering the Eocene limestones in the west and to some scattered exposures in the north.

*The Poros sections* (fig. 30, nrs. 11 and 12)

Two sections were studied, one along a roadcut opposite the cemetery of Poros, and the other in the valley west of the cemetery. The stratigraphic interrelation cannot be ascertained in the field.

The roadcut section (fig. 30, no. 11) displays an overturned succession of approximately 45 meters of alternating silty marls and medium to fine-grained sands with slight positive grading. The thickness of the individual sand beds varies between 8 and 60 cm. The dip is 80 degrees to the south.

In the valley west of the cemetery (fig. 30, no. 12), a fragmentary succession of approximately 50 m is composed of predominantly marly deposits, alternating with positively graded sandstones. Upwards, the carbonate content of the sands and marls decreases and the marls become siltier. The sandstones are medium to fine-grained, well sorted and laminated. Plant remains are common in the sands of the higher parts of the section.

The sedimentary features in both Poros sections reflect deposition by turbidity currents of mature and probably distal character.

Larger foraminifera have not been found. The marls from the roadcut section are rich in planktonics. The co-occurrence of *Globigerina tripartita*, *G. suteri*, *G. cf. kugleri*, *Globigerinoides primordius*, *G. quinqueloba* and *G. siakensis* may place these faunas in zone N4 (Late Chattian – Early Aquitanian).

*Katakhorion* (fig. 30, no. 13)

A transition from calcareous to more terrigenous-clastic sedimentation may be studied along the road leading uphill to the village of Katakhorion and close to the bifurcation with the road from Nydrion to Vasiliki. The basal part of the 30 m section consists of white, thinbedded, non-detrital limestones of wackestone texture. In thin sections, the limestones contain large numbers of planktonic foraminifera. Higher in the section, the thinbedded limestones contain intercalations of *Asterocyclina* and *Discocyclina*-bearing wackestones, which suggest an Eocene age.

Approximately 10 meters above the base of the section, the first marly interbeds were observed. Upwards, the number and thickness of the marl beds are increasing rapidly; this is accompanied with a decreasing carbonate content. In the upper part of the section, the marls are alternating with fine-grained, detrital limestone beds. The dip varies between 75° NE and 30° SE; the uppermost beds are slightly folded.

Lepidocyclinids or Miogypsinids have not been observed in the fine-grained, detrital limestones from the upper part of the section. The marly interbeds from the lower part contain *Globigerina gortanii*, *G. tapuriensis*, *G.*

cf. *angiporoides*, *G. increbescens*, *G. venezuelana*, *G. cf. galavisi*, *G. opima nana* and *Catapsydrax dissimilis*. This association is characteristic of zones P18/P19, which suggests that the supply of terrigenous-clastic material started approximately during the Early – Middle Oligocene.

#### Roadcut Nydrion – Vasiliki (fig. 30, no. 14)

Along the road from Nydrion to Vasiliki, just south of the bifurcation with the road to Poros, finely bedded, pelagic limestones with microbreccious interbeds of Eocene age are separated by an unexposed interval of 25 m from approximately 100 m of coarse limestone breccias. The general dip of the Eocene limestones and the breccias is 60° SE.

The breccias are poorly stratified and ill-sorted. The components are generally badly rounded, the diameter may be as much as one meter. Recrystallized limestones and flint are predominant. *Alveolina*, *Nummulites* and *Discocyclina* are abundant in many of the coarse limestone components. Less common are sandstone and greenish, calcareous marl components. One fragment of detrital *Lepidocyclina* limestone was found.

The amount of matrix strongly varies from bed to bed. In some levels the components are floating in a fine-grained matrix, whereas in others they are closely packed. In particular in the latter case they closely resemble the breccias from the southwestern part of the Playia peninsula and those from the eastern part of the Lazarata area.

The single *Lepidocyclina* limestone component contains numerous *Nephrolepidina*, *Eulepidina* and *Operculina*, which suggest a Rupelian Age or younger. One of the marl boulders contained a poorly-preserved planktonic foraminiferal fauna, which does not allow a correlation with any of the standard zones. The presence of *Globigerina tripartita*, *G. opima nana*, *G. cf. ciproensis* and *Catapsydrax dissimilis* suggests a Late Oligocene age. As a consequence, redeposition of the breccias must have taken place during the Late Oligocene or in the Miocene.

#### Road Katakhorion-Poros (fig. 30, no. 15)

Isolated and irregularly distributed, detrital limestone blocks were found in the northern part of the Poros-Katakhorion valley. The sedimentary position of these blocks could not be ascertained.

The limestones have a packstone texture; thin sections contain numerous larger foraminifera, including representatives of *Nephrolepidina*, *Eulepidina*, *Spiroclypeus*, *Amphistegina*, *Gypsina* and, rare, *Miogypsinoidea*. A biometrical analysis could not be performed on the *Lepidocyclinids* or *Miogypsiniids*. The absence of *Miogypsina* s.s. is negative evidence of a Chattian Age.

## *Discussion*

In the Poros area the Eocene is represented by pelagic limestones, with locally coarser material with larger foraminifera. The transition from calcareous to marly terrigenous-clastic sedimentation took place in the Early — Middle Oligocene. In the Aquitanian terrigenous-clastic fine-grained turbiditic sedimentation prevailed, and continued until the end of the Aquitanian, according to the I.F.P. (1966).

The breccias overlying the Eocene limestones in the west seem to be of (Late) Oligocene age, but they might be considerably younger. A younger age is suggested by the close similarity with the Late Burdigalian-Langhian breccias exposed in the Lazarata area, north of Nikiana. The breccias point to the existence of a pronounced relief in or close to the Poros area during their deposition. The present position of the breccias along the western margin of this area may suggest a supply from the west.

No conclusions can be drawn from the scattered limestone blocks in the north, as their Late Oligocene age is disputable and their position in the sedimentary column unknown.

### III.2.5. The Ayios Petros area

In the southwestern part of Levkas the Oligo-Miocene deposits conformably overlie Eocene limestones in the west. The contact with older rocks in the east is formed by a thrust fault system (fig. 1), which was reported to separate the Ionian Zone from the Paxos Zone (Bornovas, 1964, Aubouin, 1965, I.F.P., 1966, Bizon, 1967, B.P., 1967, 1971).

The Oligocene and Miocene sediments in the northern part of the Ay. Petros area differ from those in the Lazarata, Playia and Poros areas by the absence of coarse, calcareous breccias and conglomerates. In this northern part, finely-bedded, in part pelagic limestones of Eocene age are overlain by a relatively thin succession of detrital, neritic limestones, passing upwards into at least 400 — 500 m of marls and clays, which may reach as high as the Upper Miocene (Bizon, 1967).

Outcrops in the southeast were not investigated. Bornovas (1964) reported coarse, calcareous conglomerates from this part of the Ay. Petros area. According to his map, these deposits may be found west of the thrust fault system between the Ionian and Paxos zones, but in his composite stratigraphic column they were included in the Ionian Zone.

The exposures in the vicinity of the villages of Komilio, Ay. Vasilios and Kalamitsi (see fig. 30) may be considered representative of the Oligo-Miocene in the central and northwestern parts of the Ay. Petros area.

*Komilio* (fig. 30, nrs. 16 and 17)

The lower part of the Oligo-Miocene in the Ay. Petros area can be studied in sections exposed near the chapel of Ay. Petros, approximately 1 km south of the village of Komilio.

In a roadcut (fig. 30, no. 16), 35 meters of overturned limestone beds are visible, separated from marls in normal position. The limestones are dipping 30° NW and the marls 80° SE.

The basal part of the limestones consists of thin bedded, non-detrital limestones with a wackestone texture, containing planktonic foraminifera only. About 12 meters above the base the first larger foraminifera were found (*Nephrolepidina* and *Gypsina*). Higher up in the succession the number and the diversity of the larger foraminifera are increasing; *Nephrolepidina*, *Eulepidina*, *Spiroclypeus*, *Amphistegina* and *Operculina* are common. The first *Miogypsinoides* specimens were found at 20 meters above the base of the succession. Noteworthy is the absence of reworked Eocene larger foraminifera, which are common in many of the detrital beds of the other areas.

The increase of the faunistic diversity from bottom to top is accompanied with a gradually decreasing number of planktonic foraminifera and degree of sorting. As to their texture, the limestones in the upper part are prevalingly wackestones; some intercalations of packstones are present. All beds are strongly burrowed.

Keelid Globorotaliids are absent in the basal part of the pelagic limestones; this suggests that these limestones belong to the uppermost Eocene or to the Lower Oligocene. The presence of *Nephrolepidina* and the absence of Miogypsinidae higher up in the section may indicate a Rupelian Age, whereas the upper part of the limestones may belong to the Chattian, as indicated by rare *Miogypsinoides* and the absence of *Miogypsina* s.s. Since isolated specimens have not been obtained and the number of larger foraminifera in thin sections is low, a species designation was not possible for the *Miogypsinoides* and the *Nephrolepidina* specimens.

The second, more eastern part of the section shows steeply inclined, brown-grey marls, alternating with some very thin, calcareous detrital limestones. The marls are separated from the underlying limestones by an unexposed interval of 4 meters with a distinct fault.

Approximately 200 meters to the south, an almost identical composite succession may be observed (fig. 30, no. 17). Here also, the contact between the limestones and marls must be a fault.

Planktonic foraminifera from the lowermost marly beds in both sections contain associations with *Globorotalia kugleri*, *G. venezuelana*, *G. siakensis*,

*Globigerinoides primordius* and *Catapsydrax dissimilis*, pointing to a Late Chattain – Early Aquitanian Age (N4).

Ay. Vassilios (fig. 30, no. 18)

Near the village of Ay. Vassilios on the eastern slope of a N-S running valley, at least 400 m of fine-grained, predominantly clayey and marly deposits are exposed. From bottom to top the dips vary from 80 to 30 degrees to the east.

In the lower 30 m of the section, indurated calcareous marls are alternating with fine-grained, detrital limestone and marly limestone beds, the thickness of which does not exceed 25 cm. The marls are well bedded, multicoloured and generally strongly burrowed. The number of limestone intercalations decreases upwards.

The upper part of the succession consists of blue-grey marls and clays with some fine-grained sandstone interbeds.

Planktonic foraminifera from the base of this succession may be correlated with the interval of zones N6 – N7, as indicated by the presence of *Globigerinoides altiapertura*, *G. trilobus*, *Globoquadrina dehiscens*, *Globorotalia peripheroronda* and *G. praescitula*, suggesting a Burdigalian Age. According to the authors of the I.F.P. (1966) and Bizon (1967), the section may reach as high as the Upper Miocene.

Kalamitsi (fig. 30, no. 19)

Poorly exposed grey silty marls and thin, brown-grey sandstone beds are visible in the coastal cliff west of the village of Kalamitsi, in the extreme north of the Ay. Petros area. The medium-grained sandstone beds are positively graded; they have horizontal lamination and contain abundant lignite flakes.

According to the literature, this terrigenous-detrital succession is separated from Pre-Oligocene rocks by the major thrust-fault, which separates the Paxos and the Ionian Zones. The contact is not well exposed.

Larger foraminifera have not been found. The planktonic foraminiferal taxa *Orbulina universa*, *Globigerinoides obliquus*, *G. falconensis* and *Globorotalia menardii* (form 3 of Tjalsma, 1971) indicate a Middle Miocene age (probably Serravallian).

The sediments of Kalamitsi have been mapped as Lower Miocene "Flysch" by the authors of the B.P. (1967).

#### Discussion

The limestones of the Komilio sections indicate a gradual shift from calcareous, pelagic sedimentation to calcareous, neritic sedimentation during

the Middle Oligocene. The sedimentary and faunistic features of the Middle-Uppermost Oligocene limestones do not show evidence of any major secondary displacement of this material. During the Rupelian-Late Chattian time span, the Ay. Petros area evidently was part of a shallow platform, on which bioclastic calcareous sedimentation took place only. There are no indications for the presence of a nearby, emerging relief. The larger-foraminiferal limestones do not contain reworked older larger-foraminiferal taxa or components of Pre-Oligocene rocks.

During the Late Chattain-Early Aquitanian the calcareous platform sedimentation rather abruptly made place for a predominantly terrigenous-clastic sedimentation, as is reflected by the intercalation of marls. This change was evidently caused by a fundamental change in the paleogeographic configuration. The shallow platform rapidly subsided and marls and clays were deposited until the Late Miocene. The intercalations of thin, clastic beds in the Ay. Vassilios section, and especially of positively graded sandstones in the succession of Kalamitsi reflect the influence of density currents, which supplied slightly coarser material from a distant hinterland. The diversified planktonic foraminiferal associations and the high plankton/benthos ratio (over 90%) of the marl and clay samples indicate a considerable depth of the depositional area during the Middle and Late Miocene.

### III.2.6. Sedimentary history of Levkas – Playia

The information collected in the Lazarata, Playia, Poros and Ay. Petros areas allows a schematic reconstruction of the sedimentary history of Levkas and the opposite part of the mainland from the Late Eocene to the Middle Miocene.

Today, these four areas are separated by pre-Oligocene rocks or by the sea, but the entire region may have had an extensive marine cover with quiet sedimentation, at least during the Eocene and part of the Early Oligocene. At that time, the sedimentation consisted predominantly of an accumulation of fine-bedded, mostly pelagic limestones in the present Lazarata, Poros and Ay. Petros areas; the Playia area, however, was situated closer to some eastern basinal margin or shoal area, as indicated by the intercalation of coarse, proximal, redeposited *Discocyclus* limestones in the calcareous marls. Also the Poros area shows a shallowing tendency during the Eocene already, as may be concluded from the *Discocyclus* – *Asterocyclus* interbeds.

The transition from calcareous into predominantly terrigenous clastic sedimentation started for most of the region in the Early to Middle Oligo-

cene. Such a terrigenous clastic supply did not arrive in the Ay. Petros area until later, during the Late Oligocene to Early Miocene (Aquitanian). In this most western area it was preceded by a distinct shallowing during the Oligocene, resulting in a long-lasting platform with flourishing larger-foraminiferal faunas.

The Oligocene and Lower Miocene clastics overlying the calcareous deposits in the eastern Playia and Poros areas are prevailingly turbiditic and also the rare intercalations of calcareous beds generally bear evidence of transport from shallow towards deeper environments. The terrigenous clastics in these areas show striking similarities. In the literature, they have been indicated as "flysch". Similar deposits have been reported from scattered outcrops in the southern part of the Lazarata area (Bornovas, 1964, I.F.P., 1966, B.P., 1967, 1971). Hence, the sedimentary features and today's distribution of these "flysch" type deposits in the Lazarata, Playia and Poros areas suggest that turbiditic, terrigenous clastic successions were deposited in the single basin that continued to exist as such until the Early Burdigalian. Unfortunately, paleocurrent directions could neither be measured from the occasional sole marks of the sandstone beds nor from the calcareous interbeds. It seems reasonable to assume that the material of at least the larger-foraminiferal limestone intercalations originated in the shoals, which existed in the west during the Middle and Late Oligocene.

At about the transition Oligocene-Miocene, the western, Oligocene platform of Ay. Petros subsided; Miocene marls and clays point to quiet sedimentation conditions with only subordinate supply of displaced, slightly coarser material of a mature, distal nature. This type of sedimentation continued until the Late Miocene.

In contrast with the Ay. Petros area, no fundamental change in sedimentation conditions took place in the Lazarata, Playia and Poros areas during the Aquitanian. Turbiditic sedimentation continued from the Oligocene until the Early Burdigalian.

In the last three areas, renewed major tectonic movements must have preceded the deposition of the younger Miocene calcareous breccias. The biostratigraphic data from the Lazarata and Playia areas indicate that these movements started during the Late Burdigalian. They caused a strong fragmentation of the area with vertical movements of separate blocks, and thus a fundamental change of the paleogeographic configuration. From some time in the Burdigalian to the end of the Early Langhian, sedimentation was predominantly defined by the supply of local calcareous, immature deposits from the margins of rising blocks to areas subject to submergence. The distinct, angular unconformity between these calcareous successions and

underlying "flysch" deposits near Alexandros, in the southern part of the Lazarata area (I.F.P., 1966), also points to tilting and erosion prior to sedimentation of the calcareous successions.

The sediments in the northern part of the Lazarata area may give a good example of the structural and sedimentary processes during the Late Burdigalian and Early Langhian. Pronounced reliefs to the east and to the west bordered a rapidly subsiding smaller basin. The basin infill predominantly consisted of immature sediments, mostly for the second time displaced and transported by density currents from the basin margins to the central part. The redeposited sediments were mainly composed of older, eroded limestones and faunal elements accumulating along the basin margins. Most of the displaced sediments are of a very proximal nature; they show all transitions from hardly displaced, submarine debris fans to mudflows with a considerable amount of matrix. The regular vertical distribution of the coarse beds containing components of pre-Oligocene rocks may only be explained by assuming repeated renewal of the relief, i.e. by continuous or intermittent differential, vertical movements along the faults bordering the graben-like basin.

