UNIVERSITY OF SOUTHAMPTON

STRATIGRAPHY AND SEDIMENTOLOGY OF THE LEFKARA FORMATION, CYPRUS (PALAEOGENE TO EARLY NEOGENE)

by
Gisela Kähler

A thesis presented for the degree of
Doctor of Philosophy

Department of Geology
University of Southampton
October 1994

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF SCIENCE

GEOLOGY

Doctor of Philosophy

STRATIGRAPHY AND SEDIMENTOLOGY OF THE LEFKARA FORMATION, CYPRUS (PALAEOGENE TO EARLY NEOGENE)

by Gisela Kähler

The Lefkara Formation in Cyprus, a Tertiary deep water carbonate succession overlying newly formed ocean crust (Troodos ophiolite), has been studied in terms of stratigraphy, depositional environment, sediment transport and provenance, diagenesis and the influence of tectonics on the deposition.

The biostratigraphic work, based on planktonic foraminifera and radiolarians, reveals a Middle Palaeocene to Early Miocene age (P3-N6/7) for the whole succession, with a diachronous onset of the different lithostratigraphic units. Mixing of species from various biozones indicates common reworking.

Micro- and macrofacies, faunal and mineralogical studies of the chalks, marls and cherts suggest a deposition of the Lefkara Formation in 2000-3000m water depth, possibly between the CCD and ACD, in a basin margin environment. The sediments were deposited or influenced by pelagic, turbiditic and bottom current processes. An allochthonous component in the sediments was derived from a northern shallow water source (shallow marine organisms) and from neomorphic and weathering processes in perimarine and terrestrial environments (clay minerals palygorskite, sepiolite, smectite, illite, chlorite, clinoptilolite). Sedimentation rates vary between 0.2 and 50m/Ma and consistently reflect differences in sedimentary processes and diagenesis. Most sediments are diagenetically altered and show signs of compaction, pressure-solution, silicification and neomorphism, the degree of which is dependent on the original composition and rate of burial.

Early and Middle Eocene distal biogenic calciturbidites of a basin plain facies were deposited as a carbonate slope apron and were responsible for most of the allochthonous input, with chert developments reflecting times of rapid burial. Lateral changes in turbidite facies indicate a weaker turbidite influence to the west due to a higher topography and a topographic barrier to the north. Sediment input, lithology and timing of the fining and thinning upward turbidite deposits were strongly dependent on the tectonic development of the source area in the northern Kyrenia terrane and the Taurids, and on the basin geometry which changed due to active tectonism through time.

Contourites were identified near the top of the formation on the basis of sedimentary structures, composition and hiatuses. These could be correlated with worldwide climate-dependent hiatuses of mainly Oligocene age. The contour current-formed stratigraphically highest marls show a distinctive diachronous start and are thought to reflect, in part, underthrusting from the south and redistribution of flysch deposits from the north.

CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER 2 STRATIGRAPHY

CHAPTER 3 RESULTS OF THE SEDIMENT STUDIES

CHAPTER 4 INTERPRETATION AND DISCUSSION OF SEDIMENT ANALYSIS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

ACKNOWLEDGEMENTS

Firstly, I thank Prof John Murray and Dr Dorrik Stow for their help and supervision throughout all stages of the research and preparation of the thesis. Thanks also go to Dr Costas Xenophontos of the Geological Survey Department Nicosia, Cyprus, who was most helpful during the field work and in organisational matters. I am grateful to all members of the Geology Department who gave advice and cooperation, in particular Dr Ian West, Dr Trevor Clayton, Robin Saunders and Dave Spanner. Dr Alastair Robertson, Dr Toine Wonders and Dr Gill Harwood looked at some of the sample material and gave advice through constructive discussion. Finally, I want to thank Gilbert Marshall for proof reading the manuscript and for general support in the last four years.

The thesis was funded by the Geology Department of the University of Southampton and Prof Michael Sarnthein from Christian-Albrechts-Universität Kiel, Germany. Additionally, I thank my two supervisors and the former head of the department, Prof Norman Hamilton, for arranging financial matters for the second half of the project.

CHAPTER 1
INTRODUCTION

1.1. AIMS OF THIS RESEARCH

The Troodos ophiolite in Cyprus presents a complete sequence of ancient ocean crust from ultramafic mantle rocks up to the pelagic sediment cover (Moores & Vine, 1971) (Figs.1 and 2). The Lefkara Formation, the object of this work, forms part of the earliest sediments (Fig.3). It consists of pelagic, hemipelagic and turbiditic sediments overlying either pillow lava, hydrothermally formed umbers (Robertson & Hudson, 1973), previously displaced nappes (Moni Melange, Mamonia Complex), or radiolarites formed below the CCD (Robertson & Hudson, 1974). Being the first calcareous deposits overlying ocean crust, the sediments of the Lefkara Formation reflect the environmental evolution of this part of the Troodos ocean soon after its formation up to the onset of uplift at the first stage of ophiolite emplacement. It is a well exposed example of oceanic sediments formed in a closing ocean basin influenced by turbidity current, bottom current and pelagic processes of deposition.

