

**UTRECHT  
MICROPALAEONTOLOGICAL  
BULLETINS**

J. A. BROEKMAN

**SEDIMENTATION AND PALEOECOLOGY  
OF PLIOCENE LAGOONAL – SHALLOW MARINE DEPOSITS  
ON THE ISLAND OF RHODOS  
(GREECE)**

**8**

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J. A. BROEKMAN

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## ABSTRACT

A detailed analysis of the depositional and paleontological characteristics of a section of the Pliocene Kritika Formation on the island of Rhodos is presented. The environmental significance of sedimentary structures, the paleoecology of benthonic Foraminifera, and the sequential arrangement of sediment types are emphasized. Attention is also paid to the textural and compositional properties of the deposits and to the occurrence of other invertebrate fossils: Thecamoebina, planktonic Foraminifera, Ostracoda, Bryozoa, Mollusca, Anthozoa, Annelida and Arthropoda.

The vertical distribution in individual strata of horizontal lamination, large scale cross-lamination, small scale cross-lamination of oscillatory origin and burrowing structures is interpreted in terms of an episodic supply of silty-sandy detritus to a normally tranquil or non-depositional environment by wind-driven currents.

During phases of sediment supply, mixing of elements of neighbouring faunal communities frequently occurred. The displaced specimens were subject to hydrodynamical selection according to size, nature of hard parts and mode of life.

Gradual displacements of environmental boundaries in time and in space produced a superposition of sediments, reflecting a changing energy level and an alteration of autochthonous faunal communities, linked to modifications in the supply of allochthonous faunal components. Coarsening upward- and fining upward sequences are distinguished.

The accumulation was controlled by the repeated construction and destruction of barriers in the littoral zone, as a function of subsidence and long-shore sand supply. Several lagoonal environments are distinguished, according to proximity of the barrier-system and exposure to open marine forces. A gradual waning of long-shore supply and a concomitant change in the nature of the lagoonal environments is concluded.

The investigated sediments give a condensed picture of a part of the Pliocene history of eastern Rhodos and of the geological and physiographical framework of the Kritika Formation.

# Chapter I

## INTRODUCTION

### I.1. PURPOSE OF STUDY

The principal object of this study is the integrated analysis of depositional and paleontological characteristics of a section of Pliocene sediments on the island of Rhodos (Greece).

The combined application of sedimentary and paleoecological criteria is considered essential for the understanding of processes, which governed the accumulation of ancient sediments, particularly so if their original environment was situated in the shallow marine realm. No doubt, specialized studies of the depositional properties of the sediments alone, would have unveiled the fundamental mechanisms responsible for their formation, but several important aspects of the sedimentary framework would have remained obscure, or even unnoticed, without a study of the organic contents.

The fieldwork was performed in the context of a stratigraphical and paleogeographical study of the Upper Cenozoic of Rhodos by the departments of Micropaleontology and Paleontology of the State University of Utrecht.

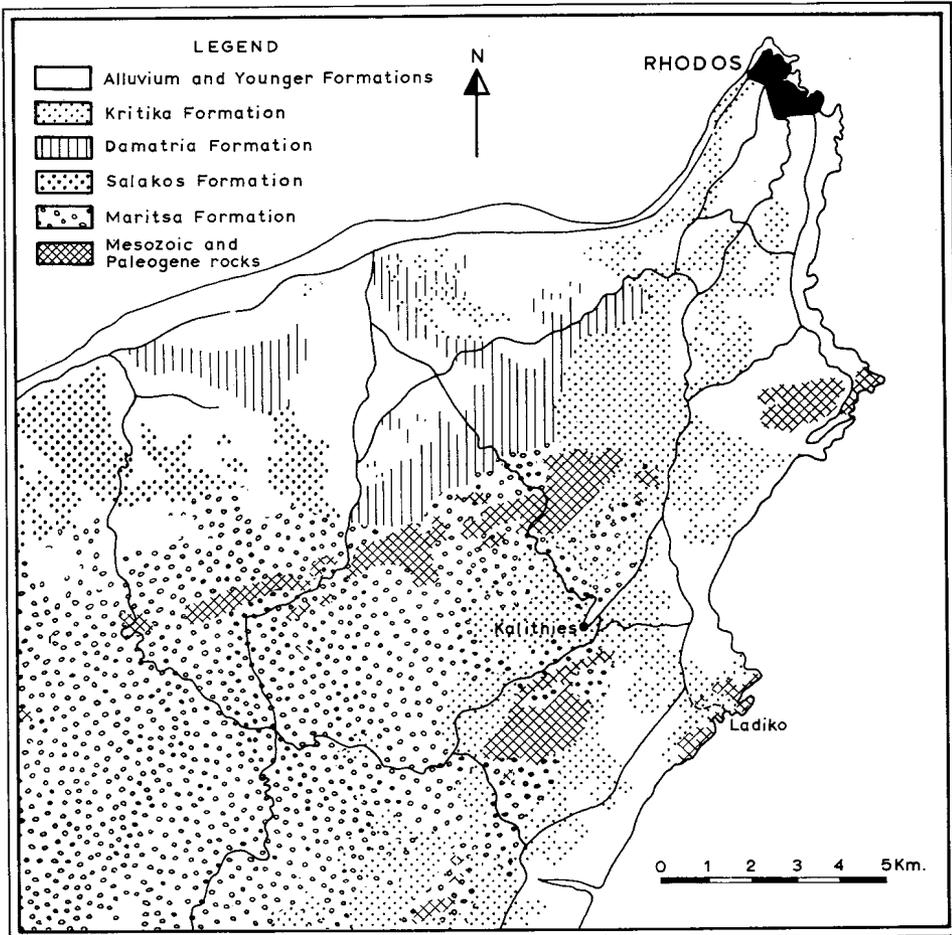
### I.2. GEOLOGIC AND STRATIGRAPHIC FRAMEWORK

The Late Cenozoic of Rhodos has been the subject of several studies of stratigraphy and paleontology in the 19th century. Bukowsky (1899) supplied the first geological map of the island, and Terquem (1878) gave a well known account of Pliocene Foraminifera and Ostracoda.

Recently, a geological and stratigraphical study of Mesozoic, Tertiary and Quaternary rocks of the island was performed by Mutti *et al.* (1970). In the years 1968–1971 the Micropaleontology and Paleontology Departments of the State University of Utrecht focused their attention on the stratigraphy and paleogeography of the younger Tertiary and Quaternary sediments of Rhodos (Meulenkamp, 1971; Meulenkamp *et al.*, 1972).

The younger Tertiary sediments of Rhodos unconformably overlie rocks of Mesozoic or Paleogene age. After a period of uplift and local accumulation in continental depressions during the Miocene and part of the Pliocene, widespread deposition was resumed in the Pliocene through fluvial supply from a mainland, situated to the east of the present-day island.

Strong subsidence of the depositional area permitted the accumulation of thick non-marine series of sediments in braided to meandering river- and lacustrine environments. These sediments correspond to Bukowski's (1899) Levantinian. In northern Rhodos, the Maritsa and Salakos Formation (Utrecht terminology) have been distinguished (textfig. 1). The general



Textfigure 1: Schematic geological map of northern Rhodos (after data of Mutti *et al*, 1970, E. F. J. de Mulder, unpubl. rep. and Meulenkamp *et al*, 1972).

fining upward trend in this part of the succession indicates a gradually waning supply.

In the Late Pliocene the area was affected by faulting and differential vertical movements. Parts of Rhodos were raised, whereas the eastern mainland was submerged. The region now became part of a mainland, situated to the west and northwest. The general eastward tilting produced a horizontal transition from fluvial-lacustrine sediments in the west (Damatria Formation) to lagoonal-marine deposits farther east (Kritika Formation). The latter formation roughly corresponds to the Sgourou Formation of Mutti *et al.* (1970).

Paleocurrent measurements show that the predominantly meandering river systems of the Damatria Formation derived their material from western and northwestern directions. Apart from the lateral transition noted above, there is also a vertical passage from the Damatria sediments into the lagoonal-marine sediments of the Kritika Formation.

In eastern Rhodos, the Kritika Formation occurs in a narrow strip along the present-day coastline, in unconformable contact with conglomerates of the Maritsa Formation or with rocks of Mesozoic-Paleogene age (textfig. 1). South of the village of Kalithies, differential movements produced a paleo-relief, in which uplifted blocks of Mesozoic limestones played an essential part during later sedimentation.

The exposure at Ladiko-bay, dealt with in this paper, is situated in the latter depositional realm. Farther north, the synsedimentary paleo-topography was less pronounced; this area was exposed to fluvial supply from the west and northwest and to marine influences from an eastern direction. Here we chose a second example of Kritika sediments, in an exposure near Kalithies, which has been treated in a separate paper (Broekman, 1973).

During the Late Pliocene-Pleistocene and up to recent days, differential vertical movements persisted; an uplift of the central part of the island took place, while tectonics also affected the present-day N.W. coast. As a result, Rhodos was separated from the mainland in the Pleistocene. The termination of appreciable fluvial supply is reflected in the clayey and calcareous nature of the marine deposits of Late Pliocene and Quaternary age.

### 1.3. METHODS OF STUDY

The following chapters present a systematic description of the investigated section, with emphasis on three major aspects of the sediments, *i.e.*:

- a. texture and composition,
- b. bedding and sedimentary structures,
- c. faunal content.

The change of these properties in a vertical sense form the basis for the subdivision of the section in successive sedimentary units, distinguished in the field. Each unit is defined either on internal consistency of texture, structure, fauna etc., or it is characterized by a gradual upward change of one or more of these properties. In both cases a unit is delimited with respect to adjacent ones by relatively distinct changes in the association of sedimentary and paleontological properties.

### **I.3.a. Texture and composition**

The textural nomenclature is based on median grain-size and degree of sorting, using the following size limits:

Gravel:	coarser than 2 mm
Coarse sand:	0.5–2 mm
Medium sand:	0.25–0.5 mm
Fine sand:	0.15–0.25 mm
Very fine sand:	0.06–0.15 mm
Silt:	0.004–0.06 mm
Clay:	finer than 0.004 mm

Mollusc shells and clay pebbles have not been included in the grain-size distribution of the surrounding sediment; in most cases they would belong the gravel-size class.

The textural field nomenclature was checked by microscopic size-analysis of wash-residues of samples destined for micropaleontological purposes. This method was combined with an examination of the lithological composition of the fraction coarser than 60 microns ("coarse fraction analysis", Shepard and Moore, 1955, 1960). The sediments revealed a high degree of heterogeneity in this respect. The following elements can be distinguished:

1. Terrigenous grains: particles of (pre-neogene) limestone, quartz and ophiolite.
2. Oolitic grains: spherical to ellipsoidal carbonate grains, with a thin, often monolayered coating of cryptocrystalline calcite around a nucleus, which consists of a fine grained calcareous aggregate in most cases. Such grains are restricted to the fine- and medium sand classes.
3. Shell-fragments: pelecypod and gastropod shell-fragments, ranging in size from very fine sand to gravel and showing all gradations from relatively fresh to strongly worn and corroded specimens.

4. Echinoid spines.
5. Fragments of calcareous algae.
6. Plant-remains.
7. Identifiable organic remains: Foraminifera, Thecamoebina, Ostracoda, Bryozoa, Pelecypoda, Scaphopoda, Gastropoda, Anthozoa, Annelida and Arthropoda.

With the exception of terrigenous grains, all of these lithological constituents are of potential significance for environmental interpretation. Types 2--5 have therefore been included in the coarse fraction analysis; the data of type 6 have been added on the basis of field observations. Type 7 will be discussed under the heading paleoecology.

The relative importance of the coarse fraction components has roughly been estimated and is designated by means of the terms frequent, common and rare. Counts of a thousand grains in a number of samples revealed that the following approximate quantitative values may be attached to these designations:

Frequent: more than 3% of total number of grains > 60 microns.

Common: 3--1% of total number of grains > 60 microns.

Rare: less than 1% of total number of grains > 60 microns.

### **I.3.b. Bedding and sedimentary structures**

A principal distinction is made between the gross external shape, dimensions and interface characteristics of sediment bodies (bedding), and the internal organization of these bodies (structure). In the description of both aspects, the author tried to act in accordance with the classification and terminology of Mc Kee and Weir (1953) and of Allen (1963a).

### **I.3.c. Faunal content**

For paleoecological interpretation the fauna has been subjected to a quantitative study. All identifiable fossils were differentiated into macroscopical and microscopical elements.

The macrofauna (> 2 mm) of the sediment (Pelecypoda, Gastropoda, Scaphopoda, Anthozoa, Annelida, Arthropoda and some Bryozoa) was determined and counted in the laboratory from samples of 800 grams.

The method of study of the microfauna had to be adapted to the great difference in abundance. The wash-residues coarser than 60 microns of all samples were subjected to the flotation method by means of carbontetrachloride, even when artificial concentration of faunal elements was in fact not necessary to collect a sufficient quantity of specimens. This method has the disadvantage of possible selection of some species due to preferential flotation. However, when every sample is treated in the same way, the

counting results may be considered comparable, though a pretension of presenting a complete and exact picture of the microfaunal composition would not be justified.

Whenever feasible, the counting of one hundred benthonic Foraminifera was used as a basis for quantitative study. The abundance of all other microfaunal elements met with during this procedure (planktonic Foraminifera, Thecamoebina, Ostracoda and micro-Bryozoa) is indicated as their number per 100 benthonic Foraminifera in these instances.

In many cases the scarcity of Foraminifera forced us to be content with 50, 25 or even less individuals. This fact hampers the comparison of different samples, although impoverished faunas with a characteristic specific composition obviously supply important environmental indications.

Because of the importance of microfaunal abundance for interpretation of the conditions of sedimentation, it has been tried to establish a measure of frequency of benthonic Foraminifera per sediment volume. Of every sample 30 cm<sup>3</sup> of the fraction coarser than 60 microns was subjected to flotation in carbontetrachloride. An index of abundance was computed, using the following procedure:

If: A = number of counted benthonic Foraminifera,

B = total volume of floating fraction,

C = volume of part of B, used to attain A,

then the "benthos-index" =  $A \times B/C$  for sands,

=  $A \times B/10C$  for clays.

It will be clear that this index only has a relative significance and that it does not represent any absolute number of specimens per sediment volume.

In the sediment description of Chapter II, the main aspects of the faunal composition are summarized; the complete counting results are given in an appendix.

#### 1.4. ACKNOWLEDGEMENTS

The author is indebted to C. W. Drooger for his stimulating interest and critical approach, to L. M. J. U. van Straaten of the State University of Groningen, who paid attention to the sedimentological and malacological aspects, and to J. E. Meulenkamp for clarifying discussions.

This study would have been impossible, without the assistance of specialists in different fields of Paleontology, who supplied the specific determinations of the elements of various faunal groups: W. Sissingh: Ostracoda, R. Lagaaij: Bryozoa, R. Daams: Mollusca, R. C. Tjalsma: planktonic Foraminifera.

The identification of the benthonic Foraminifera was performed by the author, who is also responsible for the counting results and the paleoecological interpretation of the total fauna.

Thanks are due to E. F. J. de Mulder and J. Schipper, for their field-assistance in photography and sampling. The drawings were carefully prepared by J. P. van der Linden and P. Hoonhout. The preparation of samples was performed by G. in 't Veld.

My wife and Miss Y. H. Smid attended to the typing of the manuscript; I wish to express my gratitude for their help.

## Chapter II

### THE SEDIMENTARY SUCCESSION AT LADIKO-BAY

#### II.1. LOCALITY AND GEOLOGIC SETTING

The exposure is situated on the southwestern side of the small embayment of Ladiko, on the eastern coast of the island, 17 km south of the city of Rhodes. It can be reached by way of a country road, branching off the major road to Lindos, immediately south of Faliraki (textfig. 2).

The northern side of the bay is formed by a ridge, consisting of strongly weathered, grey, cherty limestones and dolomitic limestones, assigned to the Upper Triassic and Jurassic by Mutti *et al.* (1970). Abutting against its southern flank, patches of Tertiary sands occur. Along their contact with the older rocks, bivalves in situ have been found, which probably indicate an undisturbed contact.

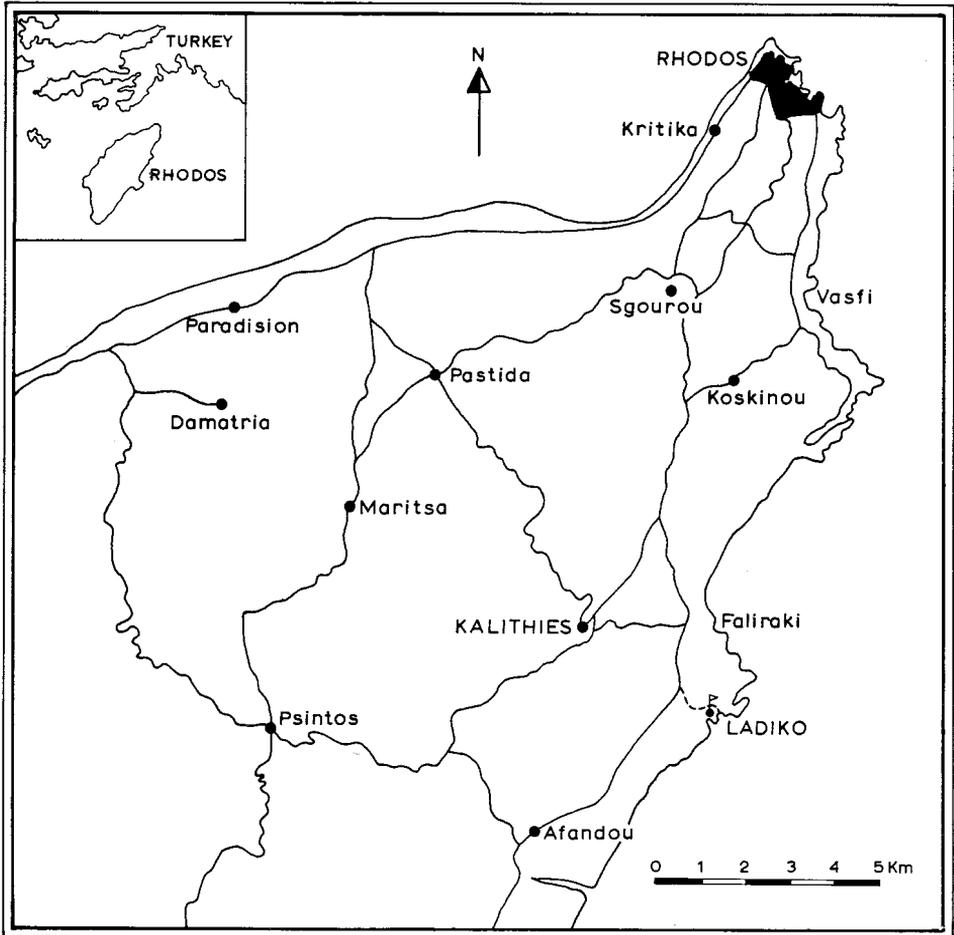
The exposure covers a total sediment thickness of about 30 m (fig. 1). The uppermost 3 m of the section, consisting of badly exposed calcareous and conglomeratic deposits, separated from the underlying sediments by a slight angular unconformity, have not been included in this study.

The strata show a slight structural dip to the east and are locally dissected by north-south trending faults with insignificant offset.

The major part of the exposure has an east-west to east-southeast-west-northwest orientation, facing north. Sections with a north-south direction, allowing a three dimensional insight in the development of stratification and sedimentary structures, are also present, but they are less accessible, particularly so in the lower 10 m of the exposure.

#### II.2. AGE OF THE SEDIMENTS

Faunal elements of biostratigraphic value are relatively scarce. Planktonic Foraminifera are represented in too low frequencies to allow any conclusion. The predominant planktonic species *Globigerinoides ruber* is present in a



Textfigure 2: Map of northern Rhodes, showing location of investigated section.

form, which seems to exist since the end of the Miocene (Cordey, 1967). The rare occurrence of *Globorotalia inflata* should also be noted; according to Blow (1969) this species occurs already in the Upper Miocene, whereas Bizon (1967) records its appearance in the Ionian area (Greece) in the Upper Pliocene. According to Gradstein's detailed analysis of Mediterranean Pliocene *Globorotalia* (1974), the species probably evolved from *G. bononiensis* in the Late Pliocene, continuing its range in the Quaternary.

More important information is supplied by some species of Ostracoda.

Our conclusions regarding their biostratigraphic significance are mainly based on data of Uliczny (1969), concerning the Pliocene of the island of Kephallina (Greece), who proposed the following ranges for species present in the section at Ladiko-bay:

<i>Aurila calciplena</i>	Upper Pliocene (present in 8 of our samples)
<i>Urocythereis margaritifera margaritifera</i>	Upper Pliocene-Recent (7 samples)
<i>Aurila cruciata minor</i>	Lower Pliocene (6 samples)
<i>Aurila ulicznyi</i>	Upper Pliocene (4 samples)

Most of these data have been confirmed by Sissingh (1972) in his study of the Neogene Ostracoda of the Aegean islands (Greece); this author considers *Aurila ulicznyi* to be of Plio-Pleistocene age and notes the appearance of *Cyprideis torosa torosa* (present in two of our samples) in the Upper Pliocene.

The Pliocene age of the greater part of the Ladiko section thus seems well established; mutually contradicting indications supplied by different species of Ostracoda make us refrain from a refinement of this assignment.

Two species of Bryozoa adapt themselves to this interpretation; according to Lagaaij (pers. commun.) *Metrarabdotos* (*Porometra*) *helveticum canariense* and *Vittaticella* sp. have disappeared from Europe and the Mediterranean region since the Pliocene.

In the absence of any form of biostratigraphic value, the age of the clayey, upper part of the investigated section, which is separated from the underlying sediments by a slight unconformity, can not definitely be established. A Pleistocene (Calabrian) age can not be ruled out; the absence of the Foraminifer *Hyalinea balthica*, whose appearance is conventionally considered to mark the Plio-Pleistocene boundary in the Mediterranean region, would then be due to particular ecological conditions, that governed the accumulation of these sediments.

### II.3. DESCRIPTION OF SECTION

The section has been subdivided into twenty-one sedimentary units, which will be treated in stratigraphical order.

**Unit I:** basal part of section, visible thickness 60 cm (see enclosure I)

*Texture and composition:* Interstratified clays-silty clays, silts and subordinate very fine sands. Thickness of clays up to 10 cm, maximum thickness of silts 7 cm, very fine sands commonly not exceeding 4 cm in thickness, but locally reaching a thickness of 12 cm. Sorting of silts and sands is poor; a considerable admixture of clay is always present.

In the coarse fraction of clays, silts and sands, shell-fragments occur as a minor constituent. In the silts and sands, oolitic grains are well represented. Plant-remains, often associated with ferruginous concretions, are distributed at random in all sediment types.

*Bedding and sedimentary structures:* The shape of the silty and sandy beds is predominantly lenticular with a horizontal base and an irregular, convex-upward top. The lower bedding-planes of these lenses show distinct lithological transitions. Small irregularities, due to horizontal organic tracks, occur along them.

The clayey sediments reveal a paper-thin horizontal lamination; vertical burrows are absent in this type of sediment.

The internal structure of the majority of the relatively thick, silty and sandy strata consists of horizontal lamination, covered by small scale cross-lamination. In thinner beds only the latter structure is found.

In some of the relatively thick, silty and sandy beds, the internal horizontal lamination is truncated obliquely and covered by clayey sediment, thus leading to the lenticular outline of the beds.

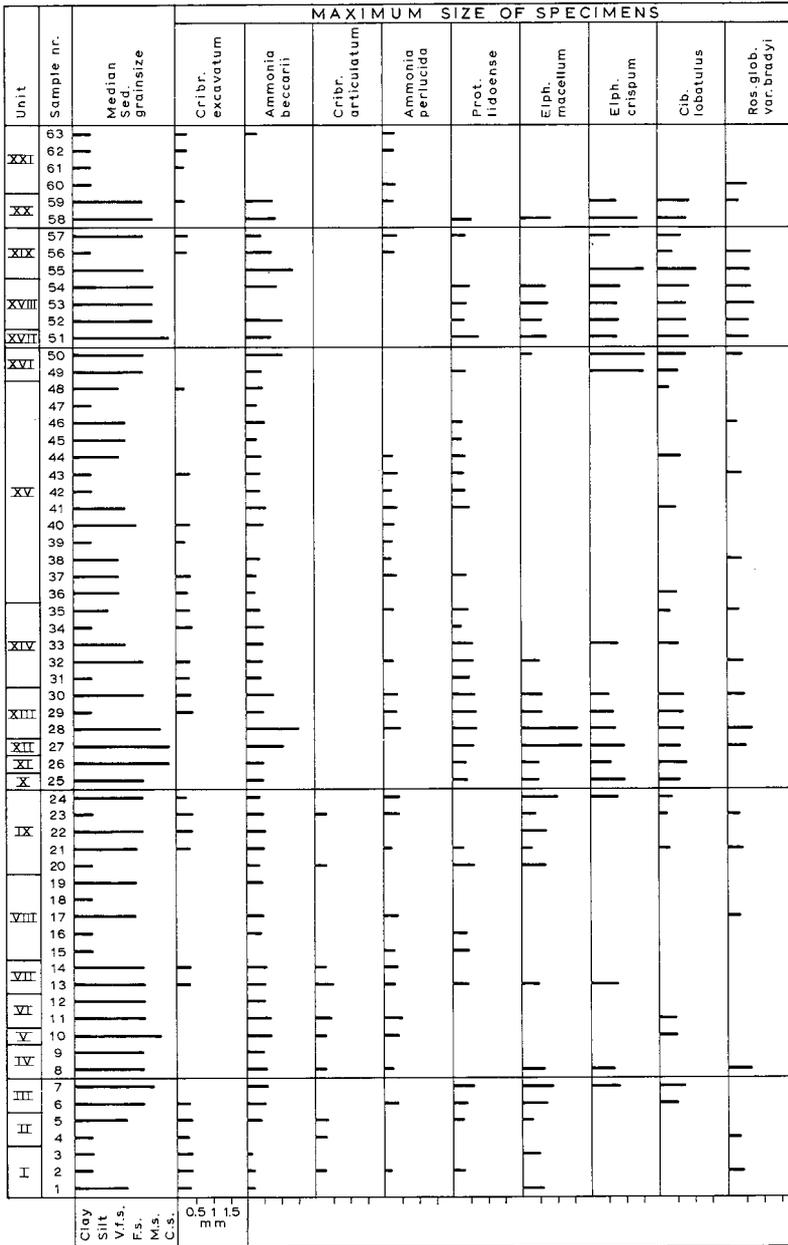
Cross-lamination on a larger scale is very subordinate. If present, it appears only on top of oblique truncation surfaces, which are locally covered by cross-stratified silts with clayey laminae, on the flanks of the silty or sandy lenses.

The primary internal structures of the sands and silts are commonly well preserved. Small vertical burrows were observed in some rare instances. The starting point of such burrows, is situated at the upper bedding-planes of the strata. In vertical sections, their somewhat sinuous course locally simulates an internal point of inception.

*Faunal content* (sample 1–3):

– Benthonic Foraminifera: As indicated by the benthos-index, the frequency of benthonic Foraminifera is low. The lowest number of specimens occurs in the sandy sample (benthos-index 30); the two clayey samples show values of 100 and 50.

Both sands and clays show a predominance of two species, *Cribronion excavatum* and *C. incertum* (up to 35%). A third species, *Nonion depressulum*, is frequent only in the upper most of the clayey samples. *Ammonia*



Textfigure 3: Vertical distribution of maximum size of some foraminiferal species and of median grain-size in the section at Ladiko-bay.

*beccarii* is fairly important in both types of sediment. *Protelphidium lidoense* reaches a comparable frequency in one of the clayey samples.

Comparison of the sandy and clayey samples reveals some preference of plano-convex forms such as *Rosalina*, *Asterigerina*, *Neoconorbina* and *Cibicides* for the fine grained deposits (3% in the sand, 7–17% in the clays). The lowermost clayey sample relatively frequently contains individuals with small and thin tests of the genera *Bulimina*, *Brizalina*, *Bolivina* and *Lagena* (total of 8%).

On the whole, the foraminiferal fauna appears to be composed of relatively small individuals, as may be seen in textfig. 3. The difference in size of tests with respect to the overlying units is particularly evident in *Protelphidium lidoense*, *Ammonia beccarii*, *Elphidium macellum* and *Ammonia perlucida*. There is no clearly smaller size for the two dominant species, *Cribrononion excavatum* and *C. incertum*.

– Planktonic Foraminifera: Rare planktonic Foraminifera, with *Globigerinoides ruber* as the major form, occur in both sediment types, with maximum abundance in the lowermost of the clayey samples (7/100 benthonic Foraminifera).

– Ostracoda: Carapaces of Ostracoda are frequent in the two clayey samples. *Leptocythere* sp. 1 seems to be predominant in samples 1 and 2, whereas *Falunia rugosa* appears to be the most important form in sample 3. The occurrence of *Xestoleberis communis* and *Aurila* ex gr. *punctata* should be noted.

Unit II: thickness 65 cm.

*Texture and composition:* Interstratified silts, very fine sands and clays. Thickness of silts up to 20 cm, maximum thickness of sands 17 cm, thickness of clays not exceeding 7 cm. The silts and sands are slightly clayey and contain fine sand particles as their coarsest constituents.

In the coarse fraction, shell-fragments are more important in the silty-sandy deposits, which also contain oolitic grains in considerable amounts. Plant-remains and ferruginous concretions are randomly distributed in the sands and along sand-clay partings.

*Bedding and sedimentary structures:* The silty and sandy beds are lenticular in shape or laterally continuous. Their lower bedding-planes reveal horizontal tracks. Horizontal lamination occurs either throughout or more frequently in the basal part of the silty and sandy strata, with small scale cross-lamination in the upper levels.

The upper bedding-planes of the silts and sands are strongly affected by bioturbation. Small burrows reach downward from their top and they often destroy the pre-existing ripple patterns and their internal cross-lamination in the upper part of the strata. Burrows of the same type are also abundantly present in the clayey intercalations.

*Faunal content* (sample nr. 4 and 5):

– Thecamoebina: In the clayey sample (nr. 4), the rare occurrence of the small and fragile *Centropyxis marsupiformis* was recorded (2/50 benthonic Foraminifera).

– Benthonic Foraminifera: As far as any conclusion may be based on the two samples obtained from this unit, a decreasing frequency of benthonic Foraminifera in the clayey sediments and an increasing abundance in the sandy strata may be inferred from a comparison with the basal unit (benthos-index 15 and 90 in clay and sand respectively).

The qualitative composition of the fauna reveals a difference between the clayey and the sandy sample. In the clay, the predominance of *Cribronion excavatum* (22%) and *C. incertum* (44%) remains unaffected. *Nonion depressulum* is also well represented.

In the sandy stratum, immediately above this clayey sediment, the latter assemblage is strongly reduced in significance. *Ammonia beccarii* (16%), *Protelphidium lidoense* (12%) and *Cribronion incertum* (12%) are the most important species here.

– Planktonic Foraminifera: Plankton is again rare; the highest frequency is reached in the clayey sample nr. 4: 4/50.

– Ostracoda: A considerable quantity of valves was found in the clayey sample (27/50). The fauna is dominated by *Falunia rugosa*; *Leptocythere* sp. 1 and *Xestoleberis communis* are also present. Though insignificant in quantity, the occurrence of *Cyprideis torosa torosa* should be noted.

The small assemblage obtained from the sand shows no great difference. The predominance of *Falunia*, however, seems to be absent here. The presence of *Aurila* ex gr. *punctata* should be mentioned.

– Bryozoa: Both the clayey and the sandy sample reveal a low content of bryozoan fragments (3/50 and 3/25 resp.). All specimens belong to the genus *Crisia*: *C. fistulosa* and *C. denticulata* amongst others.

**Unit III:** thickness 220 cm.

*Texture and composition:* Fine sands, interstratified with clays. Maximum thickness of sands irregularly increasing in an upward sense up to 50 cm,

thickness of the clays decreasing to 2–4 cm. This trend goes together with the appearance and upward increase of medium sand components in the sandy strata. An admixture of clay is always present in these sediments.

Clay pebbles with a diameter up to 3 cm, are arranged in accordance with the lamination of the sands, or they occur randomly distributed. Clay pebble frequency increases in the upper 80 cm; here the thin clayey intercalations show lateral transitions to horizontal clay pebble stringers.

In the coarse fraction of the sands, shell-fragments show a notable increase in frequency in an upward sense, whereas oolitic constituents tend to decrease. In the upper part of the unit, the appearance of echinoid spines and fragments of calcareous algae should be noted. Plant-remains are scarce.

*Bedding and sedimentary structures:* The greater part of the sandy beds is laterally continuous and shows a horizontal base and a horizontal or undulating top. Sand bodies with a concave-upward base and a horizontal top, which truncate adjacent sands along their flanks, occur locally, particularly so in the upper part of the unit. These shallow, channellike structures contain an internal cross-lamination and in some instances a basal concentration of clay pebbles.

The tabular sand beds show properties already described in Units I and II: horizontal lamination below and small scale cross-lamination in their upper part. The upper bedding-planes are sculptured by ripples, which may be completely preserved or destroyed to a variable extent.

A new structural element appears in this unit: large scale cross-lamination, consisting of delicate, often flatly dipping cross-laminae. These are arranged in tabular sets, which are bounded by small scale cross-lamination and associated ripples on the upper bedding-planes (fig. 2). The large scale cross-laminated sets locally reveal a lateral transition to horizontal lamination.

As to the distribution of the different types of primary structures, there is an upward increasing frequency of large scale cross-lamination and an upward decrease of small scale cross-lamination and associated ripples. In the upper part of the unit, the sandy beds are separated by straight, non-rippled surfaces, which truncate the internal structures of the underlying strata.

In east-west sections, a distinct preference of large scale cross-lamination for an inclination in westward directions could be observed. Owing to conditions of exposure, we had to refrain from a three-dimensional analysis. The orientation of small scale cross-laminae appears to show a wide scatter; a predominance of eastern and southeastern directions may be discernible.

Secondary deformation of stratification by organic activity is manifested by vertical burrows in the clayey intercalations and in the upper part of the

sands. In the lower 150 cm of Unit III, the burrows are always of small dimensions (diameter up to 1 cm, length up to 5 cm). Farther upwards, they occur along the surfaces of truncation, which separate sandy beds, and their size increases markedly (diameter up to 3 cm, length up to 20 cm).

*Faunal content* (sample nr. 6 and 7):

– Benthonic Foraminifera: This unit shows a strong increase in foraminiferal abundance per sediment volume in its basal part, as compared to the underlying units. Internally a further upward increase is to be noted (benthos-index 250 near the base, 400 near the top). Conditions of exposure prevented trustworthy sampling of the relatively thin clayey beds.

In the lower sample, *Nonion depressulum* (21%), *Ammonia beccarii* (14%), *Protelphidium lidoense* (11%) and *Reussella spinulosa* (9%) are the most important forms. Fairly high frequencies are reached by *Rosalina araucana*, *Cibicides lobatulus*, *Elphidium macellum* and *Cribrononion gunteri* (3–4%). Several species already met with in Units I and II occur in low quantities: *Cribrononion excavatum* and *C. incertum* amongst others.

The increasing number of individuals per sediment volume is accompanied by a growing diversity (29 species recorded near the base, 36 at the top). *Ammonia beccarii* is still an important faunal constituent in the upper level of the unit (12%), but it occurs in a different assemblage, with *Elphidium macellum* (14%), *E. crispum* (11%), *Quinqueloculina aspera* (9%) and *Cribrononion gerthi* (8%). The relatively high abundance of Miliidae (25%) is remarkable here (12% in the lower sample).

The remaining part of the fauna consists of forms, which were already registered in the lower levels, all of them occurring in low abundance. The *Cribrononion excavatum* – *C. incertum* association of the basal part of the section is virtually absent here; species like *Nonion depressulum* and *Protelphidium lidoense* appear to be strongly reduced.