It may reasonably be postulated that the coarse breccias of Katakhorion, along the western margin of the Poros area, were caused by contemporaneous strong, differential movements, which resulted in the uplift of some western block. The breccias strongly resemble those from the Lazarata and Playia areas, but they contain no components younger than Late Oligocene. Actually, certain is only the uplift and erosion of marine, Upper Oligocene deposits, which took place during the Miocene. The calcareous deposits of the Vlichos peninsula (belonging to the "séries transgressives post-aquitaniennes" of Bornovas, 1964) may also have been deposited during the Burdigalian-Early Langhian timespan of fragmentation.

In all areas of Levkas the tectonic instability seems to end rather abruptly during the later part of the Langhian. The Upper Langhian marls overlying the breccias in the eastern part of the Lazarata area and the approximately synchronous marls and clays in the top part of section Spanokhorion suggest an overall submergence and, again, a fundamental change in the paleogeographic configuration, caused by a "restabilisation" of the East Levkas - Playia region.

From these conclusions it may be inferred that the Megalo Rachi, Pirgos, Stafrota and Linaki mountains, which today constitute the backbone of Levkas, acted as highs during the Burdigalian and Early Langhian, i.e. separating the Lazarata, Playia and Poros areas of the Ionian Zone from the Ay. Petros area of the Paxos Zone. An eastern source area is likely for the

elements of Bornovas' (1964) coarse calcareous conglomerates in the south-eastern part of the Ay. Petros area along today's western margin of the Linaki mountains.

Summarizing, the following general conclusions may be presented:

- 1) Today's Playia, Poros, Lazarata and Ay. Petros areas formed part of a single large sedimentation realm until the Early Miocene. In the Middle Oligocene, a difference was accentuated between a platform area with calcareous, neritic sedimentation in the west and a basin with predominantly terrigenous clastic sedimentation in the east. These conditions persisted during the Middle and Late Oligocene. The boundary between the platform and the basin may have been an escarpment, corresponding to a "juvenile" stage of the thrust-fault system that separates the Ionian and Paxos Zones.
- 2) In the Aquitanian the platform subsided rapidly, and at the same time there may have been a beginning rise of the central parts of Levkas. The Lazarata, Playia and Poros areas remained part of the large basin with mainly turbiditic, but more sandy terrigenous clastic sedimentation until the Early Burdigalian.
- 3) A Late Burdigalian tectonic phase caused tilting, overturning and local sliding of the older strata.
- 4) This phase was accompanied or immediately followed by strong, repeated, differential vertical movements resulting in fragmentation of the large sedimentary basin. Emerging blocks were eroded and coarse, calcareous debris accumulated in relatively narrow, graben-like basins.
- 5) In the Late Langhian the relative vertical movements ceased and now also the eastern part of Levkas became subject to an overall submergence. Possibly, also today's high mountains in the central and westernmost part of Levkas were flooded again. Subsidence and quiet sedimentation continued at least until the Late Miocene.
- 6) Time and again, today's culminations of Mesozoic and Eocene rocks may have acted as highs during the sedimentary history of Levkas; this suggests that the blocks are bordered by old, deep seated fracture systems.

### III.3 KERKIRA

#### III.3.1 Introduction

The Oligocene and Lower Miocene deposits of Kerkira (Corfou) are found in the northern part of the island in the elongate, approximately W – E running depression between the villages of Spartila and Zygos, and in the

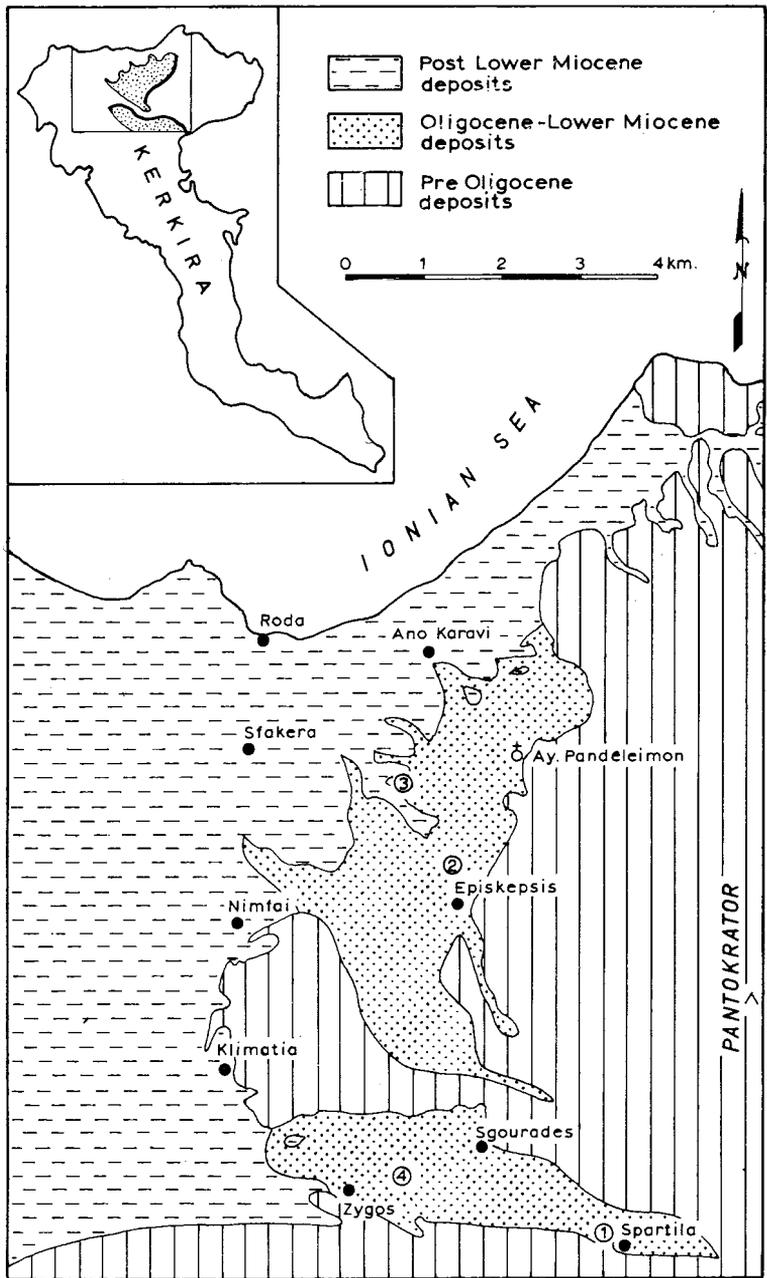


Fig. 34 Schematic geological map of a part of northern Kerkira. The numbers refer to the discussed Oligo-Miocene sediment successions (mainly after I.F.P., 1966).

area west of Episkepsis (fig. 34). The two areas are separated by a ridge of Mesozoic limestones. In the west the Oligocene – Miocene successions are separated by an angular unconformity from calcareous breccias and marls of Late Miocene – Early Pliocene age (I.F.P., 1966).

An undisturbed contact between Oligo–Miocene deposits and older rocks has been observed along the southern border of the area of Spartila; all other contacts are faulted. The predominantly terrigenous clastic deposits are rather well exposed, but they are strongly affected by faulting so that larger, continuous successions are not available.

The island of Kerkira has been included in the Ionian Zone by Aubouin (1965) and by authors of the I.F.P. (1966). The latter authors studied the successions near Spartila and those exposed in the valley of Episkepsis. Together, these successions would cover the interval from Upper Eocene to Burdigalian.

### III.3.2 Localities

Two outcrops were studied in the southern area and two others in the north (fig. 34, nrs. 1–4).

#### *Spartila* (fig. 34, no. 1)

Immediately west of the village of Spartila, a well-exposed section shows the transition from calcareous, non-detrital into terrigenous clastic sediments. The non-detrital, thin-bedded limestones are overlain by ten meters of greenish, marly limestones and detrital limestone beds (packstones). In thin sections of the non-detrital limestones and the marly limestones, only planktonic foraminifera were observed. The detrital limestone intercalations contain *Eulepidina*, *Nummulites*, *Discocyclina* and *Chapmanina*.

The alternating greenish marly limestones and detrital beds are passing upwards into about 40 meters of multicoloured, marly shales with intercalations of thin, generally discontinuous, positively graded, calcareous-detrital beds of packstone texture. In some of the detrital beds *Eulepidina*, *Gypsina* and *Heterostegina* were observed; representatives of *Nephrolepidina* were found from 15 meters above the base of the marly shale succession upwards.

*Nephrolepidina* assemblages were studied from two samples, DM 317 in the uppermost part of the section and DM 62 in the lowermost *Nephrolepidina*-bearing limestone. Data on  $A_i$  and C are given in figure 35, histograms of  $A_i$  and C classes in fig. 36. Both assemblages belong to *L. praemarginata* (Pl. 3, fig. 6, 8). The average degree of embracement in the upper sample ( $\bar{A}_i = 37.1$ ) is significantly greater than that in the lower sample ( $\bar{A}_i = 33.9$ ).

The planktonic foraminiferal association from a marl sample directly

Fig. 35 Results of counts and measurements on *Nephrolepidina* and *Miogypsina* assemblages from Northern Kerfira.

*Lepidocyclus*

sample		$A_i$	$A_o$	C	$DI\mu$	$DII\mu$	$DII/DI$	R	$\alpha^\circ$	species
DM 322	M	43.0	45.0	5.9	315	470	1.50	25.5	195	<i>L. ex. interc.</i>
	$\sigma$ M	0.9	1.0	0.3	14	20	0.02	1.4	4	<i>morgani-tournoueri</i>
	N	18	18	18	19	19	19	18	18	
	range	34.1–49.3	34.0–52.0	4–8	200–470	307–699	1.31–1.68	13.4–34.0	171–228	
DM 331	M	43.3	45.2	4.4	250	394	1.56	23.6	195	<i>L. morgani?</i>
	$\sigma$ M	1.5	1.6	0.5	11	27	0.05	3.5	6	
	N	20	20	17	20	20	20	20	20	
	range	34.4–56.4	34.3–58.9	1–8	159–383	244–696	1.20–2.03	3.8–52.0	138–236	
DM 27	M	37.7	39.3	3.1	231	308	1.33	7.5	220	<i>L. ex. interc.</i>
	$\sigma$ M	0.9	0.9	0.3	8	13	0.03	0.7	3	<i>praemarginata-morgani</i>
	N	17	17	14	17	17	17	17	17	
	range	32.2–48.9	33.3–49.5	2–5	185–339	233–459	1.12–1.59	2.0–13.3	180–237	
DM 317	M	37.1	38.5	2.4	211	279	1.32	9.3	221	<i>L. praemarginata</i>
	$\sigma$ M	0.9	1.0	0.3	6	11	0.02	1.1	3	
	N	19	19	14	20	20	20	19	19	
	range	32.0–44.0	30.5–48.2	1–4	159–227	205–418	1.15–1.51	3.3–20.6	190–240	
DM 62	M	33.9	35.0	1.7	230	293	1.27	8.7	233	<i>L. praemarginata</i>
	$\sigma$ M	0.6	0.6	0.2	10	13	0.02	1.3	2	
	N	19	19	16	19	19	19	19	19	
	range	29.6–39.0	30.3–40.2	0–2	137–302	157–398	1.11–1.42	3.6–20.8	215–246	

*Miogypsina*

sample		X	Y	$\gamma^\circ$	V	$DI\mu$	species
DM 322	M	13.4	4.7	-160	0	141	<i>M. ex. interc.</i>
	$\sigma$ M	0.5	0.4	12	–	10	<i>basraensis-formosensis</i>
	N	12	16	18	18	18	
	range	11–17	3–7	-247/-41	–	89–238	
DM 331	M	14.3	5.7	-201	0	144	<i>M. ex. interc.</i>
	$\sigma$ M	0.6	0.7	23	–	10	<i>formosensis-basraensis?</i>
	N	9	11	10	11	11	
	range	10–16	3–11	-288/-65	–	90–211	

below the upper *Nephrolepidina* bed includes *Globigerina suteri*, *G. tripartita*, *G. praebulloides*, *G. opima nana*, *G. ciproensis-angulisuturalis* and *Catapsydrax dissilimis*. This association and the absence of *G. opima opima* may point to zone N3, which has been placed in the Upper Chattian. This is consistent with the age based on the upper *L. praemarginata* assemblage. The very primitive *L. praemarginata* from the basal part of the section, however, points to a Late Rupelian – Early Chattian Age.

*Episkepsis* (fig. 34, nrs. 2 and 3)

Discontinuous outcrops of terrigenous clastic successions are present in the SE – NW valley north of the village of Episkepsis. The valley is intersected by numerous faults, and the strikes and dips of the strata vary strongly. The authors of the I.F.P. (1966) refer to these outcrops as “section Episkepsis”; they measured a thickness of 1,300 m, but they stressed that this figure may be too high because of suspected effects of faulting. Planktonic foraminifera from part of the section have been studied by Bizon (1967).

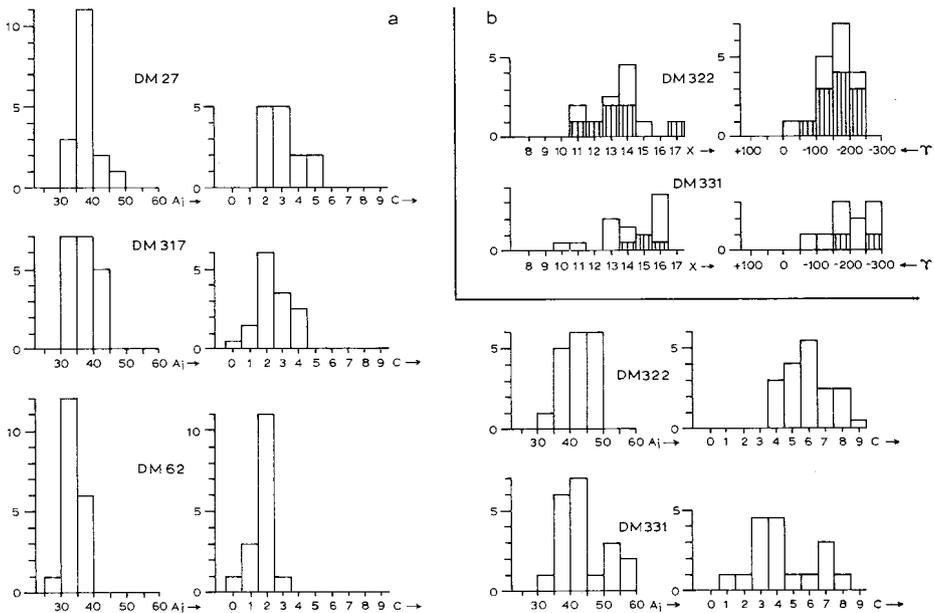


Fig. 36 Frequency distributions of *Nephrolepidina* ( $A_i$  and C classes: a), and *Miogypsina* (X and  $\gamma$  classes: b) assemblages in northern Kerkira. Shaded columns refer to *Miogypsina s.s.* specimens.

The sediments in the valley are relatively well exposed in the southeast, close to the village of Episkepsis (fig. 34, no. 2) and also at about 4 km downstream in the northwest (fig. 41, no. 3).

Approximately 500 meters NW of the village, several outcrops consist of thick successions of blue-grey, generally silty, crumbly marls with some cream-coloured, detrital limestone interbeds (fig. 34, no. 2). Since the meandering valley follows the strike of the strata, the series of outcrops cannot be combined to a distinct larger section. In some exposures the marls are overlain by alternations of thick (up to 150 cm), brown, positively graded, coarse and medium-grained sandstone beds and silty or sandy, grey-brown clays. The silty – sandy marls may contain calcareous detritus, amongst others consisting of larger foraminifera. The detrital limestone interbeds are positively graded and coarse-grained at the base; in thin sections they show a microsparitic packstone texture. The coarse basal parts contain numerous algal, bryozoan and echinid fragments and larger foraminifera, including *Eulepidina*, *Nephrolepidina*, *Gypsina*, *Spiroclypeus*, *Operculina*, *Heterostegina*, *Nummulites* and *Discocyclina*.

Free specimens of *Nephrolepidina* and *Cycloclypeus* were collected from one level in the marls (DM 27). The results of counts and measurements on *Nephrolepidina* (figs. 35, 36) suggest that the assemblage is intermediate between *L. praemarginata* and *L. morgani* (Pl. 3, fig. 7).