Although these processes have been dated roughly to have taken place between Maastrichtian and Early Miocene, an exact dating of the changes in lithology is crucial to an accurate reconstruction of the depositional and tectonic history of the area and the sedimentological response.

There are two main strands to this study, each with a corresponding set of principal aims: (1) detailed biostratigraphic study in order to (a) date the Lefkara Formation in different parts of Cyprus and (b) to check whether any diachrony exists between different areas. (2) examination of the facies and composition of the sediments of the whole formation in order to reveal more detailed information about (a) the complete depositional history of the formation, (b) the source of allochthonous material and the mechanisms of transport, (c) the relationship between the depositional environment of the deep sea sediments and the tectonic evolution of Cyprus and the surrounding areas, and (d) the influence of diagenesis on the facies in order to disentangle primary from secondary characteristics of the sediments. The complementary stratigraphic and sedimentological approach adopted here is intended to provide both a more detailed and a more holistic understanding of the Lefkara Formation than is currently available from previous work.

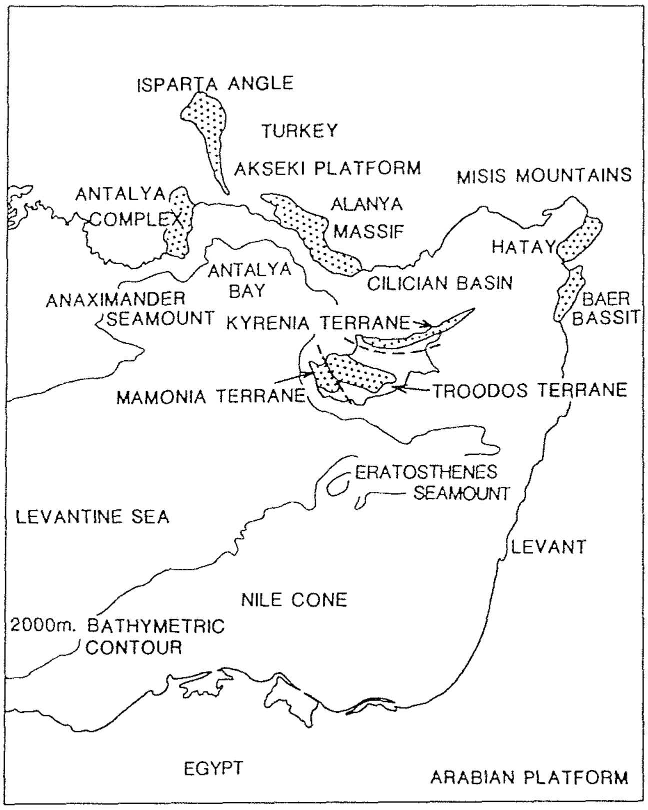


Fig.1. Position of Cyprus and further ophiolites in the Eastern Mediterranean and adjacent areas (from Robertson, 1990), the boundaries of the three terranes of the island are marked.

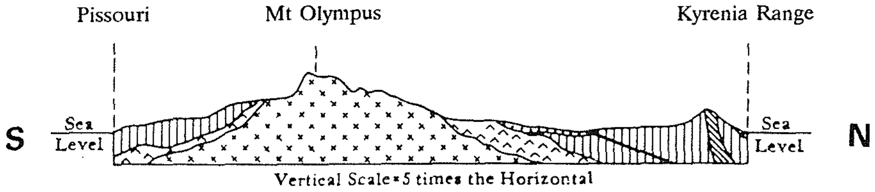


Fig.2. Cross section through Cyprus (after Pantazis, 1967). x-ornament: plutonic rocks; ʌ-ornament: pillow lavas; lines: sedimentary cover.