With respect to the underlying sediments, Unit III shows a distinct increase in maximum size of specimens, particularly due to the presence of *Elphidium macellum*, *E. crispum*, *Cibicides lobatulus* and *Quinqueloculina longirostra*. The maximum size recorded for *Ammonia beccarii* and *Protelphidium lidoense* is also distinctly larger than it is in lower levels of the succession (textfig. 3).

– Planktonic Foraminifera: Planktonic forms (mainly *Globigerinoides ruber*) occur in fairly great numbers in sample 6 (9/100), but they are rare in the upper sample (3/100).

– Ostracoda: Very common in the lower part of the unit (36/100), the number of carapaces is reduced near the top (10/100).

In the lower sample *Falunia rugosa* prevails, but it seems to lose its dominant position farther upwards. Two other species recorded earlier, *Xestoleberis communis* and *Aurila* ex gr. *punctata*, are present in both samples. *Leptocythere* sp. 1. was met with only in the lower one.

As a whole, the ostracodal fauna is characterized by the low frequency occurrence of species, which were not found at lower levels, e.g. *Aurila calciplena* and *A. ulicznyi*.

Reviewing the ostracod fauna of Units I–III, a slight increase of maximum size of carapaces may be deduced in an upward sense. In the silty-sandy strata, the relative importance of complete carapaces seems to increase in the same direction.

– Bryozoa: The frequency of bryozoan fragments, very low in Unit II, shows an important increase in Unit III (maximum 19/100). Species of *Crisia* are again prevalent, particularly *C. fistulosa* in the lower sample. In an upward sense, the diversity of the bryozoan assemblage increase, due to the low frequency presence of forms like *Scrupocellaria* sp. and *Chaperia* sp. (?).

– Mollusca: Although present in a very small quantity of relatively small specimens, the appearance of the macro-pelecypod species *Spisula subtruncata* in the upper levels of the unit, is notable. Its loose shells occur in random distribution.

Unit IV: thickness 40 cm.

This unit is separated from Unit III by an irregularly undulating surface (“amplitude” of undulations up to 25 cm., “wavelength” up to 3 m).

*Texture and composition:* The basal part of the unit shows concentrations of pebbles of pre-neogene limestone and clay pebbles in depressions of the underlying, erosional surface (diameter of pebbles up to 7 cm). These coarse components are embedded in, and covered by, a somewhat clayey, fine sand with medium sand grains as subordinate admixture. Along the upper boundary of the unit the sediment is a better sorted, fine sand with medium sand components.

The coarse fraction of the sand frequently contains shell-fragments. Echinoid spines, fragments of calcareous algae and oolitic grains occur as minor components.

*Bedding and sedimentary structures:* Internal structures are either absent or very indistinct. Patches of vague lamination occur randomly distributed. Local pockets of shell-fragments are reminiscent of burrowing structures.

*Faunal content* (sample nr. 8 and 9).

– Benthonic Foraminifera: The trend of increasing frequency of benthonic Foraminifera in Units I–III culminates in Unit IV with a benthos-index of 500. In the upper sample of relatively well sorted sand their quantity is, however, substantially reduced (80). The increased abundance of foraminiferal tests in the bulk of the sediment goes together with a further increase in faunal diversity (42 species recorded).

The most striking aspect of the composition of the assemblage is the importance of Miliolidae (46% below, 70% near the top). In the main part of the unit, *Quinqueloculina cf. costata* (10%), *Q. aspera* (9%) and *Q. longirostra* (5%) are well represented. They occur together with relatively high numbers of broken and corroded, indeterminable miliolid specimens (6%).

Remarkable is the occurrence of Textulariidae, particularly *T. agglutinans* and *T. candeiana*, which reach a total of 10%, and of *Planorbulina mediterraneensis*.

Among the species registered at lower levels of the succession, *Nonion depressulum*, *Ammonia beccarii*, *Cribrononion gerthi*, *C. asklundi*, *C. incertum*, *C. articulatum*, *Elphidium macellum* and *E. crispum* are fairly well represented.

The relatively scarce fauna in the upper few cm of the unit shows a high frequency of Miliolidae and a diversified composition, without any prevailing species.

The maximum size of foraminiferal tests shows no appreciable difference with that near the top of the preceding unit (textfig. 3).

– Planktonic Foraminifera: Planktonics occur in low quantities (4/100).

– Ostracoda: The frequency of Ostracoda is of the same order as at the top of Unit III. The fauna is affected by important qualitative changes. In the main part of the stratum, *Leptocythere* sp. 3 is the major form; *Aurila calciplena*, *A. ex.gr. punctata* and *A. cruciata minor* are present in low numbers.

– Bryozoa: Bryozoan fragments occur in relatively low abundance. Species of *Crisia* are prevalent; *Scrupocellaria*, species are present as well.

Unit V: thickness 70 cm.

*Texture and composition*: Characteristic are horizontal shell stringers; the loose shells are predominantly arranged in convex-up position. Four to five of such levels, which are laterally somewhat discontinuous, may be distinguished. Bivalves in situ and displaced shells in random position occur locally in the interjacent sands (fig. 3).

Coarse, generally well rounded, but in some instances very angular limestone pebbles occur as subordinate components of the shell-stringers. The bulk of the sediment consists of a medium grained sand with some addition of clay and coarse sandy grains.

The non-terrigenous part of the coarse fraction consists mainly of shell-fragments; echinoid spines, fragments of calcareous algae and oolitic grains are additional constituents.

*Bedding and sedimentary structures:* The sands between the shell-stringers do not reveal any primary structure. The absence of lamination is probably connected with the occurrence of bivalves in situ, as well as with the presence of burrowing structures of relatively large dimensions. These are shell-lined, cylindrical pockets with a concave-upward base. They locally descend from the shell beds, down to depths of up to 40 cm below their starting-point.

*Faunal content* (sample nr. 10 and A):

– Benthonic Foraminifera: Although distinctly lower than in the preceding unit, the abundance of Foraminifera is still considerable; faunal diversity shows a slight decrease.

Miliolidae are again important, but they reveal a clearly different assemblage with *Triloculina inflata* (6%), *Quinqueloculina aspera* (5%), *Quinqueloculina semilunum* (5%), and broken miliolid specimens (5%).

Notable is the return of *Nonion depressulum* (13%) and *Ammonia beccarii* (8%) as important species. They are accompanied by *Cribronion articulatum* (7%) and a number of low frequency forms, known from Units I–III, e.g. *C. gerthi*, *C. incertum* and *Reussella spinulosa*.

In comparison to the preceding unit, the absence of Textulariidae and of *Planorbulina mediterraneensis* is remarkable.

The maximum size of several species is high in this unit, as it is in the lower part of the succeeding one, e.g. *Ammonia beccarii*, *Quinqueloculina longirostra* and *Q. aspera*.

– Planktonic Foraminifera: Plankton is present in intermediate frequency (6/100) and is dominated by *Globigerinoides ruber*.

– Ostracoda: Ostracode valves occur in fair abundance (8/100). *Xestoleberis communis* and *Leptocythere* sp. 1 reappear as important faunal elements. *Aurila calciplena* and *A. ex gr. punctata* were also registered.

– Bryozoa: The remains of Bryozoa are relatively scarce. *Scrupocellaria scruposa/scrupea* was recorded.

– Mollusca: The rich molluscan fauna is strongly dominated by *Spisula subtruncata* ( $\pm 60\%$  of the shells in convex-up position). This species is also

frequently present in autochthonous position. *Mytilus galloprovincialis* ( $\pm 13\%$  of displaced shells) and *Anomia ephippium* ( $\pm 10\%$ ) are well represented.

As more or less subordinate forms, *Alvania cancellata*, *Bittium reticulatum*, *Nassarius cf. incrassatus*, *Rissoa* sp., *Neverita josephina*, *Ringicula auriculata*, *Diodora italica*, *Haliotis lamellosa* and *Patella lusitanica* (Gastr.) and *Ostrea edulis*, *Cardium* sp., *Beguina calyculata*, *Arca noae* and *A. diluvii* (Pel.) may be mentioned.

– Miscellaneous: Fragments of the coral *Cladocora cespitosa* and tubes of *Ditrupa* sp. (Annelida) occur as rare additional elements of the macrofauna. *Balanus* sp. is abundant on shells of *Mytilus galloprovincialis* and on angular limestone fragments.

**Unit VI: thickness 80 cm.**

*Texture and composition:* Three subunits may be distinguished from bottom to top:

1. A fine grained sand with medium sand components, containing shells and macroscopical shell-fragments in its upper portion. The coarse fraction of the sediment is dominated by shell-fragments; of the other non-terigenous components, echinoid spines are common and oolitic grains occur rarely.

2. A thin clayey intercalation.

3. A fine grained sand without macrofossils and with a slight admixture of medium grained sand. In the coarse fraction, shell-fragments and oolitic grains are well represented.

*Bedding and sedimentary structures:* As a whole, the sediment may be described as a unit with intensive internal folding and local faulting, in between horizontal, undisturbed lower and upper bedding-planes.

Subunit 1, bounded by the thin clayey subunit 2, shows local mushroom-like masses, up to 70 cm across, with a high degree of internal distortion, as is apparent from the position of shells and from the small scale folding of the clayey stratum (fig. 4).

In juxtaposition with these structures, we find half-spherical to half-ellipsoidal bodies, consisting of subunit 3, with a clear downward folding of laminae, approximately concentric with the external shape of the bodies. The folding pattern shows normal and overturned synclines, the latter without apparent preference for any direction. Folds are locally disrupted by minor faults (fig. 5). These downfolded masses are underlain by sediments,

belonging to subunits 1 and 2, generally in a regular horizontal position, with some small scale folding, adapted to the external shape of the overlying sediment bodies and laterally passing into the mushroom structures described above.

*Faunal content* (sample nr. 11–12 and B):

– Thecamoebina: In the sample obtained from subunit 1, very rare tests of *Centropyxis marsupiformis* were observed.

– Benthonic Foraminifera: In subunit 1 a benthos-index of 300 was registered, whereas subunit 3 appears to be practically barren (5).

In the lower subunit, species diversity is considerable (39 species recorded). Miliolidae are again prevalent (52%); their assemblage shows some affinity to that of Unit V: *Quinqueloculina aspera* (12%), *Triloculina inflata* (6%), *Quinqueloculina longirostra* (3%), together with *Triloculina schreiberriana* (7%) and *T. adriatica* (5%).

The increased significance of plano-convex forms (*Cibicides*, *Asterigerina*, *Rosalina* etc.), which reach a total of 10%, is the only significant difference with the preceding unit.

The maximum size of foraminiferal tests does not show an appreciable difference with Unit V (textfig. 3).

Subunit 2 could not be sampled properly. This clayey seam evidently marks an important and sharp boundary in the microfaunal composition; the upper subunit only supplied a few tests of *Ammonia beccarii*.

– Planktonic Foraminifera: Planktonics are very rare in subunit 1 (3/100) and they seem to be completely absent in the upper member.

– Ostracoda: The Ostracoda are affected by a strong reduction in diversity in subunit 1. The occurrence of *Leptocythere* sp. 1 is the only correspondence with Unit V.

– Mollusca: The thin, contorted shell stringer in the upper part of subunit 1 contains two prevalent species, *Glycymeris* cf. *violascens* ( $\pm$  50%) and *Mytilus galloprovincialis* (14%). *Spisula subtruncata*, *Ostrea edulis*, *Nassarius* cf. *incrassatus* and *Diodora italica* occur among the subordinate forms.

– Miscellaneous: Rare fragments of the coral *Cladocora cespitosa* and specimens of *Balanus* on *Mytilus* shells should be mentioned.

Unit VII: thickness 90 cm.

*Texture and composition*: Slightly clayey, fine grained sands, with an admixture of medium sand grains in the lower part of the unit.

Clay pebbles are abundant in the upper 50 cm. They occur along partings

of sandy strata or arranged according to the internal stratification of the sands.

In the non-terrigenous coarse fraction, shell-fragments have decreased with respect to Units IV–VI; echinoid spines were met with only in the lower part of the unit, whereas oolitic grains show an increase.

*Bedding and sedimentary structures:* The lower 40 cm of the unit contain a delicate horizontal lamination (fig. 5). The upper part shows horizontal lamination and large scale cross-lamination, with prevalently low angles of inclination, arranged in often wedge-shaped and mutually truncating sets.

In a northwest-southeast trending section, a remarkable type of large scale cross-lamination, consisting of convex-up cross-laminae, was observed. The curved, continuously traceable cross-laminae show two opposed directions of apparent dip. In a cross-section, oriented normally to the local trend of the exposure, an inclination to the southwest was noted.

The surfaces of truncation, which separate the wedged-shaped, cross-laminated strata, are generally distinct and regular; they are the starting-point of rare, small burrows, descending in the underlying sediment.

The uppermost levels of this unit consist of tabular beds; their upper bedding-planes show patterns of symmetrical ripples, associated with an internal small scale cross-lamination.

The directions of dip of the large scale cross-laminae show a wide scatter in both western and eastern directions. The asymmetry of small scale cross-laminae reveals a prevalence of southward directions.

*Faunal content* (sample nr. 13 and 14):

– Thecamoebina: *Centropyxis marsupiformis* is again present in low numbers in both samples.

– Benthonic Foraminifera: The composition of the fauna confirms the change which occurs in the upper part of Unit VI, though the frequency and diversity of the assemblage is not so limited as it is in the latter level.

In both samples, *Ammonia beccarii* is strongly prevalent (50%) and accompanied by some subordinate species: *Cribronion excavatum*, *C. articulatum* and *Ammonia perlucida*.

*Elphidium macellum*, *E. crispum*, *Reussella spinulosa* and *Asterigerina planorbis* were only found in the lower portion of the unit. In the upper sample, *Nonion depressulum* appears in low quantity.

The increase in the number of plano-convex Foraminifera, noted in the preceding unit is continued in the lower part of this unit to a total of 20%.

As concerns the maximum size of tests, a tendency to reduction may be present (textfig. 3).

– Planktonic Foraminifera; Ostracoda, Bryozoa, Mollusca etc. were not observed.

**Unit VIII:** thickness 100 cm.

*Texture and composition:* Irregularly interstratified very fine sands and clays. Thickness of clays varying from 5 to 25 cm, thickness of sands from 3 to 18 cm.

The sands are poorly sorted; a considerable clay content and a admixture of medium sand grains are generally present.

Characteristic is the frequent occurrence of clay pebbles, arranged according to the stratification of the sands or concentrated in lenticular bodies with a fine sandy matrix (fig. 6).

Plant-remains are abundant, especially along the lower bedding-planes of the sandy strata. The frequency of the other non-terrestrial constituents, shell-fragments and oolites, is variable; echinoid spines were not met with.

*Bedding and sedimentary structures:* A distinctive feature is the rapid horizontal variation in thickness, shape and internal structure of the strata.

The sands are either lenticular in shape, with a fairly horizontal lower boundary and a convex-upward top, or laterally continuous. A common feature is the irregularity of their lower bedding-planes, which is due to organic activity, as well as to erosion and penecontemporaneous deformation (fig. 6).

Typical are sandy strata, which abut against clayey beds along irregularly inclined contacts, which are frequently associated with a concentration of clay pebbles in the sands. The reverse situation, clayey sediments abutting against irregularly truncated sands, is also present.

The relatively thin, lenticular beds show horizontal lamination and small scale cross-lamination with associated ripples in their upper part. Sandy beds of a greater thickness often consist of one set of large scale, low angle cross-lamination, with frequent internal unconformities and lateral transitions to horizontal lamination (fig. 6).

In other cases, the structure of such beds is very complex, owing to a superposition of large scale cross-laminated sets with opposed directions of inclination of cross-laminae, which are separated by surfaces of truncation, strewn with clay pebbles or by small scale cross-laminated intercalations.

Convex-up, large scale cross-laminae, as described in the preceding unit, were observed in a stratum with maximum thickness of 7 cm, exposed in a southeast-northwest trending section (fig. 6).

The distribution of the directions of inclination of cross-laminae shows a wide scatter of the large scale structures, with a prevalence of westerly orientations and a preferential orientation of small scale structures to the south.

*Faunal content* (sample nr. 15–19):

– Benthonic Foraminifera: The frequency of foraminiferal tests is very low (benthos-index up to 50).

Among the low number of counted individuals, *Ammonia beccarii* seems to be predominant in most samples. It often occurs together with *Protelphidium lidoense*, *Ammonia perlucida* and *Reussella spinulosa* as subordinate forms.

The fauna is composed of mainly small individuals (textfig. 3).

– Planktonic Foraminifera: Planktonics were recorded in most samples (maximum of 3/25).

– Ostracoda: Carapaces of Ostracoda are extremely rare and seem to be limited to the sandy samples, which yielded *Leptocythere* sp. 1.

**Unit IX:** thickness 160 cm (lower 70 cm badly exposed).

*Texture and composition:* Alternation of very fine to fine sands and clays to silty clays. Maximum thickness of sands 20 cm, thickness of clays up to 10 cm in the lower part of the unit, decreasing to 3 cm near the top. The sands are generally badly sorted; grains of medium to coarse sand-size appear in the upper 100 cm of the unit.

At 80 cm below the top, pebbles of pre-neogene limestone (diameter up to 5 cm) occur scattered in a sandy bed.

The sands frequently contain clay pebbles, arranged in stringers according to the internal stratification. In the upper part of the unit, lateral transitions of thin clayey beds to clay pebbles seams are a common feature (fig. 7).

In the coarse fraction, shell-fragments are well represented, particularly so in the sands. The frequency of oolitic grains tends to decrease in an upward direction. Echinoid spines were recorded in the pebble bearing stratum.

*Bedding and sedimentary structures:* In comparison with the preceding unit, a greater lateral continuity of beds is to be noted. The internal structure of the sands in the partly obscured lower part of the unit seems to consist of horizontal lamination or large scale, low angle cross-lamination with superposed small scale cross-lamination and associated ripples. Small burrows are present in the clays and penetrate the upper part of the underlying sands.

Farther upwards, small scale cross-lamination is less frequent; here, the greater part of the thin clayey intercalations directly rests on horizontally or cross-stratified sands. Vertical burrows increase in dimensions up to a length of 15 cm. Reliable data regarding the orientation of small- and large scale cross-lamination could not be obtained.

*Faunal content* (sample nr. 20–24):

– Thecamoebina: *Centropyxis marsupiformis* was recorded in low frequency in two samples (maximum 3/50).

– Benthonic Foraminifera: The foraminiferal content of both the clayey and the sandy samples is considerably higher than in the preceding unit. In the sands, an irregular upward increase in abundance may be noted, with a maximum in the pebble bearing level (benthos-index 300, sample 22).

In the clayey sediments, *Ammonia beccarii* and *Nonion depressulum* are dominant in the lower part of the unit. Near the top, only the latter species reaches a considerable percentage (42%), accompanied by *Cribrononion excavatum* (12%). *Elphidium macellum*, *Cribrononion advenum* and *C. articulatum* are low frequency elements of both faunas.

In the sandy sediments, *Ammonia beccarii* decreases in an upward sense from 22 to 4%, whereas *Nonion depressulum* increases from 2 to 29%. In the lower portion of the unit, *Protelphidium lidoense* is relatively important (12%) and it is accompanied by *Cribrononion gerthi*, *Reussella spinulosa* and *Ammonia perlucida*.

In the sample obtained from the pebble bearing level (nr. 22), the miliolids *Quinqueloculina aspera* and *Triloculina trigonula* reach high frequencies (12 and 13% resp.). A considerable content of damaged and corroded Miliolidae is to be noted in addition (11%).

In the upper part of the unit, *Quinqueloculina aspera* (8%) and *Cribrononion asklundi* are important additional faunal constituents. In an upward sense, the importance of *Cibicides lobatulus* seems to increase in the sandy sediments.

Comparing the fine and coarse grained sediments in the upper part of the unit, it is remarkable to note the occurrence of a miliolid maximum in the pebble bearing level (total of 46%), a low percentage of 2 in the clayey sample nr. 23 and again 28% in the sandy sample nr. 24. In an upward sense, a trend to an increase of size of specimens is discernible in the sandy sediments.

– Planktonic Foraminifera: Planktonics display an irregular, low frequency distribution.

– Ostracoda: Ostracode carapaces reappear in this unit, without reaching

high frequencies, however (maximum of 3/50 in sample nr. 23).

The most regularly occurring species is *Leptocythere* sp. 1; *Aurila* ex gr. *punctata* is locally present in the upper part of the unit.

– Bryozoa: An upward increase in the number of bryozoan fragments reaches a maximum in the sandy sample nr. 22, which also shows the highest diversity, and in the clayey sample nr. 23. The upper part of the unit appears to be barren.

Species of *Crisia* are dominating in the lower reaches of the succession; in sample 22 *Margaretta cereoides*, *Metrarabdotos* (Porometra) *helveticum canariense* and *Entalophora* sp. are added to the assemblage. In the clayey sample 23, *Vittaticella* sp. and *Haplopoma bimucronatum* were recorded as additional species.

**Unit X:** thickness 10–30 cm (see enclosure II).

The lower boundary of this unit is formed by a more or less straight and horizontal surface, which shows local irregularities with an amplitude up to 10 cm. The upper limit is highly irregular in shape, owing to concave-upward, erosional truncations by the overlying unit.

*Texture and composition:* The basal part of the unit shows discontinuous concentrations of well rounded limestone-pebbles with a maximum diameter of 7 cm, mixed with shells and shell-fragments (fig. 7 and 8). The matrix, as well as the overlying sediment is a fine grained sand with coarse sandgrains.

The coarse fraction of the sands shows a relatively high content of echinoid spines and shell-fragments; oolites and fragments of calcareous algae are poorly represented.

*Bedding and sedimentary structures:* The local, relatively thick, conglomeratic bodies, display a cross-bedded arrangement of pebbles (fig. 7). The sands are largely homogeneous in structure.

*Faunal content* (sample nr. 25):

– Thecamoebina: One specimen of *Centropyxis marsupiformis* was registered per 100 benthonic Foraminifera.

– Benthonic Foraminifera: The frequency of foraminiferal tests is of the same order as in the upper part of the preceding unit (benthos-index 125); the faunal composition is, however, more diversified (29 species per 50 counted individuals).

The most striking property of the fauna is the predominance of Miliolidae (48%). *Triloculina inflata*, *T. trigonula*, *T. schreiberiana*, *T. adriatica*, *Quin-*

*queloculina parvula*, *Q. aspera* and *Q. cf. costata* may be mentioned, as well as the fairly high content of broken and corroded Miliolid specimens (8%).

As in Unit IV, the miliolid maximum appears to be associated with the occurrence of Textulariidae and *Planorbulina mediterraneensis* as subordinate faunal elements. Also the presence of *Miniacina miniaceae* may be remarked.

The remaining part of the fauna largely consists of forms already found in the foregoing unit: *Ammonia beccarii*, *Reussella spinulosa*, *Cribronion asklundi*, *Cibicides lobatulus*, *Cancris auriculus*, *Elphidium macellum* and *Protelphidium lidoense*, occurring in low frequencies.

A significant increase in maximum size of the tests, compared with the top of Unit IX, is not detectable, though some large specimens of *Cibicides lobatulus*, *Elphidium crispum* and *Quinqueloculina aspera* do occur.

– Planktonic Foraminifera: The frequency of planktonic tests is low (3/50).

– Ostracoda: A further increase in frequency of ostracod carapaces is combined with a growing diversity. *Leptocythere* sp., *Xestoleberis communis*, *Aurila ulicznyi* and *Urocythereis margaritifera margaritifera* were recorded in low numbers.

– Bryozoa: Fragments of Bryozoa are fairly well represented. In addition to the dominating *Crisia* species, *Savignyella lafontii* and probably *Margaritta cereoides* were registered.

– Mollusca: Micro-Pelecypoda and particularly micro-Gastropoda occur in abundance together with some macroscopic shells.

Unit XI: thickness 60–70 cm.

*Texture and composition:* Badly sorted, medium-coarse sands with abundant shells, shell-fragments and other skeletal remains, arranged according to the internal stratification.

The coarse fraction shows a composition comparable to the preceding unit, with frequent echinoid spines and shell-fragments.

*Bedding and sedimentary structures:* In southeast-northwest sections, the shell-bearing sediments display a highly complex superposition and juxtaposition of cross-stratified sets, with a thickness of up to 30 cm, irregularly concave-upward lower boundaries and two opposed directions of inclination of internal cross-strata (fig. 8). In sections oriented approximately normal to the former an irregularly horizontal internal stratification is predominant.

*Faunal-content* (sample nr. 26 and C):

– Benthonic Foraminifera: Foraminiferal abundance shows a sudden and strong increase (benthos-index 1000).

In a qualitative sense, the association of numerous Miliolidae (64%), with Textulariidae (5%) and *Planorbulina mediterraneensis* (3%) attracts our attention. Among the Miliolidae, *Quinqueloculina longirostra* (19%), *Q. cf. costata* (14%) and *Triloculina adriatica* (11%) are prevalent, whereas *Quinqueloculina aspera* is fairly well represented.

In the non-miliolid component of the fauna, *Cibicides lobatulus* and *Cancris auriculus* each occur with 7%. Species, which played an important part in Units IX–X, are less frequent, *Ammonia beccarii* and *Protelphidium lidoense* occur in low quantities.

The maximum size of foraminiferal tests is not appreciably different from that in the preceding unit; particularly *Quinqueloculina longirostra*, *Cibicides lobatulus* and *Cancris auriculus* are represented by large individuals (text-fig. 3).

– Planktonic Foraminifera: practically absent.

– Ostracoda: Relatively few (6/100). The occurrence of *Loxococoncha rhomboidea* seems to be the only important difference with Unit X. *Leptocythere* sp. 1, *Xestoleberis communis* and *Urocythereis margaritifera margaritifera* are again represented.

– Bryozoa: Remarkable is the frequent occurrence of large fragments of the Reteporiform Sertellidae. In the microscopic fraction, the Bryozoa are rare; *Savignyella lafontii* should be mentioned.

– Mollusca: The numerous specimens generally do not exceed 3 cm in diameter. *Corbula gibba* ( $\pm 14\%$ ) and *Ringicula auriculata* ( $\pm 18\%$ ) are prevalent. *Anomia ephippium*, *Laevicardium crassum*, *Cardium* sp., *Arca noae* (Pel.) and *Nassarius semistriatus*, *N. reticulatus*, *N. cf. mutabilis*, *Patella lusitanica*, *P. caerulea* (Gastr.) occur as additional elements of the fauna. The Scaphopod *Dentalium inaequicostatum* is well represented.

– Miscellaneous: Remarkable is the presence in situ of a large colony of the coral *Cladocora cespitosa*, presumably attached to one of the bounding surfaces of cross-stratified sets. Fragments of corals are very abundant in the sediment, furthermore *Ditrupa* sp. (Annelida) is a frequent faunal constituent.

Unit XII: thickness 80 cm.

*Texture and composition:* A distinct lower boundary is not discernible. The sediment is a medium-coarse grained sand, with a lower content of shells and other skeletal remains than in the preceding unit.

The coarse fraction again shows echinoid spines and shell-fragments as important constituents and relatively rare oolitic grains.

*Bedding and sedimentary structures:* The distinguishing feature of the unit is the absence of internal stratification. Shells and skeletal fragments do not show any regularity in their arrangement.

Pelecypoda locally occur in situ and in pocket-shaped concentrations (diameter up to 25 cm) of shells and shell-fragments, showing an arrangement of the shells approximately concentric with the concave-upward bottom of the pockets and a tendency to a decrease of shell-size in an upward sense (fig. 9).

*Faunal content* (sample nr. 27 and D):

The organic remains in sample 27 are strongly affected by secondary calcification; as a consequence the method of flotation in carbon tetrachloride could not be used in this case.

– Benthonic Foraminifera: Foraminifera are very abundant (benthos-index 1200); as compared with the preceding unit, the diversity of the fauna is considerably smaller.

Miliolidae are again a prominent component of the microfauna (30%), but the individual species do not reach high percentages; best represented are *Quinqueloculina aspera* (5%) and *Q. vulgaris* (3%). The high number of indeterminate Miliolidae (10%) is due to the secondary calcification and not to damage and corrosion.

The greater part of the fauna consists of plano-convex forms (42%), among which *Asterigerina rhodiensis*\* (27%), insignificant in the lower reaches of the succession, suddenly becomes an important faunal element. It is accompanied among others by *Asterigerina planorbis* (6%), *Cibicides lobatulus* (4%) and *Rosalina globularis* var. *bradyi*.

In the remainder of the assemblage, *Ammonia beccarii* (10%), *Protelphidium lidoense* (4%), *Elphidium macellum* (5%) and *Elphidium crispum* (5%) are well represented.

Several species reach considerable size: *Ammonia beccarii*, *Protelphidium lidoense*, *Elphidium macellum*, *Elphidium crispum* and *Asterigerina rhodiensis* (textfig. 3).

– Planktonic Foraminifera: Plankton was not observed.

– Ostracoda: As in the preceding units, Ostracoda are relatively rare. *Falunia rugosa*, *Aurila* ex gr. *punctata*, *A. calciplena* and *Hemicytherura videns* were registered in low frequencies.

\* We are fairly certain that our specimens are conspecific with Terquem's species, described from the Pliocene of Rhodos, notwithstanding the poor preservation of our recrystallized material and the poor quality of Terquem's figures. It is considered likely that his *A. hieroglyphica* is equally represented among our specimens.

– Bryozoa: The fragments of Bryozoa are rare (4/100). Sertellidae of smaller size than in the lower unit, are dominating.

– Mollusca: The gastropod *Gibbula* sp. very subordinate in the preceding unit is strongly dominant as this level ( $\pm 33\%$ ). Among the Pelecypoda, *Cardium* sp., *Venus* cf. *ovata* and *Callista chione* are reasonably well represented ( $\pm 8\%$ ). The Scaphopod *Dentalium inaequicostatum* is relatively rare.

– Miscellaneous: Fragments of corals are rare. *Ditrupa* sp. (Annelida) occurs in abundance.

**Unit XIII:** thickness 85 cm. (unfavourably exposed).

*Texture and composition:* Interstratified sands and silty clays. Maximum thickness of sands 10 cm, thickness of clays varying from 1 to 4 cm. The grain-size of the sands decreases from medium to fine in an upward sense.

A high content of plant-remains and the local presence of clay pebbles are notable. In the coarse fraction, shell-fragments are common, whereas echinoid spines and oolites are rare.

*Bedding and sedimentary structures:* The sands appear as laterally traceable strata, without any visible internal stratification. This property may be the result of organic activity, though neither sands nor clays show any trace of vertical burrowing. The unfavourable exposure of this unit causes some doubt regarding the validity of these conclusions.

*Faunal content* (sample nr. 28–30):

– Benthonic Foraminifera: The frequency of Foraminifera is strongly reduced as compared to Unit XII (maximum benthos-index 600).

Remarkable is the virtual disappearance of Miliolidae, with a maximum of only 4%. Yet, the assemblage shows a close similarity to the microfaunal composition of the foregoing unit, due to the prevalence of *Asterigerina rhodiensis* (decreasing upwards from 22 to 15%), *A. planorbis* (up to 11%), *Cibicides lobatulus* (maximum of 16%), *Elphidium macellum* (up to 8%), and *Protelphidium lidoense* (increasing upwards to 12%) in sands and in clays. Textulariidae (4%), accompanied by *Planorbulina mediterraneensis* and *Miniacina miniaceae*, are virtually restricted to the basal sandy sample. *Ammonia beccarii* is important only in the sandy samples (maximum 12%).

Another notable difference between the two types of sediment is the considerable frequency of *Cribronion excavatum* (7%) in the clayey stratum, where it occurs in company of *Nonion depressulum*, *Cribronion gunteri*, *Reussella spinulosa* and *Ammonia perlucida*, all in low frequency.

Due to the presence of *Cribronion excavatum*, *Nonion depressulum*,

*Reussella spinulosa* and *Ammonia perlucida*, the composition of upper sandy sample resembles the assemblage in the clayey intercalation.

Generally speaking, the fauna is composed of specimens of a somewhat smaller size than in the preceding unit, while there is an upward decrease in dimensions. A distinct difference in size between the assemblages of sandy and clayey samples could not be detected (textfig. 3).

– Planktonic Foraminifera: Plankton, mainly *Globigerinoides ruber*, reappears in low quantities (max. 4/100).

– Ostracoda: An upward increase in frequency may be inferred in combination with an increasing diversity.

*Urocythereis margaritifera margaritifera* is represented in all three samples; *Xestoleberis communis* appears to be restricted to the sandy strata, whereas *Leptocythere* sp. 1, *Falunia rugosa* and *Aurila* ex. gr. *punctata* reappear in the upper part of the unit. On the other hand, *Hemicytherura videns* seems to be restricted to the lower portion.

– Bryozoa: Bryozoan fragments also reveal a considerable increase in abundance in all three samples (maximum 12/100). Different species of *Crisia* (*C. fistulosa*, *C. denticulata*, *C. elongata*) tend to increase in significance in an upward sense. In the basal part of the unit they occur together with Sertellidae; farther upwards *Scrupocellaria scruposa/scrupea* is present.

**Unit XIV:** thickness 275 cm.

*Texture and composition:* Alternation of predominantly fine to very fine sands and generally silty clays, with local intercalation of silty sands and slightly sandy clays. Thickness of sands varying from 2 to 22 cm; maximum thickness of clays 8 cm. A distinct overall vertical trend in grain-size and sand-clay ratio was not observed; however, the upper 30 cm of the unit is characterized by a predominance of very fine to silty sands.

Plant-remains are only rarely present in the sands, which reveal a variable content of clay pebbles. In the coarse fraction of both sands and clays, shell-fragments play a major part; echinoid spines and oolites are regularly present in low frequencies.

*Bedding and sedimentary structures:* The sandy strata generally display the usual disposition of structures: horizontal lamination or large scale, often low angle cross-lamination, truncated by small scale cross-lamination and associated ripple marks. The degree of preservation of the latter structures is variable (fig. 10 and 12). Small vertical burrows are locally abundant in the clay strata.

The unit presents some well exposed examples of large scale, convex-up cross-lamination, characterized by an "anticlinal" shape of cross-laminae (fig. 11). In juxtaposition with this structure small scale channel-fills with internal cross-lamination occur.

A type of small scale cross-lamination, characterized by a relatively great set-length and straight set-boundaries, which are inclined in a direction opposed to the orientation of cross-laminae, was locally observed (fig. 12).

In sections with an approximately east-west trend, large scale cross-lamination reveals a prevalence of inclinations in western directions. A remarkable feature is the greater frequency of occurrences of convex-up cross-laminae in north-south trending sections.

*Faunal content* (sample nr. 31–37):

– Thecamoebina: *Centropyxis marsupiformis* is irregularly distributed in the sediments of this unit. The species reaches a frequency of 8/100 in the clayey stratum intercalated in the upper part of the succession.

– Benthonic Foraminifera: The sands show an upward decrease in foraminiferal content per sediment-volume (benthos-index 400 to 90). The silty stratum at the top of the unit has a relatively high frequency (600).

Both clayey samples are significantly different in their predominant species. In the lower sample (nr. 31), *Nonion depressulum* (24%) and *Protelphidium lidoense* (11%) are prevailing, in association with low frequencies of *Ammonia beccarii*, *Cribrononion asklundi*, *C. incertum*, *C. excavatum* and *C. gunteri*.

The upper sample (nr. 34) has very high numbers of *C. excavatum* (55%); *C. incertum* (13%), *C. gunteri* (8%), *Ammonia beccarii* (5%) and *C. asklundi* (4%) are well represented.

Approximately comparable differences are shown by the sandy samples. In the lower sample (nr. 32), *Protelphidium lidoense* (23%) and *Cribrononion asklundi* (20%) are dominant; *Ammonia beccarii* (8%), *C. excavatum* (5%), *Nonion depressulum* (5%), *Reussella spinulosa* (4%) and *Ammonia perlucida* (4%) are fairly well represented. The total content of plano-convex forms is considerable (12%), with *Asterigerina planorbis* (5%) as the most important form; *A. rhodiensis*, highly dominant in the preceding units, is additional only.

In the rather meagre fauna of the second sandy sample (nr. 33), *Ammonia beccarii* (20%) prevails; *Cribrononion gunteri* and *Protelphidium lidoense* occur in low frequency. As a group, plano-convex forms are again well represented.