The 12 specimens of *Cycloclypeus* show a wide variation in the number of pre-cyclic chambers including the first two chambers from 11–27. The mean is 18 ( $\sigma_M = 1.6$ ). The diameter of the protoconch (C) varies between 99 and 229 $\mu$ .  $\bar{C} = 150\mu$ ;  $\sigma_M = 9.9$ . This *Cycloclypeus* assemblage seems to be slightly more advanced than that from the so-called Rupelian of Mollere, described by Meulenkamp and Amato (1972). The Kerkira assemblage and that from Mollere closely resemble the Spanish inornate forms with respect to their position in the  $\bar{X} - \bar{C}$  scatter diagrams given by Mac Gillavry (1962) and Meulenkamp & Amato (1972).

Planktonic foraminifera from the same sample DM 27 are *Globigerina tripartita*, *G. venezuelana*, *G. praebulloides*, *G. opima nana*, *G. angulisuturalis*, *G. ciperoensis* s.s. and *Catapsydrax dissimilis*. This association is indicative of zone N3, which has been assigned to the Upper Chattian. If the latter assignment of Berggren & Van Couvering (1974) is correct, this may mean that the transition of *L. praemarginata* into *L. morgani* has taken place within zone N3.

Two other planktonic foraminiferal faunas were examined from the fine-clastic successions in the southeastern part of the valley. One of them contained *Globigerina gortanii*, *G. galavisi*, *G. opima nana*, *G. suteri*, *G.*

*tripartita*, *G. cf. ciproensis*, *G. ex. interc. anguliofficinalis-angulisuturalis* and *Catapsydrax dissimilis*; this association points to zone N2 (Lower Chattian). The other sample contains an association of *Globigerina venezuelana*, *G. suteri*, *G. tripartita*, *G. praebulloides*, *G. opima nana*, *G. angulisuturalis*, *Globigerinoides primordius*, *Globorotalia cf. kugleri* and *Catapsydrax dissimilis*, which may indicate the basal part of zone N4 (Upper Chattian – Lower Aquitanian).

The successions exposed in the northwestern part of the valley (fig. 34, no. 3) differ from those in the southeast by the much smaller relative thickness of the marly beds, the greater thickness of coarse-detrital intercalations and the much larger number of terrigenous clastic components in these coarse beds. The outcrops consist of grey-brown, positively graded, calcareous sandstones, alternating with silty marls. The calcareous sandstones have packstone textures; they may contain numerous larger foraminifera, particularly in the basal part. In addition to the elements described from the limestones in the southeast, *Miogypsinoidea* and *Miogypsina* s.s. were found. The upper parts of the graded sandstones may contain concentrations of plant remains.

Counts and measurements were made on the *Nephrolepidina* and *Miogypsina* specimens from one of the coarser beds DM 331, figs. 35, 36. The histograms of A<sub>i</sub> and C classes of *Nephrolepidina* suggest bimodal distributions, which may be explained as a mixture of a more advanced and a more primitive assemblage during resedimentation. This assumption is supported by the wide variation in the number of accessory auxiliary chambers, which ranges from one to eight. For these reasons, assigning the *Nephrolepidina* specimens to *L. morgani*? is no more than an arithmetic manipulation without much taxonomic value.

Also the X and  $\gamma$  classes of the *Miogypsinae* have irregular frequency distributions (fig. 36). There are two specimens with *Miogypsina* features, but the X and  $\gamma$  values are within the range of values found for the accompanying *Miogypsinoidea* individuals. The association might be determined as *M. (Miogypsinoidea) ex. interc. formosensis-basraensis*, but the effect of older reworked individuals is considered to be included.

Planktonic foraminifera have not been found in the samples from the northwestern part of the valley. The larger foraminifera assemblages suggest the sandstones in the northwest to be slightly younger than the marl-limestone successions in the southeast. If we try to exclude the effect of reworked specimens, both groups of larger foraminifera point to some level close to the Chattian-Aquitanian boundary.

Zygos (fig. 34, no. 4)

A well-exposed succession of 35 meters of marls and sandstones may be studied approximately halfway the road from Sgourades to Zygos. The basal part consists of blue-grey, calcareous marls, conformably overlain by brown-grey, medium-to fine-grained sandstones alternating with silty marls. The sandstones show slight positive grading and horizontal and convolute lamination. The sandstone beds are increasing from bottom to top in number and thickness. The upper part of the succession contains some thick (up to 250 cm) sandstone beds, rich in plant remains. The basal part of one of these beds contains *Nephrolepidina*, *Miogypsinoides*, *Miogypsina* s.s., *Operculina*, *Heterostegina* and *Amphistegina* (sample DM 322).

The histograms of C and  $A_i$  classes of *Nephrolepidina* and those of X and  $\gamma$  of the Miogypsinidae show fairly normal distributions (fig. 36). The means of  $A_i$  and C indicate that the *Nephrolepidina* assemblage is intermediate between *L. morgani* and *L. tournoueri* (fig. 35). The X and  $\gamma$  values of both Miogypsinid groups show good overlap. The  $\bar{X}$  and  $\bar{\gamma}$  values calculated for the total number of specimens allow the determination *M. ex. interc. basraensis-formosensis* (Pl. 3, fig. 2), which may point to some level in the Upper Chattian – Lower Aquitanian. The Lepidocyclinids, however, suggest the sample to be slightly younger.

As a result of poor preservation, reliable conclusions cannot be drawn from the planktonic foraminiferal associations.

### III.3.3 Discussion

The observations on the section Spartila indicate that the transition from a calcareous pelagic to a detrital terrigenous clastic sedimentation took place during the Oligocene. The presence of *Eulepidina* and the absence of *Nephrolepidina* in the packstone interbeds suggest that this event occurred during the Early – Middle Oligocene, but these elements have probably been redeposited, an assumption which is supported by the co-occurrence of obviously reworked Eocene elements, such as *Discocyclina*. The biostratigraphic data from the upper part of section Spartila suggest that fine-grained terrigenous clastic sedimentation was predominant in the Late Oligocene.

The sedimentary features and the faunistic data from the successions of Episkepsis and Zygos indicate a rapidly increasing supply of (relatively coarse) terrigenous clastics by density currents during the Chattian and Early Aquitanian. Such a turbiditic sedimentation may have continued into the Burdigalian, in view of the determinations of *Miogypsina* cf. *globulina*, reported by Renz (1955) and by the authors of the I.F.P. (1966). Elements,

which might belong to *M. globulina*, have not been found, however, in our material.

### III.4 KEFALLINIA

#### III.4.1 Introduction

The Post-Eocene deposits of Kefallinia can roughly be grouped on the basis of two different types of sediment succession. The first type comprises strongly faulted and partly overturned successions of detrital limestones and marls, poorly exposed in some narrow depressions between the culminations of Mesozoic and Eocene limestones (fig. 37). The second type comprises sediments of Late Miocene to Pleistocene age, predominantly clays and marls, which seem to have been affected by normal faulting only. These Upper Neogene and Pleistocene sediments are well exposed in coastal cliffs along the south coast and cover vast areas of the Paliki peninsula in the west. The distribution of the strongly disturbed older Neogene limestone and marl deposits is roughly shown in fig. 37.

There is no unanimous opinion with respect to the age of the folded successions of the more or less calcareous sediments. Dremel (1968) studied the southern exposures in detail. He recognized two Miocene transgressive sequences; the first would have started in the Aquitanian and continues into the Lower Burdigalian. After a strong deformation phase the second transgression would have taken place in the course of the Burdigalian.

According to Dremel, there are no Upper Eocene and Oligocene sediments in Kefallinia. The authors of the B.P. (1967, 1971) did not find evidence either of the presence of Oligocene deposits. These conclusions are in contrast with those presented by the authors of the I.F.P. (1966) and by Bizon (1967), who reported a fairly continuous Oligocene to Upper Miocene (Tortonian) biostratigraphic record from a section near Ano Angon, at the northern side of the isthmus connecting the Paliki peninsula with the main part of Kefallinia.

In 1958, Hagn described the microfaunas from some samples collected by Müller-Miny in the southeast. From the co-occurrence of *Miogypsina* s.s. and *Orbulina suturalis* in samples from one of the outcrops, he concluded an overlap of the ranges of both taxa. Hagn assigned these sediments to the Late Aquitanian. Drooger, in the same year, wrote a critical note to Hagn's conclusions. He considered the larger foraminifera reworked; the planktonic foraminifera may point to a Late Helvetian-Early Tortonian Age.

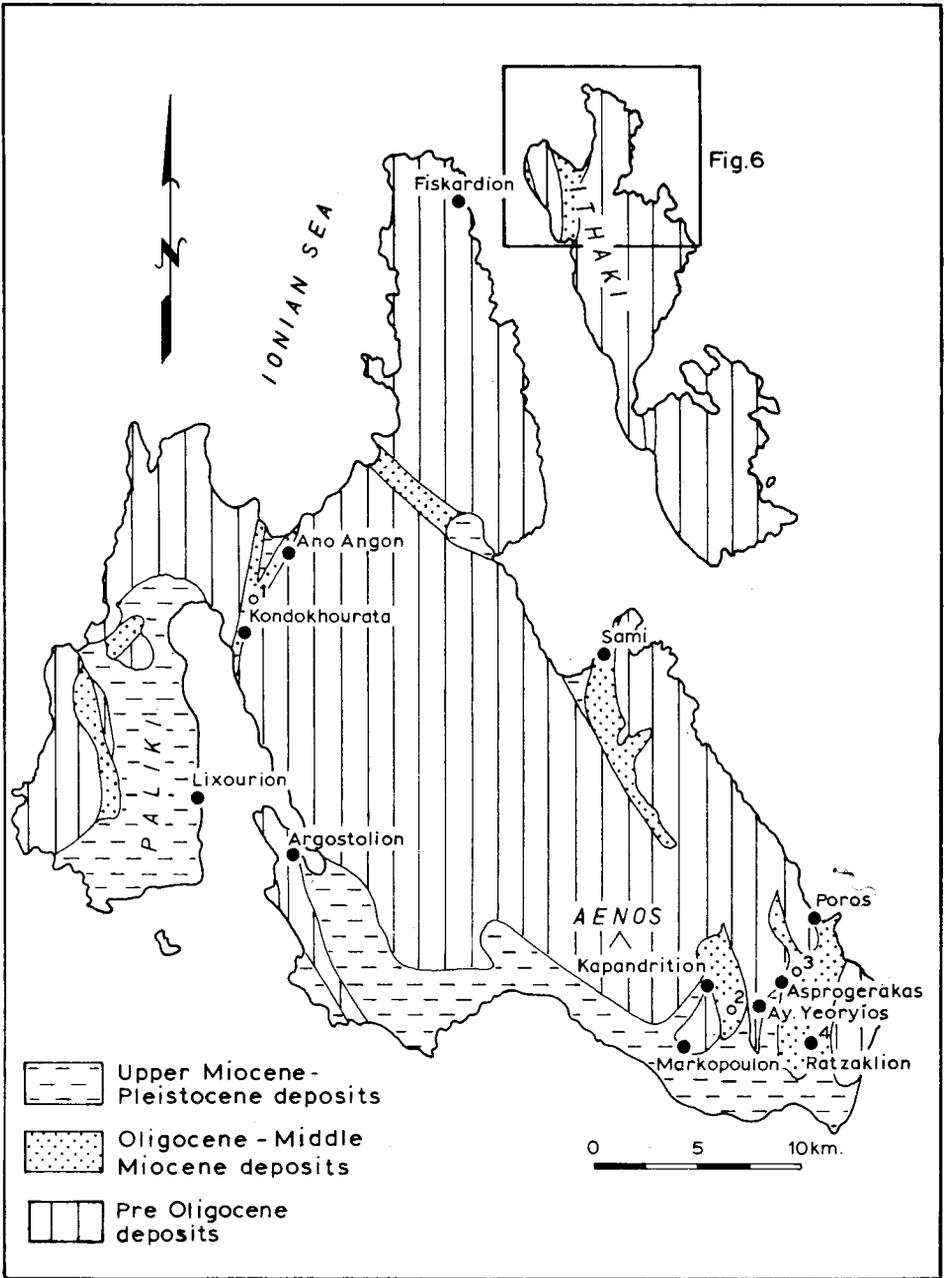


Fig. 37 Schematic geological map of Kefallinia and Ithaki. The numbers refer to the discussed Oligo-Miocene sediment successions (simplified after the B.P., 1967).

Drooger's assumption was rejected by Dremel (1968). On the basis of his own investigations on Kefallinia, Dremel concluded that there is an overlap of the ranges of *Miogypsina* s.s and *Orbulina*. Bizon (1967), however, did not find evidence of such an overlap in the Ano Angon section in the northern part of the island.

The Mesozoic limestone culmination south of Sami is considered part of the Ionian Zone (I.F.P., 1966; B.P., 1967, 1971; see also fig. 1); the rest of the island belongs to the Preapulian Zone.

### III.4.2. Localities

#### *Kondokhourata* (fig. 37, no. 1)

The authors of the I.F.P. (1966) and Bizon (1967) described Upper Burdigalian marls unconformably overlying Upper Paleocene (Bizon) or Lower Eocene (I.F.P.) limestones from the vicinity of Kondokhourata. Their sections, however, could not be accurately retraced.

In the surroundings of Kondokhourata, along the road from Ano Angon to Argostolion, approximately 1200 m north of the bifurcation with the road to Lixourion, a detrital limestone and marl succession overlies Eocene limestones with *Nummulites* and *Discocyclusina*. The Eocene limestones are overlain by 50 cm of greenish, finely-bedded, marly limestones with a poor, ill-preserved planktonic foraminiferal assemblage, which does not allow a relative age assignment. These marly limestones are followed by a poorly exposed interval of 4.50 m with boulders and pebbles of white, dense limestone and of conglomeratic limestone, embedded in greenish, calcareous marls. The mixture may reflect deposition by mass transport of a very proximal nature. Unfortunately, the contact with the underlying marly limestones is not visible.

The conglomeratic interval is overlain by 70 cm of grey - greenish, marly, partly detrital limestone with an ill-preserved planktonic foraminiferal fauna. The presence of *Globigerinoides trilobus* and *Globoquadrina dehiscens* and the absence of younger taxa suggest a correlation with the interval of zones N5 - N7 (Late Aquitanian - Burdigalian).

The next 15 - 20 m are covered by scree. The section continues with a succession of several hundred meters of silty marls, containing calcareous debris and detrital limestone boulders in the lower four meters. The conglomeratic marls are locally rich in larger foraminifera including *Nephrolepidina*, *Miogypsinoidea*, *Miogypsina* s.s. and *Nummulites*.

Counts and measurements were made on the Miogypsinids and on *Nephrolepidina* from sample DM 187, taken from conglomeratic marls at the basis

Fig. 38 Results of counts and measurements on *Nephtrolepithina* and *Miogypsina* assemblages from Kefallinia.

*Lepidocyclina*

sample		A <sub>i</sub>	A <sub>o</sub>	C	DI $\mu$	DI $\mu$	DI $\mu$ /DI	R	$\alpha^{\circ}$	species
DM 388	M	45.0	47.4	5.7	357	569	1.60	30.2	186	<i>L. tournoueri</i>
	$\sigma$ M	1.1	1.3	0.5	18	27	0.05	1.2	4	
	N	15	15	12	16	16	16	15	15	
	range	37.5–51.5	38.6–54.6	3–8	240–520	335–755	1.29–1.92	22.1–35.9	165–206	
DM 187	M	44.8	47.3	5.8	296	460	1.55	28.9	189	<i>L. tournoueri</i>
	$\sigma$ M	1.3	1.2	0.4	10	20	0.04	2.2	5	
	N	17	17	15	17	17	17	17	17	
	range	31.9–51.2	34.9–53.6	2–9	220–385	270–635	1.23–1.86	12.5–44.4	159–233	
DM 206	M	43.7	45.7	5.2	300	448	1.50	27.1	194	<i>L. ex. interc. morgani-tournoueri</i>
	$\sigma$ M	1.3	1.1	0.4	14	21	0.03	2.4	4	
	N	18	18	14	18	18	18	18	18	
	range	35.2–52.8	38.6–53.2	3–8	200–395	320–625	1.21–1.75	7.5–44.9	168–226	

*Miogypsina*

sample		X	Y	$\gamma^{\circ}$	V	DI $\mu$	species
DM 388	M	10.1	2.0	-91	5.1	165	<i>M. ex. interc. gunteri-bantamensis?</i>
	$\sigma$ M	0.8	0.5	15	2.2	8	
	N	23	23	23	23	23	
	range	5.5–23	0–8	-255/+6	0–37.6	100–240	
DM 608	M	5.3	0	+31	41.6	219	<i>M. ex. interc. globulina-intermedia</i>
	$\sigma$ M	0.3	-	11	7.5	12	
	N	6	8	9	6	9	
	range	4.5–6.5	-	-30/+84	14.5–59.9	165–265	
DM 187	M	11.1	3.4	-136	0	180	<i>M. ex. interc. gunteri-bantamensis</i>
	$\sigma$ M	0.7	0.4	15	-	19	
	N	8	10	14	14	7	
	range	8–14	1–5	-195/-15	-	130–261	

of the silty marl succession. The results are given in figs. 38 and 39.