STANDARD STRATIGRAPHIC COLUMN

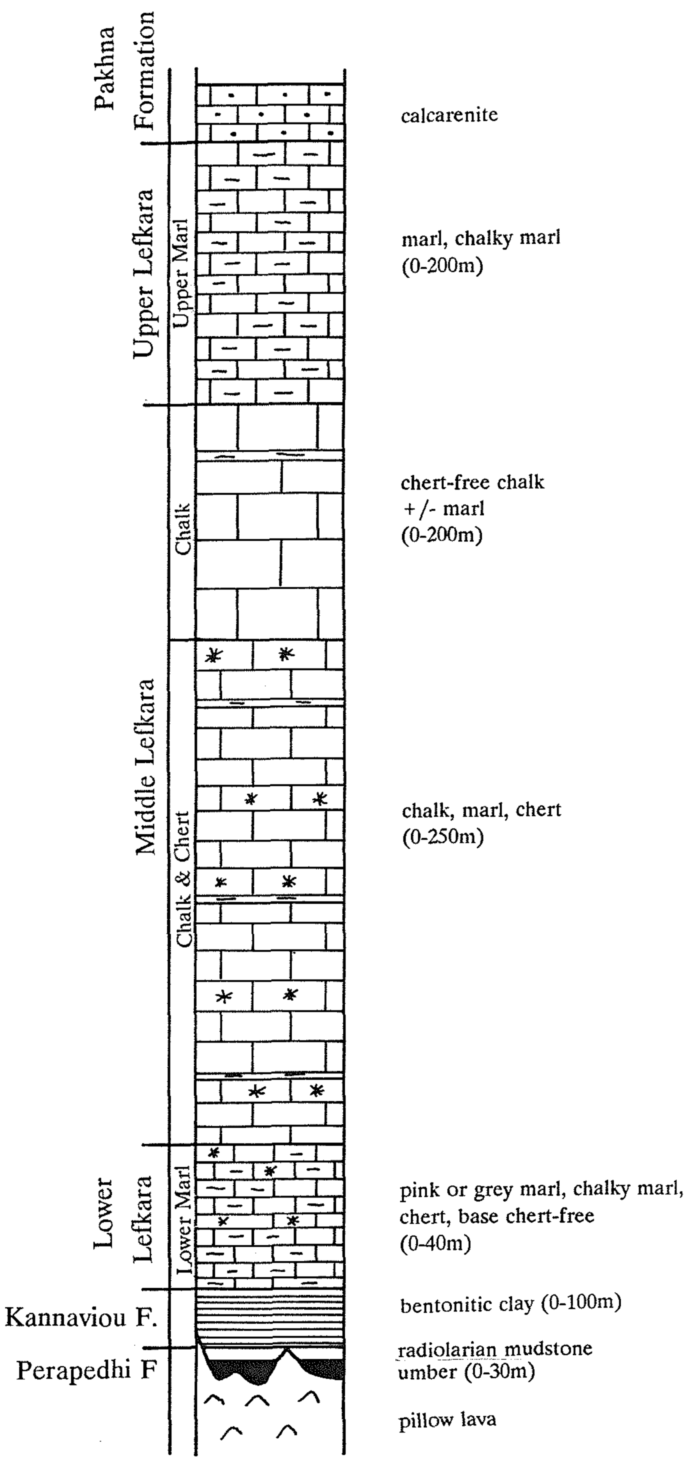


Fig.3. Standard stratigraphic column of the Lefkara Formation, modified from Robertson & Hudson (1974).

1.2. ORGANISATION OF THE THESIS

The thesis is roughly subdivided into a stratigraphic and sedimentological part. As a complete section, Chapter 2 includes the whole complex of the identification of the microfauna (planktonic foraminifera and radiolarians), the establishment of biozones, the subsequent dating of the sedimentary succession, and the discussion with previous publications. Additionally, sedimentation rates for the Lefkara Formation are calculated and discussed.

For the sedimentological studies, a strict subdivision into results and interpretation/discussion has been made, because of a more varied approach to the analysis. Chapter 3 contains all results of the studies on the facies in the field and laboratory, and the mineralogy. In Chapter 4 the results are interpreted and discussed separately for the mineralogy, the influence of diagenesis on the deposits, and the sedimentological processes forming the Lefkara Formation. The depositional environment is examined under a variety of aspects and the stratigraphy established in Chapter 2 is applied here.

Finally, in Chapter 5 the information on the environment of the deposits and their development in time are set into the framework of the local tectonics as well as the global oceanic current pattern as far as the latter ones have not been discussed in Chapter 4.

1.3. OVERVIEW Of THE GEOLOGICAL EVOLUTION OF CYPRUS

Many works on the tectonic and sedimentological evolution of Cyprus have been published. A comprehensive overview over the present stage of knowledge is presented by Robertson (1990) and this paper will be the basis for the following brief summary.