The relatively rich assemblage recorded in the silty sample nr. 35 contains

high quantities of *Cribronion excavatum* (15%), *Protelphidium lidoense* (12%) and *Ammonia beccarii* (7%); *Reussella spirulosa* (7%), *Ammonia perlucida* (4%), *Fursenkoina schreibersiana* (5%) and *Nonion depressulum* (8%) are fairly important. Plano-convex forms, particularly *Rosalina* sp. (14%) and small, thin-tested individuals of *Bulimina*, *Brizalina*, *Loxostomum* and *Globulina* (7%) are additional constituents.

Relative to the foregoing unit, the fauna consists of small specimens; an internal upward decrease in maximum size is discernible (textfig. 3).

– Planktonic Foraminifera: Planktonic Foraminifera, with *Globigerinoides ruber* as the prevailing species, are particularly frequent in the upper clayey sample (nr. 34). In the sandy samples 32 and 33 they occur in the normal low abundance.

– Ostracoda: In the lower part of the unit, the ostracod-content of sands as well as clays is very low. Fairly high frequencies were registered in the upper clayey sample and in the uppermost silty stratum.

In the lower reaches, *Falunia rugosa* is regularly present, with *Krithe* sp. as an additional species. The upper clayey sample is dominated by *Leptocythere* sp. 1; *Loxoconcha turbida* is well represented. The low frequency occurrence of *Cyprideis torosa torosa* is worth mentioning.

*Leptocythere* sp. 1 is a minor component in the uppermost silty sample, which is dominated by *Falunia rugosa*, with *Xestoleberis communis* and *Krithe* sp. as subordinate elements.

– Bryozoa: Among the very few fragments species of *Crisia* are prevalent.

**Unit XV:** thickness 610 cm.

*Texture and composition:* Regular vertical alternation of predominantly very fine sands and silty sands, brownish silty clays and whitish to pink marly clays. In the lower 120 cm of the unit, a relatively great maximum thickness of the sands (25 cm) goes together with a rare occurrence of pink marly clays (subunit 1). Farther upwards the thickness of the sands rarely exceeds 10 cm while the marly intercalations are a common feature (subunit 2).

In Unit XV as a whole, the maximum thickness of brownish silty clays is 8 cm, usually it is less than 4 cm. Thickness of the whitish to pink marly clays is up to 4 cm, commonly it is in the order of 2 cm.

The sands locally contain small clay pebbles. Notable is the high content of plant-remains, in sands as well as in clays.

The coarse fraction of the sands is dominated by shell-fragments; the

content of oolites is variable, but often considerable. Echinoid spines are absent.

*Bedding and sedimentary structures:* There is a clear arrangement of the different sedimenttypes in a regular vertical order. A "complete sequence" may be summarized as follows (fig. 13):

a. Basal member, consisting of sand or silty sand, laterally continuous within the limits of the exposure and bounded by horizontal bedding-planes. Locally these sands are lenticular with a horizontal base and a convex-upward top. The dimensions and structure of such lenses vary from small ripple-shaped bodies of a few centimeters thickness and internal small scale cross-lamination ("Linsen") to accumulations of a greater thickness and a horizontal extent of several meters, with a predominantly horizontally laminated internal structure (fig. 14), locally replaced by large scale, low angle cross-lamination.

The top of the lenses may show well preserved small scale cross-lamination with associated ripple-marks (fig. 13), but it is more often a highly irregular surface, sculptured by vertical burrows, which partly or completely destroy the pre-existing ripples (fig. 15). The upper bedding-planes of the sands show local concentrations of vegetal remains.

The lower boundary of these sandy members is always sharp; the contact with the overlying clayey sediments is either distinct or gradational.

b. A second member consisting of laminated brownish silty clays with abundant plant-remains and small vertical burrows. The upper contact of these members is of gradual nature.

c. An upper member composed of pink to whitish, marly clays with numerous vertical burrows, locally of a U-shaped variety, and with occasional plant-remains. Lamination was not detected.

Incompleteness of the succession a-b-c is in most instances due to the absence of the upper marly clays, but also an immediate superposition of c. on a. has been observed.

The occurrences of large scale, low angle cross-lamination reveal two opposed directions of inclination of the laminae. In approximately east-west trending sections there is a predominance of western directions. In the hardly accesible north-south sections, large scale, convex-up cross-lamination was observed.

*Faunal content* (sample nr. 38–48):

– Thecamoebina: Very rare *Centropyxis marsupiformis* were recorded in sandy and clayey samples.

– Benthonic Foraminifera: The benthos-index of sands and clays is gener-

ally very low (5–50); intercalations of higher frequency levels occur in sandy sediments (up to 175). The lowest values were recorded in the thin intercalations of marly clays.

In subunit 1, *Ammonia beccarii* is generally prevalent, *Ammonia perlucida* is regularly represented. *Cribronion gunteri* locally reaches a high frequency. There are dispersed occurrences of *Rosalina globularis* var. *bradyi*, *Cancris auriculus*, *Cibicides lobatulus* and *Discorbinella bertheloti*.

In a high frequency, sandy level, the assemblage of *Ammonia beccarii*, *A. perlucida* and *Cribronion gunteri* is accompanied by *Protelphidium lidoense*, whereas *Nonion depressulum*, *C. asklundi* and *C. incertum* are subordinate forms.

In subunit 2, *Ammonia beccarii* and *Protelphidium lidoense* are the leading species; *Nonion depressulum* is locally important. The irregular, low frequency occurrence of *Cribronion incertum*, *C. excavatum*, *C. gunteri*, *Rosalina globularis* var. *bradyi*, *Cibicides lobatulus* and *Cancris auriculus* should be mentioned.

– Planktonic Foraminifera: Plankton shows a scattered, low frequency distribution.

– Ostracoda: The generally poor assemblages of subunit I show the regular occurrence of *Loxoconcha turbida* (locally dominating), *Falunia rugosa*, *Leptocythere* sp. and *Krithe* sp. *Xestoleberis communis* occurs scattered and in low frequency.

Subunit II reveals the well-known association of *Leptocythere* sp. 1, *Falunia rugosa* and *Xestoleberis communis*.

Unit XVI: thickness 115 cm.

*Texture and composition:* Poorly sorted fine sand, with an admixture of medium sand-grains in its lower portion and of medium to coarse sand-grains in its upper part. Local stringer-shaped concentrations of clay pebbles with a maximum diameter of 3 cm, and intercalations of plant- and wood-remains occur along the lower boundary. Scattered clay pebbles occur farther upwards.

Levels of relative induration of a few centimeters thickness are arranged according to the internal stratification of the unit.

The non-terrigenous coarse fraction is dominated by shell-fragments; remarkable is the reappearance of echinoid spines and fragments of calcareous algae and the decreasing significance of oolites in comparison with the preceding unit.

*Bedding and sedimentary structures:* Characteristic is the disposition of mutually truncating sets of horizontal lamination and of large scale, low angle cross-lamination. The latter sets reach a thickness of 30 cm. Combination of a number of sections oriented obliquely to each other, reveals the presence of at least one large scale set of convex-upward cross-lamination with an axis oriented approximately to the southwest and a lateral extension in a section normal to this axis of about 10 m (maximum thickness 30 cm).

Vertical burrows of the large scale variety are abundant, descending from the internal surfaces of truncation.

*Faunal content* (sample nr. 49–50):

– Benthonic Foraminifera: With respect to the foregoing unit, the foraminiferal frequency is slightly higher again with an upward increase (benthos-index 70–100).

In the basal part of the unit, the assemblage is dominated by two species, which were already important in Unit XV, *Ammonia beccarii* (28%) and *Protelphidium lidoense* (20%), accompanied here by *Elphidium crispum* (20%). Notable is the presence of *Cibicides lobatulus* and Miliolidae.

The latter forms increase in significance to the top, reaching 22 and 12% respectively. *Ammonia beccarii* (22%) and *Elphidium crispum* (17%) are again important in the upper sample, whereas *Protelphidium lidoense* seems to have disappeared. Remarkable is the low frequency reappearance of *Asterigerina rhodiensis* in an assemblage, which is moreover characterized by many plano-convex forms (total of 40%), *Cibicides lobatulus*, in particular.

The maximum size of some of the species, which were also recorded in the preceding unit, shows a distinct increase: *Ammonia beccarii*, *Cibicides lobatulus*, while the appearance of large individuals of large individuals of *Elphidium crispum* is to be noted. (textfig. 3).

– Planktonic Foraminifera and Ostracoda were not recorded.

– Bryozoa: Fragments of Bryozoa reappear in low frequency.

**Unit XVII:** thickness 10 cm. (see enclosure III).

The base of this unit is a highly irregular surface, showing small depressions with a maximum depth of 15 cm.

*Texture and composition:* The irregular lower boundary of the unit is covered by a mixture of shells, macroscopical shell-fragments, fine gravel (maximum diameter 2 cm), clay and marl pebbles and subordinate limestone pebbles (diameter up to 6 cm), showing traces of boring activity of organisms.

The matrix of the sediment is a badly sorted medium-coarse sand. The thickness of this lower member varies from a few cm to 20 cm over depressions of the basal surface. On top of the coarse grained lower member occurs a fine-medium grained sand with scattered shells.

Shell-fragments are the predominant constituent of the non-terrigenous coarse fraction; echinoid spines and fragments of calcareous algae occur occasionally; oolites are absent.

*Bedding and sedimentary structures:* Internal stratification was not observed. This may be partly due to the chaotic nature of the coarse basal member, but it is evidently also influenced by the large scale burrows, descending from the overlying unit (fig. 16). The influence of secondary organic activity is attested by the random position of shells in the upper member.

*Faunal content* (sample nr. 51 and E):

– Benthonic Foraminifera: The sudden break in lithology in the succession is accompanied by an extremely strong increase in foraminiferal abundance (benthos-index 2000).

Prevalent faunal elements are *Cibicides lobatulus* (19%), *Elphidium macellum* (14%), *Elphidium crispum* (7%) and a diversified assemblage of Miliolidae (total of 34%) with *Quinqueloculina* cf. *costata* (4%), *Q. berthelotiana* (4%) and *Q.* cf. *angulata* (4%) as the most important species. The high percentage of Miliolidae is again associated with the occurrence of Textulariidae (4%) and *Planorbulina mediterraneensis* (4%). Broken and corroded Miliolids form a significant portion of the fauna (8%).

Apart from *Cibicides lobatulus*, plano-convex forms are represented by *Asterigerina planorbis*, *A. rhodiensis* and *Neoconorbina terquemi*. Of the species occurring in the preceding units, *Ammonia beccarii* and *Protelphidium lidoense* are present in low frequencies.

In a general sense, the assemblage consists of relatively large-sized individuals (textfig. 3). Although such a conclusion may not be valid for every species, a tendency to increasing size, as compared to the foregoing unit, may be inferred.

– Planktonic Foraminifera occur in low frequency (3/100).

– Ostracoda: Among the relatively numerous Ostracoda (17/100), *Aurila cruciata minor* is dominant. *Xestoleberis communis*, *Aurila uliczny*, *A. calciplena*, *A.* ex. gr. *punctata* and *Loxoconcha rhomboidea* occur as additional species.

– Bryozoa: Bryozoan fragments adapt themselves to the general picture of increasing faunal content (12/100) and reveal a relatively high degree of

diversity. Species of *Crisia* are important and accompanied by *Scrupocellaria scruposa/scrupea*, *Schizomavella auriculata*, *Metrarabdotos* sp. and *Dia-peroecia major*.

– Mollusca: The diversified macrofauna is dominated by the gastropod *Gibbula* sp. ( $\pm 33\%$ ). *Cardium* sp., *Venus* cf. *ovata*, *Corbula gibba* (Pelecypoda) and *Cerithium neogenitum*, *Bittium reticulatum* (Gastropoda) are well represented. Among the additional forms *Anomia ephippium*, *Venus gallina*, *Callista chione*, *Arca diluvii*, *Spondylus gaederopus*, *Nassarius cf. incrassatus* and *Ringicula auriculata* may be mentioned. *Dentalium inaequicostatum* (Scaphopoda) occurs rarely.

– Miscellaneous: Fragments of corals are fairly frequent. Specimens of *Ditrupa* (Annelida) were rarely observed.

**Unit XVIII:** thickness 65 cm.

*Texture and composition:* In a lithological sense, this unit is similar to the upper part of the preceding one: badly sorted fine-medium grained sand with scattered shells of smaller size. There is no distinct lower boundary.

As in Unit XVII, the coarse fraction shows a predominance of shell-fragments with a subordinate occurrence of echinoid spines and fragments of calcareous algae.

*Bedding and sedimentary structures:* Internal stratification is again absent. Characteristic is the high density of large scale burrowing structures, among which two types may be distinguished:

a. Irregular tubular burrows with a diameter varying from 2–4 cm, descending from the upper boundary of the units and reaching downward to immediately above the basal coarse-grained deposit of the preceding unit. The burrows show a knobby surface and frequent bifurcations with local horizontal stretches; their high degree of induration makes them a prominent feature of the sediment (fig. 16).

b. Pocket-shaped burrows with a concave upward base of the same nature and dimensions as described in Unit XII. The starting-point of this second type of burrows is also at the upper boundary of the unit.

*Faunal content* (sample nr. 52–54 and F):

– Benthonic Foraminifera: The increase of foraminiferal content noted in the preceding unit is continued and reaches the highest values registered in the section as a whole (benthos-index 3000).

The major features of the faunal development in a vertical sense are:

1. The frequency reached by *Cibicides lobatulus* in the middle part of the unit (50%) and its subsequent decrease. The species is accompanied by *Asterigerina planorbis*, *A. rhodiensis* and *Cibicides dutemplei*.

2. The diminishing importance of Miliolidae (34–6%); Textulariidae and *Planorbulina mediterraneensis* (max. 5%) were recorded. In the basal part of the unit, *Quinqueloculina berthelotiana* (10%) is the major representative of the Miliolidae; broken and corroded specimens are relatively abundant (9%).

3. The relatively reduced numbers of *Elphidium macellum* and *Elphidium crispum* in the basal part of the unit (total 8%) and the distinct upward increase of these species (up to about 20%).

Differences in maximum size of individuals with respect to the preceding unit could not be observed.

– Planktonic Foraminifera: They are fairly well represented in the lower part of the unit (6/100). *Globigerinoides ruber* is prevalent.

– Ostracoda: Their carapaces are relatively abundant and show a high diversity. *Aurila cruciata minor* and *Loxoconcha rhomboidea* are the most prominent and regularly occurring species, particularly so in the lower and upper part of the unit. *Xestoleberis communis*, *Aurila* ex. gr. *punctata* and *A. maculosa*, occur more or less regularly among the subordinate faunal elements.

A general characteristic of the fauna is the relatively large size of its constituents and the abundance of complete carapaces (approximately 80% of the total assemblage).

– Bryozoa: were registered in considerable frequency. Species of *Crisia* seem to increase in importance in an upward sense. *Scrupocellaria* sp., *Entalophora* sp., *Hippaliosina depressa* and *Calpensia* sp. occur as additional forms, especially in the lower part of the unit.

– Mollusca: The diversified assemblage contains the following prevalent forms: *Bittium reticulatum*, *Gibbula* sp., *Ringicula auriculata*, *Tricolia pullus* (Gastropoda) and *Cardium* sp. *Venus gallina*, *V. cf. ovata*, *Callista chione* (Pelecypoda), reaching percentages of  $\pm 5$ –10%. Among the subordinate elements *Diodora italica*, *Patella caerulea*, *Begonia calyculata*, *Arca diluvii*, *A. noae*, *Chama gryphoides* and *Triphora perversa* are to be noted. The Scaphopod *Dentalium inaequicostatum* is rare.

– Miscellaneous: *Balanus* and fragments of corals were rarely observed.

**UNIT XIX:** thickness 290 cm (unfavourably exposed).

*Texture and composition:* Interstratified fine grained sands and slightly marly clays. Thickness of sands varying from 4 to 12 cm.; thickness of

clayey intercalations 2–3 cm. Sorting of the sands is poor; significant quantities of very fine- and medium sand grains are generally present.

In the coarse fraction of the sands, shell-fragments and oolites are common, echinoid spines are rare in the lower part of the unit.

*Bedding and sedimentary structures:* Poor exposure did not allow a detailed study of the stratification. Individual strata seem to be fairly continuous in a lateral sense. Internally, the sands probably contain horizontal lamination or large scale, low angle cross-lamination, underlying small scale cross-lamination with associated ripples along the upper beddingplanes. Small vertical burrows are present in the clays.

*Faunal content* (sample nr. 55–57):

– Benthonic Foraminifera: The lithological change from continuously sandy sediments to a sand-clay alternation goes together with a considerable decrease in foraminiferal content per sediment-volume. The benthos-index seems to show an upward diminuation in the sandy strata (500–200), but the lowest value (80) was obtained in the clayey sample.

In the lowermost sandy sample, *Elphidium crispum* (38%), *Cibicides lobatulus* (16%), *Cancris auriculus* (10%) and *Ammonia beccarii* (10%) are the dominant forms in an assemblage, which also shows a high quantity of plano-convex species (30%) and a low content of Miliolidae (5%).

Farther upwards, *Ammonia beccarii* reaches a percentage of 15%; it is accompanied by *Ammonia perlucida* (12%), *Protelphidium lidoense* (10%), *Cibicides lobatulus* (10%), *Cribrononion advenum* (7%), *Reussella spinulosa* (7%), and low numbers of *Nonion depressulum*, *Cribrononion incertum*, *C. excavatum* and *Fursenkoina schreibersiana*. Plano-convex forms show a marked decrease (18%); Miliolidae are completely lacking.

In the clayey sample obtained from this unit, *Ammonia beccarii* is again prevalent ( $\pm 27\%$ ), *A. perlucida*, *Cribrononion excavatum*, *Nonion boueatum*, *Cancris auriculus* and *Cibicides lobatulus* are well represented ( $\pm 8\text{--}13\%$ ). *Cribrononion incertum*, *C. asklundi*, *C. gunteri*, *Fursenkoina schreibersiana* and *Reussella spinulosa* occur in low abundance.

A general upward tendency to decreasing size of specimens is indicated by textfig. 3.

– Planktonic Foraminifera reveal an irregular low frequency distribution.

– Ostracoda: Ostracod carapaces occur in considerable numbers and diversity in the lower part. There is a strong decrease in frequency in an upward sense.

The most important species in the lower sandy sample are: *Loxoconcha turbida*, *L. rhomboidea* and *Aurila* ex gr. *punctata*. *Falunia rugosa* and

*Xestoleberis communis* were also recorded.

With respect to the preceding unit, complete carapaces are less frequent in the lower sample (about 60%).

Unit XX: thickness 70 cm (badly exposed).

The basal contact of this unit is unfavourably exposed: it probably shows small scale irregularities of an erosional nature. From a distance a slightly unconformable position of the overlying strata with respect to the underlying units can be observed.

*Texture and composition:* The sediment is composed of an irregular mixture of limestone pebbles (diameter up to 4 cm), rare shells and shell-fragments in a matrix of clayey fine-medium grained sand in the lower 40 cm, grading upwards into a sandy marl.

In the coarse fraction of the sediment, shell-fragments are a common constituent, whereas echinoid spines and oolitic grains were rarely observed.

*Bedding and sedimentary structures:* Primary internal stratification is absent. The random position of coarse components, in particular of shells, probably points to an intensive organic reworking of the sediment.

*Faunal content* (sample nr. 58–59):

– Benthonic Foraminifera: Foraminiferal frequency is affected by a sudden and strong increase (benthos-index 1500 near the base). In this basal sample *Bulimina gibba* is dominating (30%) together with *Fursenkoina schreibersiana* (17%), *Elphidium crispum* (15%) and *Cibicides lobatulus* (10%). *Elphidium macellum*, *Ammonia beccarii* and *Cancris auriculus* are fairly important (6–7%). The low frequency occurrence of Textulariidae must be mentioned.

As a whole, this basal assemblage is a mixture of relatively large foraminiferal specimens (*Elphidium crispum*, *E. macellum*, *Cibicides lobatulus*, *Cancris auriculus*) and small and thin-tested species (*Bulimina gibba*, *Fursenkoina schreibersiana*).

The decreasing grain-size in an upward sense is accompanied by a diminishing significance of the larger forms mentioned above and a augmentation of the total of *Bulimina gibba* and *Fursenkoina schreibersiana*. The appearance of forms like *Brizalina catanensis*, *Ammonia perlucida* and *Cribrononion incertum* suggests a gradual transition to the assemblage obtained in the overlying marly sediments (see below).

– Planktonic Foraminifera are rare.

– Ostracoda: Carapaces of Ostracoda were rarely met with; *Loxoconcha turbida* was recorded amongst others.

**Unit XXI:** thickness 350 cm.

*Texture and composition:* The lower boundary of this unit is of a gradual nature due to the progressive proportional increase of the marly matrix of the preceding unit and the disappearance of coarse constituents, ultimately leading to a slightly silty and sandy marl, containing rare and randomly dispersed shells.

Within the coarse fraction of the sediment, shell-fragments have decreased in importance. Oolitic grains occur as a very minor component; echinoid spines are absent.

*Bedding and sedimentary structures:* In a structural sense, the bulk of the sediment may be described as homogeneous. The absence of internal lamination must be attributed to organic reworking, though traces of burrowing or mottled structures seem to be absent.

*Faunal content* (sample nr. 60–63):

– Benthonic Foraminifera: In comparison with the clayey sediments, intercalated in the underlying units, the sediment shows a high frequency of Foraminifera, with possibly a slight decrease in the upper part of the unit (benthos-index 600–400).

The assemblage as a whole is strongly dominated by *Bulimina gibba* (up to 54%) and *Fursenkoina schreibersiana* (up to 36%).

*Brizalina catanensis*, some probably mutually related *Nonion* species (like *Nonion boueanum*, *N. grateloupi* and *Nonionella turgida*), *Ammonia per lucida*, *Cribronion asklundi*, *C. excavatum*, *C. incertum* occur regularly as subordinate elements of the fauna. *C. incertum* locally reaches important values up to 10%.

The qualitative composition of the assemblage points to the prevalence of small and thin-tested individuals.

– Planktonic Foraminifera are irregularly distributed in low frequency.

– Ostracoda: In the bulk of the sediment Ostracoda are rare; notable quantities were obtained only from the uppermost sample.

Near the top of the unit *Loxoconcha turbida* was registered.

– Mollusca: Bivalves were locally observed in living position.

## Chapter III

### SEDIMENTARY STRUCTURES AND DEPOSITIONAL SEQUENCES

#### III.1. SMALL SCALE CROSS-LAMINATION AND RIPPLE MARKS

Small scale cross-lamination consists of oblique laminae, with a maximum length of 8 cm, arranged in sets with a thickness, which generally does not exceed 5 cm.

At Ladiko-bay, the structure is represented by innumerable examples, particularly in the upper parts of the relatively coarse grained beds. It is commonly associated with ripple marks along the upper bedding-planes.

For the distinction of different types, much information could be gained from the horizontal variation in structure within individual beds. The juxtaposition of sets with a different external shape and a different internal disposition of cross-laminae, allows the recognition of types of cross-lamination, which appear to be intimately related.

On the other hand, an analysis of different types met with in vertical succession, reveals the presence of two structural categories, which, although individually heterogeneous, do not appear associated in the same sediment level.

It seems warranted to regard the latter types of cross-lamination as structural classes, which originated under conditions of sediment movement of a different nature. This approach forms the basis of the differentiation of small scale cross-lamination in two types.

#### *Type I*

A general characteristic is the arrangement of cross-laminae in sets of relatively short length (2–8 cm, generally 4–6 cm).

The sets may have a ripple shape, or appear in cosets, consisting of mutually truncating sets, without preservation of the ripple shape. Ripple form sets occur as solitary, lenticular intercalations in clayey sediment (“Linsen”) or along the upper bedding-planes of silty-sandy strata; in the latter case their relation to underlying small scale cross-laminated cosets is revealed in vertical sections.

The approximately symmetrical shape in cross-section of ripple form sets is a striking feature; the symmetry-index (ratio of projections of ripple-flanks, see Tanner, 1967) varies from 1 to 1.7. The crests may be rounded and low (height 1–2 cm) or sharp and high (height 2–4 cm).

When intercalated in clayey sediments, the lower boundary of the ripple form sets is straight. When appearing on top of a silty-sandy bed, the basal contact is concave-upward or undulating, in sections parallel to the directions of inclination of the cross-laminae (fig. 2, 6 and 10).

The nature of the concave-upward and undulating lower boundaries is distinctly erosional. The upper boundaries of ripple form sets may be sharp or gradational; in the latter case a gradual transition to the overlying clayey sediment is brought about by an increasing admixture of clay during the last phases of the ripple building (fig. 6).

The arrangement of cross-laminae within sets is variable. An asymmetrical, unidirectional orientation is, however, clearly prevalent. In such instances, the cross-laminae may show one conformable series or a juxtaposition of several bundles, separated by slight unconformities. A bidirectional orientation of cross-laminae is locally produced by the unconformable superposition of two bundles of cross-laminae with opposed directions of inclination within one ripple form set (fig. 6).

As far as could be ascertained, the greater part of the ripple patterns on the bedding-planes seems to consist of long and straight crests with parallel arrangement. The presence of two systems of crests, oriented normally to each other, was inferred in some instances.

#### Discussion:

The main contribution of the interpretation of small scale cross-lamination and associated ripple marks to paleogeographical reconstruction, is the differentiation between current- and wave-dominated environments. For this purpose the nature of ripple patterns, the external shape of ripple form sets, as well as their internal structure may be applied.

As has been pointed out by several authors (Tanner, 1967; Reineck and Wunderlich, 1968), straight, long and parallel crested ripple patterns are largely restricted to wave-agitated sediments; current action generally produces sinuous patterns, often of the short crested variety. Under conditions of oscillatory water movements, interference patterns, consisting of a superposition of two systems of crests, oriented normally to each other, are frequently developed.

The symmetry or asymmetry of ripple cross sections supplies another criterion of distinction. Generally speaking, the asymmetry of current-

formed ripples is conspicuously greater than it is in oscillatory ripple marks (Tanner, 1967; Reineck and Wunderlich, 1968). According to Tanner, the maximum symmetry-index of wave ripples (ratio of projections of steep and gentle slopes) is 3.0; current-formed types may display higher values with a minimum of 2.5. The observed variation from I to I.7 thus distinctly falls in the range of the wave-formed category. The occurrence of rounded and more or less sharp crested ripples in this group is a well known phenomenon.

Additional evidence regarding the origin of this type of cross-lamination may be derived from the study of distinguishing features of wave and current ripple structures by Boersma (1970). Sets of relatively small length with concave-upward to undulating lower boundaries and internal unconformities, and the occurrences of horizontal variations in structure within ripple systems or of gradual transitions to fine grained sediments, are characteristic properties of oscillatory small scale cross-lamination.

### *Type II*

Small scale cross-lamination characterized by a relatively great set length (up to 15 cm), an asymmetrical orientation of cross-laminae and prevalently straight lower boundaries of sets, showing an inclination in a direction opposed to the orientation of the cross-laminae.

The tangential position of cross-laminae with respect to the lower boundary of the sets is a characteristic feature, which is often associated with a strong development of bottomsets, simulating an alternation of parallel and cross-laminated levels (fig. 12).

Cosets of this type of cross-lamination may grade upwards and sideward into ripples with a nearly symmetrical cross-section; this transition is often associated with marked decrease in grain-size and an increasing intercalation of clayey laminae, which locally display a symmetrical, bidirectional disposition.

This type of structure is relatively rare; its occurrence seems to show a preference for some levels of the succession. Being comparatively frequent in Unit I, the structure is rare in Units II, III, VIII, XIV and XV. There seems to be a preference for silts and silty very fine sands.

As to its relation to other primary structures, type II of small scale cross-lamination was observed on top of horizontally laminated and large scale cross-laminated sands, and in beds with a continuously small scale cross-laminated structure.

### Discussion:

Our type II of small scale cross-lamination is a well known structure, generally described as climbing ripple lamination (see Mc Kee, 1939;

Reineck, 1961 and Allen, 1963b). As indicated by the tangential foreset-base, the frequent development of bottomsets and the inclined position of set boundaries, the structure is generated by migrating ripples under conditions of strong net-sedimentation.

Appreciable net-accumulation during ripple migration may ensue from the addition of fines from suspension, which may be expected to occur particularly in sediment-laden waters, when the movement is slowing down. The relative frequency of climbing ripple lamination in silts and silty very fine sands and the transition to clayey sediments, observed in the section at Ladiko-bay, are clear expressions of this process.

As has been pointed out by Mc Kee (1965) and Boersma (1970), climbing ripple lamination may be of the currentformed or oscillatory category. According to the second author, climbing oscillation ripples will often contain a cross-lamination, which is in some respects reminiscent of the normal wave ripple structures described above, *i.e.* there is a tendency to partial preservation of concave-upward lower boundaries of sets and of unconformities, separating successive bundles of cross-laminae.

In the section at Ladiko-bay, climbing ripple lamination is generally devoid of such features. Internal unconformities were observed in rare instances and set-boundaries generally appear as straight partings. Yet, the upward transition to nearly symmetrical ripples, conformably covered by clayey drapes, points to wave action during the ultimate phases of ripple building.

Summarizing, the data at our disposal probably point to an origin of our type II of small scale cross-lamination under the influence of currents of ephemeral nature. During and after the return of tranquil conditions these currents made way for oscillatory water movements.

### III.2. LARGE SCALE CROSS-LAMINATION

Large scale cross-lamination is defined as a structure consisting of strata oriented obliquely to the horizontal bedding-plane, with a length exceeding 10 cm in vertical sections normal to the strike of cross-strata, and arranged in sets with a thickness generally greater than 5 cm. At Ladiko-bay it is represented by three major varieties and a fourth type of subordinate significance.

#### *Type I*

Large scale, cross-lamination, consisting of delicate cross-laminae, arranged

in sets with a horizontal lower boundary, which is generally of a non-erosional nature.

The shape of the cross-laminated sets is variable; tabular shapes are prevalent, but wedge-shaped and lenticular forms were also observed. The upper bedding-planes of such strata are formed by prevalently symmetrical ripple marks with internal small scale cross-lamination of oscillatory origin. The maximum thickness of the type I cross-laminated sets varies between 3 and 40 cm, values from 10–20 cm being predominant.

The structure is most common in poorly sorted fine grained sands with a considerable clay admixture, but it was also met with in silty, very fine sands as well as in fine sands with medium sand components. Poor sorting may thus be considered a general property of these deposits.

The individual cross-laminae show no indications of lateral or vertical sorting. Small clay pebbles may occur in concentrations arranged along the cross-laminae or distributed at random. They appear to be strewn over the foreset front and reveal no concentration at the base of the cross-laminae. Concentration at the lower end of foresets is locally discernible if clay pebble size exceeds the diameter of 1 cm (fig. 2 and 6).

The maximum angle of inclination of cross-laminae, in sections normal to their strike, is  $25^\circ$  in relatively coarse grained sediments. In the majority of the observed examples, however, an inclination of  $15^\circ$  is not exceeded. In silty very fine sands values below  $10^\circ$  were recorded.

In addition to the delicacy of cross-laminae and the often low angle of their inclination, the tangential nature of the lower contact of foresets is a striking feature. The ensuing development of bottomsets may locally give rise to a lateral transition into horizontal lamination.

The absence of a conspicuous difference in grain-size between foresets and bottomsets is a typical feature of this type of cross-stratification. Transitions to horizontal lamination generally reveal the same feature, although an increasing concentration of small clay pebbles was locally observed in the horizontally laminated stretches. (fig. 2).

Generally speaking, the cross-laminae are arranged in a conformable series, displaying a unidirectional inclination. However, in a number of cases, the cross-laminated sets are composed of several bundles of oblique laminae, with a near-identical orientation, but separated by minor unconformities. Such unconformities may either increase or decrease the angle of inclination of cross-laminae (fig. 2 and 6).

The structural sequence within individual sandy strata, which contain this type of cross-stratification, usually consists of one set of large scale cross-lamination, overlain by small scale cross-lamination. In some cases, horizon-

tal lamination appears at the base or at the top of the large scale cross-laminated member. A superposition of two sets of large scale cross-lamination was observed in but very rare instances.

The overall direction of inclination of this type of structure appears to be scattered between southwest and northwest. Only in Unit VIII, a highly irregular directional pattern with orientations in western as well as in eastern directions was observed.

#### Discussion:

Generally speaking, large scale cross-stratification may originate under a variety of conditions. When we are dealing with tabular to lenticular bodies with horizontal lower boundaries and a clear preference for a certain orientation, an origin due to migrating large scale ripples seems the most plausible interpretation.

However, the structures discussed here, differ in several respects from the well known types of large scale cross-stratification in, for instance, fluvial and tidal deposits.

Our attention is attracted by the delicacy of the lamination, the often low angle of inclination of the cross-laminae, the absence of lateral and vertical sorting within the cross-laminae, the lateral transitions to horizontal lamination, the occurrences of internal unconformities within sets, the generally poorly sorted texture of the sediments and the prevalence of solitary sets.

As has been shown by several authors (see Jopling, 1965), the angle of inclination of a foreset-slope and the nature of its basal contact (angular or tangential) is primarily determined by the relative amounts of bed load and suspended load, that participate in the construction of the cross-stratified sediment. Under conditions of considerable bed load transport, intermittent avalanching down the foreset-front will maintain an angle of inclination approaching the angle of repose and will produce an angular basal contact.

Increased participation of suspended material, segregated by the lee-side vortex, will result in the formation of a toe-set at foreset-base (tangential lower contact) and may ultimately lead to reduction of the angle of inclination to less than  $20^\circ$ .

Due to the interaction of intermittent avalanching and deposition from suspension, a clearly definable alternation of coarse and fine cross-strata will come into being. Gravitative slip will lead to a distinct lateral and vertical sorting within the foresets. A diminishing significance of avalanching will cause a decreasing contrast between adjacent cross-laminae and a disappearance of internal sorting within foresets.

During the migration of the foreset-front, suspended particles may be

affected by selection according to their setting-velocity. Generally, finer particles will settle at a greater distance from the slope edge, thus causing a clear differentiation in grain-size of bottomsets and overlying foresets. Under conditions of decreasing flow competency, the increasing accumulation of fines will cause a lateral transition of a cross-stratified sediment to a relatively fine grained, horizontally laminated deposit. The influence of selection due to different particle trajectories, downstream of the foreset front, will, however, be reduced when high sediment concentrations are transported by high velocity currents. As pointed out by Jopling (1964), collective settling from sediment-laden eddies will cause an increasing rate of sedimentation and a decreasing contrast between foresets and bottomsets.

Accordingly, a horizontal passage of a cross-stratified sediment to a horizontally laminated deposit, without an appreciable change in grain-size, can be attributed to an increased velocity of flow in sediment-laden waters.

Internal unconformities, separating successive bundles of large scale cross-laminae, are indicative for erosional phases along the foreset front. Comparable phenomena are known from modern tidal megaripples and are regarded as being due to a partial destruction of the ripple front after a reversal of current direction (Boersma, 1969). Jopling (1965) experimentally produced corresponding features under the influence of waves, acting in an upstream direction.

A striking aspect of this type of cross-stratification at Ladiko-bay, is the prevalence of solitary sets. Under conditions of net-sedimentation, a continuous migration of ripple trains gives rise to a coset of cross-strata. In contrast, we may expect the occurrence of isolated cross-stratified bodies in environments, characterized by an intermittent supply of sand during high energy events of short duration. Rapid accumulation occurred during the waning phases of water agitation and the ripple movement was discontinuous as a result of fluctuating current velocities.

After the change of regime to a lower energy level, the newly formed silty and sandy bottoms were subjected to a superficial reworking, manifested by small scale cross-lamination and ripple marks of oscillatory origin.

Transitions from unidirectional currents to oscillatory water movements may be expected to occur in wind-induced currents, generated by the shearing stress, exerted by high velocity winds, blowing over the water surface (Tickner, 1961). Such currents are known to produce considerable sediment movement in shallow water (Fisk, 1959; Shepard and Moore, 1960; Ball et al, 1967). Large scale, low angle cross-stratification, attributed to wind-driven currents during storm-tides, is reported by Imbrie and Buchanan (1965) from the Bahamas. Ball (1967) describes large scale ripples, formed

during high energy events of short duration, from the same region.