The frequency distributions of X and  $\gamma$  classes show almost identical ranges for *Miogypsinoidea* and *Miogypsina* s.s. (fig. 39). Separation on the basis of the combinations between X and  $\gamma$  and the values for the diameter of the protoconch could neither be made. As a consequence, the species

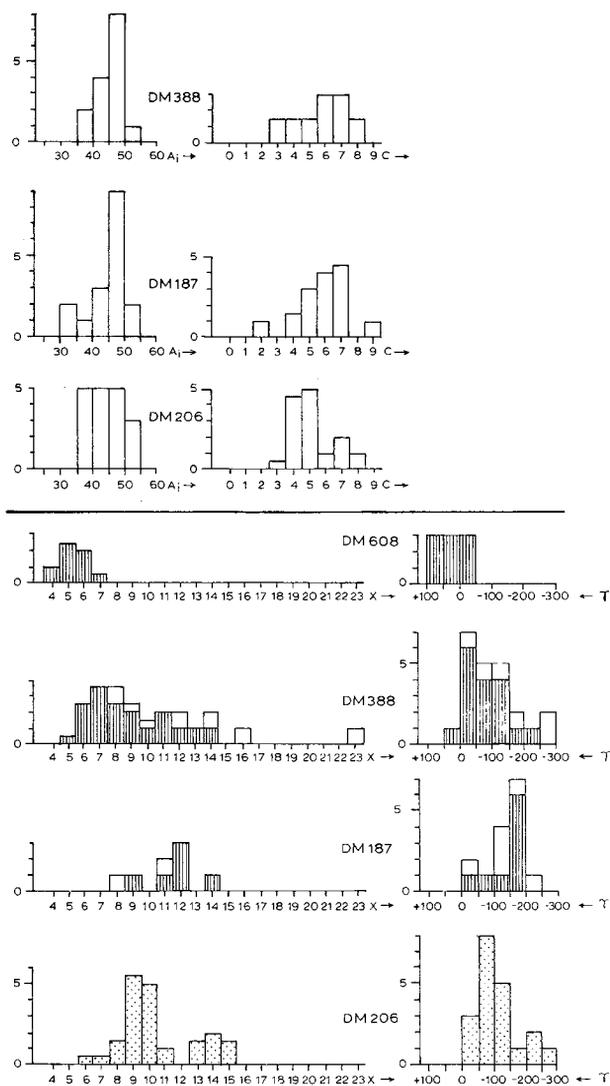


Fig. 39 Histograms of  $A_i$  and C classes of three *Nephrolepidina* assemblages and of X and  $\gamma$  classes of four *Miogypsina* assemblages from Kefallinia.

designation is based on the mean number of spiral chambers of both groups together: *Miogypsina* ex. interc. *gunteri-bantamensis*.

According to the mean number of accessory auxiliary chambers and the average degree of embracement of the protoconch by the deuterococonch, the *Nephrolepidina* assemblage is to be determined as primitive *Lepidocyclina tournoueri*, not far from the limit with *L. morgani*.

The Miogypsinidae point to an Aquitanian Age for the calcareous debris in this part of the Kondokhourata section; if we attach great value to the Lepidocyclinids, a Burdigalian Age might be assumed.

Ay. *Yeoryios* (fig. 37, no. 2)

In a roadcut between Ay. Yeoryios and Kapandrition, 2½ km NW of the former village, 3.5 m of detrital limestones (packstone) with positive grading are passing gradually into calcareous marls via laminated, fine-grained, marly limestones. The lower two meters of the coarse-grained limestone contain marl pebbles with a diameter up to 12 cm. Upwards, the marl components become more flattened, they are oriented parallel to the bedding planes, and the average diameter decreases. The graded limestones are overlying poorly exposed marls.

The limestones are rich in *Eulepidina*, *Nephrolepidina*, *Miogypsinoides*, *Miogypsina* s.s., *Gypsina*, *Spiroclypeus*, *Operculina* and *Heterostegina*. Free specimens of *Miogypsina* and *Nephrolepidina* have been isolated from the lowermost meter. The results of counts and measurements are summarized in figs. 38 and 39 (sample DM 388).

The histograms of C and A<sub>i</sub> classes of *Nephrolepidina* show a fairly normal distribution (fig. 39). The means allow the determination *Lepidocyclina tournoueri*.

The histograms of X and  $\gamma$  classes for the Miogypsinidae (fig. 39) display a wide variation. The irregular X distribution suggests that the assemblage is heterogeneous. A clear separation between *Miogypsinoides* and *Miogypsina* s.s. specimens can neither be made on the basis of X and  $\gamma$  values, nor on the relation between X or  $\gamma$  and the diameter values of the protoconch (not figured). A species designation, based on all X observations together may refer the assemblage to *Miogypsina* ex. interc. *gunteri-bantamensis*, but assuming a mixture of populations, even *M. globulina* may be the youngest species represented.

The larger foraminifera point to an Aquitanian – Burdigalian Age for the graded limestones. This result is in conflict with that concluded from the planktonic foraminifera in a marl boulder in the basal part of the same detrital limestone succession. The boulder is extremely rich in planktonic

foraminifera (P/B ratio more than 90). The association includes *Orbulina universa*, and is comparable to those known from zones N9 – N14. (Late Langhian – Serravallian). Index species allowing a more accurate assignment are absent. Such species are present in a sample from the calcareous marls from the top of the graded sequence. This sample contains *Orbulina universa*, *O. suturalis*, *Globigerinoides obliquus*, *G. trilobus*, *Globoquadrina dehis-cens*, *G. altispira*, *Globigerina nepenthes* and *G. pseudobesa*. This association fits in well with that of zone N15, thus assigning a Late Serravallian – Early Tortonian Age to the graded sequence of Ay. Yeoryios; this confirms the reworked character of all older components.

#### *Asprogerakas* (fig. 37, no. 3)

In a roadcut 200 m east of the village of Asprogerakas, along the road to Poros, a heavily disturbed succession is exposed, consisting of grey marls with some thin, slightly positively graded, calcareous sandstone interbeds. According to the schematic topographic map and the sediment description of Müller-Miny (1958), the sample with the *Miogypsina* – *Orbulina* association, described by Hagn and by Drooger, is probably from this locality.

Several of the coarser grained beds contain rich larger-foraminiferal faunas. One of our samples (DM 608) contained *Eulepidina*, *Nephrolepidina* (rare), *Miogypsina* s.s., *Gypsina*, *Spiroclypeus*, *Cycloclypeus* (rare), *Nummulites*, *Discocyclina* and *Alveolina*. Free specimens of *Miogypsina* s.s. were studied biometrically. The histogram of X classes (fig. 39) shows a fairly normal distribution; the mean of V points to *Miogypsina* ex. interc. *globulina-intermedia*, which may indicate a Burdigalian Age.

Planktonic foraminifera from one of the marl beds include *Globigerina* cf. *venezuelana*, *G. siakensis*, *Globigerinoides trilobus*, *G. bulloides*, *Globorotalia scitula*, *G. aff. peripheroronda* and *Catapsydrax dissimilis*. This association may point to zone N6, thus suggesting a Burdigalian Age, which is consistent with the age based on the larger foraminifera.

Apparently, our samples were not taken from the same horizon as those studied by Hagn (1958), since *Orbulina suturalis* was not found in any of our eight samples.

#### *Ratzaklion* (fig. 37, no. 4)

A small hill in the center of the village of Ratzaklion contains an isolated outcrop with about 3 m of steep and overturned, positively graded, glauconitic sandstones. Free specimens of *Nephrolepidina*, *Miogypsinoidea* and *Miogypsina* s.s. were obtained from the basal part.

The histograms of C and A<sub>i</sub> classes of *Nephrolepidina* are given in fig. 39 (sample DM 206).  $\bar{C}$  and  $\bar{A}_i$  values (fig. 38) indicate that the assemblage may

belong to *L. morgani* or *L. tournoueri*.

Axial sections of the Miogypsinidae from DM 206 show several specimens to have some small lateral chambers (*Miogypsina* s.s.), whereas others clearly belong to *Miogypsinoides*. During the grinding of equatorial sections, however, a differentiation could not be made. The histograms of X and  $\gamma$  (fig. 39) suggest a bimodal distribution; as a consequence, the assemblage may be considered heterogeneous. For the *Miogypsinoides* specimens it is suggested that *M. bantamensis* is represented, for the *Miogypsina* s.s. group *M. gunteri* and *M. tani*.

No reliable age assignment can be given to the time of deposition of these turbiditic sandstones, since the larger foraminifera, roughly indicating an Aquitanian Age, may be reworked and planktonic foraminiferal data are not available.

### III.4.3 Discussion

Our data from Kefallinia are too scarce for a sufficiently reliable picture of the Miocene sedimentation in the area.

The Miocene successions of Kondokhourata in the northwest and of Ay. Yeoryios in the southeast contain evidence of periodical supply through mass transport of coarse, mainly calcareous debris, including Mesozoic and Eocene limestone elements. The intercalation of such coarse beds in the open marine marls with high plankton/benthos ratios suggests that the Kondokhourata and Ay. Yeoryios successions were deposited in a relatively deep sea, close to a pronounced relief. The turbiditic beds of Asprogerakas and of Ratzaklion reflect a more mature resedimentation. These different types of sedimentation cannot be placed in relation to each other in the time scale.

Since the coarse conglomeratic beds of Kondokhourata and those in the southeastern part of the island are close to the present culminations of Mesozoic and Eocene limestones (e.g. the Aenos Mountains), it may be assumed that these culminations existed as such during the Early Miocene already. From their emerged parts and adjoining shoal areas, coarse material was periodically transported towards the deeper parts of the basins. Such transport may have been triggered by differential vertical block movements, but our data are insufficient to mark fluctuations in the intensity of such movements. The details of the Ay. Yeoryios section and the presence of coarse, displaced elements in the clay succession near Markopoulon (not described here) indicate that the differential movements continued into Tortonian times.

Dremel's (1968) assumption of the unusual overlap of the ranges of *Miogypsina* s.s. and *Orbulina* seems to be unwarranted, considering the clearly displaced character of the components of the *Miogypsina* beds, found in association with *Orbulina*-bearing marls. The exposures of his "Aquitainian" and "Burdigalian" onlap conglomerates, which may represent the bases of two successive transgressive cycles, could not be retraced in the field. According to Dremel's lithological descriptions, these conglomerates might closely resemble the mass-transported coarse beds found in the same area.

### III.5 EPIRUS

#### III.5.1 Introduction

In Epirus, Paleogene and Lower Miocene deposits, widely distributed between the Ionian Sea and the Pindos Mountains, have recently been studied in detail by the authors of the I.F.P. (1966) and by Bizon (1967). The Tertiary successions are mainly found in NNW-SSE trending synclines (see fig. 40). It is beyond the scope of the present investigation to report on the Epirus successions in detail. Some data will be presented on the transition from the calcareous, predominantly pelagic deposits into the overlying terrigenous clastic sediments, and on the larger foraminiferal associations obtained from beds of calcareous detrital sediment in some of the synclines (Ekklesia, Botzara, east of Igoumenitsa). These synclines, located in the Ionian Zone, are filled with predominantly terrigenous clastic, generally turbiditic deposits, which have been subdivided into three units by the I.F.P. geologists. From bottom to top these authors distinguished the flysch, the Radhovici Formation, and the Burdigalian. The Radhovici Formation is thought to represent "une série de passage" between the underlying flysch and the overlying "molasse-type" Burdigalian. Detrital limestone beds containing larger-foraminiferal associations have been reported as most common in the Burdigalian part of the successions.

#### III.5.2 Localities

*Ekklesia* (fig. 40, nrs. 1, 2)

A composite section of 2,450 m has been described from the syncline of Ekklesia by the I.F.P. authors (1966) and by Bizon (1967). It is considered the most typical section for the successions in the central part of the Ionian Zone. The section consists of 450 m of flysch, 300 m of the Radhovici

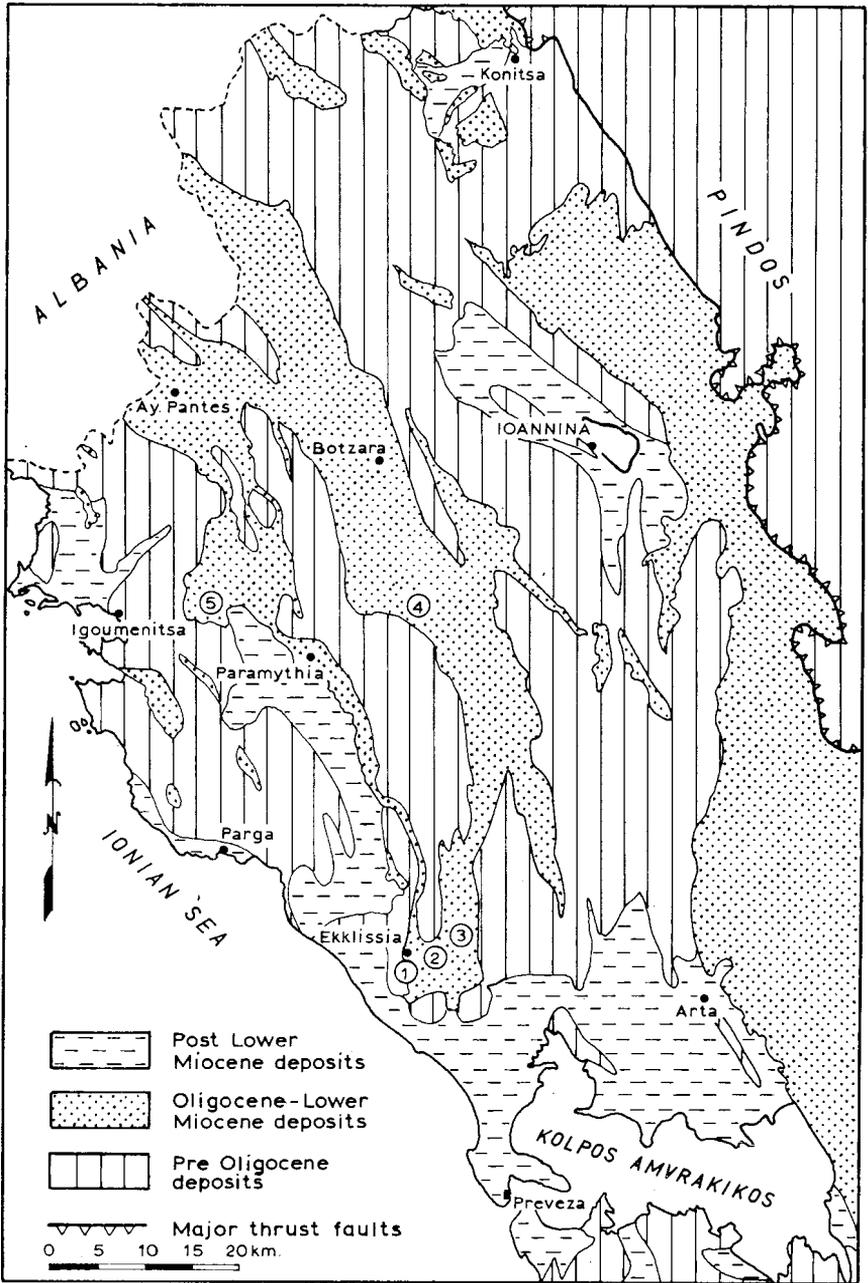


Fig. 40 Schematic geological map of Epirus. The numbers refer to the discussed Oligocene – Lower Miocene sediment successions (mainly after Bizon, 1967).

Formation and 1700 m of Burdigalian deposits. For our work special attention was paid to outcrops showing the transition from calcareous pelagic to terrigenous clastic sediments, and to exposures with coarser sediments mapped as Burdigalian. These outcrops are situated in the western limb of the syncline.

The lowermost terrigenous clastic beds overlying the pelagic limestones southwest of the village of Ekklisia (fig. 40, no. 1) contain *Globigerina* cf. *tapuriensis*, *G. ampliapertura*, *G. angiporoides*, *G. cf. tripartita* and *G. cf. increbescens*. This association might be indicative of zones P18/P19 of Blow (1969). According to Berggren & Van Couvering (1974), this implies an Early to Middle Oligocene age.

The lower part of the so-called Burdigalian was studied in a section along the road from Mirsini to Parga, 2 km east of the village of Ekklisia (fig. 40, no. 2). The well-exposed section shows 70 meters of marls alternating with calcareous sandstones and detrital limestone beds. The dip of the strata varies between 50° and 20° to the east. The coarser beds show positive grading and the coarser grained basal parts in some places contain marl pebbles. The thickness of these beds ranges from 5 to 375 cm. Horizontal and convolute lamination are common features in many of these sandy and calcareous beds. Generally, they pass gradually into the overlying, mostly crumbly marls.

The basal parts of several of the coarser intercalations contain *Eulepidina*, *Nephrolepidina*, *Miogypsina* s.s. and *Miolepidocyclina*. Three Miogypsinid assemblages were studied in detail; in stratigraphic order they are from samples DM 114, DM 116 and DM 117. The vertical distance between the samples is 47 and 15 meters, respectively. The results of counts and measurements are shown in fig. 41. Histograms of V classes (fig. 42) have a fairly normal distribution. The mean values of V indicate that the assemblages belong to *M. globulina*. *Miolepidocyclina* was found in minor numbers (N = 3) in the highest sample, DM 117. The V values (15, 59 and 97) suggest an assignment to *M. negrii*. No biometrical analysis was performed on *Nephrolepidina*, because of the scarce specimens.

The poorly preserved planktonic foraminifera from the marls just below DM 117 suggest a correlation with zones N5/N6, because of the co-occurrence of *Globigerinoides trilobus*, *G. acrostoma*, *Globoquadrina altispira* and *Catapsydrax dissimilis*.

The *Miogypsina* data point to a Burdigalian Age for the Ekklisia roadcut succession; this conclusion is not in conflict with that deduced from the planktonic foraminifera, which suggest a Late Aquitanian to Early Burdigalian Age.

sample		X	Y	$\gamma^{\circ}$	V	DI $\mu$	species
DM 117	M	5.7	0	+14	38.4	190	<i>M. globulina</i>
	$\sigma$ M	0.3	—	3	4.8	10	
	N	16	20	20	17	20	
	range	4.5–8	—	–10/+35	8.9–75.9	131–350	
DM 116	M	6.1	0.1	+16	39.0	188	<i>M. globulina</i>
	$\sigma$ M	0.4	0.1	7	6.2	10	
	N	14	16	15	16	15	
	range	4.5–10	0–1	–25/+55	0–99.6	123–250	
DM 114	M	6.5	0.1	+4	34.3	183	<i>M. globulina</i>
	$\sigma$ M	0.5	0.1	6	5.3	9	
	N	10	15	14	14	14	
	range	4.5–9	0–1	–35/+42	0–67.7	123–240	
DM 684	M	4.7	0	+40	56.9	180	<i>M. intermedia</i>
	$\sigma$ M	0.2	—	4	3.6	6	
	N	16	18	18	17	18	
	range	3.5–5.5	—	+11/+67	30.1–82.4	128–223	
DM 107	M	5.0	0	+35	58.1	177	<i>M. intermedia</i>
	$\sigma$ M	0.2	—	4	5.0	8	
	N	11	14	14	14	14	
	range	3.5–6	—	+13/+70	28.6–88	127–225	
DM 106	M	5.1	0	+41	47.2	165	<i>M. ex. interc. globulina-intermedia</i>
	$\sigma$ M	0.1	—	4	3.3	8	
	N	12	15	14	14	14	
	range	4.5–5.5	—	+11/+60	26.6–72.5	125–210	
DM 85	M	15.3	7.7	–216	0		<i>M. formosensis</i>
	$\sigma$ M	1.4	1.0	30	—		
	N	10	16	8	20		
	range	10–23	3–15	–335/–85	—		
DM 83	M	12.5	6.2	–216	0		<i>M. ex. interc. formosensis- bantamensis</i>
	$\sigma$ M	1.2	0.7	3	—		
	N	4	4	2	9		
	range	10–15	4–8	–220/–212	—		
DM 88	M	14.9	7.9	–290	0		<i>M. formosensis</i>
	$\sigma$ M	1.7	0.9	54	—		
	N	6	12	4	19		
	range	11–19	5–14	–405/–173	—		
DM 89	M	14.0	5.8	–202	0		<i>M. formosensis</i>
	$\sigma$ M	1.7	0.6	33	—		
	N	4	16	7	20		
	range	12–19	2–11	–360/–70	—		

Fig. 41 Results of counts and measurements on 10 *Miogypsina* assemblages from Epirus.

Sfinoto (fig. 40, no. 3)

The authors of the I.F.P. (1966) and Bizon (1967) described a succession of 830 m of Burdigalian deposits in the vicinity of the village of Sfinoto, located in the eastern flank of the Ekklesia syncline. The basal part of the succession would consist of 40 meters of marly and sandy, fossiliferous, neritic limestones ("Calcaire à Polypiers") with numerous Corals, Gastropods and Bryozoa. This calcareous level would unconformably overlie the "flysch". The limestones in turn would be overlain by 410 m of indurated marls with some coarser interbeds with *Miogypsina*.

Both the neritic limestones and the marly beds are well exposed in a section approximately 1 km east of Sfinoto. In contrast to the overall western dip of the marls near the village, the coral limestones are dipping east. This suggests that they are separated from the marls by an angular unconformity. About 200 m north of the road at the eastern side of a small valley, however, similar marls underlying the coral limestones also have eastern dips. An

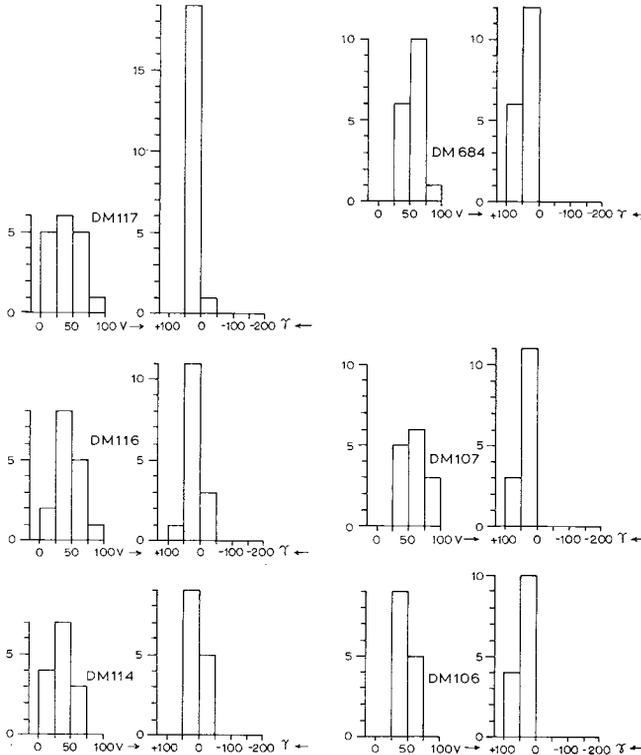


Fig. 42 Histograms of V and  $\gamma$  classes for *Miogypsina* s.s. assemblages from Epirus.

approximately N – S running fault affecting the marls may be assumed through this valley.

Our section was measured in the eastern slope of this small valley. The basal part consists of approximately 30 meters of grey-brown silts and silty marls, locally rich in lignite flakes. The fine clastics show some brown, generally discontinuous, calcareous sandstone interbeds. From one of the coarser layers, free specimens of *Miogypsina* s.s. have been isolated. According to the average degree of symmetry of the protoconchal spirals, the *Miogypsinids* belong to *M. intermedia* (fig. 41, sample DM 684, Pl. 3, fig. 4). The histograms of both  $V$  and  $\gamma$  show a fairly homogeneous assemblage in figure 42.

The planktonic foraminiferal association from the marls directly below this bed (sample DM 685; Pl. 2, fig. 8) is heterogeneous, containing *Globigerinoides trilobus*, *G. primordius*, *G. altispira*, *Globigerina obesa*, *G. opima nana*, *G. siakensis*, *G. ciperoensis*, *G. angulisuturalis* and *Globoquadrina dehiscens*. This association does not allow a good correlation with the standard zones; it might fit within the range of zones N5 – N7.

The contact between the silty marls and the overlying coral limestones is not exposed.

The limestone succession consists of 20 m of irregularly stratified deposits, becoming less calcareous and less indurated towards the top. The basal part shows packstones with numerous pelecypod and gastropod fragments, rotaliids and *Amphistegina*. Coral colonies appear some 10 meters above the base. One meter higher strongly burrowed calcareous marls and sands are found, rich in Molluscs, Echinids and locally *Heterostegina*. No other larger foraminifera were found. This type of sediment continues as far as the top of the succession; some beds contain oysters and other pelecypods.

Our data from Sfinoto are not in agreement with those given by the authors of the I.F.P. (1966) and by Bizon (1967). The presence of *M. intermedia* below the limestones is in contradiction with their assumption that the “Calcaire à Polypiers” constitutes the basis of the Burdigalian. These shallow marine limestones are more likely to belong to a younger (i.e. post-*Miogypsina* and probably post-Burdigalian) depositional period in some type of embayment.

#### *Tirja* (fig. 40, no. 4)

Strongly folded and faulted blue-grey marls with some intercalations of up to 15 cm thick, detrital limestone beds are exposed along the small road from Dodoni to Paramithia, some 500 m SW of the village of Tirja. These sediments are situated in the central part of the Botzara syncline.

The detrital limestone beds are positively graded and generally coarse-grained in the basal part. They may contain numerous Bryozoan, Echinid, Algal and Mollusc fragments, *Operculina*, *Miogypsina* s.s., *Gypsina*, and rare *Nephrolepidina* and *Cycloclypeus*.

Free specimens of *Miogypsina* were collected from calcareous debris in some of the marls. Two samples were studied; the results of counts and measurements from the lower (DM 106) and the higher sample (DM 107) point to *M. ex. interc. globulina-intermedia* and *M. intermedia* respectively (figs. 41, 42), which suggest a Burdigalian Age.

The planktonic foraminiferal associations from the same samples include *Globoquadrina dehiscens*, *Globigerina siakensis* and, probably reworked, elements of the *G. ciperoensis*-group. The co-occurrence of the first two species and the absence of other Miocene elements may suggest that the autochthonous parts of the associations fit in with the range of zones N5 – N7.

Ay. Yeoryios – Plakoti (fig. 40, no. 5)

Along the road from Igoumenitsa to Ioannina, between the villages of Ay. Yeoryios and Plakoti, several roadcuts show thick (up to 10 m) detrital, positively graded calcareous packstones, intercalated in blue-grey marls. The deposits have been incorporated in the Ay. Pantos Formation by the authors of the I.F.P. (1966). This formation overlies the “flysch de base” in the eastern part of the external Ionian Zone; it may range up into the Aquitanian.

The basal part of the packstones is rich in Miogypsinidae, but free specimens could not be obtained. In thin sections the Miogypsinids invariably appear to belong to *Miogypsinoides*. The few reliable measurements on X and  $\gamma$  (fig. 41) suggest that the four assemblages may belong to *M. formosensis* and in one sample might be determined as *M. ex. interc. formosensis-bantamensis*. This may imply a Chattian Age for these limestones.

### III.5.3 Discussion

The transition from calcareous to terrigenous clastic sedimentation may be studied in numerous outcrops all over Epirus. In the eastern and central parts of the area coarse-grained, in some cases breccious beds may be present in the uppermost part of the calcareous, predominantly pelagic beds. They may contain *Discocyclina* and *Nummulites*. Such beds seem to be absent in the west. The first terrigenous clastic beds can be dated as Early-Middle Oligocene near Ekklisia; the planktonic foraminiferal faunas from three other outcrops (not described here) are consistent with this age assignment.

The authors of the I.F.P. (1966) and Bizon (1967) considered the lowermost terrigenous clastic interbeds to belong to the uppermost Eocene.

The thick, Oligocene and Lower Miocene successions of Epirus indicate enormous volumes of predominantly fine-grained terrigenous clastics to have been supplied to the area. Especially most of the coarser beds point to deposition by turbidity currents of a mature type. The supply probably must have been in longitudinal direction. Calcareous beds are relatively rare; they seem to be present mainly in the west. The same holds true for coarse-grained, redeposited sediments of a more proximal nature, which, for instance, were observed near Ekklisia and east of Igoumenitsa. Data pointing to strong differential vertical movements during the Oligocene – Early Miocene are almost absent in Epirus.

All data point to a fairly continuous, rapid, and mainly turbiditic sedimentation in a basin or a system of basins. The rare calcareous beds with larger foraminifera suggest some supply of debris from shoal areas, which were probably situated to the west.

## Chapter IV

### CONCLUSIONS

In the first part of this chapter, general conclusions will be presented on the *Miogypsina* and *Lepidocyclina* species suites from northwestern Greece. They will be compared with the evolutionary sequences in other Mediterranean areas. The zonations based on these groups will be related to the one based on planktonic foraminifera. Some remarks will be given on the translation of the combined scale of these zones in terms of Oligocene and Lower – Middle Miocene chronostratigraphy.

The outlines of Late Eocene – Middle Miocene paleogeography and structural development of the area will be discussed in the second part of this chapter.

#### IV.1 PALEONTOLOGICAL AND BIOSTRATIGRAPHICAL CONCLUSIONS

##### IV.1.1 Miogypsinidae

The results of the biometrical analyses of the *Miogypsina* assemblages from the Ionian islands and western Epirus seem to confirm the evolutionary trends described by Drooger (1952), and subsequently recognized by several authors in Oligo – Miocene successions all over the world. Our data are fairly good in agreement with those from the Mediterranean bioprovinces and allow some detailed conclusions regarding the co-occurrence of *Miogypsina* s.s. and *Miogypsinoides*. These co-occurrences create a considerable number of exemplum intercentrale determinations. The relatively large number of such notations may have been enhanced by the generally poor preservation (hard rock, recrystallization) and especially by the wide variation per assemblage, presumably caused by reworking effects.

Most of the taxa of the main lineage of the Miogypsinidae, known from the Mediterranean, appear to be present in the successions from northwestern Greece. The most distinct gap in the biostratigraphic record covers the larger part of the range of *Miogypsina tani*. This might be explained by incomplete sampling, but it might mean just as well that environmental conditions in the area were unfavourable for the Miogypsinidae during the

Late Aquitanian. The latter assumption might explain why *M. socini*, the contemporary of *M. tani* in Italy, is absent as well.

The most highly developed Mediterranean representatives of the main lineage, *M. cushmani* and *M. mediterranea* were not found in our samples. These taxa have been reported from Egypt (Souaya, 1961), Majorca (Colom, 1958), Algeria and Morocco; their geographic distribution in the Mediterranean may be explained by climatic control (Drooger, 1963).

Specimens probably belonging to *M. complanata*, the most primitive representative of the Mediterranean lineage, were found only in thin sections from some localities and in a reworked assemblage from Ithaki. The scanty information prevents us from drawing detailed conclusions on the early stages of the phylogenetic development of *Miogypsinoides* in northwestern Greece.

Assemblages of the *Miolepidocyclus* side-branch, observed in samples from Ithaki, Playia and Epirus, are all within the range of the successive species *Miogypsina burdigalensis* and *M. negrii*. The absence of *M. socini*, the most primitive taxon of this lineage, suggests that the *Miolepidocyclus* populations arrived as immigrants and did not evolve from the main lineage in the Greek area.

Mixed assemblages of *Miogypsinoides* and *Miogypsina* s.s. are common in our samples; in general, the determinations range from *M. ex. interc. formosensis-basraensis* to *M. ex. interc. bantamensis-gunteri*. Scatter diagrams on the relation between the number of spiral chambers and the diameter of the protoconch show fairly homogeneous clusters, in which *Miogypsinoides* and *Miogypsina* s.s. specimens are distributed at random. This implies that in such mixed assemblages no difference exists in the protoconchal diameter between *Miogypsinoides* and *Miogypsina* s.s. This conclusion is in contrast with the observations of Raju (1974) on Indian assemblages, in which the *Miogypsina* s.s. specimens have the smaller protoconch diameters in mixed *Miogypsinoides*-*Miogypsina* s.s. populations.

One of the samples from Ithaki contains an association of *M. ex. interc. complanata-formosensis*, *M. (ex. interc. tani-)globulina* and *M. ex. interc. burdigalensis-negrii*. This peculiar association was explained by reworking of the few *Miogypsinoides* specimens and not by a retardation of the *Miogypsinoides* lineage. Such a retardation, as assumed by several authors (Drooger, 1966; Felix, 1973; Brun & Wong, 1974) in various circum-Mediterranean and African regions, cannot be proved to have existed in NW Greece. This seems to indicate that for the Miogypsinidae, NW Greece belonged to another (sub)province than nearby Sicily or Egypt during the Burdigalian.