During the deposition of the section at Ladiko-bay, the currents were oriented in western directions; the wave-formed low energy structures, however, point to sediment movement to the southeastern quadrant.

### *Type 2*

Large scale cross-lamination, characterized by a convex-upward, anticlinal shape of delicately developed cross-laminae in random sections (fig. 6 and 11) and a unidirectional inclination of cross-strata in sections parallel to the anticlinal axis.

The apparent angle of inclination in random sections generally does not exceed  $15^\circ$ ; in sections parallel to the axial orientation values up to  $20^\circ$  were observed.

The basal contact of cross-laminae may be angular, as well as tangential, within the same cross-stratified set.

The thickness of strata, which contain this structure varies from 10 to about 30 cm. The greater part of the observed occurrences were in fine grained sands with a considerable clay admixture (Units VII and XIV–XV); in Unit XVI it is found in fine sands with medium sand components.

The lower boundary of the cross-laminated sets is prevalently horizontal and of a non-erosional nature. The shape of the upper boundary in random sections is variable. Convex-upward outlines, conformable to the internal lamination, are most typical; the greater part of the observed occurrences was found, however, in laterally continuous, tabular beds. In the latter instances, the structure is bounded by a truncating upper bedding-plane, sculptured by symmetrical ripples; a partial destruction by small vertical burrows may also occur (fig. 11).

In the tabular beds, structures of a different nature may occur in juxtaposition with the convex-up cross-laminated sets, *e.g.* horizontal lamination, small scale cross-lamination and type 3 of large scale cross-stratification, described in the next paragraph.

Remarkable is the relative quantity of occurrences of convex up cross-strata in the differently oriented sections. In the east-west to east-southeast-west-northwest trending sections, which form the greater part of the exposure, they are rare. Many examples were met with, however, in sections with a north-south orientation, particularly so in Unit XIV.

### Discussion:

Summarizing our data, we must be dealing with lobe-shaped sediment bodies, which show a preferential orientation of their axes and a gradually changing strike of the internal cross-laminae.

The differential distribution of convex-up cross-strata in differently oriented sections is evidently due to the three dimensional arrangement of cross-laminae within the sediment bodies. The preferential occurrences of convex-up cross-strata in north-south sections points to an orientation of their axes in east-west directions.

The author is aware of only one earlier described occurrence of this remarkable type of cross-lamination. In his study of the modern carbonate sand bodies of Florida and the Bahamas, Ball (1967) reports the occurrence of convex-up cross-lamination in spill-over-lobes, constructed by severe storms, washing over sand-belts along the borders of the Bahamian platform.

These structures are formed during intermittent high energy events and are superficially reworked by waves and tides, after the return of quiet conditions. These processes thus give rise to sequences, consisting of a basal set of large scale cross-strata, overlain by small scale sets. The spill-over-lobes occur in association with large scale ripples and channels. The correspondence in structural characteristics and associated sedimentary phenomena thus warrants the interpretation of our type 2 of large scale cross-stratification as spill-over-lobes.

In modern environments, spill-over-lobes occur on the leeside of sedimentary obstructions to current- and wave action, such as shoals and barrier islands (Fisk, 1959; Shepard and Moore, 1960; Rusnak, 1960). Coalescence and superposition of spill-over-lobes, formed during successive storms, contributes to the accumulation of wash-over-fans along the landward margin of the barriers. The internal structure of the lobes will be oriented towards the area of relative protection. For Ladiko-bay, this area must have been situated westward of a region of shoals or emergent barriers.

### *Type 3*

Large scale cross-stratification, occurring in lenticular bodies with an erosional, slightly concave-upward or irregular lower boundary.

The top of the cross-stratified sets is horizontal in isolated occurrences. In Unit XI, a superposition of several of such sets was observed (fig. 8).

The maximum thickness varies from 10–30 cm; the lateral extent of the sets reaches up to 3 m in Unit XI.

The internal arrangement of cross-laminae and the texture of the sediment appear to be variable. A unidirectional orientation of low angle cross-strata is most common; a superposition of several bundles of oblique laminae, with opposed directions of inclination was also observed.

In the upper part of Unit III, and in Unit XIV, the structure is developed

in fine grained sands. In Unit XI, a high content of shells, shell-fragments and other skeletal remains, strewn along the cross-strata, is notable (fig. 8).

In the shell bearing sediment of Unit XI, a three dimensional insight was rendered possible by the presence of natural cross-sections. In approximately east-west trending sections, the cross-stratified sets show an irregularly horizontal arrangement of laminae, with subordinate intercalations of oblique laminae.

#### Discussion:

Because of the erosional nature of the lower boundary of the sets, the three dimensional arrangement of cross-strata and the heterogeneity in a textural sense, these structures are regarded as scour-and-fill phenomena, owing to the filling of generally small and shallow channels.

In Units III and XIV, these channel-structures occur in association with large scale cross-lamination, attributed to spill-over-lobes and large scale ripples, formed by wind-induced currents. In these instances, a preferential orientation of channel-axes could not be determined.

In the superposed channel-structures of Unit XI, the arrangement of cross-strata and the differential aspect of east-west and north-south sections, are indicative of an east-west trend of channel-axes.

#### *Type 4*

Large scale cross-lamination, occurring in silty sediments, with intercalations of clayey laminae. Lateral transitions to completely clayey sediments were locally observed.

The height and lateral extension of the cross-laminated sets is variable, but generally relatively small (maxima of 10 and 20 cm respectively).

The cross-laminae are concave-up in shape and show a strongly tangential basal contact.

The occurrence of this structure is limited to Unit I, where it appears on the-flanks of lenticular bodies of very fine grained sand or silt.

#### Discussion:

The fine grained character of the cross-stratified sediment points to an origin under comparatively quiet conditions. The occurrence of the structure on the flanks of lenticular, convex-up sediment bodies probably warrants an interpretation as accumulations from suspension, which were formed on the lee side of bottom-highs, which are remnants of previous erosional processes.

### III.3. HORIZONTAL LAMINATION

Horizontal lamination is present in all lithological types: clays, silty clays, silts and sands. In the silts and very fine sands of Units I, II and XV, it is the most characteristic type of internal lamination.

The structure occurs in tabular or lenticular bodies with a horizontal, non-erosional base and a planar or convex-upward top. The upper bedding-plane of these strata often shows symmetrical ripples of oscillatory origin, or it is irregularly developed, owing to small burrows, descending from the sand-clay parting.

Typical is very delicate type of lamination; the individual laminae are laterally traceable to a variable extent.

#### Discussion:

Horizontal lamination in silts and sands may originate under the influence of two modes of transport and deposition, *e.g.* bed load movement along a plane bed in upper flow regimes (Simons and Richardson, 1963) or transport in, and direct accumulation from suspension. Given the relatively fine grained composition of the sediments, and in view of their often considerable clay content, the first case seems to offer an unlikely explanation. Deposition from suspension would fit better for our examples at Ladiko-bay.

The correspondence in the textural characteristics of the sediment, in the delicacy of the lamination and in the nature of the lower and upper boundaries of the strata to types I and 2 of large scale cross-stratification, suggests a comparable mechanism of formation for these structural categories. As stated in our discussion of type I of large scale cross-lamination, the essential difference in the conditions of origin of our horizontally laminated and cross-stratified sediments is caused by the interaction of higher current velocities and the changing and lower ratio of bed load and suspension load. These higher current velocities will then give rise to a horizontally laminated structure if the density of the suspension is sufficiently high to allow deposition.

For the greater part of the occurrences of horizontal lamination at Ladiko-bay, an origin under the influence of wind-induced currents with a high concentration of suspended material may thus be postulated.

For the relatively thick, horizontally laminated interval in the lower part of Unit VII, another explanation seems more plausible. An alternative mode of formation of laminated sands is a relatively slow accretion by wave action. Under conditions of continuous turbulence, a well sorted sand will ensue. As remarked by Kruit (1955), an addition of fines, resulting in a somewhat

clayey sand, may take place in more or less protected regions with a discontinuous agitation.

#### III.4. DISTORTED LAMINATION

Secondary deformation of stratification of non-organic origin is of limited significance in the section at Ladiko-bay.

The most conspicuous example is offered by Unit VI. The sands show an intensive internal folding of laminae and an undisturbed, horizontal position of the lower and upper boundary.

In the folding pattern, the originally lower member of the unit is deformed into mushroom-like masses, which occur in juxtaposition with downward folded bodies, constituted by the upper member (fig. 4). A striking difference in the mode of deformation of the two members is the restriction of minor faults to the upper one (fig. 5).

The coarse fraction composition and the microfaunal content of the two subunits clearly reflect an important change in the conditions of sedimentation at the onset of accumulation of the upper member.

#### Discussion:

The stability of a sediment is determined by the vertical distribution of density in the deposit. Under conditions of continued slow deposition, a regular downward increase in density, and consequently an increase in shearing resistance will be developed, when important changes in textural and mineralogical composition are left out of account (see Terzaghi, 1955).

The extent to which this process of consolidation may be effective is primarily determined by the initial pore-volume and watercontent of the deposit. Consolidation being a gradual process, a secondary factor is the time available for the establishment of conditions, which are in equilibrium with an increasing shearing stress owing to increasing overload. In a continuously sandy sediment both factors are governed by the rate of sedimentation; under conditions of rapid deposition, a sediment with a large pore-volume and water-content and a consequent loose packing of grains will accumulate.

A variable rate of sedimentation may cause temporary vertical discontinuities in the density gradient of the sedimentary column, owing to the interstratification of sediments with different initial pore-volume. Slowly accumulating, well packed sands may find themselves in an unstable position, covering rapidly formed sands with a low shearing resistance.

When a critical value of shearing stress is exceeded, the stratified sediment

will react with secondary deformation. The main characteristic of this disturbance will be the local downward movement of the upper stratum ("load casting") and the concomittant upward flow of the lower sediment in the intervening spaces. The difference in sediment fabric will cause a differential mode of distortion. Whereas intensive folding will occur in the lower, loosely packed stratum, the upper bed may partially react with local faulting.

The occurrence of such distorted layering in Unit VI supplies the important information, that the inferred change in environmental conditions was accompanied by a probably swift transition from rapid to slow deposition.

### III.5. BURROWING STRUCTURES

Secondary deformation of stratification due to bottom dwelling organisms is reflected in a variety of internal structures and bedding-plane features. All transitions from only slightly disturbed laminations to more or less completely homogenized deposits have been observed.

Although incorrect in a strict sense, horizontal tracks, present on the clay-sand partings in Unit I and II, have been included in this category. They consist of sand-filled, upward-concave semireliefs, which show a meandering-sinuuous course, reminiscent of the grazing patterns, distinguished by Seilacher (1964).

Real burrowing structures have been differentiated into:

1. Small scale burrows (diameter less than 1 cm, length up to 5 cm)
2. Large scale burrows (diameter greater than 1 cm, length up to 60 cm)
3. Homogeneous structures, showing a virtually complete obliteration of primary laminations, without distinct preservation of organic structures.

Small scale burrows are characteristic for the greater part of the succession (Units II–III, VII–IX, XIV–XV, XIX). They are concentrated in the clayey intercalations of these sediments, descending into the upper part of the silty-sandy beds.

The density and shape of the burrows is variable; irregular forms, often displaying a contorted aspect, presumably owing to compaction of the surrounding sediment, are prevalent. U-shaped varieties were locally met with in Unit XV (fig. 12 and 15).

In a general sense, a differential vertical distribution of burrowing structures may be brought about by variations of ecological factors, such as salinity, oxygen-supply etc., or by intermittent changes in the rate of sedimentation. Since we are dealing with frequent variations of burrow-

density within limited sediment thicknesses and since these variations are clearly linked to changes in sediment composition, an episodic, rapid deposition of the silty-sandy sediments seems the most plausible explanation. The subsequent return of quiet conditions permitted the return of bottom-dwelling organisms and the consequent destruction of primary sedimentary structures, immediately below the newly formed water-sediment interface.

Among the large scale burrowing structures, two main groups may be distinguished at Ladiko-bay:

a. Tube-shaped burrows, consisting of loosely cemented or strongly indurated sand, with a maximum diameter of 4 cm and a length up to 60 cm.

b. Pocket-shaped- ellipsoidal, shell-lined burrows, with a diameter up to 10 cm and a maximum length of 40 cm.

Tube-shaped burrows with a maximum length of 20 cm are restricted to the upper parts of Units III and IX and to Unit XVI. They appear as loosely cemented, straight to slightly curved, downward penetrations in the sandy strata. Their starting-point is situated at sediment partings; at their lower end, they often show a slight enlargement (fig. 7).

In shape and dimensions, these structures show a strong resemblance to the burrows of some decapod crustaceans, described by Frey and Mayou (1971) from modern barrier island environments, e.g. the burrows formed by *Uca pugilator* or *Ocypode quadrata*.

Burrows of a comparable nature, but of still larger dimensions (length up to 65 cm) were recorded in Unit XVIII (fig. 16). Characteristic for this type of structure is a strong cementation of sand-grains, a knobby outer surface and the occurrence of bifurcations and horizontal stretches.

The properties of this type of organic structures are correspondent to those of the burrows of the decapod *Callinassa major*, described by Weimer and Hoyt (1964) and Frey and Mayou (1971) from recent barrier beaches.

The origin of the shell-lined, pocket-shaped or ellipsoidal structures, found in Units V, XII and XVIII, is doubtful. The mode of concentration of shells from the surrounding sediment and the processes, responsible for the remarkable size-grading of shells (fig. 9), are not understood. The structures may be due to the feeding and burrowing activities of some representatives of the Crustacea (see Seilacher, 1961 and Schäfer, 1962).

Complete obliteration of primary structures in sandy sediments was registered in Units IV, V, X, XII, XIII (?), XVII, XVIII and XX. In Units V, XII and XVIII, crustacean activity will probably have been a major factor in sediment disturbance. The frequent occurrence of Pelecypoda in living position at some places in Unit V, suggests that these organisms also contri-

buted to the homogenization of the sediment. The total absence of primary and secondary structures in Units IV, X, XVII and XX, suggests an origin under the influence of a community of bottom dwellers of a divergent nature.

### III.6. SEDIMENTARY SEQUENCES

For the recognition of large scale depositional trends in the section at Ladiko-bay several ways of approach may be followed, which ultimately lead to the same sequential subdivision of the succession.

The section shows four major stratigraphical discontinuities of a disconformable or unconformable nature, which appear to be linked to relatively coarse grained, pebble bearing sediments with an approximately total obliteration of primary stratification (Units IV, X, XVII and XX). These discontinuities occur at the base of, or within thick sandy intervals (Units IV–VII, X–XII, XVI–XVIII and XX), which contain frequent macrofaunal elements, either displaced or autochthonous.

The sediments between the sandy intervals and below the lowermost, consist of interstratified, relatively thin bedded, silty, sandy and clayey deposits, with very small amounts of coarse grained constituents and a virtual absence of macrofossils (Units I–III, VIII–IX, XIII–XV and XIX). On top of the fourth level of homogeneous sands, the series shows unstratified marls, gradually evolving from the latter sediment (Unit XXI).

*Units I–III* (see enclosure I).

This part of the succession displays a distinct tendency to an upward increase in sand content, in maximum grain-size of the sands and in thickness of the sandy strata, which goes together with a decreasing thickness of the clayey intercalations. This coarsening upward change in textural characteristics appears to be associated with a vertical order of occurrence of primary and secondary sedimentary structures, types of bedding, and coarse fraction components, as manifested by:

a. The change from horizontally laminated and small scale cross-laminated silts and sands in Unit I to sands with a prevalence of large scale cross-stratification in Unit III.

b. The diminishing importance of small scale cross-lamination along the upper bedding planes of the sands in Unit III.

c. The appearance of channel-structures in the latter unit.

d. The changing character of organic reworking. The predominantly

horizontal tracks of Unit I make way for small scale vertical burrows in Unit II, whereas large scale burrows appear near the top of Unit III.

e. The upward increase in lateral continuity of the sandy strata, connected with a higher frequency of a lenticular shape of the clayey intercalations.

f. The decreasing significance of oolitic constituents in the sands, and the increasing importance of shell-fragments. Plant-remains are largely restricted to the lower part of the succession, whereas echinoid spines and fragments of calcareous algae make their appearance in the upper part of Unit III.

The vertical trends depicted above reflect a more or less gradual, but discontinuous change in environmental conditions, *i.e.* increasing intensity of high energy phases of sediment-supply, increased rate of sedimentation during these phases and decreasing significance of deposition of sediment from suspension during the periods of relative quiet in between. As shown by the changing character of bioturbation, biological conditions were also subject to change in an upward sense.

In the coarse fraction of the sediment, oolites are joint farther upward by elements of a possibly marine nature (echinoid spines and calcareous algae). An upward increase of the supply of components of open marine affinity may perhaps be concluded.

As discussed in the preceding paragraphs of this chapter, silt and sand supply took place under the influence of episodic wind driven currents, oriented in westerly directions. These currents penetrated into a more or less restricted, approximately lagoonal environment. Sand, containing organic components of marine origin, was washed into the latter area and created fan-like sediment bodies, dissected by channels, on the lee of shoals or barriers. These wash-over-fans, which contained a superposition and juxtaposition of large ripples and spill-over-lobes, gradually encroached on the lagoonal environment of thereby produced the sequence described above.

In Unit I, the prevalence of clay and the occurrence of horizontally laminated and small scale cross-laminated silts and very fine sands is indicative of a regime with relatively infrequent turbulent conditions at a comparatively low energy level. The irregular lenticular shape of the silty-sandy strata and the large scale cross-laminated silts on the flanks of these lenses point to reworking, without supply of new sediment. The sediment may thus be regarded as a lagoonal deposit, which accumulated at the landward, distal margins of wash-over-fans.

The succession of Units II and III shows the upward transition from distal-to proximal (near-barrier) wash-over sediments. As a whole, Units I–III form an upward coarsening sequence, originating from the slow approach of a barrier system, which moved in a western direction.

From top to bottom, the succession of sediments is comparable to the lagoonward decrease in grain-size on the lee of a barrier, shown by recent lagoonal deposits (Rusnak, 1960). This decrease ensues from the energy-loss in wind-induced currents, due to flow-expansion after the passing of the obstructing barrier, as well as to the counteraction of the relatively stagnant lagoonal waterbody.

The resulting horizontal change in texture of one time level causes a vertical trend in grain-size in successions, whenever the environmental boundaries become displaced in time and space.

The landward movement of the barrier is mainly brought about by the erosion and lagoonward transport of sediments of the outer, marine barrier face. The back barrier wash-over sands are thus mainly derived from the latter source (Fisk, 1959; Shepard and Moore, 1960; Oomkens, 1967).

The upward coarsening character of sequences constructed during the lagoonward movement of wash-over-fans and barriers has been shown in stratigraphic sections of Holocene barrier and lagoonal deposits along the Texas Gulf Coast (Fisk, 1959; Shepard and Moore, 1960). Other Holocene equivalents have been described from the Rhône delta by Oomkens (1967).

The large scale burrowing structures in the upper part of Unit III find a modern analogue in the decapod burrows occurring in the higher, near-barrier parts of wash-over-fans of Sapelo Island, Georgia, U.S.A. (Frey and Mayou, 1971).

#### *Unit IV*

The upward coarsening sequence of Units I–III is disconformably truncated by an erosional surface, strewn with pebbles. The overlying sediment is a largely homogeneous, fine to medium grained sand with an admixture of clay. In the coarse fraction, echinoid spines, fragments of calcareous algae and oolitic grains occur as minor components.

The nature of the lower boundary suggests the removal of sediments formed on the higher, seaward parts of the previously formed wash-over-fan complex. Given the presence of coarse grained constituents immediately above the surface of truncation, a high energy erosional episode must be assumed.

The overlying sands may have accumulated shortly after the formation of the pebble pavement. A considerable time lapse between the deposition of the two sediment types can, however, not be excluded.

On purely sedimentological grounds, little can be said concerning the source of the sands. An at least partial derivation from reworked wash-over-

fan sediments is of course suspected; whether newly supplied sand played a part, remains obscure.

Without taking resort to the microfaunal composition of the sediment, the environment of deposition of Unit IV cannot soundly be interpreted. The homogeneous structure of the sands is merely indicative of one or more episodes of slow sedimentation or non-deposition and of the presence of a burrowing fauna of another nature than that found in the upper part of Unit III.

#### *Unit V*

In the medium-coarse grained, prevalently homogeneous sands of this unit a number of horizontal shell stringers are intercalated. The shells are arranged in convex-up position; pebbles occur as a minor constituent of these levels. In the interjacent sands, bivalves in living position occur in local concentrations. A number of shell-lined large scale burrows descend from the shell bearing levels. Among the sand-grains, echinoid spines, calcareous algae and some oolitic grains are again present.

Apart from the intermittent character of its accumulation and the occurrence of non-depositional phases, the main characteristic of this unit is the presence of pebble bearing shell stringers, which most probably are lag deposits, formed under high energy conditions. Judging from the composition of the coarse fraction, the sands were at least partly derived from a marine source.

#### *Unit VI*

A high degree of internal distortion is the most conspicuous feature of this sediment level. As discussed in paragraph 4 of this chapter, a sudden change from rapid to slow accumulation at the onset of the deposition of the upper member of the unit may be inferred.

For the lower subunit, some affinity to Unit V may be concluded from the occurrence of a shell stringer and of echinoid spines in the coarse fraction of the sand. In the upper subunit both constituents are absent. The change in conditions of sedimentation may thus have been linked to an alteration of supply.

#### *Units VII–VIII*

In this part of the succession, an upward decrease in median grain-size of the sands appears to be associated with an increasing importance of clayey intercalations. In the upper part of Unit VII, clay is only represented in reworked condition (clay pebbles); farther upwards it appears in actual strata.

As to the coarse fraction of the sediment, a disappearance of components of marine affinity and a growing importance of oolitic grains may be observed. In Unit VIII, plant-remains occur frequently. Judging from these data, decreasing energy and rate of sand supply go together with an increasing importance of deposition from suspension and a diminishing supply of marine components.

The relatively thick interval of horizontal lamination, without burrowing structures in the lower part of Unit VII, is succeeded by a level, part of which shows large scale cross-stratification with convex-up cross-laminae, attributed to spill-over-lobes. The appearance of this structure is linked to the return of small scale burrows at sediment partings, manifesting intermittent accumulation of the sands.

As pointed out in paragraph 3 of this chapter, the origin of the abnormally thick interval of horizontally laminated, somewhat clayey sand in the lower part of Unit VII is explained as a result of wave action under protected conditions. This interpretation can now be understood in terms of a back barrier position of its environment.

In the upper part of Unit VII, small scale cross-lamination of oscillatory origin reappears, attesting a trend to increased importance and better preservation of low energy structures.

The most striking property of Unit VIII is the irregular aspect of its stratification. Small escarpments, consisting of sand or clay, often with adjacent clay pebble accumulations, are associated with large scale cross-laminated sands. Large scale cross-lamination of presumed spill-over origin was recorded in one instance.

Summarizing these considerations, the succession of Units VII–VIII expresses the gradual return of restricted conditions. The presence of structures, which characterize wash-over-fans implies the nearness of a shoal or barrier.

The near barrier origin of Unit VIII is attested by the occurrence of frequent small scale escarpments. Comparable phenomena have been reported from the marginal areas of recent lagoons (Kruit, 1955). The high frequency of plant-remains in these sediments is relevant in this respect. Their occurrence is reminiscent of marsh environments.

In conclusion, Unit VII and VIII may be regarded as members of a fining upward sequence, which ensued from a seaward movement of a barrier system during deposition of this part of the succession. Roughly speaking, the sequence forms an inversion of the coarsening upward sequence of Units I–III.

### *Unit IX*

In Unit IX, a distinct upward decrease in frequency and thickness of clayey intercalations is to be noted; in the upper part of the unit, the thin clayey beds are often strongly affected by reworking, resulting in lateral transitions into clay pebble seams.

The succession also shows a tendency to an upward increase in median and maximum grain-size of the sands. The coarsest, pebble bearing, level does not occur at the top of Unit IX, however.

Among the non-terrigenous sand grains, oolites show a diminished frequency with respect to Unit VIII; echinoid spines make their reappearance in the pebble bearing level, but they are not present farther upwards.

The main features of the vertical distribution of sedimentary structures in Unit IX are the disappearance of small scale cross lamination near the top of the unit and the occurrence of large scale burrows at this level, whereas the small scale variety can be observed farther below. As far as could be ascertained in this less favourably exposed part of the section, the internal stratification of the sands in Unit IX corresponds to the structures described for Unit III.

The transition from Unit VIII to IX and the vertical succession of Unit IX express a trend to an increasing frequency and intensity of high energy phases of sand supply. As manifested by the pebble bearing bed at some distance below the top of Unit IX, this trend was of irregular nature. The discontinuous course of depositional events naturally implies a variation in energy of successive phases of sediment-supply, which tends to obliterate the large scale vertical trends. The mode of formation of the coarse grained intercalation is probably not comparable to the mechanisms assumed for Unit IV, given the absence of an erosional surface below the pebble pavement, the lack of homogeneous sands above it and the occurrence of large scale burrows above and not below the conglomeratic level.

The decreasing importance of oolites, is not distinctly linked to an augmented frequency of constituents, indicative of a marine source of supply. Remarkable is, however, the apparent correlation between the maximum energy level and the presence of such components.

The upward change in hydrodynamic conditions and nature of supply is clearly connected to an alternation of ecological conditions, as shown by the replacement of small scale burrows by large scale forms in the upper part of Unit IX.

In summary, the succession of Units VIII and IX probably reflects a discontinuous lagoonward movement of a shoal or barrier system and its leeward wash-over-fans, culminating in proximal, near barrier sediments at the top of Unit IX.

*Unit X* (see enclosure II)

Unit IX is disconformably truncated at its top by an irregular surface of erosion, which is covered by a conglomeratic level of variable thickness and a relatively coarse grained sand. The sediment contains echinoid spines, fragments of calcareous algae and oolites; a few shells are distributed at random.

On account of its stratigraphic position on top of an upwards coarsening sequence, as well as its textural, compositional and structural characteristics, this sediment is comparable to that of Unit IV. As in the latter case, a purely sedimentological approach does not lead to an understanding of the derivation and conditions of origin of the sediment.

#### *Units XI–XIV*

These sediments comprise a change from sandy to interstratified deposits. In an upward sense, the succession shows a decrease of maximum and median grain-size of the sands, a slight tendency to an increase in thickness of the clayey intercalations, a reduced importance of echinoid spines, the disappearance of calcareous algae in the sands and the return of small scale cross-lamination and small scale burrows in Unit XIV.

Several aspects of this vertical trend are already known from deeper levels of the section (Units VII–VIII). Other features do not fit in the picture designed there.

The most conspicuous properties of Unit XI are the high frequency of mollusc shells and other skeletal remains, and the cross-stratified structure of the relatively coarse grained sediment. The structures were attributed to an intermittent process of erosion and filling of channels (see paragraph 2 of this chapter). Because of the presence of a coral colony in situ, the high energy currents must have been active in an essentially marine environment.

These sediments grade upward into the homogeneous, coarse grained sands of Unit XII, which show a considerably lower frequency of macro-faunal elements. Large scale burrows, attributed to decapod crustaceans (see paragraph 5 of this chapter) are locally intercalated and suggest a discontinuous course of the accumulation of the unit. The unstratified nature of the deposit is also indicative of episodes of slow- or non-deposition.

In Unit XIII, clayey intercalations reappear. Apart from the strikingly high content of plant-remains, the sedimentary data regarding this unit are subject to doubt owing to conditions of exposure.

The types of stratification met with in Unit XIV, particularly the frequent occurrence of convex-up large scale cross-lamination, leave no doubt regarding its origin as a back-barrier, wash-over-fan sediment. In this unit, a distinct vertical trend in the thickness of sandy strata is absent, its upper

part is, however, characterized by silts and silty very fine sands. Remarkable is the continuous presence of rare echinoid spines in the sandy beds.

The presence of spill-over-lobe structures probably expresses a near-barrier position of the wash-over-fan complex, as is also suggested by the occurrence of components of marine affinity. The decrease of grain-size in the upper part of Unit XIV may reflect a growing distance from the barrier system, in other words a seaward movement of the latter. Since this decrease is not related to a distinct upward change of the sand-clay ratio, the latter inference remains doubtful.

Apart from the distance to the barrier system, the sand content of wash-over-fan deposits may be influenced by a number of other factors:

- a. Variation in energy of successive phases of sand supply.
- b. The position of the locus of sedimentation with respect to low portions of the barrier, which will more frequently be subject to breaching by storm-driven currents than the more elevated parts of the latter.
- c. The maturity of the barrier system as a whole. In the case of a limited, generally low development of the sand body, in combination with the occurrence of numerous passes, the lagoonal realm will be subject to greater exposure to open marine forces and thus to a greater supply of sand (see Shepard and Moore, 1960; Rusnak, 1960).

Since the sands in a wash-over-fan complex are largely derived from eroded barrier face sediments, the question arises, whether changes in grain-size of back-barrier deposits may be linked to an alteration in texture of the source material. Such a control of wash-over sedimentation would account for the absence of a vertical trend in sand content in Unit XIV.

A definite choice of the determining factors is not possible without the introduction of paleoecological criteria.

The high frequency of plant-remains in Unit XIII is reminiscent of marsh environments along the lagoonal margins of barriers. A still more proximal back barrier position might tentatively be inferred for the coarse and homogeneous sands with large scale burrows of Unit XII. As reported by Pérès and Picard (1964), some decapod species show a preference for sandy bottoms on the lee of sand spits and barriers in the present-day Mediterranean.

The superposition of sands of possible back barrier origin on top of the shell bearing, evidently largely marine, channel-sands of Unit XI is interesting from a sequential point of view. A current dominated regime, more or less fully exposed to marine influences (Unit XI) was replaced by a definitely more tranquil environment of a presumably restricted nature (Unit XII). In modern lagoonal areas, a comparable succession of events occurs through the

partial or complete blocking of inlets by sandy spits, constructed by long-shore currents (Fisk, 1959; Shepard, 1960; El-Ashry and Wanless, 1965).

These ideas may throw some light on the origin of the succession of Units XI–XIV, but they are clearly in need of additional, ecological data concerning the nature of the environments involved.

#### *Unit XV*

In the occurrence of silty to very fine sands and in the presence of spill-over-lobe structures, the sediments of this unit are comparable to those in the upper part of Unit XIV. Remarkable differences are the regular small scale sequential arrangement of silty-sandy deposits, laminated silty clays and marly clays and the considerably higher frequency of small scale burrows and plant-remains. Furthermore, echinoid spines are absent in the sands.

The lagoonal, wash-over origin of the sands is obvious; on account of the relatively fine grained texture of these sediments and because of the absence of echinoid spines, one would be tempted to assume a relatively distal position of the environment with respect to the greater part of Unit XIV. Yet, the continued presence of spill-over-lobe structures of presumable near-barrier origin is not in accordance with this interpretation.

On account of the association of depositional properties of this unit, we suppose they reflect the combined occurrence of relatively fine grained, near-barrier sediments, a more or less continued low energy turbulence and an essentially normal marine salinity. Such a complex of environmental factors would imply a relatively reduced development of the barrier system (see discussion of Unit XIV) and a better exposure to open marine influences. In turn, a limited growth of obstructing sand bodies in the littoral realm, would involve a decreased sediment-supply, which might be responsible for the occurrence of periods of very slow deposition, as attested by the homogeneous, marly clays of this unit. The diminished rate of deposition on the seaward side of the system of shoals may have been linked to a decrease of grain-size of the sediments in this area, which in turn caused a relatively fine grained texture of the wash-over deposits. These tentative ideas will have to be checked in the next chapter.

#### *Unit XVI*

The relatively fine grained, interstratified sediments of Unit XV are separated by a sharp contact from the continuously sandy deposits of this unit. Internally, the sands show an upward increase in grain-size and horizontal- as well as large scale cross-lamination. Convex-up cross-laminated sets of con-

siderable height occur. Large scale burrows descend from sediment partings. In the composition of the non-terrigenous coarse fraction, the reappearance of echinoid spines and the lack of oolites in the upper part of the unit is notable.

The vertical trend in grain-size and composition of the sediment and the association of primary and secondary structures clearly point to an origin as proximal wash-over-fan deposits, comparable to the upper parts of Units III and IX.

However, an important divergence with respect to its lower equivalents is the absence of a gradual transition at its base. An upward coarsening sequence is not developed. Its sudden appearance in the succession may express a rapid lagoonward movement of a barrier and its leeward fans or a swift repair of the barrier system after a period of incomplete development, during the accumulation of Unit XV.

#### *Unit XVII (see enclosure III)*

The preceding unit is disconformably truncated at its top by an irregular surface of erosion, which is covered by a pebble, gravel and shell bearing sand of relatively coarse texture and without traces of stratification. Echinoid spines and fragments of calcareous algae are represented in the sand, whereas oolites are absent.

Although its conditions of origin are not understood, it is remarkable to note the reappearance of a surface of disconformity associated with a coarse grained, unstratified deposit, containing components of marine affinity, on top of a sediment of inferred near-barrier origin (see Units IV and X).

#### *Unit XVIII*

Without a distinct boundary, Unit XVII passes upward into a somewhat finer grained sand with randomly distributed shells of relatively small size. The sediment again contains echinoid spines and calcareous algae. Internal stratification is absent. Very conspicuous are frequent large scale burrows of the tubular and pocket-shaped varieties, which descend from the upper boundary of the unit.

From a sedimentary point of view, a high energy supply of sands from a marine source area and breaks in the deposition can be inferred.

The occurrence of tubular large scale burrows, attributed to the decapod *Callianassa* (see paragraph 5 of this chapter), may throw some light on the environmental conditions, that prevailed immediately after the accumulation of the sediment. Burrows of identical origin were reported from recent marine foreshore sediments by Weimer and Hoyt (1964) and Frey and

Mayou (1971). A present-day Mediterranean representative of this crustacean, *C. tyrrhena*, prefers somewhat protected habitats, on the lee of sandy barriers or of subaquatic meadows of marine phanerogams, the well known *Posidonia* (Pérès and Picard, 1964).

#### *Unit XIX*

The burrowed, relatively coarse sands of Unit XVIII are separated by a sharp contact from the interstratified fine sands and clays of this unit. A vertical trend in grain-size and thickness is not found here. In the coarse fraction of the sands an upward disappearance of echinoid spines and a return of oolitic constituents is to be noted. The association of sedimentary structures is believed to be largely comparable to that found in similar deposits lower down in the succession.

With respect to the underlying sands, these sediments give evidence of diminished energy and sand supply, an increased low energy accumulation from suspension and a decreased frequency of components derived from marine source areas. A return to conditions of a restricted nature must thus be inferred.

In the absence of further sedimentary indications, a comparison with the lower approximate equivalents of this unit must be postponed to the next chapter. A correspondence in conditions of origin is suggested by the renewed occurrence of interbedded sediments on top of shell bearing, bioturbated sands (see Unit XII–XIV).

#### *Units XX–XXI*

The sediments of Unit XIX are truncated by a slightly unconformable surface of erosion, which is overlain by an unstratified pebble and shell bearing sand with considerable clay content. Both echinoid spines and oolites are present. The basal sands grade upwards into a slightly silty-sandy marl of homogeneous structure, which contains scattered bivalves in living position.

The origin of this upper part of the succession involves an initial tectonic tilting of the underlying strata. Subsequently, a period of high energy erosion and supply occurred, which gave way to a slow accumulation of suspended sediment.

The absence of sandy intercalations in Unit XXI virtually excludes an origin on the lee of sandy barriers. In a general sense, a termination of sand supply may be related to an increasing distance to the potential source area of arenaceous sediments, to an increase of depth or to changes in the paleogeographic frame-work on a regional scale. As has been shown by

studies of the Cenozoic evolution of the island of Rhodos, the area was cut off from major fluvial supply in the Late Pliocene (Meulenkamp, 1971, Meulenkamp et al., 1972; see also paragraph 2 of Chapter I). Although the age of our sediments could not be established with such accuracy, the change in the nature of deposition near the top of our section fits in well with this picture.