The relation between mean protoconch diameter and  $\bar{X} - \bar{V}$  values for all

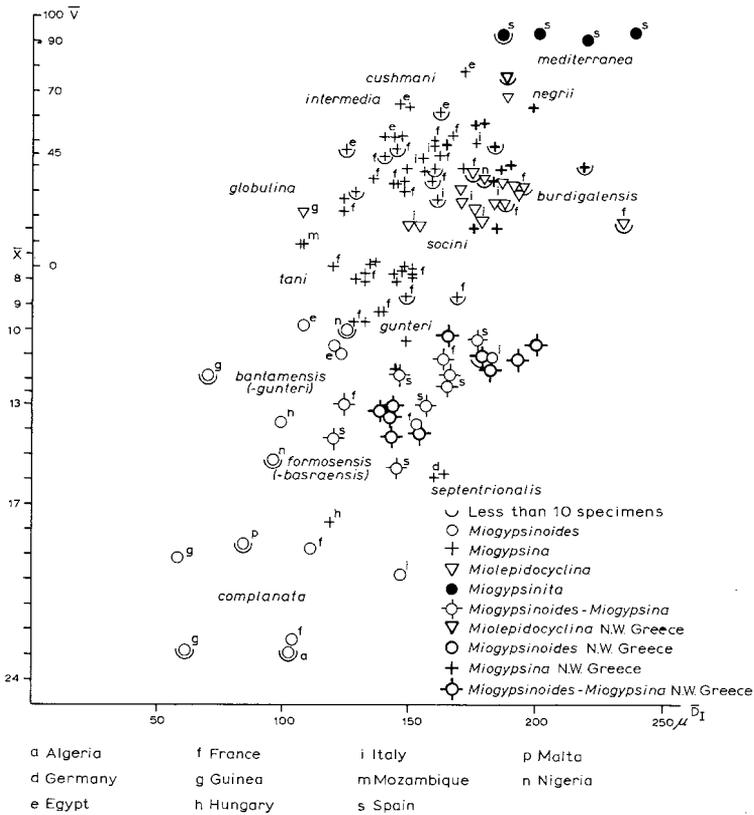


Fig. 43 Relation between mean protoconch diameter and values of the  $\bar{X} - \bar{V}$  scale in assemblages of the Miogypsinae from Europe and Africa (mainly after Drooger and Raju, 1973).

assemblages from northwestern Greece is represented in fig. 43. The diagram illustrates the gap in the biostratigraphic record, which roughly corresponds to the greater part of the range of *M. tani*. Data from various other Mediterranean localities, mainly after Drooger and Raju (1973), have been included. These data indicate that the assemblages from the Ionian islands and western Epirus cannot be proved to fall outside the cluster of Mediterranean associations.

#### IV.1.2 Lepidocyclina (Nephrolepidina)

The three successive species of *Nephrolepidina*, known from the Mediterranean, can be recognized in our material from the Ionian islands and Western Epirus. In particular, the early representatives of this lineage belong-

ing to *L. praemarginata* are relatively common in the Oligocene deposits of the area, whereas the most highly evolved taxon, *L. tournoueri*, was found only in a few samples from the Miocene of Ithaki and Kefallinia.

The average degree of embracement of the protoconch by the deuteroconch ( $\bar{A}$ ) and the mean number of accessory auxiliary chambers ( $\bar{C}$ ) are considered the most suitable criteria for a taxonomic subdivision of the lineage. The expression of the degree of embracement in terms of the angle between the lines from the centre of the protoconch towards the attachment points of the deuteroconchal and protoconchal walls ( $\alpha$ ) seems to be a more practical parameter than  $A$ : it can easier be measured and, in general, it has a satisfactorily high degree of precision. In some cases, however, irregularly shaped protoconches prevent a reliable fixation of the hypothetical centre. In addition, the taxonomic subdivision of our assemblages by means of  $\alpha$  hampers a comparison with the data from the literature and, as a consequence, such a procedure causes taxonomic confusion. For these reasons it was decided to rely on the factor  $\bar{A}$ , calculated from measurements along the inner walls ( $A_i$ ).

On the basis of the material from the Afales-bay section in northern Ithaki, a delimitation of the three successive species is proposed. *L. praemarginata*, the most primitive species, is defined by a mean number of accessory auxiliary chambers smaller than 3 and an average degree of embracement smaller than 40. *L. morgani* includes assemblages with  $\bar{C}$  values larger than 3 and smaller than 5.25, and  $\bar{A}_i$  values between 40 and 45. The most highly evolved species, *L. tournoueri*, is fixed on the basis of  $\bar{C}$  values larger than 5.25 and  $\bar{A}_i$  values larger than 45.

In fact, the most primitive *L. praemarginata* assemblages from the Ionian islands represent the most primitive stages of *Nephrolepidina* development in the entire Mediterranean region. Our lowest  $\bar{C}$  value ( $\bar{C} = 1.58 \pm 0.20$ ) is significantly smaller than the lowest  $\bar{C}$  value described thus far, which is given by Vervloet (1966) for *L. praemarginata* ( $\bar{C} = 2.40 \pm 0.21$ ), from the type-locality Costa Lupara, Italy. No significant difference is found in the  $\bar{A}_i$  values.

In our assemblages from northwestern Greece, parameters  $A_i$  and  $C$  display an overall, but staggered pattern of increasing mean values, which is consistent with earlier observations by Drooger and Freudenthal (1964) on European localities. As to the younger Lepidocyclinid material from the Ionian islands and western Epirus, the average degree of embracement may be a more reliable factor for correlation purposes than  $\bar{C}$ , since in many samples the number of accessory auxiliary chambers cannot be counted accurately, due to the bad preservation.



comparisons with the accompanying Miogypsinids and planktonics. Nevertheless, the *touroueri* assemblage from Ithaki shows the highest mean C values in Europe and the Mediterranean, especially so considering that this figure might even be too low because of the presence of most probably reworked, primitive specimens in the sample.

From figure 45, showing the relation between the average size of the protoconch and the mean number of accessory auxiliary chambers for Mediterranean and some West African assemblages, an overall increase is noticeable of  $\bar{D}I$  in the course of time, but along a rather broad path. Such a pattern of irregularly increasing mean protoconch sizes has been described in

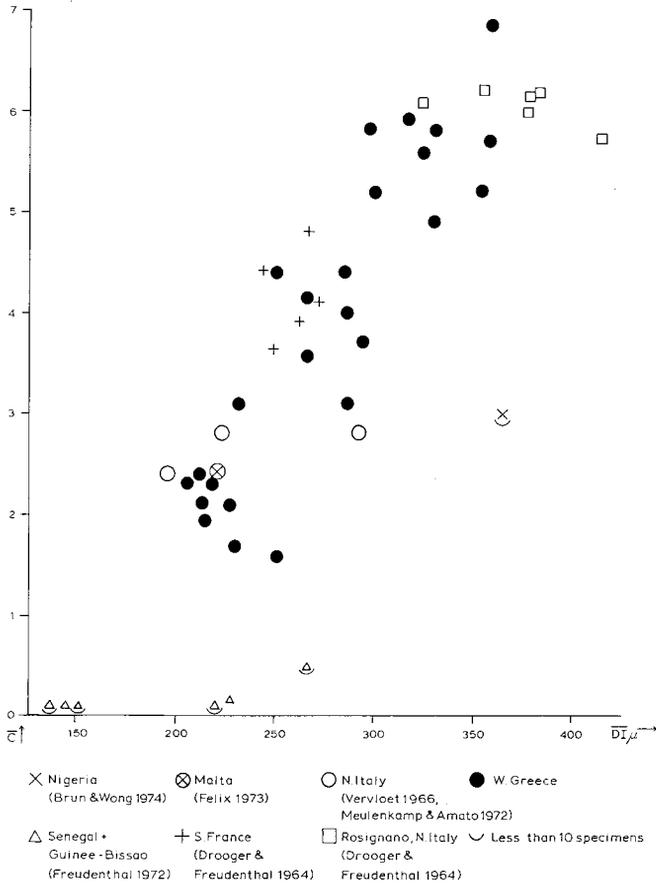


Fig. 45 Relation between mean protoconch diameter and  $\bar{C}$  values in *Lepidocyclina* assemblages from Europe and Africa.

the literature for various groups of larger foraminifera. The assemblages from West Africa fall beyond the cluster of Mediterranean assemblages because of their low  $\bar{C}$  values (Senegal, Guinea-Bissao) or their relatively high  $\bar{DI}$  value (Nigeria). If we accept the average number of accessory auxiliary chambers as a basis for time-stratigraphic correlations, a comparison of the West African and Mediterranean  $\bar{DI}$  values is of particular interest in view of Drooger and Raju's hypothesis (1973) on the relation between geographical latitude and protoconchal size. The distribution of some of the few African Lepidocyclinid assemblages in fig. 45 seems to be in disagreement with their hypothesis, but significant conclusions cannot be drawn from these scarce data from the lower latitudes.

#### IV.1.3 Biostratigraphic correlations

At first sight the Oligocene and Lower Miocene deposits of the Ionian islands and western Epirus would be expected to be suitable for a correlation of zones of larger and planktonic foraminifera. Beds containing Miogypsinids and Lepidocyclinids are generally alternating with strata rich in planktonic foraminifera, and in several samples both groups of microfossils are found together. The attempt to establish a refined correlation table, however, is severely hampered by a number of inaccuracy factors inherent to this Greek material. Nearly all larger-foraminiferal assemblages are found in beds consisting of displaced material, so that the supposed mixtures of populations and variable time lags between life and final deposition of the animals have a blurring effect on biostratigraphic applicability. Furthermore, the impossibility of assigning the planktonic associations from most of the samples to a single zone of Blow's scale (1969) is another drawback.

In the literature especially Blow's zones are variously correlated with the chronostratigraphic scale. Notwithstanding these difficulties it appears possible to fit the larger and planktonic foraminiferal zones into one, generalized table, based on a compilation of the data on northwestern Greece, because the general development of all three groups is in correspondence with the successions known from other regions.

The planktonic and larger-foraminiferal biostratigraphic data of the sections in Ithaki, Levkas/Playia, Kefallinia, Kerkira and Epirus are summarized in figure 46. In the left part of this table only those larger-foraminiferal index species have been included that are found together with planktonics below the *Praeorbulina* "datum". *Miogypsina* and *Lepidocyclina* assemblages found together with *Orbulina* are considered reworked and are of no use in attempting to establish a correlation between the larger and planktonic

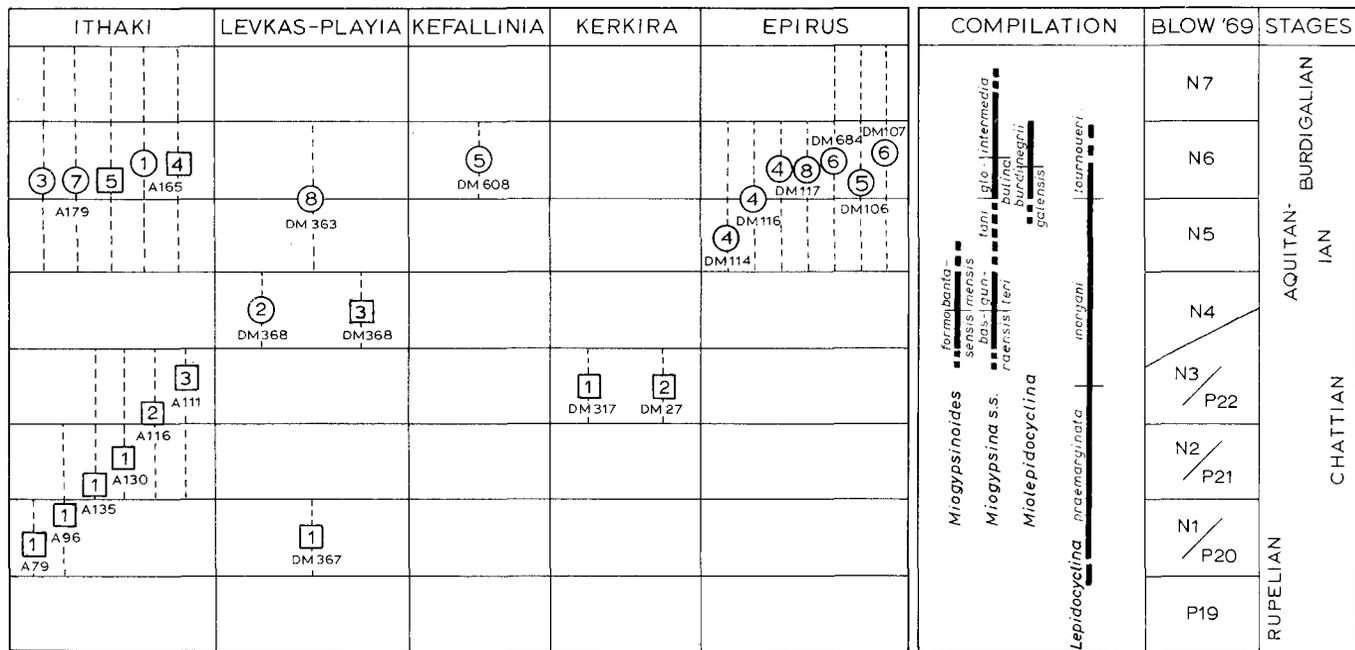
foraminiferal zones.

It is remarkable that *L. praemarginata* is never found together with Miogypsinid species, which confirms the data from the literature. This most primitive representative of *Nephrolepidina* is found in combination with the *Globigerina ampliapertura* Partial-range zone (N1 = P20), the *Globigerina angulisuturalis*/*Globorotalia opima opima* Concurrent-range zone (N2 = P21) and the *Globigerina angulisuturalis* Partial-range zone (N3 = P22). The available data suggest that *L. praemarginata* evolves parallel to the succession of these three planktonic zones.

Assemblages transitional between *L. praemarginata* and *L. morgani* and primitive *L. morgani* are also associated with planktonics indicative of zone N3, but *L. morgani* continues its range into the *Globigerinoides primordius*/*Globorotalia kugleri* Concurrent-range zone (N4). Actually, the higher *Nephrolepidina* assemblages, i.e. *L. morgani* and border-line assemblages to both sides and even occasional *L. tournoueri* (DM 187 and DM 388, Kefallinia) seem to have an irregular stratigraphic distribution. Accompanying planktonic associations are difficult to place in Blow's scheme (zones N3 – N7) and also the Miogypsinid species show a wide variation. Only the sample containing the highest representatives of *L. tournoueri* (A 179, Ithaki) has a planktonic foraminiferal fauna, which belongs somewhere in the interval of the *Globoquadrina dehiscens praedeheiscens*/*Globoquadrina dehiscens* Partial-range zone (N5) to the *Globigerinatella insueta*/*Globigerinoides trilobus* Partial-range zone (N7). The Miogypsinids confirm the Burdigalian Age here also.

Our samples from NW Greece do not add much new information to the correlation between the planktonic standard zones and *Miogypsina* lineage zones. This is mainly due to the impossibility of recognizing specific zones of Blow's scale and to the effects of heterogeneous assemblages and reworking. For instance, an assemblage of *Miogypsina* ex. interc. *formosensis-basraensis* (A 165, Ithaki) is found in combination with planktonics which can be placed in the interval of zones N5 – N7, whereas the more advanced *M. gunteri* is associated in Levkas (DM 368) with planktonics indicative of zone N4. Free specimens of *M. ex. interc. complanata-formosensis* were only found as reworked elements together with *M. (ex. interc. tani-)globulina* and *M. ex. interc. burdigalensis-negrii*. In various parts of the area, *M. globulina* and *M. intermedia* are present in strata belonging to the same large N5 – N7 interval of the planktonic scale and to higher levels.

In Ithaki, Kefallinia and Epirus, *Miogypsina globulina* and *M. intermedia* are found in beds which may be correlated with the N5 – N7 zonal interval. In Kefallinia an assemblage intermediate between *M. globulina* and *M.*



*Miogypsina* ① *formosensis-basraensis*  
 ② *gunteri*  
 ③ *tani-globulina*  
 ④ *globulina*

⑤ *globulina-intermedia*  
 ⑥ *intermedia*  
 ⑦ *burdigalensis-nagrii*  
 ⑧ *negrii*

*Lepidocyclina* ① *praeamarginata*  
 ② *praeamarginata-morgani*  
 ③ *morgani*  
 ④ *morgani-tournoueri*  
 ⑤ *tournoueri*

Fig. 46 Tentative correlation between larger foraminiferal lineage zones and the standard plankton zonation of Blow (1969), based on larger foraminiferal assemblages associated with or closely related to planktonic faunas.

*intermedia* was found in the *Globigerinatella insueta*/*Globigerinita dissimilis* Concurrent-range zone (N6). In Levkas, however, *M. globulina* and *M. ex. interc. globulina-intermedia* were found as high as the *Globigerinoides sicannus*/*Globigerinatella insueta* Partial-range zone (N8), which again suggests reworking of the larger foraminifera.