However, the absence of obstructing sand bodies, owing to a waning of longshore transport, does not account for all of the features shown by Unit XXI. The total absence of lamination is not in accordance with an origin in a shallow embayment. The continuous, slow deposition of fines is best explained by an increase of depth with respect to the underlying units.

This conclusion implies a tectonic subsidence of the area and a marine transgression, which invaded the approximately lagoonal realm of Unit XIX and which caused its transformation into a marine, most probably upper neritic environment.

In the sediment, the transgressive event is represented by the erosional lower boundary and the homogeneous, pebble and shell bearing sands of Unit XX. In the nature of their basal contact, in their vertical textural trend and in their structural characteristics these sediments correspond to transgressive deposits and their upward transition to shelf-facies muds, known from Holocene successions (see Fisher, 1961; Oomkens, 1967).

### *Conclusion*

Concluding these considerations, the analysis of depositional features in the section at Ladiko-bay allows the recognition of several large scale sequential types:

1. Upward coarsening sequences of back barrier origin. This category is best represented by the sequence of Units I–III; the succession of Units VIII–IX offers a less distinct example. In a genetic sense, the superposition of Unit XV by Unit XVI may manifest a corresponding succession of events; objectively it may, however, not be classified under the same heading.

2. Upward fining sequences of back barrier origin. The best example of this type is the succession of Units VII–VIII. Units XII–XIV might belong to this group; the interrelation and environment of deposition of the lower members is, however, not sufficiently understood. The same holds true for the succession of Units XVIII–XIX, which is furthermore not a fining upwards sequence in a descriptive sense.

3. An upward fining sequence of transgressive origin, as exemplified by Units XX–XXI.

The section furthermore contains a number of sediment types which are

incompletely understood as far as their conditions of origin and their relation to adjacent units are concerned:

- a. Sediments linked to disconformities: Units IV, X, XVII.
- b. Sediments showing concentrations of macrofauna: Units V, VI, XI, XII, XVIII.
- c. Sediments of inferred, more or less lagoonal origin, with mutual similarities and differences, which need further enlightenment: Units I, VIII, XIII–XV, XIX.

## Chapter IV

### PALEOECOLOGY

#### IV.1. INTRODUCTION

Our approach in the interpretation of the quantitative data on the faunal elements in the section at Ladiko-bay will be twofold. Primarily our attention will be focused on the behaviour of micro- and macrofossils in the framework of depositional processes discussed in the preceding chapter. Secondly we will try to arrive at a recognition of possible recent equivalents of the faunas, to get information concerning environmental factors, which are not directly reflected in the sediment itself.

Even when we are dealing with relatively young sediments, serious problems hamper the application of data on the distribution of organisms in modern environments to fossil deposits. The paleoecological value of the majority of studies in this field is strongly limited by some evident deficiencies in approach.

The basis shortcoming is the lack of taxonomic uniformity, which particularly affects a number of groups of the benthonic Foraminifera. The rather desperate state of the systematics of genera like *Elphidium*, *Cribronion* and *Nonion* is generally tacitly accepted; as a consequence references to certain species, without adequate illustration, are useless.

Also we may point to the lack of studies integrating sedimentary processes and ecology. To permit a paleoecological application, the distinction of different communities inhabiting adjacent (sub)environments should also involve an account of the conditions of sedimentation and the resulting deposits. Given the importance of current- and wave-action in shallow water, it is surprising to note the relative scarcity of data on displacements of microfaunal elements in such environments.

Last but not least, we are hindered by the inadequacy of our knowledge regarding the physical, chemical and biological factors, which govern the distribution of species. Typical, but not very encouraging, is the great number of papers presenting a general consideration of potential environmental factors and a subsequent more or less arbitrary choice of the

controlling elements of the total complex. The paleoecological application of such data evidently inherits these drawbacks.

#### IV.2. FAUNAL DISTRIBUTION AND ACTUALISTIC COMPARISONS

*Units I–III* (see enclosure I)

Characteristic for the relatively fine grained basal part of the sequence (Unit I) is the absence of a qualitative difference between the foraminiferal assemblages of the very fine sands and the clays. In all three samples *Cribronion excavatum* and *C. incertum* are strongly prevalent; three other species are regularly represented, generally in low frequencies, *Ammonia beccarii*, *Nonion depressulum* and *Rosalina araucana*. In the sandy sample nr. 1, four additional species were recorded, which appear to be absent in the clayey samples.

In Unit II, a distinct difference in foraminiferal contents of clays and sands becomes apparent. In the clayey sample nr. 4, *Cribronion incertum*, *C. excavatum* and, to a lesser extent, *Nonion depressulum* are again predominant. In the immediately overlying sandy stratum this assemblage is strongly reduced in relative numbers. *Ammonia beccarii*, *Protelphidium lidoense* and *Cribronion incertum* are the most important species here. As a whole, the fauna shows a greater diversity and it contains eight subordinate forms, which were not recorded in the clayey sample nr. 4.

In Unit III, the clayey intercalations could not be sampled adequately. The sands of this unit show a continuation of change in qualitative composition of the faunas and an upward increase in faunal diversity, which is linked to an increase in size of the specimens (textfig. 3).

In the lower part of the unit (sample nr. 6), *Nonion depressulum*, *Ammonia beccarii*, *Protelphidium lidoense* and *Reussella spinulosa* have definitively replaced *Cribronion incertum* and *C. excavatum* as prevalent forms. Near the top of the succession, *Ammonia beccarii* is associated with *Elphidium macellum*, *E. crispum*, *Quinqueloculina aspera* and *Cribronion gerthi*. The changes in faunal composition in this unit are accentuated by the increase in numbers of Miliolidae in an upward sense.

The difference in foraminiferal contents of adjacent clays and sands in Unit II might be attributable to a preference of some species for sediment bottoms of a particular nature, but the absence of such a differentiation in Unit I is not in accordance with such an assumption.

The changes in faunal composition are better explained in the context of the sedimentary framework designed in the preceding chapter. As a whole,

the succession expresses a transition from a relatively restricted environment, which was incidentally subjected to a low energy supply of arenaceous material, to a realm characterized by an increased supply of sediment of marine derivation and an augmented frequency and intensity of high energy episodes.

The sedimentation was of a discontinuous nature; phases of turbulence and supply alternated with tranquil periods, which allowed the accumulation of fines, particularly during the deposition of the lower part of the succession. These discontinuities in sedimentation were superimposed on a general trend, which is due to a gradual displacement of environmental boundaries.

The understanding of the depositional processes outlined above is an essential contribution to the interpretation of the faunal assemblages. If our conclusions are accepted, these associations may be expected to contain three major components:

1. An autochthonous component, representing the fossilized remainder of an indigenous association, which was not subject to displacement. This component is to be expected especially in the clayey intercalations.

2. A parautochthonous component, consisting of the hard parts of organisms, which were subject to short distance transport to a variable degree, but which did not cross important environmental boundaries; in other words, they came to rest within the area of their own habitat.

3. An allochthonous component, constituted by faunal elements of a non-indigenous nature, which were transported from some adjacent environment, characterized by its own biocoenosis.

This latter two types of displaced faunal components are of course primarily to be expected in the silty and sandy strata.

Judging from the virtual absence of differences in the foraminiferal faunas of clays and sands in Unit I, we are largely dealing with assemblages of an autochthonous-parautochthonous nature, without notable addition of foreign elements. The main forms of the indigenous assemblage are *Cribronion excavatum*, *C. incertum*, *Ammonia beccarii*, *Nonion depressulum* and possibly *Rosalina araucana*. Because of the high frequency of *Protelphidium lidoense* in one of the clayey samples, this species might also be an autochthonous element.

The homogeneity of these faunas, irrespective of sediment type, expresses the practical absence of an allochthonous component in the sandy sediment. During episodes of turbulence, the area of deposition was not reached by an appreciable quantity of foreign elements. Theoretically, this feature may reflect a total absence of supply from adjacent environments, due to obstructions to transport. In the context of the sedimentary framework, a relatively

remote position of the locus of sedimentation with respect to potential source areas, is a more plausible solution.

During the phases of relatively high energy, transported Foraminifera were subjected to hydrodynamical selection according to size, shape, density of tests and buoyancy. Size most probably being the main factor, the decrease of grain-size of the sediment in the direction of transport diminished the number of allochthonous elements.

Remarkable is the considerable number (8%) of small and fragile individuals of *Bulimina*, *Brizalina*, *Bolivina* and *Lagena*, in combination with a relatively high abundance of planktonic Foraminifera, in the lower clayey sample nr. 2. As has been shown by experiments performed by Grabert (1971), foraminiferal tests are hydrodynamically equivalent to sediment particles of considerably smaller size. This feature is substantiated by studies of the foraminiferal content of fine grained intertidal sediments, which reveal an enrichment of small and thin-tested individuals as a result of hydrodynamical selection induced by tidal currents (Freydanck, 1955 and Loose, 1970). These specimens thus accumulated in sediments, which were largely transported in suspended condition. A clear example of benthonic Foraminifera in suspension has been described by Murray (1965) from plankton samples collected in the English Channel after a period of storms. Striking was the distinct size sorting of the tests and their thin-walled nature; species of *Bolivina* were well represented.

It may be concluded that the accumulation of some of the clayey strata in Unit I may have been influenced by clouds of suspended sediment, containing allochthonous foraminiferal tests. These clouds were dispersed during turbulent phases and did not supply coarser grained detritus to the locus of sedimentation.

Comparison of the sandy and clayey samples of Unit I shows some preference of plano-convex forms, such as *Rosalina*, *Asterigerina*, *Neoconorbina* and *Cibicides*, for the fine grained deposits. A well known feature of most of these forms is their frequent occurrence attached to subaquatic vegetation (see Blanc-Vernet, 1969). Their presence may perhaps be correlated with the abundance of plant-remains in these sediments. Transport of Foraminifera, adhering to plants, may thus have been another way of supplying allochthonous forms during tranquil periods.

The appearance of a distinct divergence in the foraminiferal faunas of clays and sands in Unit II is indicative of a greater supply of foreign elements during agitated episodes. The assemblage in the clayey sample still shows a clear affinity to the associations recorded in Unit I. *Cribrononion incertum*, *C. excavatum*, and *Nonion depressulum* are the prevalent forms of local derivation.

The greater diversity of the fauna and the prevalence of other species in the sandy sample reflect the allochthonous nature of part of this association. *Cribrononion incertum* may be of parautochthonous origin, but the greater part of the specimens of *Ammonia beccarii* and *Protelphidium lidoense* were probably derived from an adjacent environment, given their absence in the clayey sample and their increasing importance in the overlying sediments of Unit III.

In the absence of data concerning the foraminiferal content of the clayey sediments in Unit III, the distinction of autochthonous and allochthonous components of the faunas cannot be performed by comparison of the assemblages in the different sediment types. Here we must take resort to the sequential development of the succession.

In the preceding chapter, this sequence was interpreted as a result of a lagoonward movement of wash-over-fans, located on the inner margin of shoals or barriers. During the successive phases of high energy sand supply in lagoonward direction, a decrease of volume and of grain-size of transported sediment occurred in the direction of flow. Acting as sedimentary particles, the displaced foraminiferal specimens must have been subject to the same effect, e.g. a decreasing number and a diminishing size.

Along these lines of reasoning, a culmination in frequency and size of a particular species at some level of the succession may be the expression of a (par)autochthonous position. Other factors, which determine the frequency and size of specimens of some species in a sample will, however, be their original abundance and the original size distribution of the population. A definite distinction of (par)autochthonous and allochthonous forms is thus impossible, without taking resort to data regarding their recent distribution.

The greater part of the wash-over-sands is derived from the outer, open marine barrier face; faunal elements of marine origin will thus have been displaced to the back barrier environment. These marine components will comprise a relatively diversified assemblage, as compared to the more ecotypical fauna inhabiting the lagoonal realm. Consequently a distinct prevalence of a few species may be a further criterion of recognition of the parautochthonous elements.

In the lower part of Unit III, four species with scattered distribution in the deeper levels of the sequence reach high percentages in combination with a relatively large size, i.e. *Nonion depressulum*, *Ammonia beccarii*, *Protelphidium lidoense* and *Reussella spinulosa*. These forms replace *Cribrononion excavatum* and *C. incertum* as prevalent species of local origin. In the upper part of this unit, *Elphidium macellum*, *Ammonia beccarii* and *Cribrononion gerthi* seem to be parautochthonous. *Elphidium crispum* and *Quinquelocu-*

*lina aspera* may also belong to this assemblage, their absence at lower levels of the succession may, however, express an allochthonous position.

The upward change in composition of presumably (par)autochthonous faunas confirms the change of biological conditions, which was inferred from the alteration of the character of organic reworking in a vertical sense.

On the other hand, the upward increase in diversity of the faunas is at least partly related to the growing importance of supply of open marine forms. Particularly the greater part of the Miliolidae, which show an upward increase in frequency, culminating in Units IV–VI, reflect this trend.

The high frequency of worn miliolid specimens near the top of the Unit III is relevant; the damaged tests possibly point to a derivation from a more or less continuously agitated environment, which may have been situated outside the protected lagoonal realm.

Several features of the vertical distribution of Foraminifera in Units I–III are known from Holocene and recent sediments of identical origin. An upward increase in faunal diversity, connected to a growing marine affinity of the assemblages, has been reported from coarsening upward sequences of back barrier origin in the Rhone delta complex by Oomkens (1967) and ter Keurs (1971). A horizontal lagoonward decrease in the number of species was recorded by J. and Y. le Calvez (1951) in brackish lagoons on the Mediterranean coast of France.

The upward increase in frequency of Foraminifera per sediment volume in Unit I–III is seemingly in contradiction to the observed upward decrease in abundance in comparable sequences in the Holocene Rhone delta (ter Keurs, 1971). In the latter case, this vertical trend is caused by an upward increase in the rate of accumulation of sediments, derived from a deltaic realm. The high rates of sedimentation in front of the delta produce an initially low content of Foraminifera in the source area of the wash-over sediments and a consequent dilution of the back barrier community. Outside the deltaic realm, the opposite holds true; here a strong lagoonward decrease in the number of specimens was noted by J. and Y. le Calvez (1951). The rate of sedimentation on the open marine barrier face thus seems the determining factor in this respect.

Turning our attention to the recent distribution of the main foraminiferal forms in Units I–III, the prevalence of species possessing some tolerance for low or variable salinities is a striking feature. The only species not clearly fitting in this context is *Reussella spinulosa*, being considered as a littoral, stenohaline form by Lévy (1971).

The vertical development of the foraminiferal community finds a partial equivalent in the recent sediments of the Baltic Sea, studied by Lutze

(1965). *Cribrononion incertum* (= *C. incertum* subsp. A sensu Lutze) and a thick-walled variety of *Cribrononion excavatum* (= *C. excavatum clavatum*) are the main calcareous Foraminifera in relatively deep, often stagnant basins, containing brackish waters of low temperature (salinity down to 10‰).

Although some specimens, which approach Lutze's *clavatum* form were recorded in the basal part of the sequence, our *Cribrononion excavatum* corresponds better to the thin-walled variety *C. excavatum excavatum* (sensu Lutze), which appears in the brackish, shallow water zones of the Baltic, characterized by higher summer temperatures (salinity down to about 13‰).

Since the paleontological attributes of the section at Ladiko-bay point to climatic conditions comparable to those of the present-day Mediterranean, the association of Lutze's *Cribrononion incertum* subsp. A and *C. excavatum excavatum* in the Pliocene sediments can be attributed to generally higher watertemperatures, possibly together with a smaller depth.

A close comparison of salinity data is not warranted, given the possibly greater salinity tolerance of calcareous Foraminifera at higher water temperatures, which is also indicated by the data presented by Lévy (1971), who recorded our *Cribrononion excavatum* in mesohaline waters along the French Mediterranean coast (salinity 18–5‰).

In the recent Baltic, *Ammonia beccarii* is restricted to areas affected by marine, inflowing waters of relatively high salinity (17‰). *Cribrononion gerthi* occurs in brackish, shallow waters with a salinity varying between 10 and 20‰ approximately. The occurrence at Ladiko-bay of two other brackish water species known from the Baltic, *Cribrononion articulatum* (= *C. cf. alvarezianum* sensu Lutze, 1965) and *C. asklundi*, is to be noted.

Although perhaps favouring higher salinities and higher temperatures, *Ammonia beccarii* evidently has a greater salinity tolerance than might be expected from Lutze's data. In the present-day Mediterranean region, the species occurs, in association with *Nonion depressulum* and *Protelphidium lidoense*, in oligo-mesohaline basins of the Rhone delta (Kruit, 1955). Ter Keurs (1971) adds *Ammonia perlucida*, *Criboelphidium aff. poeyanum* (most probably corresponding to our *Cribrononion incertum*) and *Cribrononion selseyense* (= *C. excavatum*) as constituents of brackish-lagoonal faunas in Holocene sediments of this area. Comparable assemblages have been described by J. and Y. le Calvez (1951) from brackish lagoons in southern France.

In the context of these considerations, the rare presence in Units I–III of several forms, reported from brackish-lagoonal sediments should be men-

tioned: *Triloculina oblonga*, *Cribronion advenum* and *C. gunteri* (see Blanc-Vernet, 1969; Lévy 1971 and ter Keurs, 1971).

On the other hand, it is remarkable to note the concentration of species with a relatively low tolerance for fluctuating salinities at the top of the sequence. As reported by Lévy (1971), *Elphidium macellum*, *Elphidium crispum* and *Quinqueloculina aspera* are constituents of polyhaline faunas along the French Mediterranean coast (salinity 30–18‰).

Combination of these actualistic data from different regions permits the interpretation of the development of the foraminiferal faunas in Units I–III in terms of an upward increase in minimum and maximum salinity. Although such an interpretation evidently involves a simplification, the salinity range is considered as the prime factor that determined the microfaunal distribution. An upward transition from an (oligo?)-mesohaline to a polyhaline environment is assumed. The possible role of additional environmental attributes – waterdepth, nature of substrate, temperature and oxygen contents – can not be evaluated separately.

The main part of the inferred allochthonous component of the foraminiferal fauna of Units I–III can be differentiated into four groups: Miliolidae, plano-convex forms, species with small and thin tests, and planktonic specimens.

The registered species of *Quinqueloculina* and *Triloculina* were apparently largely derived from shallow marine sand bottoms. The same will probably hold true for the plano-convex forms, which are characteristic elements of the biocoenoses in recent vegetated zones. The principal habitat of the Buliminidae in the modern Mediterranean is situated somewhat deeper, starting at about –40 meters in the upper neritic muds. Although the total number of obtained specimens is evidently too low to permit definite inferences, they might have been supplied from such an environment, during high energy episodes, that caused a bottom disturbance at relatively great depth.

Among the planktonic Foraminifera, the predominance of *Globigerinoides ruber* is an expectable feature, since this species is frequently found in shallow, near-shore waters (Parker, 1958).

The data on the distribution of other faunal groups in Units I–III do not allow direct inferences. However, the vertical trend shown by the Ostracoda and by Bryozoan fragments fits in well with the picture given above. Both groups reveal an irregular tendency to an increasing frequency per sediment volume and an augmented number of species.

Among the Ostracoda, an upward increase in maximum size of carapaces is linked to a growing relative frequency of complete valves. These features

give a good expression of the influence of hydrodynamic selection.

In an upward sense, an association of *Leptocythere* sp. 1 and *Falunia rugosa* seems to be replaced by a *Falunia rugosa*-*Xestoleberis communis* assemblage. These associations may both be of autochthonous origin. The appearance of *Aurila calciplena* and *A. ulicznyi* at the top of Unit III, suggests a derivation from the shallow marine realm.

The ostracode fauna of assumed indigenous origin poses a problem. *Leptocythere* sp. 1 probably is a new species, preventing actualistic comparisons. In general, the genus *Leptocythere* contains several species of an euryhaline-eurythermal nature (see Elofson, 1941). The habitat of *Leptocythere* sp. 1, may have been comparable to the brackish lagoonal environments inhabited by *Leptocythere petiti* in the modern Rhone delta (ter Keurs, 1971).

The two other important elements of the ostracode fauna, *Falunia rugosa* and *Xestoleberis communis* show a preference for shallow marine environments in the present-day Mediterranean (Puri et al, 1964). They are not reported from lagoonal, low salinity waters. Some tolerance for fluctuating salinities may, however, be inferred from their occurrence in shallow embayments with fresh water supply or evaporation. Kruit (1955) recorded *Cythereis quadridentata* (= *Falunia rugosa*) in the Gulf of Fos in the Rhone delta area. Barbeito Gonzàles (1969) mentions *Xestoleberis communis* as a faunal element in bays of the isle of Naxos (Greece).

The discrepancy between the fossil and modern occurrences of the two species might cast some doubt on their autochthonous position in the lagoonal sequences at Ladiko-bay. In fact, *Cyprideis torosa torosa* is the only clearly euryhaline species represented in our sediments (Elofson, 1941; Kruit, 1955; ter Keurs, 1971); however, it occurs in very low frequency. The lack of correspondence in data may perhaps be attributed to an incomplete knowledge of modern distribution patterns. Possibly we are dealing with seasonal penetrations in the lagoonal environment by species of a fundamentally marine affinity.

The regular, low frequency occurrence of *Aurila* ex gr. *punctata* (= *A. ex gr. convexa* of authors) may be explained along the same lines of reasoning. This species is of an essentially marine nature and shows occasional overlap on low salinity environments (Puri et al, 1964; Yassini, 1969).

As far as known from recent sediments, the possibly allochthonous component of the ostracode fauna confirms supply from the shallow marine realm through the presence of *Semicytherura sulcata* and *Loxoconcha turbida* (see Masoli, 1969).

In the Bryozoan assemblage, the Cellariiform zoarial type, characterized

by erect and flexible zoaria, is strongly prevalent (see Stach, 1936). Lagaaij and Gautier (1965) report a predominance of this growth-form in thanatocoenoses of the present-day Rhone delta region. The high frequency of species of *Crisia* and *Scrupocellaria* was attributed by the latter authors to the desintegration of colonies in individual internodes, as well as to a tolerance for sediment accretion. Stach (1936) inferred an adaptability to life in the littoral zone. Although the turbulent, littoral environment is not the exclusive habitat of this group of Bryozoa, a derivation from such a realm seems most plausible in this instance. The original substrate of the colonies may have been a sandy or rock bottom.

Finally, attention should be paid to some subordinate elements of the faunas in Units I–III. The rare occurrence of the fresh water Thecamoebian *Centropyxis marsupiformis* is perhaps connected with river water entering the lagoonal area (see discussion of Unit XIV). One of the recent habitats of the only macrofaunal element of the sequence, the pelecypod *Spisula subtruncata*, which appears near the top of Unit III, consists of fine well sorted littoral sands down to a depth of about 35 m (Pérès and Picard, 1964). Van Straaten (1960) reports the species to be particularly frequent between 0 and 25 m in the Rhone delta region. The recorded specimens may thus have been derived from the marine littoral zone.

Summarizing these considerations, the faunal composition of Units I–III gives a reflection of the discontinuous addition of a littoral marine component to an autochthonous community, which inhabited low and/or fluctuating salinity waters. The inferred upward change to more marine conditions is confirmed by the vertical trend in faunal composition and by the environmental significance of recent equivalents of these faunas.

With the exception of the Ostracoda, the modern distribution of the representatives of all faunal groups generally agrees well with the framework of sedimentation depicted in the preceding chapter. Some features, which, however, cannot easily be explained in view of the faunal assemblages of recent lagoons, are the apparent absence of a macrofaunal community of indigenous origin and the surprisingly low number of displaced molluscan specimens of marine derivation in the wash-over-sediments.

The inference of a lagoonal environment with waters of relatively low and variable salinity can be added to our picture of the conditions of sedimentation. The dilution of near-shore waters by run-off or precipitation involves the assumption of an adequately protected lagoon on the lee of a well developed system of barriers or shoals.

#### Unit IV

The microfaunal composition of this level can be regarded as a continuation of the vertical trend, recorded in the underlying sequence. The fauna shows a further increase in frequency and diversity.

Among the benthonic Foraminifera, the Miliolidae now approach 50% of the total assemblage. *Quinqueloculina aspera*, already important near the top of Unit III, occurs together with two other forms, with a high frequency, which were not recorded below: *Q. cf. costata* and *Q. longirostra*. A high content of worn and corroded miliolid specimens is to be noted.

Other forms, which make their first appearance in the section and which reach considerable frequencies are *Planorbulina mediterraneensis* and the Textulariidae.

The greater part of the additional species was already observed in Units I—III, among others *Nonion depressulum*, *Ammonia beccarii*, *Cribronion gerthi*, *C. incertum*, *Elphidium macellum* and *E. crispum*.

As stated in the preceding chapter, the origin of this unit implies an initial phase of high energy erosion of back barrier sediments, one or more depositional periods and episodes of slow- or non-deposition. The composition of the foraminiferal fauna can be explained accordingly. Two major faunal components may be distinguished:

1. A component, which contains a number of species, which were already met with in the underlying sediments and which may thus represent the back barrier community in reworked state (*Quinqueloculina aspera*, *Ammonia beccarii* and *Nonion depressulum*).

2. A component of shallow marine origin, which probably comprises the greater part of the Miliolidae. Some forms, which make their first appearance at this level of the succession, such as *Planorbulina mediterraneensis* and the Textulariidae, may also belong to this group.

The second faunal component most probably is of a heterogeneous nature. Theoretically three different assemblages may be its constituting elements:

- a. An assemblage of allochthonous nature, derived from the open marine barrier face and supplied during the deposition of the sands.

- b. An assemblage of originally the same derivation, which became incorporated in the sediment through reworking of pre-existing back barrier deposits.

- c. An autochthonous community, which was established after the accumulation of the sands, or during intermediate phases of slow- or non-deposition. This component may partly have been introduced in the sediment during its organic homogenization.

A distinction of these three groups is virtually impossible; this particularly holds true for the assemblages a and b. Anticipating on our discussion of the higher levels of the succession, it is remarkable to note the regular presence of *Planorbulina mediterranensis* and Textulariidae in units with corresponding depositional characteristics (X, XVII) and in adjacent sediments, which are considered to be of approximately open marine origin (XI, XVIII). These forms appear to be linked to some particular miliolid species: *Quinqueloculina cf. costata*, *Q. longirostra* and *Q. berthelotiana*. Although this assumption cannot definitely be proved, the regular stratigraphic distribution of these species may express an autochthonous position (group c).

It is well understood, that such a distinction of faunal components may lead to oversimplification of the problem, since several of the species may not have been limited to one habitat.

Concerning the relation of the two main components, a prevalence of the presumed barrier face assemblage over reworked lagoonal specimens may be concluded. This suggests a considerable supply of new sediment during the formation of the unit and not a mere reworking of older barrier back sediments, such as those of Unit III.

In the present-day Mediterranean, *Quinqueloculina cf. costata*, *Q. longirostra*, *Q. berthelotiana*, *Planorbulina mediterranensis*, *Textularia agglutinans*, *T. candeiana* and *T. conica* are all known from shallow marine sands and are often represented in environments subject to current- or wave action (J. and Y. le Calvez, 1951; Kruit, 1955; Blanc-Vernet, 1969). Although the individual species may occur under other circumstances, the total association is characteristic for such conditions.

Owing to the prevalence of unknown or extinct species, an actualistic evaluation of the ostracode fauna is impossible. It is interesting to note the occurrence of the species *Aurila calciplena* and *A. cruciata minor* in coarse, marine sands in the Pliocene of the isle of Kephallina, Greece (Uliczny, 1960).

The ecological information supplied by the Bryozoan assemblage is comparable to that obtained in Units I–III. Littoral sand or rock-bottoms must have been the original habitat of the species of *Crisia* and *Scrupocellaria* (see Lagaaïj and Gautier, 1965).

On the grounds of these paleoecological considerations, the conditions of origin of Unit IV are now better understood. The sediment manifests a transformation of the originally lagoonal realm into an area with open marine conditions and shallow depth. The initial phase of erosion was followed by a strong supply of sand of marine derivation, which was mixed with some reworked material of back barrier origin. The resulting sediment

was subjected to bioturbation under conditions of non-deposition or very slow accretion, which may have permitted the establishment of a new autochthonous community of a marine nature.

These conclusions imply the absence, eastward of our section of the protecting barrier system, which was responsible for the upbuilding of the sequence of Units I–III. Continued subsidence of the area permitted an erosional truncation of the barrier and its wash-over-fans by marine forces. The sediments of the higher parts of the pre-existing barrier were redistributed in a landward direction over lagoonal deposits.

These considerations are only valid for the locality of study and its immediate surroundings. Farther west(land)wards, the evolution of the lagoonal area remains obscure. We have no data at our disposal, that allow a choice between several theoretical possibilities, *i.e.* a complete transformation of the restricted environment in a littoral marine area, with or without a submergence of the adjacent hinterland, or a partial alteration, accompanied by the construction of new barriers westward of the locality of study.

As mentioned already, comparable stratigraphic phenomena are known from Holocene barrier and back barrier sediments (Fisher, 1961; Oomkens, 1967). The origin of the erosional truncation of back barrier sands and of the overlying homogeneous deposits was attributed by these authors to marine transgressions. The use of the term transgression however implies a receding shoreline (see Curray, 1964). There is no need for the assumption of a westward migration of the landward limits of the lagoon, in the case of Ladiko-bay.

The upper few centimeters of the unit were subjected to winnowing processes before being covered by Unit V, as shown by the better sorting of the sediment. The disappearance of fine grained material is linked to an appreciable reduction in frequency of Foraminifera per sediment volume. Comparable features are known from recent environments (see Lutze, 1965).

#### *Unit V*

The foraminiferal fauna of this level shows several important changes with respect to the underlying sediments:

1. The absence of *Quinqueloculina cf. costata*, *Q. berthelotiana*, *Planorbulina mediterraneensis* and the Textulariidae.

2. The appearance of other prevalent species among the frequent Milioliidae, which are often in worn condition: *Triloculina inflata*, *Quinqueloculina aspera* and *Q. semilunum*.

3. The return in fairly high frequency of *Nonion depressulum* and *Ammo-*

*nia beccarii* in company of *Cribrononion articulatum* and a number of other species known from Units I–III: *C. incertum*, *C. gerthi* and *Reussella spinulosa*.

Among the Ostracoda, the main feature is the return of *Leptocythere* sp. 1 and *Xestoleberis communis*.

The most conspicuous aspect of this unit is the abundance of clearly displaced mollusc shells, arranged in stringers. The bivalves *Spisula subtruncata* and *Mytilus galloprovincialis* are strongly predominant. The prevalence of *Spisula* can be correlated with its frequent occurrence in living position in the interjacent sands. *Mytilus*, however, was not observed in situ.

An interrelation of sediment and fauna is suggested by the combined occurrence of relatively coarse sands, limestone pebbles, shell stringers and foraminiferal specimens of relatively large size. These features confirm the postulated influence of high energy currents, which were probably responsible for the formation of shell-lag deposits.

The return of foraminiferal and ostracode species of restricted affinity goes together with the disappearance of a number of forms of presumably marine origin. An environment with a somewhat protected position with respect to open marine influences is also suggested by the low diversity of the macrofauna of local origin.

The importance of the Miliolidae and the frequency of worn representatives of this group most probably express a marine, littoral derivation of the sands.

Among the Foraminifera, *Triloculina inflata*, *Quinqueloculina aspera*, *Q. semilunum*, *Nonion depressulum*, *Ammonia beccarii* and *Cribrononion articulatum* may be considered as the main forms of indigenous origin. In recent environments, all of these species show a tolerance for divergences in salinity. *Triloculina inflata* is reported from hypersaline waters (Lévy, 1971) and from zones of active sediment transport (Kruit, 1955). As a whole, the remainder of the association is indicative of polyhaline conditions (salinity 30–18‰, Lévy, 1971). The joint occurrence of some miliolid species and forms of lagoonal affinity can thus be interpreted in terms of moderately subnormal salinities.

In the macrofauna, the frequent occurrence of species able to adapt to at least slightly lowered salinities is striking: *Spisula subtruncata*, *Mytilus galloprovincialis*, *Anomia ephippium*, *Cardium* sp., *Nassarius* cf. *incrassatus*, *Bittium reticulatum*, *Rissoa* sp. and *Ostrea edulis*. (see Mars, 1950; van Straaten, 1956; Cadée, 1968).

The prevalent molluscan species of autochthonous origin, *Spisula subtruncata*, is a fundamentally marine form, which is frequently observed in

displaced position on European beaches and in tidal inlets (van Straaten, 1956). In the modern Mediterranean, it is an important element of the "biocoenosis of fine, well sorted sands", distinguished by Pérès and Picard (1964). According to these authors, this community shows an impoverished development and an enrichment in euryhaline forms, near estuaries and coastal lagoons. A decrease in species-diversity of the assemblage can also be noted in environments, subject to turbulent conditions.

The epifaunal suspension feeder, *Anomia ephippium*, living attached to shells in current-swept environments, may be an additional element of the autochthonous community (Cadée, 1968; Le Campion, 1970). The growth of *Balanus* on molluscan shells is an expectable feature in such a habitat.

The remainder of the macrofauna can be regarded as a mixture of specimens derived from shallow marine sand bottoms (*Alvania cancellata*, *Ringicula auriculata*, *Neverita josephina*) and a prevalent component, which probably inhabited littoral, rocky substrates (*Mytilus galloprovincialis*, *Begonia calyculata*, *Arca noae*, *A. diluvii*, *Nassarius cf. incrassatus*, *Diodora italica*, *Haliotis lamellosa* and *Patella lusitanica*) (van Straaten, 1960; Pérès and Picard, 1964).

The most important representative of the latter group, *Mytilus galloprovincialis*, is evidently not restricted to rocky beaches. However, since the species occurs in company of several forms typical for this habitat, headlands seem to be its most plausible source area.

Summarizing these considerations, we must be dealing with an environment of somewhat restricted nature, subject to probably slightly subnormal salinities and influenced by current action and phases of supply of material of marine derivation. Such conditions are best fulfilled in an area, situated between or slightly on the lee of obstructing sediment bodies, in other words in or near a lagoonal inlet system.

The inferred presence of inlet sediments at this level of the succession implies a renewed construction of a system of barriers or shoals, at or slightly eastward of the locality of study, after a period of open marine conditions, manifested by Unit IV.

#### Unit VI

The faunal composition of the lower member of this unit is to a large extent comparable to that of the preceding unit.

*Triloculina inflata*, *Quinqueloculina aspera*, *Ammonia beccarii*, *Nonion depressulum* and *Cribronion articulatum* are again well represented among the Foraminifera, which also show damaged miliolid specimens. The size of foraminiferal tests is again relatively large.

In the low frequency ostracodal fauna, *Leptocythere* sp. 1 was recorded.

The shell stringer in the upper part of subunit 1 does not show the prevalence of *Spisula subtruncata*, which was noted in Unit V. Here, *Glycymeris* cf. *violascens* is the most important form, together with *Mytilus galloprovincialis*. These data do not point to important changes in environmental conditions and in the nature of supply with respect to Unit V. The lack of a predominance of *Spisula* is obviously related to its absence in living position.

*Glycymeris* cf. *violascens* may have been a constituent of a community, which inhabited littoral sands. Since species of *Glycymeris* are also reported from current-swept environments, a parautochthonous position cannot be excluded (see Pérès and Picard, 1964).

The only appreciable difference in the microfaunal composition with respect to that of Unit V is the increased frequency of plano-convex Foraminifera, such as *Rosalina*, *Asterigerina* and *Cibicides*. As will be discussed below, the augmented importance of epiphytal Foraminifera can be regarded as the expression of a development of subaquatic vegetation on the lee of the system of shoals. In turn, this feature may reflect a tendency to a closure of the inlet, which was responsible for the origin of Units V and VI<sup>1</sup>.

The boundary between subunits 1 and 3 marks a sudden change in fossil contents. In the overlying sediment, Ostracoda, Bryozoa and Mollusca are entirely absent. Only a few tests of *Ammonia beccarii* were recorded. The change from relatively rapid to slow deposition, inferred from sedimentary data, is thus accompanied by the appearance of a microfauna of restricted affinity. As will be shown in greater detail below, this change, and the total absence of faunal elements of marine derivation, is indicative of the closure of the inlet system by a sandy barrier.

#### Units VII–VIII

The microfauna of this succession, virtually limited to the Foraminifera, confirms the change in conditions of sedimentation, manifested by the boundary of subunits 1 and 3 of Unit VI and further reveals an upward decrease in frequency and diversity.

In the lower part of Unit VII, *Ammonia beccarii* strongly prevails. It is accompanied by a number of low frequency forms, such as *Elphidium macellum*, *E. crispum*, *Reussella spinulosa*, *Cribronion articulatum* and *C. excavatum*. Remarkable is the relatively great number of plano-convex species, which show a further increase with respect to Unit VI<sup>1</sup>.

In the upper part of Unit VII, *Ammonia beccarii* is again predominant. A strong decrease of plano-convex forms and the disappearance of *Elphidium*

*macellum* and *E. crispum* are to be noted. *Nonion depressulum* occurs in addition to the other species mentioned above.

In the sediments of Unit VIII, the fauna reaches a minimum in frequency and diversity. *Ammonia beccarii* is predominant in most samples. It occurs together with a number of species with a scattered, low frequency distribution, e.g. *Cribronion incertum*, *Protelphidium lidoense*, *Nonion depressulum* and *Reussella spinulosa*. *Leptocythere* sp. 1 was locally recorded as the sole representant of the Ostracoda.

Although the irregular distribution and low abundance of most species prevents a definite conclusion, a trend towards an upward decrease in size of foraminiferal tests may be present in Units VII–VIII.

The quantitative and qualitative composition of the faunas are indicative of a sudden return, half way Unit VI, to restricted, approximately lagoonal conditions, which reach their maximum in Unit VIII. This conclusion is in accordance with our sedimentary data, which point to near-barrier, wash-over-fan deposits in the upper part of Unit VII and in Unit VIII.

The thin clayey seam, which separates subunits 1 and 3 of Unit VI, thus marks the closure of the inlet environment of Units V and VI<sup>1</sup> by a barrier. In view of the extremely rare and ecotypical foraminiferal fauna in Unit VI<sup>3</sup>, the obstructing sand body must have been formed at a considerable distance eastward of the locality of study.

The clayey stratum acts as the first expression of the establishment of protected conditions, which permitted the settling of fines. Later, the originally horizontally laminated sands of the upper part of Unit VI and their counterparts in the lower part of Unit VII came into existence under conditions of wave action in a relatively tranquil environment (see Chapter III, paragraph 3). Sediments, washed over the newly formed barrier, ultimately formed the upper part of Unit VII and Unit VIII.

The presence of species like *Elphidium macellum* and *E. crispum*, in association with a predominance of *Ammonia beccarii*, in Unit VII, might be an indication of polyhaline conditions in the back barrier environment. The influence of fluctuating salinities is also suggested by the occurrence of *Cribronion articulatum*, *C. excavatum* and *Protelphidium lidoense* (see discussion of Units I–III).

The relatively high content of plano-convex Foraminifera in the lower part of Unit VII is in favour of an origin on the inner margin of a barrier. Such areas are often the habitat of a dense subaquatic vegetation. The plant-remains, which occur abundantly in Unit VIII, could have been derived from such a realm.

In comparison to the near-barrier, wash-over deposits in the upper part of

Unit III, the sediments of Unit VIII show a surprisingly low frequency and diversity of the microfauna. The virtual absence of supply of allochthonous marine elements in Unit VIII is best explained by assuming a dilution in density of microfaunal elements in the source area, as a consequence of high rates of sedimentation on the open marine barrier face. A rapid supply of sand by longshore currents must thus be inferred. In turn, this process favoured the swift accretion of barriers at the seaward side and a more adequate protection of the lagoonal realm by a well developed barrier system.

The environment of deposition of Unit VIII might be comparable to the coastal lakes along the margins of the present-day Rhone delta, described by Kruit (1955). This author mentions the importance of processes of erosion and reworking and strong variations in salinity as the main characteristics of such basins. The poor assemblage of Foraminifera of Unit VIII is tentatively interpreted as the remainder of a community, which inhabited a mesohaline to strongly saline coastal basin of a largely enclosed nature.

Finally, attention should be paid to the relation of Units VII–VIII to the sediments of Units V–VI. The succession of Units V–VIII contains the rather sudden change from an inlet environment, by way of back barrier sediments to near barrier, wash-over deposits. The superposition of these sediments can be regarded as a sedimentary sequence of a fining upward nature, which attests the reconstruction of the lagoonal environment. This development was probably accompanied by a gradual seaward displacement of the barrier front.

#### *Unit IX*

The foraminiferal fauna of this unit reveals an irregular upward trend to increasing frequency and diversity, which have their maximum in a pebble bearing intercalation (sample 22). The size of specimens shows an upward increase in the sandy sediments.

The *Ammonia*-dominated, impoverished assemblage of Unit VIII is replaced by an association of *Ammonia beccarii* and *Nonion depressulum* in a clayey sample in the lower part of this unit. *Cribrononion articulatum*, *C. advenum*, *Protelphidium lidoense* and *Elphidium macellum* occur among the subordinate elements.

Near the top of the unit, *Nonion depressulum* is prevalent in the presumably autochthonous community; *Cribrononion excavatum* is well represented. *Ammonia beccarii*, *A. perlucida*, *Cribrononion articulatum*, *C. incertum*, *C. asklundi*, *C. advenum*, *C. gerthi* and *Elphidium macellum* were also recorded.

The sandy sediments in the lower and upper parts of the unit are characterized by a considerably greater faunal diversity than the associated clayey sediments. The dominating species, mentioned above, are always more or less well represented. In addition to a greater number of subordinate forms, the occurrence of Miliolidae is a prominent difference with the clayey deposits. The frequency of this group shows an irregular upward increase with a maximum in the pebble bearing level. Here, *Quinqueloculina aspera* and *Triloculina trigonula* occur as important elements; they are associated to a great number of worn Miliolidae. Another notable feature of the foraminiferal distribution is the upward increase in plano-convex species, particularly of *Cibicides lobatulus*.

On sedimentary grounds, this succession was considered as a less regularly developed, approximate equivalent of the sequence of Units I—III. An origin as a wash-over-fan sediment, formed during a landward displacement of a barrier system, was concluded.

The analogy in a depositional sense is confirmed by the differential foraminiferal contents of clays and sands, implying a supply of allochthonous components during high energy phases. The large scale vertical trend, consisting of a changing composition of autochthonous communities, an increasing admixture of allochthonous components (Miliolidae, partially in damaged condition) and an upward increase in frequency and size of specimens, is also correspondent.

As in Units I—III, the presence of several species with a known tolerance for low and/or fluctuating salinities is remarkable (Lutze, 1965, Lévy, 1971). The *Cribronion excavatum*-*C. incertain* assemblage, recorded in Units I—II is, however, absent. This difference is probably related to some divergencies in environmental conditions. Higher minimum salinities, the absence of stagnant water bodies and the occurrence of higher temperatures may be involved.

The autochthonous assemblages of Unit IX may be approximately comparable to the faunas found in the lower part of Units III. An assignment of salinity values is hazardous, owing to the apparent lack of a vertical trend in the composition of the indigenous assemblages. Approximately mesohaline conditions may be inferred.

In analogy to the upper part of Unit III, the considerable frequency of *Quinqueloculina aspera* in the upper, sandy sediments of Unit IX is remarkable. Because of its absence in a clayey intercalation in this part of the unit, the autochthonous position of the species can not be proved. Its appearance might be indicative of the establishment of higher ( $\pm$  polyhaline) salinities or for the nearness of a lagoonal realm, characterized by such conditions.

With respect to the top of the succession of Units I—III, the possibly epiphytal foraminiferal assemblage, dominated by *Cibicides lobatulus* shows a considerable increase. This species shows two preferential habitats in modern environments: areas with subaquatic vegetation and shell bearing sands in current-dominated environments (Blanc-Vernet, 1969; Le Campion, 1970). Without further information, the derivation of this species can not objectively be determined.

The distribution of Ostracoda and Bryozoa in Unit IX is too scattered to allow an individual analysis. Both groups, however, reveal an upward increase in diversity, which is consistent with the vertical trend noted above. The Bryozoa, belonging to the allochthonous faunal component, reach their highest frequency and diversity in the pebble bearing level. Among the Ostracoda, an autochthonous assemblage, dominated by *Leptocythere* sp. 1, must be assumed in the lower part of the unit.

*Unit X* (see enclosure II).

In the sediments above the second surface of disconformity, the depositional indications for high energy supply are linked to a considerable size of foraminiferal specimens and a great diversity of the total faunal complex.

In the foraminiferal fauna, the Miliolidae are the prevalent group; the content of damaged individuals is high. *Triloculina inflata*, *T. trigonula*, *Quinqueloculina aspera* and *Q. cf. costata* may be mentioned. As in Unit IV, the miliolid maximum and the occurrence of *Q. cf. costata* go together with the appearance of *Planorbulina mediterraneensis* and Textulariidae.

The remainder of the fauna consists of forms, which were recorded in the preceding unit, e.g. *Ammonia beccarii*, *Elphidium macellum* and *Protelphidium lidoense*.

In analogy with the Unit IV, a component of marine derivation, an apparently reworked component and a doubtful new assemblage of autochthonous origin may thus be recognized. The major part of the fauna belongs to the allochthonous group.

In addition to *Quinqueloculina cf. costata*, *Textularia candeiana* and *Planorbulina mediterraneensis*, *Triloculina inflata* may be taken into consideration as an element of the indigenous association, since this species is adapted to littoral, turbulent conditions (Kruit, 1955).

A distinct difference with Unit IV is the greater significance of species like *Cibicides lobatulus*. This species is an element of the biocoenosis in recent *Posidonia* meadows in the Mediterranean (Blanc-Vernet, 1959, 1969). Its higher frequency may point to a more wide-spread occurrence of submarine vegetation in the littoral realm.

Remarkable is the low frequency presence of *Miniacina miniacea*, which is known from present-day vegetated bottoms, coarse sandy sediments and rocky substrates (Blanc-Vernet, 1969).

The reworked foraminiferal component is completely comparable to the presumably polyhaline and mesohaline assemblages, registered in Unit IX.

In the ostracode association, the occurrence of *Leptocythere* sp. 1 together with some species, which were not found in the underlying sediments, suggests a mixing of faunal components. The reappearance of the Pliocene form *Aurila calciplena* in coarse sands may point to an autochthonous position of the species. This may also hold true for *Urocythereis margaritifera margaritifera*, which is known from very shallow sand bottoms in the modern Mediterranean (Puri et al, 1964).

With the prevalence of Cellariiform types, such as *Crisia* spp. and *Margaretta cereoides*, the bryozoan fauna confirms its derivation from marine littoral sands. The occurrence of *Savignyella lafontii*, which inhabits this zone down to a depth of 40 m, living attached to algae and invertebrates, fits in well with the general picture (Lagaaij and Gautier, 1965).

In conclusion, the fauna of this unit gives expression to the reworking of barrier- and back barrier sediments and to the establishment of open marine conditions in a turbulent environment. With respect to Unit IV, the only appreciable difference in the conditions of origin may have been the greater importance of vegetation in the littoral realm. This would indicate a lower rate of accretion, owing to a reduction of longshore sand supply.

#### Units XI–XIV

In Unit XI, the relatively large size of foraminiferal specimens, the prevalence of forms like *Quinqueloculina* cf. *costata* and *Q. longirostra*, and the occurrence of *Planorbulina mediterraneensis* and Textulariidae is in accordance with our postulation of a current-swept environment of marine nature. *Q.* cf. *costata* is reported from inlets of southern French coastal lagoons by J. and Y. le Calvez (1951); the other species are also adapted to turbulent conditions (Kruit, 1955; Blanc-Vernet, 1969).

The relatively high frequency of *Cibicides lobatulus* might be an indication of an indigenous origin of this form, since it is also found on shell bearing channel bottoms (Le Campion, 1970).

The remainder of the foraminiferal fauna is difficult to understand in terms of the original habitat of its constituents. In addition to some possible additional species of a parautochthonous nature (*Triloculina adriatica*, *Cancris auriculus*), the assemblage probably contains specimens, derived from open marine littoral environments (particularly Miliolidae) and a small

number of representants of an adjacent polyhaline, lagoonal community (*Ammonia beccarii*, *Elphidium macellum*, *E. crispum* and *Protelphidium lidoense*).

The rather meagre ostracode assemblage contains species of lagoonal affinity (*Leptocythere* sp. 1, *Xestoleberis communis*) and the littoral marine form *Urocythereis margaritifera margaritifera*. The recent habitats of the fourth species, *Loxoconcha rhomboidea*, are too variable to permit a definite conclusion. Its original environment may have consisted of marine sandy-rocky bottoms or of a vegetated zone. Since the species displays a tolerance for fluctuating salinities and turbulence, an autochthonous position must also be considered (see Whatley and Wall, 1969; Puri et al, 1969).

A conspicuous aspect of this unit is the abundance of mollusc shells, bryozoan fragments, coral stems and annelid tubes. In addition to the diversified nature of the macrofauna, its well sorted character is striking.

The macrofaunal association differs in several respects from the assemblage recorded in the lower shell bearing levels (Units V–VI<sup>1</sup>). The diversity of the total fauna is considerably greater in this instance. Although several species of Pelecypoda and Gastropoda with a potential tolerance for lowered salinities can be found (among others *Gibbula* sp. and *Bittium reticulatum*), they do not appear among the prevalent forms. As far as fluctuating salinities have played a part, their influence must have been relatively slight.

In view of their recent habitats, some constituents of the macrofauna can be taken into consideration as elements of parautochthonous nature. *Corbula gibba* and *Anomia ephippium* are both forms with a preference for coquina substrates (van Straaten, 1960). *Laevicardium crassum*, *Dentalium* sp. and *Ditrupa* sp. occur, in association with *Corbula gibba*, in the "biocoenosis of instable bottoms", distinguished by Pérès and Picard (1964). According to these authors, this community of suspension feeders is typical for sand bottoms, which are subject to a destruction of the superficial nutritive film by turbulent waters.

The large fragments of Sertellidae can also be regarded as representatives of an indigenous faunal component. These Reteporiform Bryozoa are particularly adapted to high energy environments (Stach, 1936; Lagaaij and Gautier, 1965).

The in situ occurrence of the coral *Cladocora cespitosa* accentuates the largely marine waters of the environment.

By far the greater part of the possibly allochthonous Mollusca was derived from littoral sand bottoms, *Neverita josephina*, *Nassarius semistriatus*, *N. reticulatus*, *N. cf. mutabilis*, *Alvania reticulata*, *Pecten jacobaeus*. Some original inhabitants of rocky shores were, however, also recorded (*Patella lusitanica*,

*P. caerulea* and *Arca noae*, see van Straaten, 1960; Pérès and Picard, 1964).

In summary, the recent distribution of the micro- and macrofaunal of Unit XI is in accordance with our postulation of a turbulent realm of approximately normal marine salinity. The supply of littoral marine components and the presence of some microfaunal forms of restricted affinity under such conditions, is best explained by the assumption of a lagoonal inlet system. With respect to its lower environmental equivalent, Unit V, a much stronger open marine influence is obvious.

The transition to the burrowed sands of Unit XII goes together with several important changes in micro- and macrofauna:

1. A decreasing importance of the Miliolidae and the disappearance of *Planorbulina mediterraneensis* and the Textulariidae.

2. Higher frequencies of two species of restricted affinity: *Ammonia beccarii* and *Nonion depressulum*.

3. A very strong development of plano-convex Foraminifera, particularly of *Asterigerina rhodiensis* and *A. planorbis*.

4. The reappearance of *Falunia rugosa* among the Ostracoda.

5. A strong decrease in frequency and diversity of the macrofauna. The Gastropod *Gibbula* sp. becomes prevalent; tubes of *Ditrupa* are also abundant.

6. The disappearance of the greater part of the molluscan forms, considered to be adapted to current-swept environments: *Corbula gibba*, *Anomia ephippium*, *Laevicardium crassum*. The reduced frequency of *Dentalium inaequicostatum* and the absence of macroscopical fragments of Sertellidae (Bryozoa) are striking in this connection.

7. The virtual disappearance of forms, which inhabit rocky shores.

These features are clear indications of a waning open marine influence, together with an increasing restriction of the environment. This change is apparently linked to a strong augmentation of elements, which might point to the presence or nearness of an area with subaquatic vegetation. With respect to the current-dominated, more open marine realm of Unit XI, the growth of an obstruction to currents and marine supply must be inferred.

In the present-day Mediterranean, a species of the gastropod *Gibbula* (i.e. *Gibbula adansoni*) is characteristic for protected areas on the lee of *Posidonia* meadows or behind spits ("biocoenosis of muddy sands under tranquil conditions" of Pérès and Picard, 1964). Our *Gibbula* sp. may have inhabited similar environments. In the absence of a prevalence of foraminiferal forms, which are typical for modern *Posidonia* meadows (such as *Cibicides lobatulus*, see Blanc-Vernet, 1969), a back barrier environment seems the most plausible solution.

The growth of a sandy barrier across a lagoonal inlet explains the disappearance of micro- and macrofaunal forms, which prefer agitated sand bottoms and the lack of supply of allochthonous components, derived from rocky substrates.

Consequently, the greater part of the macrofaunal complex can be regarded as being of autochthonous origin, although some addition of organic remains from a near-by, migrating lagoonal pass cannot be excluded.

*Ditrupa* sp., *Dentalium inaequicostatum*, *Cardium* sp. and *Callista chione* may have been inhabitants of the local muddy sands. *Venus ovata* often occurs on shell bearing bottoms. If these conclusions are accepted, salinity fluctuations must have been very slight, notwithstanding the presence of species with a wider salinity tolerance, such as *Gibbula* sp. and *Ostrea edulis* (see Mars, 1950; van Straaten, 1960).

A modern equivalent of the foraminiferal fauna of this unit has not been found in the literature. *Asterigerina rhodiensis*, which suddenly becomes important, most probably is a fundamentally marine form; its plano-convex test might be an indication of an adhering mode of life, attached to shells or to subaquatic vegetation on the lee of sand spits. It occurs together with a number of forms with a corresponding mode of life: *A. planorbis*, *Cibicides lobatulus* and *Rosalina globularis* var. *bradyi*.

Also represented is a group of species, which characterize polyhaline environments lower down in the succession: *Ammonia beccarii*, *Elphidium macellum*, *E. crispum*, *Quinqueloculina aspera* and *Protelphidium lidoense*.

The greater part of the low frequency miliolid species probably reflects the decreased supply from the marine, littoral realm. Such a supply is also indicated by the occurrence of small specimens of Sertellidae, apparently derived from a near-by, migrating inlet. The increasing distance to the latter environment is well illustrated by the decrease in size of these allochthonous components with respect to their indigenous counterparts in Unit XI.

Among the Ostracoda, the regular, low frequency occurrence of *Hemicytherura videns* in this unit and in the overlying sediments is remarkable in view of the modern distribution of this form. The species is of a fundamentally marine nature and shows a clear preference for vegetated bottoms (Puri et al, 1964; Yassini, 1963).

In the interstratified sands and clays of Unit XIII, the main features of the faunal composition are the lack of macrofossils, the virtually complete absence of miliolid Foraminifera, the continued importance of plano-convex Foraminifera, the return of foraminiferal species of lagoonal affinity and the low frequency reappearance of *Planorbulina mediterraneensis* and the Textulariidae.

The foraminiferal assemblage of restricted nature is best developed in the clayey sample nr. 29. Here, *Cribrononion excavatum* reaches a considerable percentage; it is accompanied by, for instance, *Nonion depressulum*, *Cribrononion gunteri*, *Ammonia perlucida* and *Reussella spinulosa*.

A detailed analysis of faunal differences between clayey and sandy sediments seems less useful in this instance, owing to the suspected influence of burrowing. It is, however, important to note the divergence in composition between the lower sandy and the clayey sample, as well as the greater correspondence of the microfaunal composition of the latter to that of the upper sandy sample. These features witness the supply of allochthonous components, which are best represented in the sandy deposits, and the upward decrease in frequency of these foreign elements.

The foraminiferal fauna appears to be composed of a mixture of three main groups:

1. An assemblage of supposed lagoonal affinity.
2. A component, which was probably derived from near-by zones of subaquatic vegetation and which is comparable to the prevalent association found in Unit XII: *Asterigerina rhodiensis*, *A. planorbis* and *Cibicides lobatulus*.
3. An association of apparently marine derivation, represented by *Planorbulina mediterraneensis* and the Textulariidae.

With respect to Unit XII, group 1 and 3 show an increase in frequency, whereas group 2 reveals a tendency to an upward decrease.

In summary, a continued trend to an increasing restriction of the environment of deposition was linked to a renewed supply of microfaunal elements from a fully marine habitat. Because of the importance of plano-convex Foraminifera, the depositional area must have been close to a back barrier realm, with yet fairly marine circumstances. These features are indicative of a nearbarrier environment, which was episodically subjected to sand supply from the littoral zone by wash-over processes. Such conditions are also suggested by the diversity of the ostracode assemblage and the relative increase of micro-bryozoan fragments with respect to Unit XII.

Characteristic for the foraminiferal fauna of the overlying deposits of Unit XIV is the practical absence of Miliolidae, *Planorbulina mediterraneensis* and *Textularia* species. These changes go together with an augmented frequency of species of presumed lagoonal origin: *Cribrononion excavatum*, *Nonion depressulum*, *Ammonia beccarii*, *Protelphidium lidoense*, accompanied by *Cribrononion gunteri* and *Ammonia perlucida*. In an upward sense, a decreasing importance of plano-convex Foraminifera is to be noted.

The possibly epiphytal forms are relatively abundant in the sandy strata,

whereas the supposed lagoonal association is most prominent in the clayey intercalations.

In the relatively fine grained sands in the upper part of the unit, these trends converge to a strong reduction of the first group and a prevalence of the latter. The decrease of faunal diversity goes together with a reduction in frequency of specimens per sediment volume and a diminishing size of tests.

In some of the samples of this unit, the influence of hydrodynamic size-sorting on the qualitative composition of the faunas is evident. In one of the clayey samples (nr. 34) and in the very fine sandy to silty strata near the top of the unit, a high content of small and thin tested forms like *Bulimina*, *Bolivina*, *Brizalina*, *Loxostomum* and *Globulina* appears to be connected to the occurrence of frequent planktonic Foraminifera or Thecamoebina.

The data regarding the Ostracoda allow the recognition of a *Leptocythere* sp. 1. — *Falunta rugosa-Xestoleberis communis* assemblage, which is already known from deeper levels of inferred lagoonal origin. The rapid upward disappearance of bryozoan fragments is a further indication of the waning of marine influence in an upward sense.

The return of a foraminiferal and ostracode association of assumed (oligo?)- mesohaline origin (see Units I–III) witnesses the influence of an, at least periodical, fresh water supply. The same holds true for the locally frequent occurrence of Thecamoebina. The species *Centropyxis marsupiformis* has been reported from the former Zuiderzee (The Netherlands), in front of the mouth of the river IJssel, by Hofker (1922). It is also known from the fresh water Lagoa da Mangueira (Brazil, Closs and Madeira, 1962) and from fresh water to very low salinity zones of the Lagoa dos Patos (Brazil, Closs, 1962).

The small and fragile tests of *Centropyxis* are particularly disposed for transport in pseudo-planktonic condition. The occurrence of concentrations of this form in clayey sediments, which also contain a considerable number of planktonic Foraminifera and small benthonic specimens, is best explained by a lagoonward dispersion during the simultaneous occurrence of high energy turbulence and an increased river discharge.

In conclusion, the fauna of Unit XIV confirms our interpretation of a wash-over-fan deposit. In an upward sense, an increasing distance to the barrier system must be inferred, involving a seaward displacement of the latter during the accumulation of the unit. Referring to our discussion of Units I–III, the superposition of Units XI to XIV implies a change from approximately normal marine salinities, by way of subnormal-polyhaline conditions to (oligo?)- mesohaline waters. The fairly regular presence of species like *Ammonia perlucida*, *Cribronion gunteri* (Foraminifera),

*Loxoxoncha turbida* and *Krithe* sp. (Ostracoda) in Unit XIV probably points to divergent environmental conditions, which will be treated in our discussion of the overlying unit.

#### Unit XV

The often very low number of collected specimens of Foraminifera and Ostracoda in this unit prevents a detailed analysis of the fauna.

In the relatively sandy, lower subunit, *Ammonia beccarii*, *Protelphidium lidoense*, *Ammonia perlucida* and *Cribrononion gunteri* are the most important species of Foraminifera. *Cribrononion excavatum*, *C. incertum* and *Nonion depressulum* show a scattered low frequency distribution. Plano-convex Foraminifera are more or less regularly represented in low abundance.

As far as present, the Ostracoda show an assemblage of *Leptocythere* sp. 1, *Falunia rugosa*, *Xestoleberis communis*, *Loxoxoncha turbida* and *Krithe* sp.

In the upper part of the unit, the association shows a further decrease in diversity. *Ammonia beccarii*, *Protelphidium lidoense*, *Leptocythere* sp. 1, *Falunia rugosa* and *Xestoleberis communis* seem to be the prevalent forms. Plano-convex Foraminifera occur in still lower numbers.

With respect to Unit XIV, the change in sedimentary properties goes together with the development of a particular association of restricted affinity and a virtual disappearance of allochthonous elements of marine derivation. The sole recognizable component of displaced nature is constituted by plano-convex Foraminifera, such as *Cibicides lobatulus* and *Cancris auriculus*. The difference in composition of the latter association to that of the presumed epiphytal community in the barrier back sediments of Unit XII, might express a derivation from another, possibly open marine, habitat in this instance. The same may hold true for the abundance of plant-remains in this unit; root levels, indicative of an autochthonous position of the latter, were not observed.

The foraminiferal assemblage of subunit 1 is very similar to the fauna obtained from the landward parts of the Lagoon of Venice by Cita and Premoli Silva (1967). Apart from the clayey nature of the substrate and the possible influence of salinity fluctuations, the latter authors could not supply further insight in the characteristics of the habitat of this community.

In its type area (Clare Island, W. Ireland), *Ammonia perlucida* was obtained from marine deposits, bordering an indented coast at a maximum depth of about 20 m. (Heron-Allen and Earland, 1913). Kurc (1961) describes the species as *A. beccarii* var. *tepida* in a coastal lagoon of approxima-

tely normal marine salinity in southern France. In combination with the recordings by Cita and Premoli Silva (1967) from the Lagoon of Venice and by ter Keurs (1971) from brackish-lagoonal sediments in the Holocene Rhone delta, one is tempted to consider *A. perlucida* as a form with salinity tolerance, but also a definite marine affinity.

Anticipating on our treatment of the faunas in the higher parts of the section at Ladiko-bay, this statement appears to be confirmed by the regular presence of *A. perlucida* in sediments, which are considered to have accumulated in environments with a relatively great marine influence (Units XIX and XXI). On the other hand, it is very subordinate in the lagoonal sequences in the lower part of the section at Ladiko-bay.

These observations also hold true for the second typical element of the fauna, *Cribronionion gunteri*. This form is only rarely reported in European literature; however, it is a frequent constituent of foraminiferal communities in North and South America. *C. gunteri* is known from very low salinity waters (Lankford, 1959) and from hypersaline lagoons (Rusnak, 1960). In his statistical study of Texas foraminiferal facies, Lehmann (1957) recorded its presence in the open marine, littoral realm and concludes a preference for bay environments with a relatively free circulation of normal marine waters.

In view of these data, it is interesting to note the corresponding character of the ostracode fauna of this unit. The marine affinity of *Falunia rugosa* and *Xestoleberis communis* has already been discussed (see Units I–III). A distinguishing feature of the assemblage in this unit is the occurrence of *Loxoconcha turbida* and of *Krithe* sp. The former species is virtually restricted to Units XV and XXI. In the present-day Mediterranean its distribution points to a shallow marine habitat (Masoli, 1969) and a tolerance for high salinity waters in partly enclosed bays (Kruit, 1955, *L. tamarinda*).

The genus *Krithe* generally acts as a member of marine communities. Some of its species may possess a weak tolerance for subnormal salinities (Barbeito-Gonzàles, 1969).

The combined occurrence of *Ammonia beccarii*, *Protelphidium lidoense*, *Falunia rugosa* and *Xestoleberis communis*, together with the foraminiferal and ostracode forms, treated above, is tentatively interpreted as an indication of maximum salinities, which approached, or even periodically exceeded, normal marine values.

In this context, it is remarkable to note the possible derivation of all presumably allochthonous forms from marine vegetated areas, the *Posidonia*-meadows: *Cibicides lobatulus*, *Cancris auriculus*, *Discorbinella bertheloti*, *Rosalina globularis* var. *bradyi*, *Planorbulina mediterraneensis* and *Triloculina plicata*. With respect to the underlying units, a greater exposure to open

marine influences can thus be correlated with an augmented importance of vegetation in the littoral zone. These features point to a reduced development of the barrier system, eastward of the locus of sedimentation, in consequence of a diminished supply of sand by longshore currents.

Together with the decreasing sand content of the sediment, the disappearance of *Ammonia perlucida*, *Cribrononion gunteri*, *Loxochoncha turbida* and *Krithe* sp. as important faunal elements in subunit 2 and the decreasing frequency of possibly epiphytal Foraminifera at this level, can be explained in terms of a lessened marine influence. During the accumulation of Unit XV, the barrier system slowly moved in a seaward direction; the sediments and faunas of subunit 2 are expressions of the relatively remote position of the locality of study with respect to the barrier and its passes.

Typical for this unit is the presence of homogeneous marly clays with a very low microfaunal content. From sedimentary data, a relatively low rate of sedimentation must be inferred. Normally, one would expect a high benthos-index as a result of such circumstances. On grounds of this seeming contradiction, an influence of other environmental factors, which caused a low microfaunal density under conditions of slow sedimentation, must be assumed. The exact nature of these factors remains obscure. Augmented salinities may have coincided with a waning of supply. The combined occurrence of such events would point to climatic influences, which caused the slow settling of the marly clays during hot and dry seasons.

#### *Unit XVI*

The reappearance of continuously sandy sediments is connected to an increase in frequency, diversity and specimen-size of the foraminiferal fauna and to a return of micro-bryozoan fragments.

In the lower part of the unit, *Ammonia beccarii*, *Protelphidium lidoense* and *Elphidium crispum* are the major foraminiferal species; the low frequency occurrence of *Cibicides lobatulus* and Miliolidae is to be noted.

Near the top of the unit, *Ammonia beccarii* and *Elphidium crispum* are still important, but they are accompanied by *Cibicides lobatulus* and Miliolidae in much higher frequency than in the lower sample. *Protelphidium lidoense* seems to have disappeared. Notable is the importance of plano-convex Foraminifera at this level.

The main changes in the foraminiferal fauna are the alteration of the autochthonous community in an upward sense and an increasing addition of allochthonous elements. As is suggested by the presence of Miliolidae and bryozoan fragments, the latter component was at least partly derived from a marine source area.

Referring to our discussion of Units I–III, one would be tempted to explain the appearance of *Elphidium crispum* in this unit in terms of an increasing maximum salinity. However, we have no additional data at our disposal, which point to such a change. In this instance, the *Ammonia beccarii-Elphidium crispum* assemblage should probably be regarded as a community, which inhabited sandy bottoms in a more or less turbulent realm with a direct marine influence.

The upward change in composition of the indigenous fauna is connected with an augmented supply of Foraminifera, which occur as constituents of the modern *Posidonia*-biocoenosis: *Cibicides lobatulus*, *Cancris auriculus*, *Rosalina globularis* var. *bradyi*, *Quinqueloculina berthelotiana* and *Triloculina planciana* (J. and Y. le Calvez, 1958; Blanc-Vernet, 1959, 1969).

The faunal distribution in Unit XVI fits in well with our interpretation of proximal wash-over-fan deposits (see Chapter III, paragraph 6). The importance of epiphytal Foraminifera of marine origin is a distinctive feature of this unit with respect to its depositional equivalents lower in the succession (Units III and IX). This difference would again express a lower rate of sedimentation in that area.

#### *Unit XVII* (see enclosure III)

The third surface of disconformity manifests a sharp break in foraminiferal frequency, which reaches the highest values recorded up to now. This change is linked to an increase of specimen-size and diversity of species. Important is the reappearance of a macrofaunal assemblage.

Among the Foraminifera, *Cibicides lobatulus*, *Elphidium macellum* and *Elphidium crispum* are the most important species. They are accompanied by frequent Miliidae, e.g. *Quinqueloculina* cf. *costata* and *Q. berthelotiana*. A considerable content of worn miliolids is to be noted; *Planorbulina mediterranensis* and *Textularia* species are also represented. *Ammonia beccarii* and *Protelphidium lidoense* occur as low frequency representatives of the faunas found in the preceding unit.

Both Ostracoda and Bryozoa show a strong increase in frequency and number of species. The prevalent Ostracode, *Aurila cruciata minor*, confirms its preference for sediment levels with a relatively great marine influence during deposition. In the molluscan fauna, *Gibbula* sp. is the prevalent species; fragments of coral stems and annelid tubes were also recorded.

As a whole, the fauna is of distinctly marine affinity. An important part of it consists of plano-convex Foraminifera; their high frequency in a sediment with a relatively high benthos index probably reflects low rates of sedimentation in their shallow marine source area.

In analogy with the lower depositional equivalents of this units, Units IV and X, a doubtful, possibly autochthonous community may be represented by the associated species *Quinqueloculina* cf. *costata*, *Q. berthelotiana*, *Planorbulina mediterranensis* and the Textulariidae.

The assemblage of *Ammonia beccarii*, *Protelphidium lidoense*, *Elphidium macellum* and *E. crispum*, known from the underlying sediments, may be of partially reworked origin. The relatively high frequency of *E. macellum* and *E. crispum*, however, suggests a parautochthonous origin of some of their specimens.

In view of the recent habitats of *Gibbula* and *Cibicides lobatulus*, their joint occurrence in high percentages is remarkable. As already discussed, they occur in and near zones of submarine vegetation (*Posidonia* meadows) in the present-day Mediterranean. *G. adansoni* is found in the protected zone behind the vegetal obstruction to marine forces. *C. lobatulus* lives in adhering condition on the leaves of the phanerogams (Pérès and Picard, 1964; Blanc-Vernet, 1969). Although species of *Gibbula* are evidently not restricted to such realms of deposition, the association of *Gibbula* sp. and *Cibicides lobatulus* may be an indication of their origin as elements of a phytal biocoenosis.

Additional indications of the influence of submarine vegetation are furnished by the presence of several other potential inhabitants of such environments: *Bittium reticulatum* (Gastr.), *Rosalina globularis* var. *bradyi*, *Asterigerina planorbis*, *Neoconorbina terquemi*, *Planorbulina mediterranensis*, *Textularia pseudogramen*, *Quinqueloculina berthelotiana* and *Q. vulgaris* (see J. and Y. le Calvez, 1958; Pérès and Picard, 1964; Blanc-Vernet, 1969). It is of course impossible to arrive at a definite assignment of a phytal source area for all of these forms, since virtually none of them is limited to such regions. The abundance, diversity and qualitative composition of the fauna, however, speaks in favour of our interpretation.

The original surroundings of the remainder of the fauna were of a diversified nature. *Nassarius* cf. *incrassatus* (Gastr.), *Arca diluvii* and *Spondylus gaederopus* (Pel.) are representants of a rock bottom community. *Ringicula auriculata* (Gastr.), *Cardium* sp., *Venus gallina* and *Callista chione* (Pel.) probably inhabited littoral sand bottoms. An autochthonous origin may perhaps be attributed to *Corbula gibba*, *Venus* cf. *ovata*, *Laevicardium crassum* and *Anomia ephippium* (Pel.) given the preference of these forms for coquina-sand bottoms.