*Miogypsina burdigalensis* and *M. negrii* may be correlated with the zonal intervals N5 – N7. They are commonly found together with assemblages of the *M. globulina* and *M. intermedia* levels, as might be expected from the literature data.

In the columns on the right side of fig. 46, a tentative correlation between the idealized ranges of larger-foraminiferal lineage zones and planktonic foraminiferal zones is presented.

As to the chronostratigraphic scale, it must be emphasized that no common opinion is expressed in the literature on several parts of the correlation between Blow's zones and this chronostratigraphic scale, especially so for the Oligocene. The position of the Rupelian stratotype and the Chattian neostatotype sections in relation to the standard zonation of Blow is highly arbitrary, which is understandable because in the North Sea basin both stages are frequently thought to be largely overlapping in time. Blow (1969) restricted the planktonic foraminiferal associations of the Rupelian to zone P19, and assigned the Chattian to zones N1, N2 and the basal part of zone N3. Martini (1971), on the basis of second order correlations with calcareous nannofossils, placed the type Rupelian from the top part of zone P19 up to the lower part of zone N1. Berggren (1972), on the basis of radiometric data, assumed in his figures 3, 6 and 9 an overlap of the Rupelian and the Chattian, corresponding to zone N1 and the basal part of zone N2; in his figure 4, however, no such overlap is indicated and the boundary is drawn at the transition of zones P19 and N1/P20. In 1974 Berggren & Van Couvering placed the base of the Chattian at the base of zone N1. Evidently, the Rupelian – Chattian boundary is an unrealistic item that cannot be fixed in the planktonic zonation because of too specialized faunas and too poor field data in the North Sea basin.

From these deviating opinions it is inferred that there is a Rupelian – Chattian overlap interval approximately covering the range of zone N1 (and even N2).

Consequently, the first occurrence of *L. praemarginata* in NW Greece may have been in Early Chattian or Late Rupelian times. Following the earlier authors on Lepidocyclinids and Miogypsinids, the pre-*Miogypsina* range of *L. praemarginata* might just as well be considered of Rupelian Age. The probable overlap of zones N3 and N4 gives a rather arbitrary position to the

Chattian – Aquitanian boundary (see II.4 and III.1.4.2). The suggested position in N4 is not necessarily in contradiction with the Chattian Age given to *M. formosensis* and *M. bantamensis*.

Another chronostratigraphic problem in our area is the lack of positive evidence for recognizing the Late Aquitanian. Its typical *Miogypsina* species have not been found and planktonic zone N5 cannot be singled out in our assemblages. The base of the Langhian is placed at the *Praeorbulina* datum level, as discussed in chapter II, paragraph 4 and chapter III, paragraph 2.

#### IV.2 PALEOGEOGRAPHICAL AND STRUCTURAL DEVELOPMENT

From the Eocene into the Oligocene, the entire region of western Epirus and the Ionian islands was part of a comprehensive seabottom with exclusively calcareous, and predominantly pelagic sedimentation. The sea was not necessarily a very deep one. The absence of terrigenous clastics simply means that there were no emerged areas nearby. Actually, there must have been shoals in the Eocene sea, since there are intercalations of more or less displaced coarser sediments with Eocene larger foraminifera. The large numbers of *Discocyclina* and other Eocene forms as reworked elements in many younger Oligo-Miocene strata also point to the existence of Eocene shoals in and around the area. The areal distribution of these shoals cannot be determined. Considering the later history of the region, it might be imagined that elongate updomings parallel to the present tectonic strike originated in the Late Eocene already. In Ithaki there are indications for such a shoal area in western direction, in Epirus and Levkas – Playia eastern source areas of shallow water calcarenites have been concluded.

During the Early and Middle Oligocene, differential vertical movements must have become more apparent, and evidently erosion in adjacent emerging areas, located probably to the east and north, caused terrigenous clastics to be formed, which mainly through density currents were distributed over the entire sedimentation area. Whether this change in depositional pattern was of the same age everywhere, cannot be determined. A western shallow platform with calcareous sedimentation must have been continuously present throughout the Oligocene, at least west of Levkas, but possibly a much larger block supplied products with larger foraminifera eastward to Epirus.

Fragmentation and relative movements of elongate roughly NNW – SSE trending blocks affected the region throughout the Oligocene, and the individual areas gradually started to have a sedimentary history of their own.

Since in the west most of the area is covered by sea today, a detailed

reconstruction is rather illusionary. It is quite certain, however, that already during the Oligocene the complexity in the pattern of rising and subsiding submarine blocks increased from east to west, just as the degree of final distortion of the Oligo-Miocene strata increases in the same direction today.

Especially for the Middle and Late Oligocene there is ample proof that in the strip of the Ionian islands emerging western blocks started to supply eroded older material and contemporaneous calcareous debris to the troughs; this material became superimposed on the mature turbidite sequences. In the end of the Oligocene, the amount of calcareous detrital supply decreased, as indicated by the decreasing number and thickness of calcareous interbeds in the successions of Kerkira, the eastern part of Levkas – Playia, and Ithaki. In the eastern part of Epirus, terrigenous clastic sedimentation prevailed throughout the entire Oligocene.

The conclusions drawn from the Oligocene successions suggest that sedimentation took place in larger depressions which were still fully interconnected. In the Late Oligocene, however, differential topography became accentuated in the southwestern part of the area, which was transformed into a mosaic of subsiding and rising, even emerging blocks.

Farther east, topographic changes were less dramatic. For Kerkira, the scanty evidence shows no great changes, and in Epirus the fairly continuous sequences indicate that terrigenous clastic, turbiditic sedimentation continued from the Oligocene onward into the Burdigalian. The differences in lithology and thickness of these successions, described in the literature, may be explained by fluctuations in the rate of subsidence of the depressions relative to the ridges in between. Coarser, clastic, proximal, mass-transported intercalations are locally found in the relatively fine-grained, mature successions. They point to episodic supply from emerging ridges. Such coarse beds are common in the Upper Chattian in the North and in the Burdigalian in the South. In the North, they consist of calcareous beds up to 10 m thick; those in the South are composed of coarse, calcareous sandstones. Our scanty data and those from the literature suggest that such beds are mainly found along the western margins of the former depressions, where the successions are thickest. This may imply that these basins were asymmetrical and had steep western and more gentle eastern slopes.

Returning to the southwest, we see that beginning in Late Oligocene time, the area was transformed into an archipelago with several islands and shoals with flourishing larger-foraminiferal populations. The sedimentary records from Levkas, Ithaki and Kefallinia bear ample evidence of major fluctuations in the role of the rising blocks during the Late Oligocene and Early Miocene. Repeated and abrupt changes in the amount of coarse calcareous detritus of

local origin reflect a periodicity in the intensity of the differential, vertical movements along faults bordering the emerging blocks and shoal areas. The coarse, breccious-conglomeratic beds are generally composed of mixtures of eroded pre-Oligocene limestones and larger-foraminiferal debris, which had accumulated on shoals and along the emerging blocks. From here, these ill-sorted mixtures were periodically transported towards the deeper parts of the basins.

As to the Upper Oligocene and Lower Miocene successions, the age assignments based on the larger foraminifera from such mass-transported beds are in many cases consistent with those based on the planktonic foraminifera. This implies a fairly continuous cleaning of the basin margins, which may only be explained by assuming frequent, strong differential movements, which repeatedly or constantly renewed the relief. The fluctuations in intensity of such movements in space and time may account for the considerable differences in the sedimentary development of time-equivalent strata in Ithaki, Levkas and Kefallinia.

It is not possible to locate the faults separating the individual blocks. In some cases these faults may have been the same as those delimiting today's culminations of Mesozoic and Eocene limestones. In Ithaki e.g., strong, differential movements may have taken place along the fault which today separates the Mesozoic limestone culmination of the Kavellares Mountains in the West and the Oligo/Miocene sediments of Afales-bay. Such a hinge line, however, may have been situated farther west. There must have been an emerging block during the Late Chattian and Burdigalian, whereas indications of a pronounced, nearby relief in the Aquitanian deposits are practically absent. This implies that at that time this culmination participated in a more general subsidence. Following the noticeable absence of Langhian sediments, the same holds true for the Serravallian, as indicated by the open marine, fine-grained terrigenous clastics at both the eastern and western side of the culmination. The scarce data from Kefallinia suggest that faults separating emerging blocks and rapidly subsiding grabens must have been active throughout the Miocene. Coarse, mass-transported, calcareous beds of a proximal nature are found in Burdigalian and Middle to Upper Miocene open marine, pelagic deposits, which indicates that the differential, vertical movements have lasted into the Tortonian.

The Upper Oligocene – Middle Miocene sedimentary record of Levkas and the adjacent Playia peninsula reflects a highly complicated pattern of fragmentation, relative block-movements, tilting and erosion. Displacement along the faults bordering the calcareous platform in the West caused the beginning of subsidence of this former shoal area in Late Chattian/Early

Aquitanian time. The western part of Levkas became separated by a sill from the continuously subsiding basin to the East. The western block continued to subside until the Late Miocene (Tortonian or Messinian), but the eastern block became fragmented, while horsts developed and grabens rapidly subsided in the course of the Burdigalian. There is ample proof of local emergence, tilting and erosion. Gradually the reliefs were equalized and during the Late Langhian also this eastern part of Levkas became involved in an overall submergence.

The sedimentary record of the Upper Eocene to Upper Miocene strata of western Epirus and the Ionian islands show a history of gradually increasing effects of differential vertical movements up to the end of the Early Miocene. As marine sediments of Middle Miocene and younger are practically horizontal, the recent topography seems to have originated from normal faulting and differential vertical movements of elongated blocks with preferential NNW – SSE strikes since the Middle Miocene or later. The lack of information on younger movements along the faults makes it difficult to prove this tensional interpretation of the last tectonic phases.

Assuming this picture to be correct, it is tempting to assume this mechanism to be equally valid for the Eocene to Early Miocene history, because evidently the same lines of weakness or parallel ones can be inferred to have played a role during this earlier period. Active horst and graben tectonics of the pre-Oligocene basement might have caused the paleogeographic configuration and the types and distribution of the sediments, as reconstructed for western Epirus, and all sedimentary features of the Ionian Oligo-Miocene might have resulted from block movements in a tensile stress pattern. It cannot be ignored, however, that the tectonic theory considers thrust faulting for the area during the Middle Tertiary as the most likely mechanism for the structures from Pindos Mountains to the Ionian Sea. Even plate tectonics have been applied to the area, considering some western Ionian block underthrusting the Greek mainland. Anyhow, the final phase of movements of the blocks in the southwest of the area in Middle Miocene time requires sliding or strong distortion of the entire sedimentary cover. In Ithaki e.g., underthrusting of a western block along an eastward dipping fault plane in Langhian time seems to give the easiest explanation of the structural pattern of the sediments in Afales-bay. If this type of movements is believed to have taken place, it might explain the steep dips of the Oligo-Miocene strata in some of the other islands as well, though final movements were not everywhere of exactly the same age. The concept of underthrusting towards the East along a series of eastward dipping, parallel fault planes is more difficult to reconcile with the steeper western limbs of the Epirus synclines during the

Chattian and Burdigalian.

Combining these data and assumptions into one overall tectonic framework, it might be suggested that strike-slip movements and various additional vertical movements of elongated blocks were the prevailing pattern from Eocene to Burdigalian. Over- and underthrusting movements, most active in the West, seem to have influenced the area in Middle Miocene times to varying degrees, whereas later block movements primarily might have been vertical adjustments to tension stresses.

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Plate 1

- Figs. 1, 3      *Globigerina tapuriensis* Blow and Banner, sample A 27, Afales-bay, Ithaki.  
Fig. 2        *Globigerina* cf. *linaperta* Finlay, sample A 22, Afales-bay, Ithaki.  
Fig. 4        *Globigerina ouachitaensis* Howe and Wallace, sample A 27, Afales-bay, Ithaki.  
Fig. 5        *Globigerina angiporoides* Hornibrook, sample A 22, Afales-bay, Ithaki.  
Figs. 6a–b    *Globigerina gortanii* (Borsetti), sample A 27, Afales-bay, Ithaki.  
Figs. 7a–b    *Globigerina increbescens* Bandy, sample A 22, Afales-bay, Ithaki.  
Fig. 8        *Globigerina tripartita* Koch, sample A 138, Afales-bay, Ithaki.  
Figs. 9a–c    *Globigerina opima opima* (Bolli), sample A 97, Afales-bay, Ithaki.  
Fig. 10       *Globigerina ciproensis* Bolli, sample A 138, Afales-bay, Ithaki.

all specimens X 85.

Plate 1

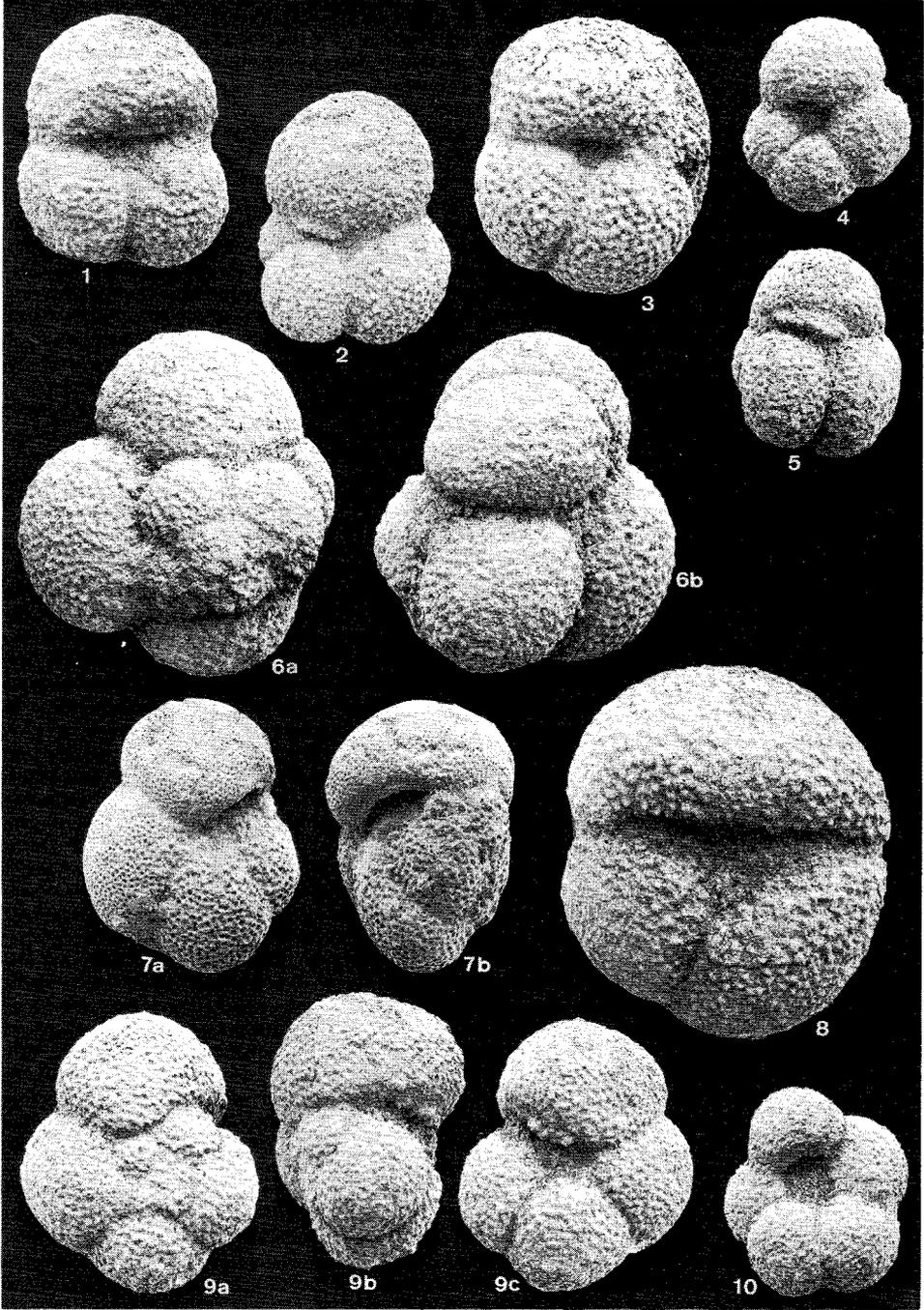


Plate 2

- Fig. 1 *Globigerina ampliapertura* Bolli, sample A 27, Afales-bay, Ithaki.  
Fig. 2 *Globigerina galavisi* Bermudez, sample A 77, Afales-bay, Ithaki.  
Fig. 3 *Globigerina angulisuturalis* Bolli, sample A 138, Afales-bay, Ithaki.  
Fig. 4 *Globigerina suteri* (Bolli), sample A 27, Afales-bay, Ithaki.  
Fig. 5 *Catapsydrax dissimilis* (Cushman and Bermudez), sample A 138, Afales-bay, Ithaki.  
Fig. 6 *Globigerina venezuelana* Hedberg, sample A 27, Afales-bay, Ithaki.  
Figs. 7a–c *Globorotalia kugleri* Bolli, sample A 110, Afales-bay, Ithaki.  
Figs. 8a–b *Globigerinoides primordius* Blow and Banner, sample DM 685, Sfinoto, W. Epirus.  
Figs. 9a–b *Globigerina opima nana* (Bolli), sample A 138, Afales-bay, Ithaki.  
Fig. 10 *Globiquadrina dehiscens* (Chapman, Parr and Collins), sample DM 668, Apolpaina, Levkas.  
Fig. 11a–c *Globorotalia peripheroronda* Blow and Banner, sample 668, Apolpaina, Levkas.  
Fig. 12 *Globigerinoides sicanus* de Stefani, sample DM 637, Spanokhorion, Levkas.

all specimens  $\times 85$ .