The Ostracoda and Bryozoa do not supply direct evidence for the presence of a vegetated area during deposition. *Aurila cruciata minor*, *A. calciplena*, *Aurila* ex gr. *punctata* and *Xestoleberis communis* may have

belonged to the *Posidonia* biocoenosis (Puri et al, 1969).

Among the Bryozoa, the occurrence of *Schizomavella auriculata* is notable. According to Lagaaij and Gautier (1965), this species flourishes under conditions of slow- or non-deposition; its original habitat may have been a rock bottom.

In summary, the fauna of Unit XVII reflects the mixing of elements derived from vegetated marine sands, loose sand bottoms, rocky substrates and lagoonal back barrier environments, as well as the possible establishment of a new community in an open marine area. In essence, the composition of the fauna is comparable to those of Units IV and X; the major difference with the latter sediments is the prominence of a phytal biocoenosis due to a diminished rate of sedimentation in the littoral zone.

#### *Unit XVIII*

The qualitative change in the macrofaunal composition with respect to Unit XVII goes together with a distinct decrease in size of the greater part of the molluscan specimens and an increased importance of small forms, such as *Bittium recitulum* and *Tricolia pullus*.

The foraminiferal assemblage shows an augmentation of the total of plano-convex forms, particularly of *Cibicides lobatulus*. On the other hand, the Miliolidae, dominated by *Quinqueloculina berthelotiana*, are subject to decrease.

As noted by Blanc-Vernet (1969), plano-convex Foraminifera, and Miliolidae form an important part of the *Posidonia* biocoenosis. The former, however, show a preference for an actual epiphytal mode of life, whereas the greater part of the miliolids lives in the sediment. An increasing significance of *Cibicides lobatulus* and equivalents at the expense of the Miliolidae might thus point to a lessened susceptibility of sand bottoms to erosion, as a consequence of a growing density of submarine vegetation.

Given the relative enrichment of small molluscan forms, the qualitative changes of the fauna may also be related to an increasing distance to the vegetated source area. Such a development of the depositional realm would point to a gradual seaward displacement of the phytal zone with respect to the locality of study.

Comparable conditions of sedimentation are known from shallow marine environments, characterized by slow deposition, in the modern Mediterranean (Molinier and Picard, 1952). A dense submarine vegetation may act as an obstruction to marine currents and waves. Behind the "phytal barrier", a relatively tranquil area is created. The subaquatic vegetation moreover acts as a sediment trap, which causes a slow seaward accretion.

The occurrence in Unit XVIII of large scale burrows, attributed to the crustacean *Callianassa* (see Chapter III, paragraph 6), fits in well with the picture designed above. The protected zone on the lee of *Posidonia* meadows is one of the preferred habitats of this species in the modern Mediterranean (Pérès and Picard, 1964).

During the formation of Unit XVIII, the supply from rock bottom areas remained unaffected, as shown by the presence of *Diodora italica*, *Patella caerulea*, *Triphora perversa*, *Arca noae*, *A. diluvii*, *Begonia calyculata* and *Chama gryphoides* (van Straaten, 1960).

Concerning the Ostracoda, littoral conditions and the occurrence of vegetated areas are suggested by the occurrence of *Aurila cruciata minor*, *A. calciplena*, *A. ex gr. punctata*, *Loxiconcha rhomboidea* and *Xestoleberis communis*.

The Vinculariiform bryozoan *Entalophora* sp. was most probably derived from a rocky substrate (see Lagaij and Gautier, 1965).

The development of the foraminiferal fauna during the progressive increase of restriction behind a phytal barrier, shown by this unit, is remarkable correspondent to that of the lagoonal phases of deposition, represented by the lower reach of the succession. The *Elphidium crispum*-*E. macellum*-*Ammonia beccarii* assemblage in the upper part of Unit XVIII, is reminiscent of the presumably polyhaline associations, recorded earlier. Yet, an environment of normal salinity must be inferred in this instance.

### Unit XIX

The return of interstratified sands and clays in this unit is again connected with the disappearance of macrofaunal elements and a decrease of frequency and size of foraminiferal specimens.

In the lower sandy sample, plano-convex Foraminifera are still important. *Cibicides lobatulus* occurs together with *Elphidium crispum*, *Ammonia beccarii* and *Cancris auriculus*. Miliolidae are scarcely represented.

Farther upwards, a sandy sample contains *Ammonia beccarii*, *A. perlucida*, *Protelphidium lidoense* and *Cibicides lobatulus* as the main species. The presence of *Cribrononion excavatum*, *C. incertum* and *Nonion depressulum* is notable, as well as the absence of miliolids.

In a clayey sample, *Ammonia beccarii* is prevalent and occurs in association with *A. perlucida*, *Cribrononion excavatum*, *Nonion boueanum*, *Cancris auriculus* and *Cibicides lobatulus*. *Cribrononion incertum* and *C. gunteri* are low frequency forms.

In an upward sense, a decreasing importance of planoconvex Foraminifera is discernible. With respect to the preceding unit, the main aspects of the

faunal composition are the augmented frequency of species of restricted affinity and the decreasing supply of forms, derived from vegetated areas.

These features can be understood in terms of a gradual seaward migration of a zone of submarine vegetation, situated eastward of the locus of sedimentation. In a purely depositional sense, the evolution of the environment was essentially comparable to the historical development of sandy barriers, inferred for the lower levels of the succession at Ladiko-bay. The fundamental difference in the nature of the barrier and its leeward lagoon is best reflected in the composition of the allochthonous component of the microfauna.

Concerning the indigenous microfaunal community, the presence of *Ammonia perlucida* as an important element, and the appearance of *Nonion boueanum* as an additional form, seem to be the sole differences with the actual lagoonal assemblages, recorded earlier. Associations of a comparable nature are indeed known from "backmeadow" environments in the recent Mediterranean (Blanc-Vernet, 1969). The occurrence of such faunas in a marine realm of sedimentation supplies a good example of the dangers involved in the interpretation of foraminiferal assemblages, merely in terms of salinity.

On the ground of these considerations, the succession of Units XVIII–XIX can now be considered as a large scale sedimentary sequence, which comprises the sediments formed after the growth of a phytal barrier in the littoral zone and during its subsequent seaward displacement. In a descriptive sense, this sequence is of a fining upwards nature and, moreover, to some extent comparable to the successions of Units V–VIII and XI–XIV.

#### *Units XX–XXI*

The pebble and shell bearing, homogeneous sands above the erosional surface of unconformity at the base of Unit XX, contain a foraminiferal fauna, which can be regarded as a mixture of relatively large forms (*Elphidium crispum*, *E. macellum*, *Cibicides lobatulus*, *Cancris auriculus* and *Ammonia beccarii*) and an association of two small species of hitherto subordinate significance (*Bulimina gibba* and *Fursenkoina schreibersiana*).

The gradual upward decrease in grain-size, shown by this succession, is accompanied by a diminishing frequency of the larger specimens, which ultimately disappear completely. In the homogeneous marly clays of Unit XXI, the fauna is strongly dominated by *Bulimina gibba* and *Fursenkoina schreibersiana*.

In view of the microfaunal composition of Units XVIII–XIX, three assemblages may be recognized among the larger forms in Unit XX:

1. An association of plano-convex species, dominated by *Cibicides lobatulus*, which is comparable to the prevalent component in Unit XVIII.

2. An assemblage, which is reminiscent of the fauna recorded in the upper part of Unit XVIII and near the base of Unit XIX: *Elphidium crispum*, *E. macellum* and *Cancris auriculus*.

3. A component of restricted affinity, which prevailed in the remainder of Unit XIX, mainly represented by *Ammonia beccarii*.

The occurrence of a mixture of these associations, which inhabited adjacent environments in the littoral zone, reflects the initial phases of high energy erosion and supply. During these episodes, marine faunal elements, derived from a realm of submarine vegetation and forms, which lived immediately on the lee of the previous area, were supplied to the locus of sedimentation. Here, they were added to an assemblage of reworked origin.

During the subsequent establishment of conditions of slow and tranquil deposition, a fourth component was introduced in the sediment by burrowing. The *Bulimina gibba-Fursenkoina schreibersiana* assemblage of Unit XXI thus formed the new autochthonous community, after the transformation of the original littoral zone through a combination of tectonic and depositional processes.

Perhaps the closest known, modern equivalent of the microfauna is the *Bulimina gibba-Fursenkoina fusiformis* assemblage, described by Murray (1970) from the western English Channel at depths varying from 24–91 m.

In their study of the foraminiferal distribution on the Orinoco shelf, Drooger and Kaasschieter (1958) recorded high frequencies of *Virgulina pontoni* (= *Fursenkoina schreibersiana*) in pelitic sediments off the Orinoco mouth at depths from 25 to 40 m. In addition to a number of species, which are not represented at Ladiko-bay, these faunas also contain *Nonionella atlantica* (= *Nonion boueanum*) and *Nonion grateloupi*.

The Orinoco fauna is concentrated around the transition from the near-shore, laminated silty pelites and the homogeneous offshore pelites (Nota, 1958). Apart from a definite preference of *V. pontoni* for pelitic sediments, the causal factors of this distribution are difficult to understand. An intermediate rate of sedimentation and a considerable supply of organic nutrients from near-by rivers may be responsible.

For the *Bulimina gibba-Fursenkoina schreibersiana* assemblage of Unit XXI, an open marine platform, with a depth between 20 and 50 m, seems the most plausible environment. The exact nature of the factors, which caused the low diversity of the foraminiferal fauna, remains obscure. An influence of river-supply cannot be excluded.

These conclusions imply the intervention of considerable subsidence

before, and possibly during the accumulation of Units XX–XXI. The fining upward sequence gives a documentation of the landward movement of a transgressive front over sediments, which were tilted in an eastern direction. Subsequently, an area of slow and quiet deposition, situated at some distance from the receding shoreline, came into being, as a termination of the sedimentary evolution of the area of Ladiko-bay, treated here.

### *Conclusion*

Reviewing our analysis of the faunal distribution in the section at Ladiko-bay, we may conclude, that our approach has given confirmation and further refinement of our ideas regarding the origin of several units, as well as regarding their interrelation (Units I–III, IX, XI–XIV, XVI and XX–XXI). concerning the origin of other parts of the succession, it, moreover, supplied more relevant information than could be derived from sedimentary data (Units IV, X, XVII; V–VI and XVIII–XIX).

Information of major importance for the interpretation of the succession as a whole, which could not be derived from the sediment alone, is furnished by the ecological indications for changes in the rate of sedimentation in the littoral zone.

## Chapter V

### SYNTHESIS

The Pliocene sediments at Ladiko-bay came into being in a coastal topography, comparable to that of today's east-coast of Rhodos. The depositional framework was formed by pre-neogene rocks, sculptured by faulting and fluvial erosion, which became partially submerged during the Late Pliocene (Meulenkamp et al, 1972).

The vertical variation of the depositional and paleontological properties of the succession was primarily caused by the lack of equilibrium between the forces that affected the littoral realm. The interplay of sand supply by longshore currents from a northern direction, the erosional activity of marine currents and waves and the overall subsidence of the coastal area produced a continuous modification of the depositional pattern.

When sand supply by longshore currents exceeded its removal by currents and waves, subsidence could effectively be compensated by net-deposition. Projecting headlands, consisting of pre-neogene limestones, probably formed the points of inception of sandy barriers or shoals, which were generally situated seaward of the locality of study. On the lee of these sand-bodies, relatively tranquil, lagoonal areas came into being.

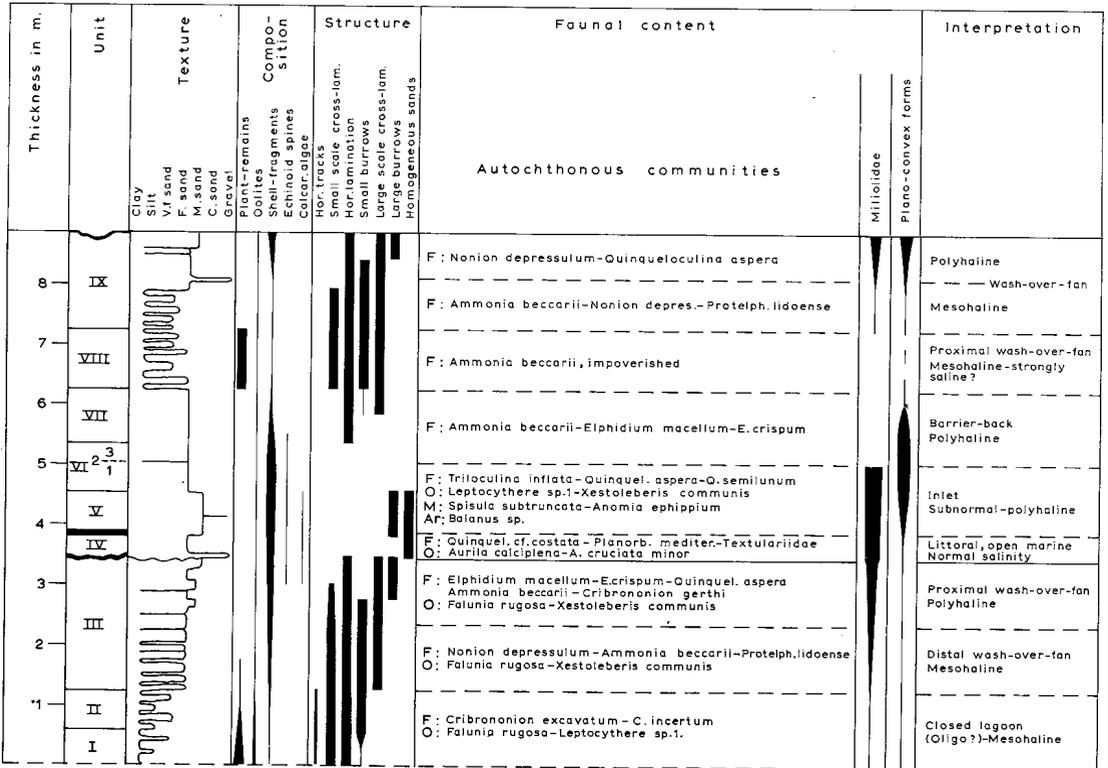
The original delimitations of the lagoonal realm can but incompletely be reconstructed from the present-day geologic setting of the section. The presence of a rocky headland, immediately to the north of the Ladiko-lagoons, is rather well established.

Within the protected water-bodies, an intricate pattern of subenvironments came into existence. Their distribution was controlled by the rate of exposure to marine influences, with waterdepth, nature of substrate, degree of turbulence and salinity as accompanying factors. The horizontal distribution of these properties produced a number of indigenous faunal communities in the lagoonal realm and the adjacent shallow marine zone.

The barrier system was frequently attacked by marine currents, oriented in western directions. These currents were of a wind-induced origin. During storms, sands derived from the outer barrier face were transported westward, to be dumped in the lagoonal back barrier environment. Along the landward

margins of the barrier, wash-over-fans were constructed by these processes. Owing to a diminishing energy of the currents in a lagoonward direction, the wash-over sediments showed a horizontal transition from relatively coarse grained near-barrier deposits in the east, to finer grained silts and sands in the west. The discontinuous course of supply, moreover, caused a vertical alternation of sediments, which were formed at different energy levels.

During the phases of water agitation, the elements of the lagoonal and shallow marine faunas, either living or dead, were subject to transport. In consequence of these displacements, the original delimitations of adjacent biocoenoses were obscured in the resultant thanatocoenoses. At Ladiko-bay, instances of addition of allochthonous marine faunal components to indigenous lagoonal assemblages and of a landward dispersion of the restricted communities were common.



Textfigure 4a-c: Main depositional and paleontological features and their environmental interpretation in the section at Ladiko-bay. F: Foraminifera, O: Ostracoda, M: Mollusca, B: Bryozoa, Ar: Arthropoda, Anth: Anthozoa, An: Annelida.

During the upbuilding of the section, the barrier system and its lee-side sediments were subject to gradual changes in position. When the accretion of material supplied by longshore currents could not keep pace with erosion and subsidence, a lagoonward displacement of the barrier complex ensued. In our section, the resulting westward encroachment of wash-over-fans over lagoonal deposits is shown by successions with a more or less regular, coarsening upward trend, such as found in Units I–III, IX, and XVI (textfig. 4 a-c).

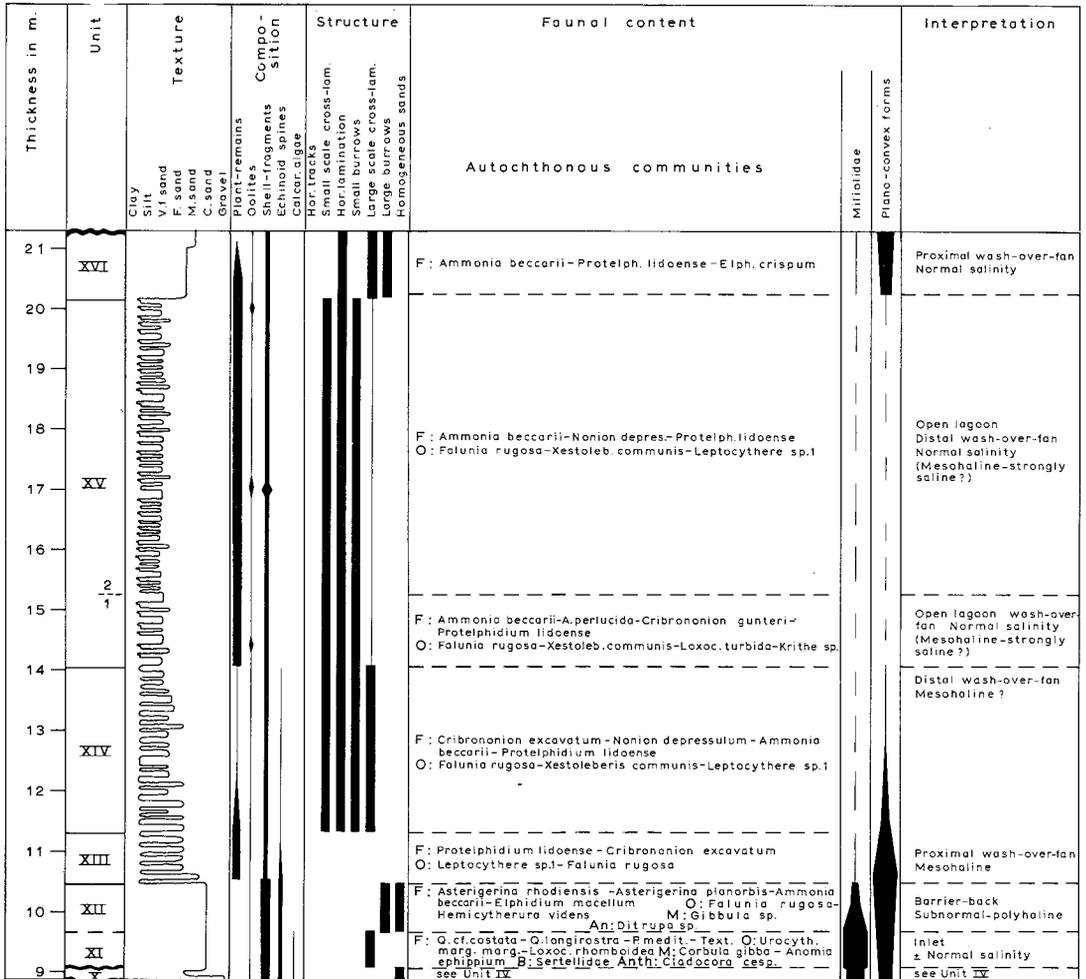
The upward transitions from lagoonal sediments or distal wash-over deposits to near barrier sediments show a vertical arrangement of textures and structures, which expresses the increase of maximum energy level during phases of supply. Structures, formed by burrowing organisms reveal a differential vertical distribution, which point to upward changes in the nature of the bottom dwelling community. For what concerns their fossil content, such successions comprise a discontinuous passage from ecotypical associations of indigeneous origin, without a considerable addition of foreign elements, to more diversified assemblages with frequent allochthonous forms, largely derived from the open marine barrier face.

At the locality of study, the phases of westward movement of the barrier complex culminated in an erosional truncation of the proximal wash-over sediments by marine currents and waves. The coarsening upward sequences are delimited at their top by irregular surfaces of disconformity, strewn with pebbles and covered by homogeneous sands (Units IV, X, and XVII). The fauna of these levels reveals the reworking of pre-existing barrier back sediments, the supply of marine sands and probably also the establishment of a new autochthonous community of shallow marine origin.

The relatively thin development of the sediments, which originated under littoral, open marine conditions, is most probably largely due to a low rate of sedimentation after the disappearance of the barrier-system eastward of our section.

After the partial, or even complete, transformation of the original lagoonal realm in an area of shallow marine sedimentation, a renewed construction of barriers or shoals could take place at or slightly seaward of the locality of study. In the new balance of forces, Ladiko-bay firstly became the domain of the system of shoals and its passes. Characteristic for this stage in the evolution of the area are relatively coarse grained sands with a high content of macrofaunal elements, which reflect the turbulent and largely marine nature of the inlet environments.

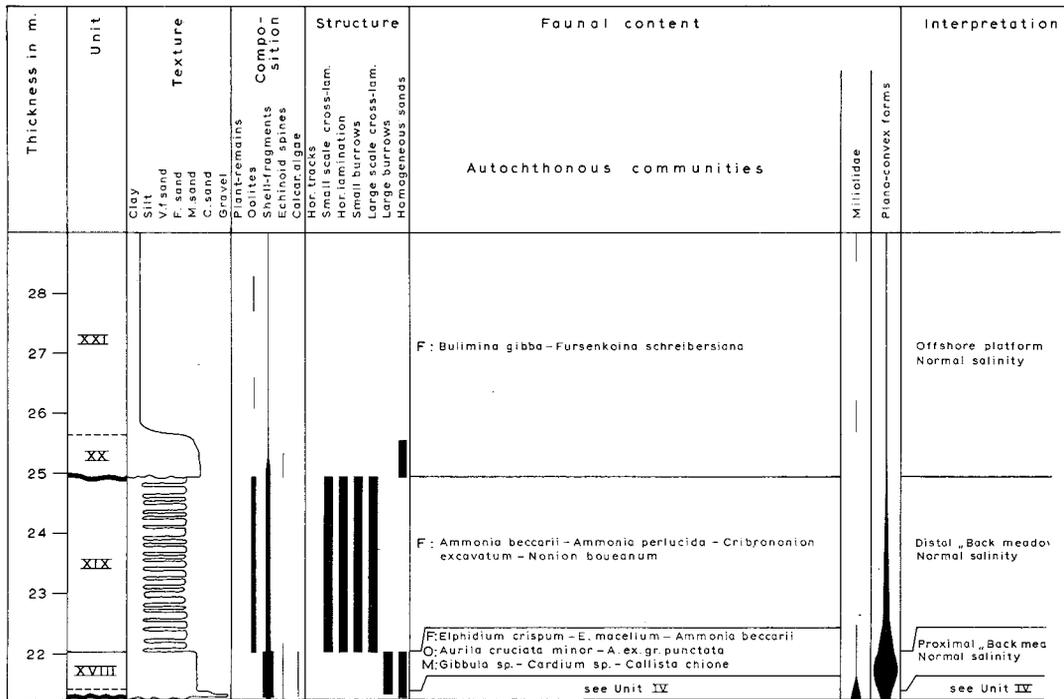
Subsequently, continued accretion of sand in the littoral zone, caused a seaward displacement of the barrier system. In combination with the closure



Textfigure 4b

or migration of the lagoonal passes, this process produced back barrier conditions at the locality of our section. The faunas of the sediments, formed in such environments, show the return of restriction. Their marine affinity may be preserved to a variable extent (Units VI<sup>2-3</sup>, VII and XII).

During the continuation of barrier displacement in an eastern direction, sedimentation at Ladiko-bay was again controlled by wash-over processes. The discontinuous supply of sands or silts to the lagoonal area was superimposed on a gradual upward transition from proximal-, to relatively fine grained, distal wash-over-fan deposits. The changing nature of sedimentation



Textfigure 4c

goes together with an increasingly oligotypical character of the faunal assemblages, as shown by Units VII–VIII and XIII–XIV.

In contrast to their counterparts, which originated under conditions of slow landward movement of the barrier, the successions, which manifest a gradual repair of lagoonal circumstances at Ladiko-bay, are of a fining upward nature.

The prevalently fine grained texture of the sands in the section as a whole must most probably be attributed to a relatively distal position of the Ladiko-area with respect to a coastal region, which was subject to direct fluvial supply, farther northward.

The paleogeographical history of the coastal area was not merely controlled by landward or seaward movements of a system of shoals or barriers. The degree of development of the protecting sand bodies, in other words their width, height and continuity, played an important part. The deeper, lagoonal sediments of the section at Ladiko-bay accumulated behind adequately developed barrier complexes (Units I–III, VIII and possibly XIV). Westward of these barriers, fresh water supply caused lowered and fluctuating salini-

ties, particularly so in the more landward portions of the lagoons. The dilution of lagoonal waters is reflected in the microfaunal composition of the sediments.

Farther upwards, we find indications of reduction of barrier development, owing to a decreasing rate of sandy supply by longshore currents. In Units XV–XIX, the indigenous microfaunal communities are indicative of salinities, which either approached, or reached normal marine values. These changes in the composition of the autochthonous microfaunal components with respect to the lower levels of the succession went together with an increased importance of allochthonous epiphytal Foraminifera. The latter feature witnesses the more widespread and/or more dense development of submarine vegetation in the coastal area of Ladiko, as a consequence of the relatively low rate of sedimentation.

During the deposition of Units XVIII–XIX, this trend culminated in the replacement of sandy- by phytal barriers, comparable to the present-day *Posidonia*-meadows of the Mediterranean. The depositional evolution of the vegetated coastal zone was to a large extent comparable to the development of the actual barrier and lagoonal environments. Acting as a sediment trap, the vegetated zone was subjected to a slow seaward accretion. In the protected zone on the lee of the meadows, this eastward movement is reflected in a fining upward sequence.

Towards the end of the Pliocene history of the Ladiko area, a sudden intervention of tectonic forces caused a total modification of the depositional framework. Strong subsidence, accompanied by a tilting in an eastern direction, was followed by a marine transgression. The original lagoonal-littoral realm was transformed into an offshore environment, characterized by a slow accumulation of fines. The submergence of the coastal area is manifested by an erosional, unconformable truncation of older sediments, which is covered by homogeneous sands, grading into marly clays at the top of the section (Units XX–XXI). The strong divergence in microfaunal composition of these sediments with respect to that of the lower reaches of the succession, confirms the radical change in the conditions of sedimentation at Ladiko-bay.

The evolution of the coastal area of Ladiko described above, gives a condensed picture of a part of the Pliocene history of the present-day island of Rhodos (Meulenkamp et al, 1972).

The lagoonal and shallow marine sediments of our section form part of the Kritika Formation. These sediments show a partial horizontal passage to fluvial-lacustrine deposits (Damatria Formation), exposed in the northern part of the island. These terrestrial sediments were derived from a mainland,

which was situated to the west and northwest of modern Rhodos. The present-day east-coast of the island formed the easternmost extension of this area of emergence.

Fluviatile supply from the west and northwest and subsequent longshore transport of sand in southern direction, permitted the accretion of barriers in a coastal topography, dominated by pre-neogene culminations.

During the Late Pliocene, the area was broken up by differential vertical movements owing to block-faulting and tilting in eastern directions. These tectonic movements were the initial phases of an ultimate disengagement of Rhodos from the mainland in the Pleistocene.

The gradual waning of fluviatile supply from the west and northwest is expressed in an upward decrease in grain-size of the Damatria sediments. The consequences of these changes on a regional scale for the sedimentation in the shallow marine realm along the east coast, are well documented by the vertical arrangement of sediment types and faunal assemblages in the section at Ladiko-bay.

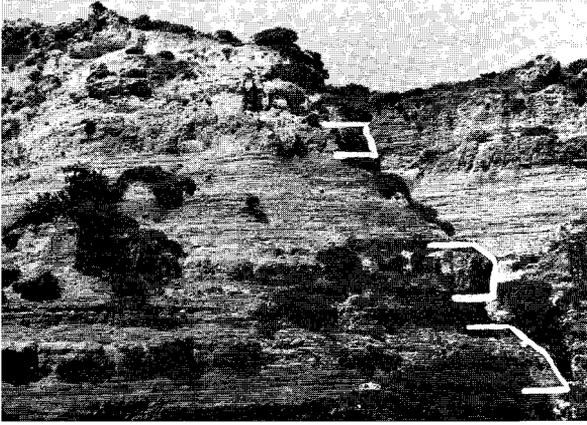
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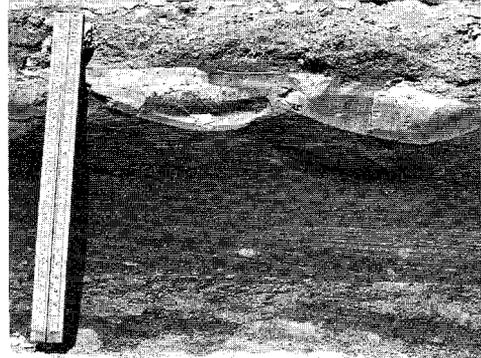
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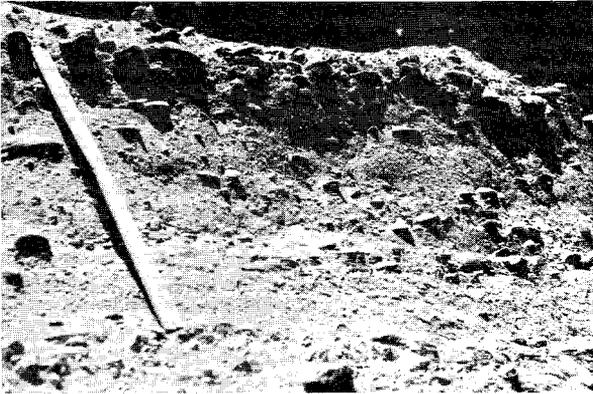
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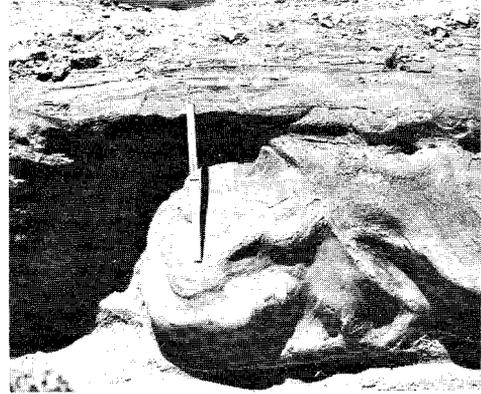
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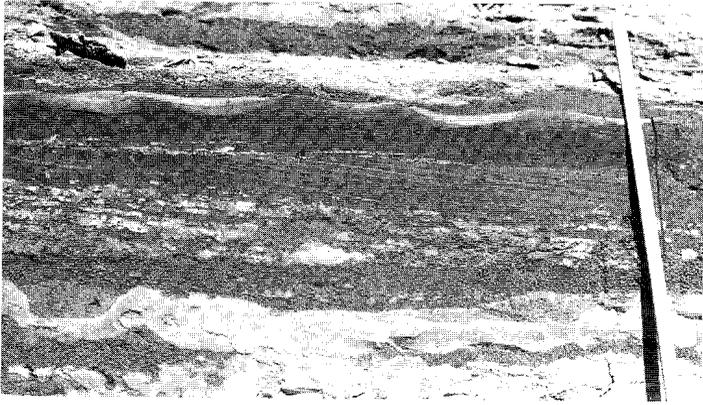


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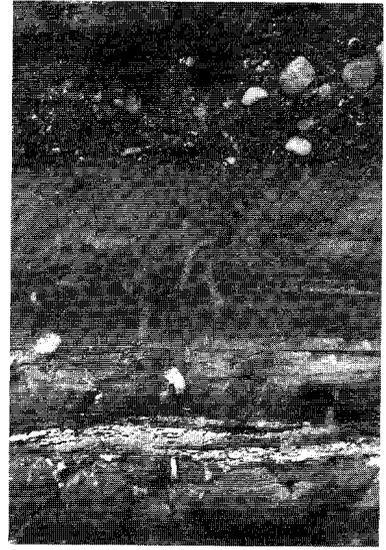


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- Figure 1: Exposure at Ladiko-bay, general view. Note the three sandy levels of the succession (Units III–VII, IX–XII, XVI–XVIII).
- Figure 2: Unit III. Large scale, low angle cross-lamination, passing into horizontal lamination with intervening unconformity. Slightly asymmetrical, sharp crested ripples at top of stratum; internal structure with short sets, concave-upward to undulating lower setboundaries and asymmetrical orientation of cross-laminae. Distinct contact with overlying clay. Scale 25 cm.
- Figure 3: Unit V. Shell-stringers with prevalence of *Spisula subtruncata* and *Mytilus galloprovincialis* in convexup position. Scale 50 cm.
- Figure 4: Unit VI. Mushroom-shaped body, consisting of lower sandy member, showing contortion of shell-stringer and overlying clayey seam, surrounded by internally folded masses formed by upper sandy member. Scale 50 cm.
- Figure 5: Unit VI. Synclinal folding in upper member, associated with minor, penecontemporaneous fault. Note horizontally laminated base of Unit VII. Scale 50 cm.



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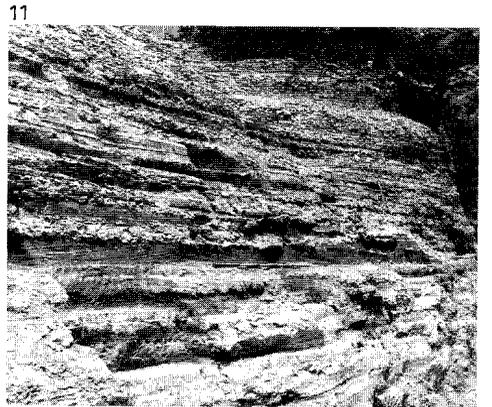
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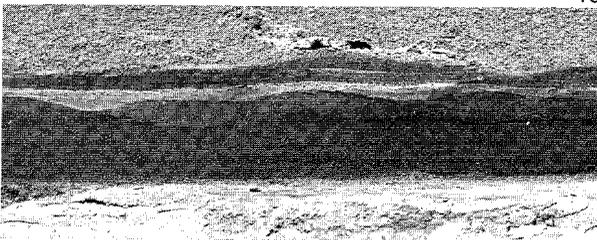
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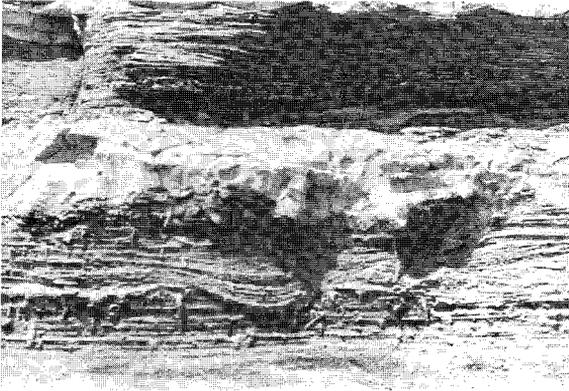


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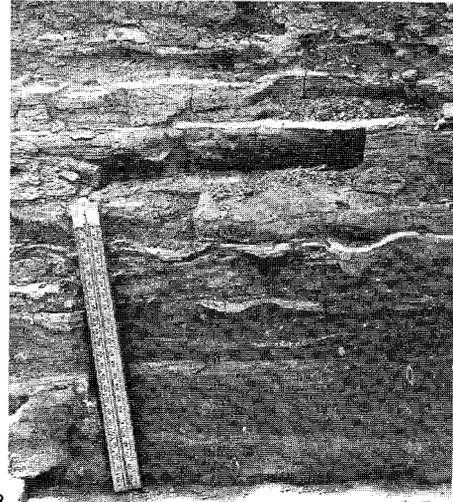


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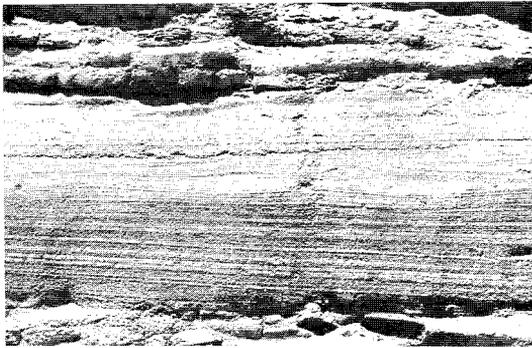
- Figure 6: Unit VIII. Sandy bed with irregular lower bedding-plane (organic activity + pene-contemporaneous deformation + erosion?). Internal structure of major sand-bed with two sets of large scale cross-lamination. Upper set contains convex-up cross-laminae (indistinct). Small scale cross-lamination and approximately symmetrical ripples along upper bedding-plane, gradual transition to overlying clay. Thickness of sand bed 17 cm.
- Figure 7: Unit IX–X. Top of Unit IX, showing horizontally- and large scale cross-laminated sands, with thin clayey intercalations, partly broken-up. Large scale burrows, particularly near top of unit. Distinct base of Unit X. Note cross-stratified conglomeratic deposit of Unit X. Thickness of pebble bearing level 20 cm.
- Figure 8: Unit X–XII. Relatively thin development of conglomeratic base of Unit X, overlain by burrowed sands. Irregular basal contact of Unit XI, covered by large scale cross-stratified, shell bearing sand. Gradual transition to unstratified sands with rarer shells of Unit XII. Scale 1 m.
- Figure 9: Unit XII. Pocket-shaped concentration of shells with internal size-grading. Scale 25 cm.
- Figure 10: Unit XIV. Horizontally laminated sand with upper small scale cross-laminated member. Note concave-upward shape of lower boundaries of sets and lateral variability in structure. Thickness of stratum 9 cm.
- Figure 11: Unit XIV. Interstratified sands and clays. Sand bed with convex-up cross-lamination. Note “anticlinal” shape of cross-laminae and irregular, burrowed nature of upper bedding-plane. Scale 1 m.