Plate 2

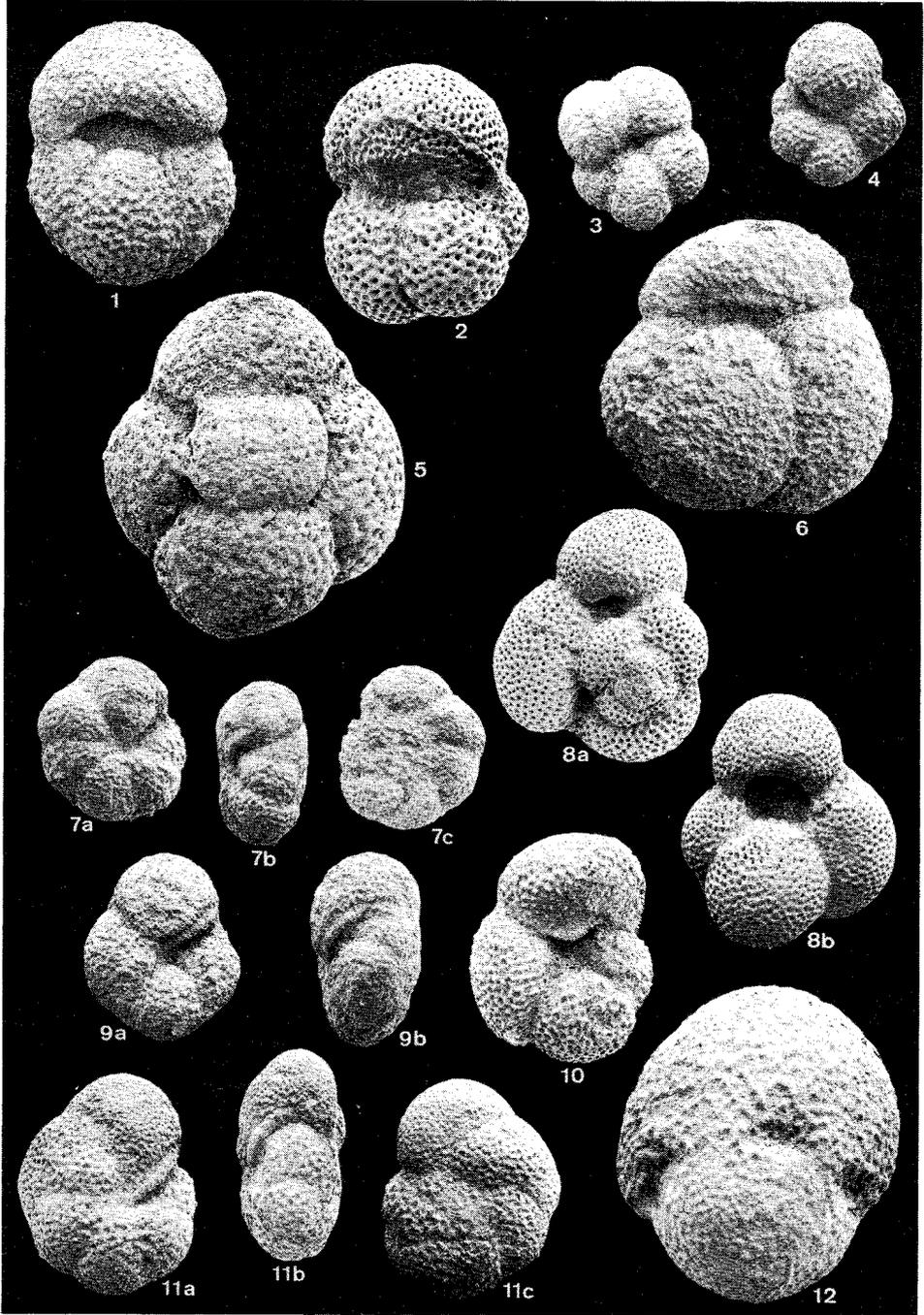


Plate 3

- Fig. 1 *Miogypsinoïdes* specimen with  $\times = 16$  from the *M. ex. interc. formosensis-basraensis* assemblage of sample A 190, Afales-bay, Ithaki CH 2491
- Fig. 2. *Miogypsina* specimen with  $\times = 13$  from the *M. ex. interc. basraensis-formosensis* assemblage of sample DM 322, Zygos, Kerkira CH 3083
- Fig. 3 *Miogypsina* specimen with  $\times = 11$  from the *M. gunteri* assemblage of sample DM 368, Playia CH 2948
- Fig. 4 *Miogypsina* specimen with  $\times = 3\frac{1}{2}$  and  $V = 66.4$  from the *M. intermedia* assemblage of sample DM 684, Sfinoto, Epirus CH 3290
- Fig. 5 *Miolepidocyclus* specimen with  $\times = 5\frac{1}{2}$  and  $V = 37.1$  from the *M. ex. interc. burdigalensis-negrii* assemblage of sample A 179, Afales-bay, Ithaki CH 2618
- Fig. 6 *Nephrolepidina* specimen with  $C = 0$  and  $A_i = 30.0$  from the *L. praemarginata* assemblage of sample DM 62, Spartila, Kerkira CH 3069
- Fig. 7 *Nephrolepidina* specimen with  $C = 2$  and  $A_i = 35.1$  from the *L. ex. interc. praemarginata-morgani* assemblage of sample DM 27, Episkepsis, Kerkira CH 3019
- Fig. 8 *Nephrolepidina* specimen with  $C = 2$  and  $A_i = 33.3$  from the *L. praemarginata* assemblage of sample DM 62, Spartila, Kerkira CH 3081
- Fig. 9 *Nephrolepidina* specimen with  $C = 4$  and  $A_i = 41.2$  from the *L. ex. interc. morgani-tournoueri* assemblage of sample A 190, Afales-bay, Ithaki CH 2756
- Fig. 10 *Nephrolepidina* specimen with  $C = 7$  and  $A_i = 48.8$  from the *L. ex. interc. morgani-tournoueri* assemblage of sample A 140, Afales-bay, Ithaki CH 2830

All figured specimens have been retouched slightly. The CH numbers refer to the storage in the collection of the Department of Micropaleontology of the State University of Utrecht. All figures  $\times 37$ .

Plate 3

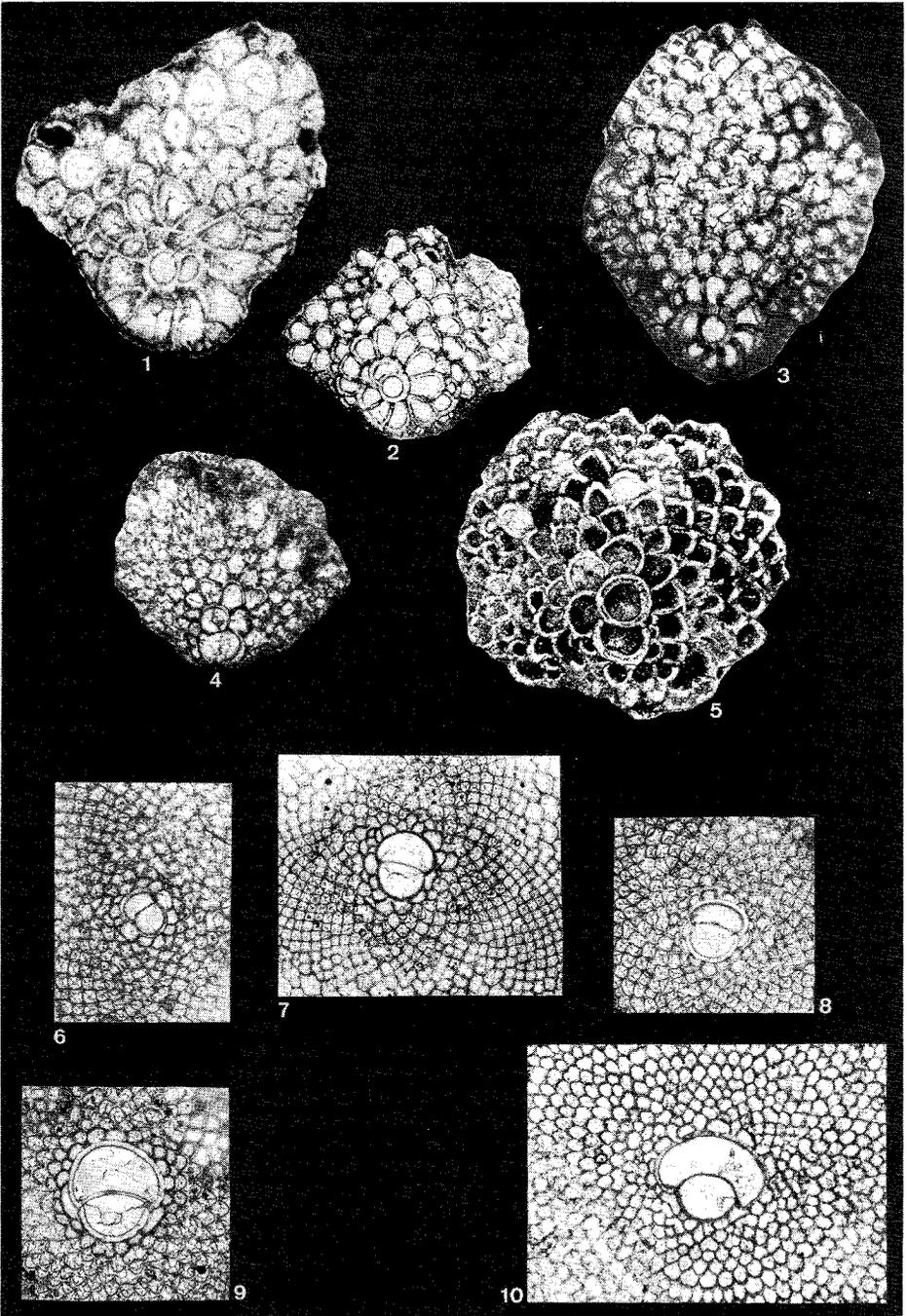
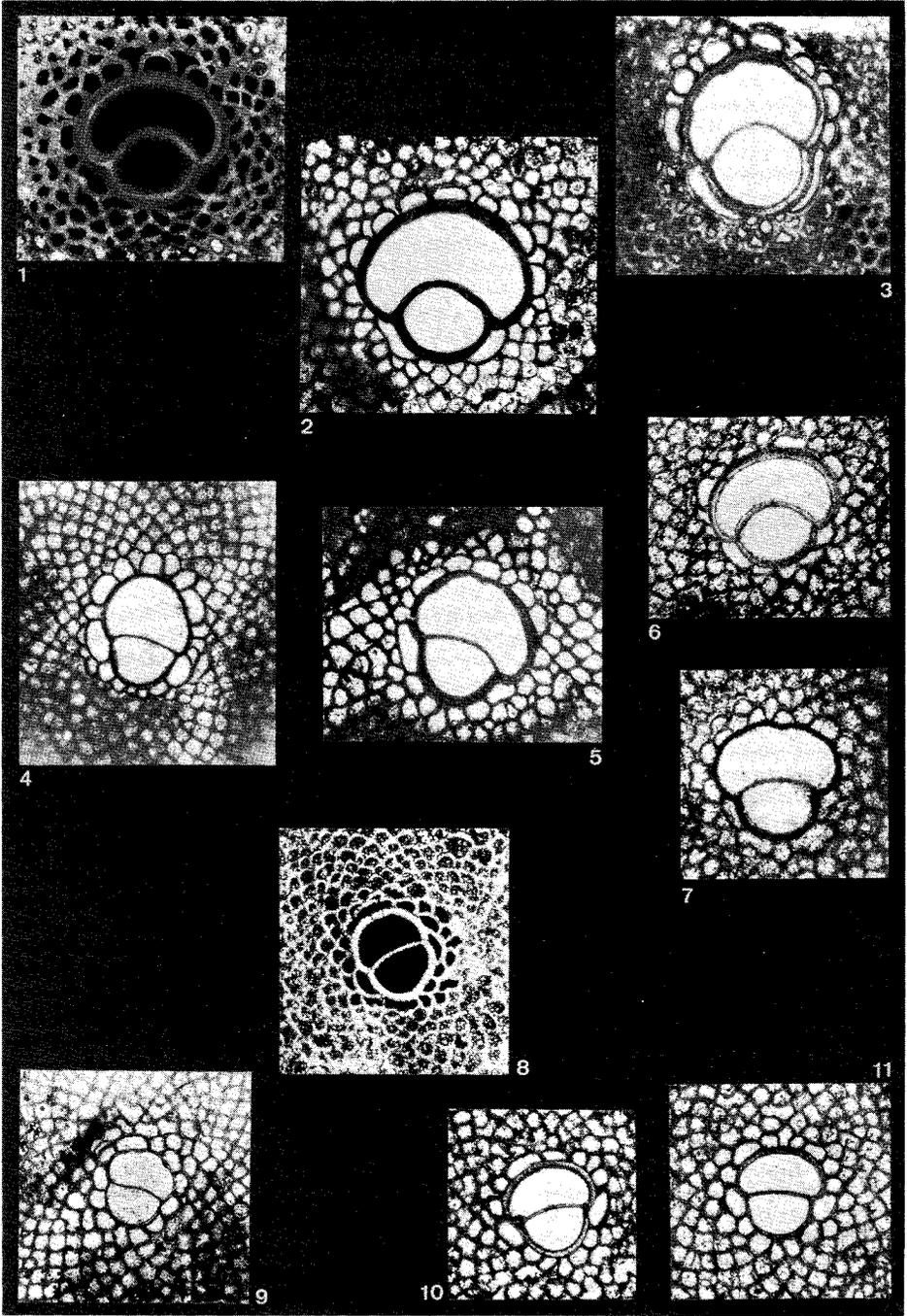


Plate 4

- Figs. 1–3 *Lepidocyclina (Nephrolepidina) tournoueri* from the type area at Rosignano, N. Italy. Fig. 1:  $A_1 = 50$ ,  $C = 6$ ; fig. 2:  $A_1 = 46.2$ ,  $C = 8$ ; fig. 3:  $A_1 = 38.6$ ,  $C = 6$ .
- Figs. 4–7 *Lepidocyclina (Nephrolepidina) morgani* from the type area at Puente Viejo, Guadalquivir Basin, S. Spain. Fig. 4:  $A_1 = 38.8$ ,  $C = 3$ ; fig. 5:  $A_1 = 40.9$ ,  $C = 4$ ; fig. 6:  $A_1 = 43.5$ ,  $C = 4$ ; fig. 7:  $A_1 = 38.1$ ,  $C = 5$ .
- Figs. 8–11 *Lepidocyclina (Nephrolepidina) praemarginata* from the type-locality Costa Lupara, N. Italy. Fig. 8:  $A_1 = 40$ ,  $C = 1$ ; fig. 9:  $A_1 = 35.3$ ,  $C = 2$ ; fig. 10:  $A_1 = 36.8$ ,  $C = 1$ ; fig. 11:  $A_1 = 33.3$ ,  $C = 2$ .

all specimens  $\times 34$ . Most specimens have been retouched.

Plate 4



- Bull. 12. J. T. VAN GORSEL – Evolutionary trends and stratigraphic significance of the Late Cretaceous *Helicorbitoides-Lepidorbitoides* lineage. 100 p., 15 pl., 14 figs. (1975) f 37,—
- Bull. 13. E. F. J. DE MULDER – Microfauna and sedimentary-tectonic history of the Oligo-Miocene of the Ionian Islands and western Epirus (Greece), 140 p., 4 pl., 47 figs. (1975) f 45,—
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