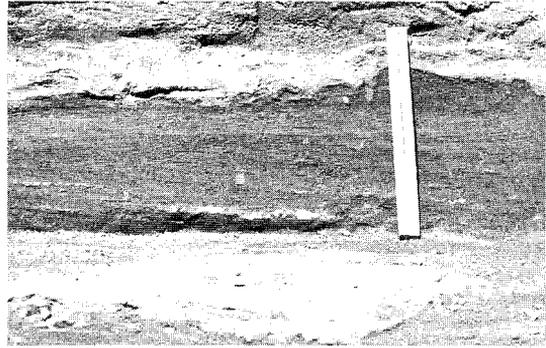
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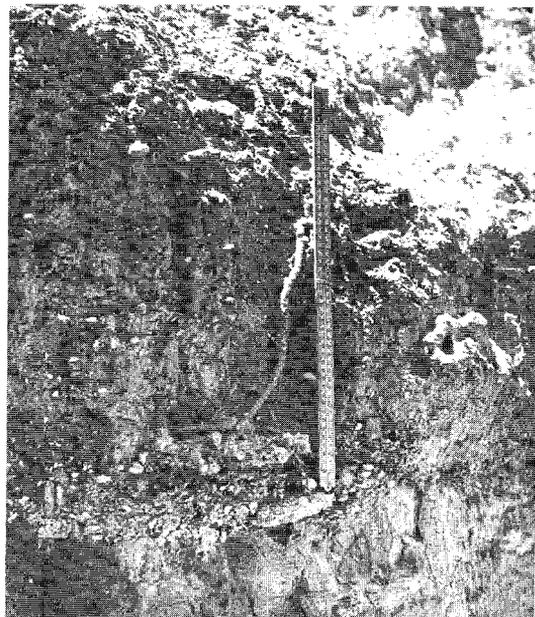
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- Figure 12: Unit XIV. Horizontal lamination, truncated by small scale cross-lamination in lower stratum. Small burrows along surface of truncation and along upper bedding-plane. Small scale cross-lamination with climbing sets in upper bed, covered by symmetrical ripples. Maximum thickness of lower stratum 10 cm.
- Figure 13: Unit XV. Sequential development with regular interbedding of very fine sands, laminated silty clays and thin marly clays. Scale 25 cm.
- Figure 14: Unit XV. Horizontal lamination with intercalated small scale cross-lamination in very fine sand. Thickness of stratum 12 cm.
- Figure 15: Unit XV. Very fine grained sand with complex large- and small scale cross-laminated structure. Burrowed remnants of ripples along upper bedding-plane. Maximum thickness of bed 15 cm.
- Figure 16: Units XVII–XVIII. Basal concentration of pebbles and shell along irregular lower boundary of Unit XVII. Large, tube-shaped burrows in Unit XVIII. Scale 50 cm.

PLATE 1

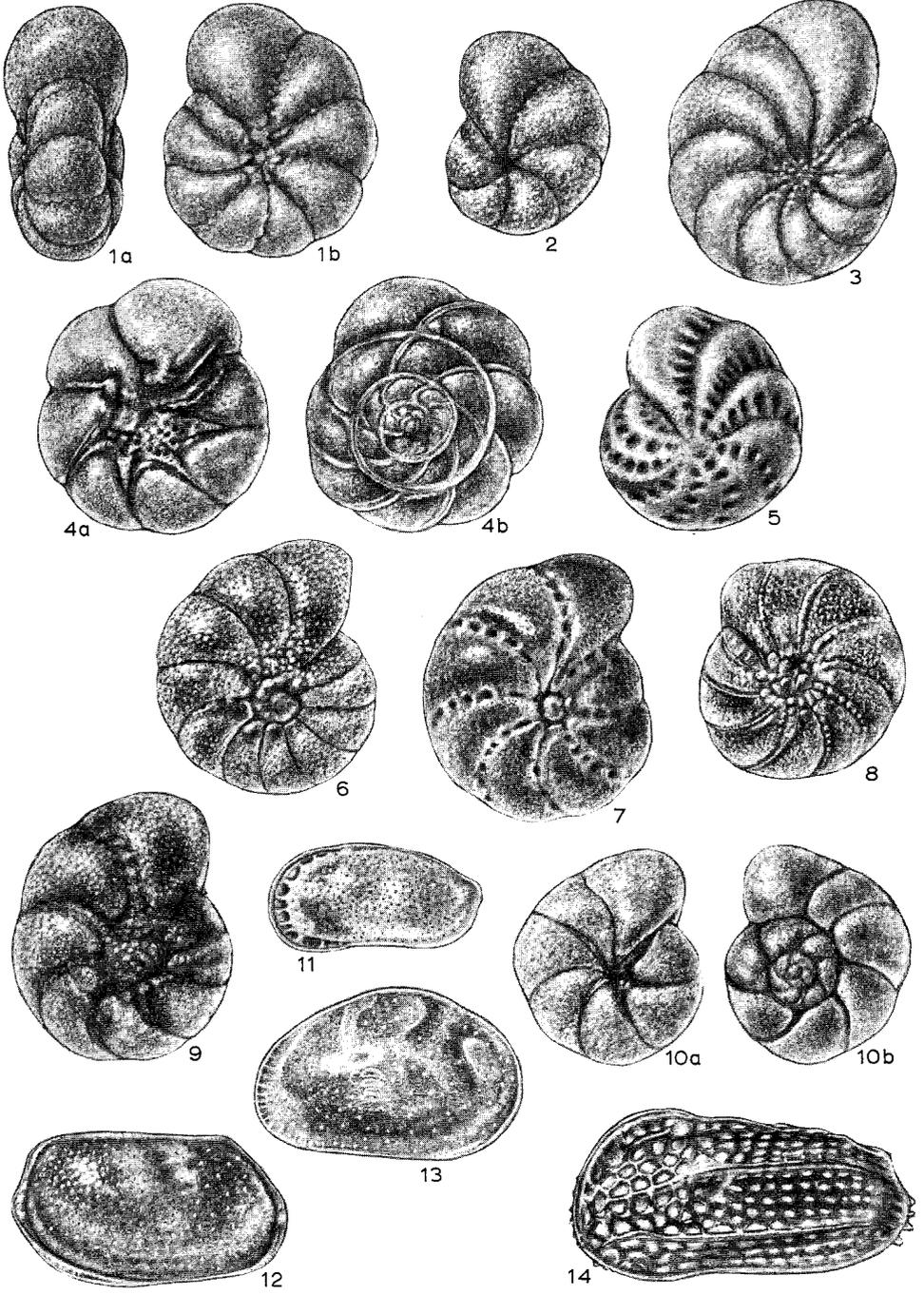


PLATE 1

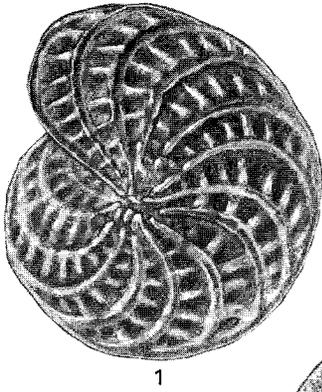
**Foraminifera:**

- 1a, b: *Cribrononion excavatum* (Terquem)  
x 75, sample 2.
- 2: *Cribrononion incertum* (Williamson)  
x 110, sample 1.
- 3: *Nonion depressulum* (Walker and Jacob)  
x 110, sample 35.
- 4a, b: *Ammonia beccarii* (Linné)  
x 50, sample 30.
- 5: *Cribrononion articulatum* (d'Orbigny)  
x 45, sample 11.
- 6: *Protelphidium lidoense* (Cushman)  
x 75, sample 46.
- 7: *Cribrononion gerthi* (van Voorthuysen)  
x 110, sample 48.
- 8: *Cribrononion gunteri* (Cole)  
x 45, Sample 41.
- 9: *Cribrononion asklundi* (Brotzen)  
x 75, sample 24.
- 10a, b: *Ammonia perlucida* (Heron-Allen and Earland)  
x 75, sample 41.

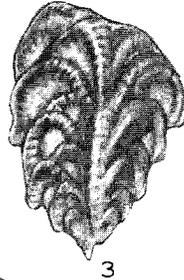
**Ostracoda:**

- 11: *Leptocythere* sp. 1  
x 75, sample 2.
- 12: *Loxoconcha turbida* Müller  
x 45, sample 6.
- 13: *Xestoleberis communis* Müller  
x 45, sample 4.
- 14: *Falunia* (*Hiltermannicythere*) *rugosa* (Costa)  
x 45, sample 4.

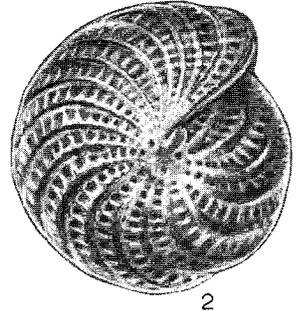
PLATE 2



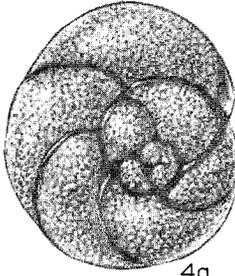
1



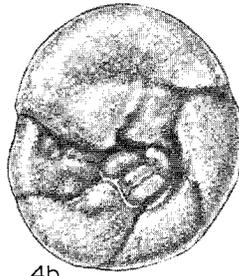
3



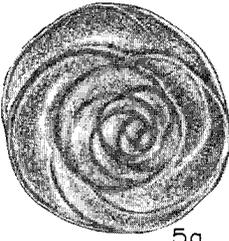
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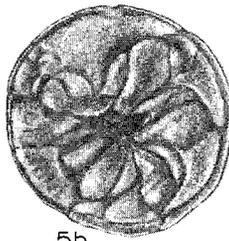
4a



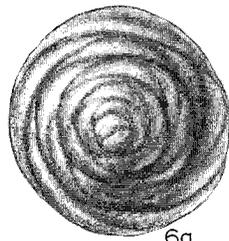
4b



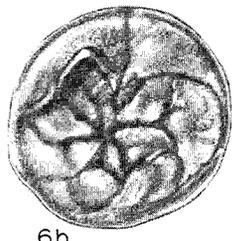
5a



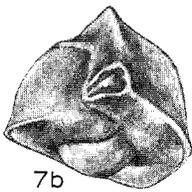
5b



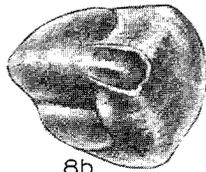
6a



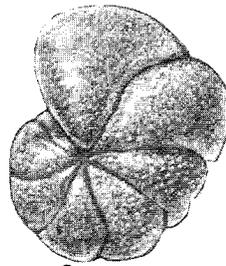
6b



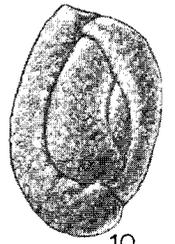
7b



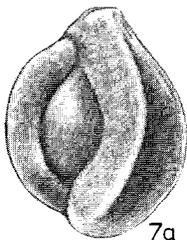
8b



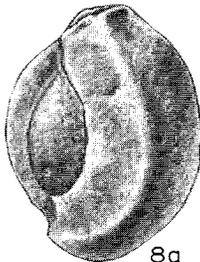
9



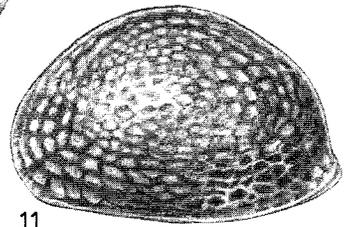
10



7a



8a



11

PLATE 2

**Foraminifera:**

- 1: Elphidium macellum (Fichtel and Moll)  
x 75, sample 26.
- 2: Elphidium crispum (Linné)  
x 40, sample 51.
- 3: Reussella spinulosa (Reuss)  
x 45, sample 6.
- 4a, b: Rosalina globularis d'Orbigny var. bradyi Cushman  
x 40, sample 54.
- 5a, b: Asterigerina planorbis d'Orbigny  
x 45, sample 22.
- 6a, b: Asterigerina rhodiensis Terquem  
x 25, sample 27.
- 7a, b: Triloculina adriatica J. and Y. Le Calvez  
x 40, sample 26.
- 8a, b: Triloculina trigonula (Lamarck)  
x 45, sample 22.
- 9: Cibicides lobatulus (Walker and Jacob)  
x 40, sample 11.
- 10: Quinqueloculina aspera d'Orbigny  
x 45, sample 26.

**Ostracoda:**

- 11: Aurila ex gr. punctata (von Münster)  
x 40, sample 55.

PLATE 3

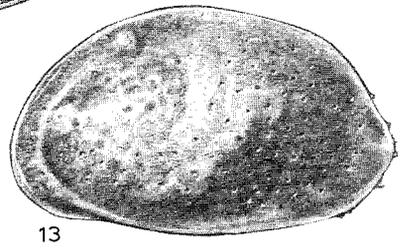
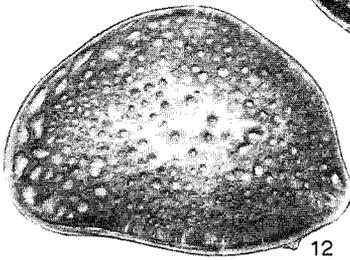
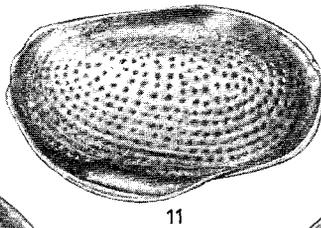
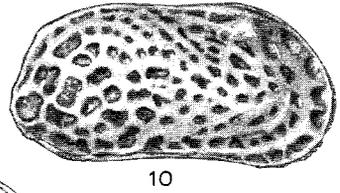
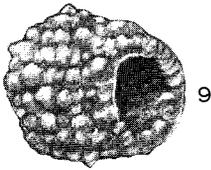
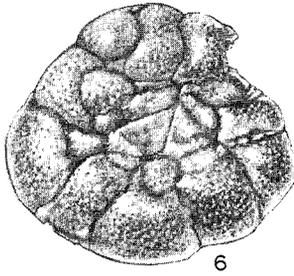
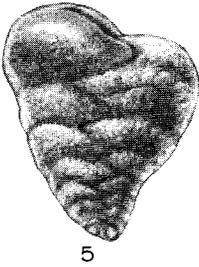
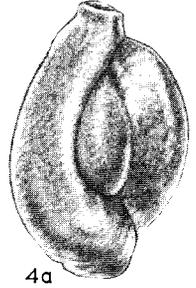
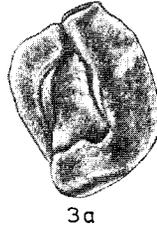
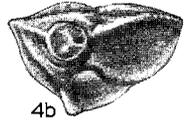
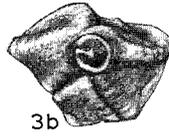
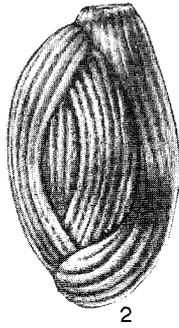
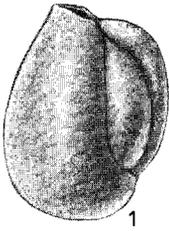


PLATE 3

**Foraminifera:**

- 1: *Triloculina inflata* d'Orbigny  
x 45, sample 11.
- 2: *Quinqueloculina* cf. *costata* d'Orbigny  
x 40, sample 26.
- 3a, b: *Quinqueloculina berthelotiana* d'Orbigny  
x 45, sample 52.
- 4a, b: *Quinqueloculina longirostra* d'Orbigny  
x 25, sample 26.
- 5: *Textularia candeiana* d'Orbigny  
x 45, sample 8.
- 6: *Planorbulina mediterranea* d'Orbigny  
x 45, sample 26.
- 7: *Fursenkoina schreibersiana* (Czjzek)  
x 45, sample 62.
- 8: *Bulimina gibba* Fornasini  
x 75, sample 62.

**Thecamoebina:**

- 9: *Centropyxis marsupiformis* (Wallich)  
x 160, sample 34.

**Ostracoda:**

- 10: *Urocythereis margaritifera margaritifera* (Müller)  
x 40, sample 54.
- 11: *Loxococoncha rhomboidea* (Fisher)  
x 45, sample 26.
- 12: *Aurila cruciata minor* Uliczny  
x 40, sample 54.
- 13: *Aurila calciplena* Uliczny  
x 40, sample 52.

PLATE 4

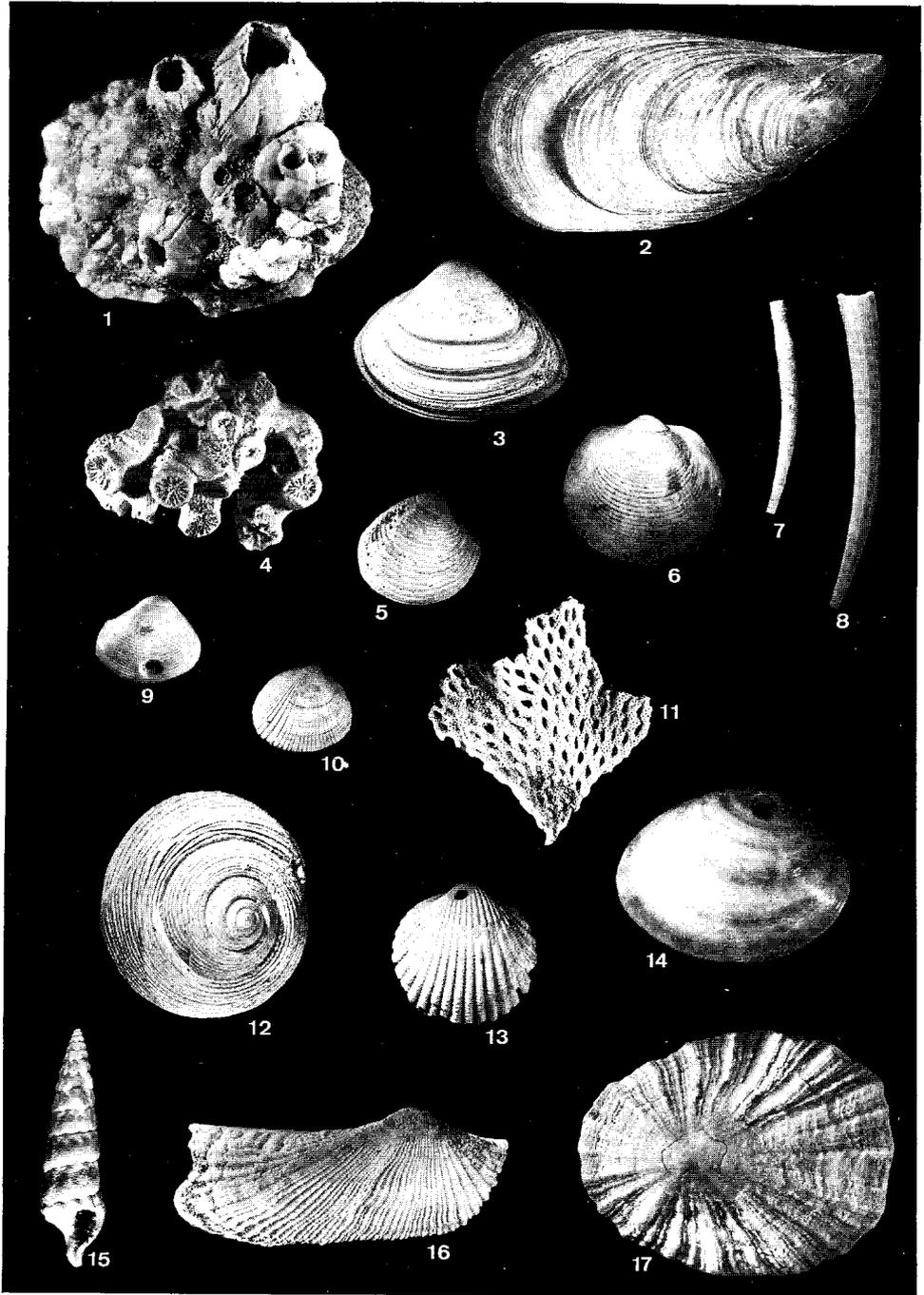


PLATE 4

Arthropoda:

- 1 Balanus sp.  
x 1, sample A.

Mollusca:

- 2 Mytilus galloprovincialis (Lamarck)  
x 1, sample A.
- 3 Spisula subtruncata (da Costa)  
x 1, sample A.

Anthozoa:

- 4 Cladocora cespitosa (Gualtieri)  
x 1, sample C.

Mollusca:

- 5 Venus gallina (Linné)  
x 1, sample F.
- 6 Glycymeris cf. violascens (Lamarck)  
x 1, sample B.

Annelida:

- 7 Ditrupa sp.  
x 1, sample D.

Mollusca:

- 8 Dentalium inaequicostatum (Dautzenberg)  
x 1, sample C.
- 9 Corbula gibba (Olivi)  
x 2, sample C.
- 10 Venus cf. ovata (Pennant)  
x 2, sample F.

Byozoa:

- 11 Colony of Sertellidae  
x 1, sample C.

Mollusca:

- 12 Gibbula sp.  
x 1, sample F.
- 13 Cardium sp.  
x 1, sample F.
- 14 Callista chione (Linné)  
x 1, sample F.
- 15 Cerithium neogenitum (Mayer)  
x 1, sample E.
- 16 Arca noae (Linné)  
x 1, sample C.
- 17 Patella caerulea (Linné)  
x 1, sample C.



		Sample number	
1	1	41	<i>Elphidium crispum</i>
2	1	42	" <i>lessonii</i>
3	1	43	" <i>macellum</i>
4	2	44	" var.
5	1	45	<i>Eponides frigidus</i> var. <i>granulatus</i>
6	4	46	<i>Fursenkoina schreibersiana</i>
7	11	47	<i>Gaudryina pseudoturris</i>
8	1	48	<i>Gavellinopsis praegeri</i>
9	1	49	<i>Glabratella</i> sp.
10	1	50	<i>Globobullimina</i> sp.
11	2	51	<i>Globulina gibba</i>
12	1	52	" <i>inaequalis</i>
13	2	53	<i>Guttulina irregularis</i>
14	1	54	" <i>lactea</i>
15	3	55	" <i>pulchella</i>
16	1	56	<i>Lagena</i> sp.
17	1	57	<i>Lamarckina scabra</i>
18	1	58	<i>Lenticulina</i> sp.
19	2	59	<i>Lexostomum alatum</i>
20	1	60	<i>Miliolidae</i> indet.
21	1	61	<i>Miliolinella subrotunda</i>
22	1	62	" sp.
23	1	63	<i>Miniacina miniacae</i>
24	1	64	<i>Neoconorbina terquemii</i>
25	1	65	<i>Nonion asterizans</i>
26	1	66	" <i>boveanum</i>
27	1	67	" <i>depressulum</i>
28	1	68	" <i>granosum</i>
29	1	69	" <i>grateloupi</i>
30	1	70	" spp.
31	1	71	<i>Nonionella turgida</i>
32	1	72	<i>Patellina corrugata</i>
33	1	73	<i>Panorbulina mediterranea</i>
34	1	74	<i>Planulina wuellerstorfi</i>
35	1	75	<i>Protelphidium lidoense</i>
36	1	76	<i>Pyrgo</i> sp.
37	1	77	<i>Quinqueloculina agglutinans</i>
38	1	78	" cf. <i>angulata</i>
39	1	79	" <i>aspera</i>
40	1	80	" <i>berthelotiana</i>
41	1	81	" <i>bicornis</i>
42	1	82	" <i>candeliana</i>
43	1	83	" <i>contorta</i>
44	1	84	" cf. <i>costata</i>
45	1	85	" <i>disparilis</i>
46	1	86	" <i>ferusacci</i>
47	1	87	" <i>laevigata</i>
48	1	88	" <i>lata</i>
49	1		
50	1		
51	1		
52	1		
53	1		
54	1		
55	1		
56	1		
57	1		
58	1		
59	1		
60	1		
61	1		
62	1		
63	1		



Planktonic Foraminifera  
Thecamoebina

Sample number	Nr. of counted specimens	
1	2	1 <i>Globigerina bulloides</i>
2	2	2 "
3	2	3 "
4	4	4 "
5	1	5 "
6	9	6 <i>Globigerinoides ruber</i>
7	3	7 "
8	4	8 "
9	3	9 "
10	6	10 <i>Globorotalia inflata</i>
11	3	11 "
12		12 <i>Indet. planktonic Foraminifera</i>
13		13 "
14		14 "
15	3	15 <i>Centropyxis marsupiformis</i>
16		
17		
18	1	
19	1	
20	5	
21	1	
22	3	
23	1	
24	4	
25	3	
26	1	
27		
28	5	
29	2	
30	4	
31	4	
32	4	
33	1	
34	1	
35	1	
36	15	
37	5	
38		
39	2	
40		
41	6	
42	1	
43	1	
44	2	
45	1	
46	2	
47		
48	5	
49		
50		
51	3	
52	6	
53	5	
54	3	
55	2	
56	3	
57	6	
58		
59	3	
60	2	
61		
62		
63	6	

Ostracoda

Sample number		Nr. of counted specimens
1	2	1
2	9	2
3	13	5
4	27	2
5	6	1
6	36	1
7	10	1
8	11	2
9	5	1
10	8	1
11	8	3
12		4
13		2
14		2
15		2
16		2
17		2
18		2
19		1
20		1
21		4
22		4
23		2
24		1
25		1
26		1
27		1
28		2
29		1
30		1
31		1
32		1
33		2
34		2
35		1
36		1
37		1
38		3
39		1
40		1
41		2
42		1
43		1
44		4
45		2
46		1
47		2
48		2
49		1
50		1
51		1
52		1
53		1
54		4
55		2
56		1
57		1
58		2
59		1
60		7
61		1
62		1
63		1
64		1
65		1
66		1
67		1
68		1
69		1
70		1
71		1
72		1
73		1
74		1
75		1
76		1
77		1
78		1
79		1
80		1
81		1
82		1
83		1
84		1
85		1
86		1
87		1
88		1
89		1
90		1
91		1
92		1
93		1
94		1
95		1
96		1
97		1
98		1
99		1
100		1

## Bryozoa (&lt; 2 mm)

Sample number		Nr. of counted specimens	
1		1	<i>Calpensia</i> spp.
2		2	<i>Cellepora</i> ? sp.
3		3	<i>Chaperia</i> ? sp.
4		4	<i>Crisia denticulata</i>
5		5	" <i>elongata</i>
6	19	6	" <i>fistulosa</i>
7	18	7	" spp.
8	8	8	<i>Diaperoecia major</i>
9		9	<i>Entalophora</i> sp.
10		10	<i>Haplopoma bimicronatum</i>
11		11	<i>Hippaliosina depressa</i>
12		12	<i>Margaretta cereoides</i>
13		13	<i>Metrarabdotos (R) helveticum can.</i>
14		14	" sp.
15		15	<i>Lichenopora</i> ? sp.
16		16	<i>Savignyella lafontii</i>
17		17	<i>Sertellidae</i>
18		18	<i>Schizomavella auriculata</i>
19		19	<i>Scrupocellaria reptans</i> ?
20		20	" <i>scruposa/scruposa</i>
21		21	" sp.
22		22	<i>Vittaticella</i> sp.
23		23	Indet. Cheilostomes
24		24	" Cyclostomes
25		25	" Bryozoa
1			
2			
3			
4			
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59			
60			
61			
62			
63			

Mollusca  
 Bryozoa (> 2 mm)  
 Annelida  
 Arthropoda

Sample number		Sample number
Nr. of counted specimens		Nr. of counted specimens
A	297	1
B	57	4
C	195	2
D	52	3
E	123	5
F	214	24
A	1	1
B	1	2
C	1	3
D	1	4
E	1	5
F	1	6
A	30	7
B	1	8
C	1	9
D	1	10
E	1	11
F	1	12
A	1	13
B	1	14
C	1	15
D	1	16
E	1	17
F	1	18
A	1	19
B	1	20
C	1	21
D	1	22
E	1	23
F	1	24
A	1	25
B	1	26
C	1	27
D	1	28
E	1	29
F	1	30
A	1	31
B	1	32
C	1	33
D	1	34
E	1	35
F	1	36
A	1	37
B	1	38
C	1	39
D	1	40
E	1	41
F	1	42
A	1	43
B	1	44
C	1	45
D	1	46
E	1	47
F	1	48
A	1	49
B	1	50
C	1	51
D	1	52
E	1	53
F	1	54
A	1	55
B	1	56
C	1	57
D	1	58
E	1	59
F	1	60
A	1	61
B	1	62

Enclosure I																							
Thickness in m.										Unit													
Sample nr.										Grain-size distr.													
Coarse fraction composition										Sed. structures													
Benthonic Foraminifera										Benthonic Foraminifera													
Ostracoda										Ostracoda													
Bryozoa										Bryozoa													
Mollusca										Mollusca													
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[Stratigraphic column with lithological symbols and Roman numerals I-XXIV]											Clay Silt Very fine sand Fine sand Medium sand Coarse sand Gravel												
[Plant-remains, Oolites, Shell-fragments, Echinoid spines, Calcar. algae]											Plant-remains Oolites Shell-fragments Echinoid spines Calcar. algae												
[Horizontal tracks, Small scale cross-lam., Horizontal lam., Small scale burrows, Large scale cross-lam., Large scale burrows, Homogeneous sands]											Horizontal tracks Small scale cross-lam. Horizontal lam. Small scale burrows Large scale cross-lam. Large scale burrows Homogeneous sands												
[Nr. of counted specimens (<100)]											Nr. of counted specimens (<100)												
[Benthos index]											Benthos index												
[Cribronion excavatum]											Cribronion excavatum												
[Cribronion incertum]											Cribronion incertum												
[Nonion depressulum]											Nonion depressulum												
[Ammonia beccarii]											Ammonia beccarii												
[Protelphidium lidoense]											Protelphidium lidoense												
[Cribronion gunteri]											Cribronion gunteri												
[Ammonia perlucida]											Ammonia perlucida												
[Cribronion articulatum]											Cribronion articulatum												
[Cribronion asklundi]											Cribronion asklundi												
[Cribronion gerthi]											Cribronion gerthi												
[Reussella spinulosa]											Reussella spinulosa												
[Fursenkoina schreibersiana]											Fursenkoina schreibersiana												
[Bulimina gibba]											Bulimina gibba												
[Elphidium macellum]											Elphidium macellum												
[Elphidium crispum]											Elphidium crispum												
[Plano-convex species]											Plano-convex species												
[Asterigerina rhodiensis]											Asterigerina rhodiensis												
[Asterigerina planorbis]											Asterigerina planorbis												
[Concis auriculus]											Concis auriculus												
[Cibicides lobatulus]											Cibicides lobatulus												
[Miliolidae]											Miliolidae												
[Triloculina schreibersiana]											Triloculina schreibersiana												
[Quinqueloculina aspera]											Quinqueloculina aspera												
[Triloculina trigonula]											Triloculina trigonula												
[Triloculina adriatica]											Triloculina adriatica												
[Triloculina inflata]											Triloculina inflata												
[Quinqueloculina longirostra]											Quinqueloculina longirostra												
[Quinqueloculina cf. costata]											Quinqueloculina cf. costata												
[Quinqueloculina berthelotiana]											Quinqueloculina berthelotiana												
[Miliolidae indet.]											Miliolidae indet.												
[Textularidae]											Textularidae												
[Planorbulina mediterraneensis]											Planorbulina mediterraneensis												
[Small benthonic specimens]											Small benthonic specimens												
[Planctonic foraminifera]											Planctonic foraminifera												
[Thecamoebina]											Thecamoebina												
[Leptocythere sp I]											Leptocythere sp I												
[Falunia (H) rugosa]											Falunia (H) rugosa												
[Xestoleberis communis]											Xestoleberis communis												
[Loxoconcha turbida]											Loxoconcha turbida												
[Krithe sp.]											Krithe sp.												
[Aurilia ex gr. punctata]											Aurilia ex gr. punctata												
[Loxoconcha rhomboidea]											Loxoconcha rhomboidea												
[Aurilia calciplena]											Aurilia calciplena												
[Aurilia cruciata minor]											Aurilia cruciata minor												
[Urocythereis marg. marg.]											Urocythereis marg. marg.												
[Crisia spp.]											Crisia spp.												
[Others]											Others												
[Ditrupe sp.]											Ditrupe sp.												
[Cladocora cespitosa]											Cladocora cespitosa												
[Spisula subtruncata]											Spisula subtruncata												
[Anomia ephippium]											Anomia ephippium												
[Bittium reticulatum]											Bittium reticulatum												
[Glycymeris cf. violascens]											Glycymeris cf. violascens												
[Gibbula sp.]											Gibbula sp.												
[Dentalium inaequicostatum]											Dentalium inaequicostatum												
[Cardium sp.]											Cardium sp.												
[Corbula gibba]											Corbula gibba												
[Venus cf. ovata]											Venus cf. ovata												
[Ringicula auriculata]											Ringicula auriculata												
[Cerithium neogenitum]											Cerithium neogenitum												

LEGEND

- Lithology :
-  Gravel-pebbles
  -  Shells, shell-fragments
  -  Clay pebbles
  -  Sand
  -  Silt
  -  Laminated silty clay
  -  Clay, silty clay, marl
  -  Homogeneous marly clay, pink
  -  Bivalves in situ

- Benthos index :
- ≥1000
  - 500-999
  - 300-499
  - 100-299
  - <100

- Plankton, Thecamoebina etc.
- ≥ 10/100 benthon. Foram. } 50-100 counted benthon. Foram.
  - 5-9/100 " " }
  - < 5/100 " " }
  - x Present < 50 counted benthon. Foram.

- Ostracoda, Bryozoa, Mollusca etc.
- X Dominant
  - x Important
  - x Present

- Grain size distr. :
- Median grain-size
  - Size-range

- Coarse fraction comp. :
- Frequent
  - Common
  - Rare

- Sedimentary structures :
- Frequent
  - Common
  - ! Rare

- Benthonic Foraminifera :
- ≥ 50% } 50-100 counted specimens
  - 40-49% }
  - 30-39% }
  - 20-29% }
  - 10-19% }
  - 4-9% }
  - 1-3% }
  - Dominant } <50 counted specimens
  - Important }
  - Present }