Cyprus consists of three terranes each having an independent tectonic history until they were finally sutured. These are the Troodos, the Mamonia, and the Kyrenia terranes, with the Troodos terrane being subdivided into four sub-terranes: the Troodos ophiolite, the Arakapas transform fault, the anti-Troodos ophiolite and the Akamas ophiolite. During **Permian** time the Kyrenia Range formed an unstable shelf along the northern continental margin of Gondwana. In the **Middle to Late Triassic** sedimentation in a fault-controlled rift basin took place in the palaeo-locations of the Kyrenia and the Mamonia terranes. Both terranes formed parts of a passive continental margin in **Jurassic and Middle Cretaceous** time with initially stable but later subsiding conditions. The Troodos terrane formed in the **Late Cretaceous** (Cenomanian to Turonian, Blome & Irving, 1985) as newly produced ocean crust (Gass, 1968) above a northeast dipping intra-oceanic subduction zone (Moores *et al.*, 1984), which was caused by the compression due to Africa-Eurasia convergence. The palaeogeographical position of the Troodos area at this time was 21^{0}N (Moores & Vine, 1971).

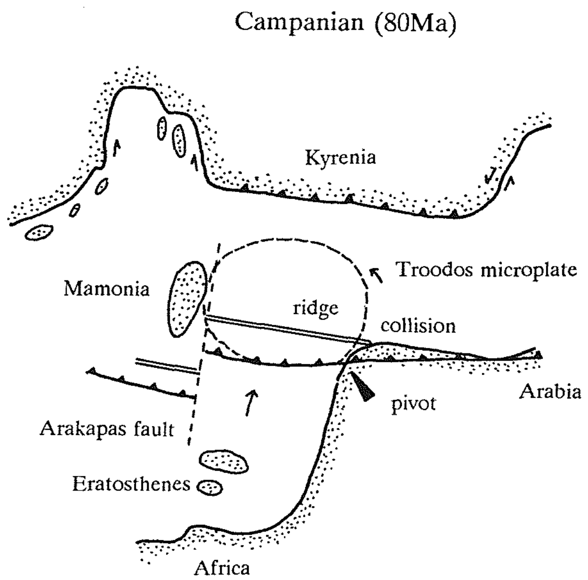


Fig.4. Plate tectonic setting of the Eastern Mediterranean in Upper Campanian (after Robertson, 1990). Arrows: direction of plate movement.

Supra-subduction zone spreading was initiated by extension of the oceanic crust due to a roll-back effect during subduction. In the Late Cretaceous, the Mamonia Complex was juxtaposed (but not accreted) to the Troodos terrane and amalgamation occurred in Middle Eocene time. Similarly, the Kyrenia Range was most likely juxtaposed by subduction to the northern margin of the Troodos plate in the Late Cretaceous (Robertson & Woodcock, 1986). Between the **Campanian** and the **Early Eocene**, a continent-trench collision of the northwards approaching Arabian continental margin with the subduction zone in the east of the Troodos area most likely initiated a 90^0 anti-clockwise rotation of the Troodos microplate (Moores & Vine, 1971; Clube & Robertson, 1986; Fig.4; compare also Fig.87) while the still independent Mamonia and Kyrenia terranes did not rotate. This ended the spreading activity but caused volcanism resulting in the Kannaviou Formation (Baroz, 1980). Probably by Maastrichtian time, 60° of the rotation of the Troodos plate was completed whereas the last 30° rotation took place during the deposition of the early Lefkara Formation. A northward movement of Cyprus took place most likely after the major rotation and, as proposed by Abrahamsen & Schönharting (1980), after obduction as a part of the African plate.

In the **Late Eocene to Early Oligocene**, amalgamation of the Kyrenia Range with the Troodos terrane took place combined with southward thrusting, deformation, and uplift of the range (Robertson & Woodcock, 1986). The time between **Oligocene and Late Pliocene** is characterised by compressional tectonics in southern Cyprus and extension with subsequent subsidence in the northern Kyrenia Range and the Mesaoria plain. The compression and uplift in the south, which started most likely in the **Early Miocene**, was mainly caused by the onset of underthrusting of continental crust from the south in addition to serpentine diapirism (Poole & Robertson, 1991). This tectonic event led to major changes in the pattern of deposition and caused the clear demarcation of the boundary between the Lefkara and Pakhna Formations in around Aquitanian time. The main phase of uplift took place during the **Pleistocene** and was centred near Mount Olympus. Earthquakes and the dating of fossil shorelines indicate that the process continued into the Quaternary and recent time (Poole & Robertson, 1991; Vita-Finzi, 1990) which is why Cyprus is still considered to be an active plate boundary.

1.4. PREVIOUS WORK ON THE SEDIMENTS OF THE LEFKARA FORMATION

A detailed chronology of the research on the Lefkara Formation has been given by several authors (e.g. Pantazis, 1967; Robertson, 1975) and will not be repeated here. Only references on the lithology of the formation important for this study will be summarised in this section while the publications on the stratigraphy are discussed in Chapter 2.3.2.

The first systematic studies on the sedimentary cover in Cyprus including first stratigraphic approximations have been done by Henson *et al.* (1949). They treated the marl and chalk bearing succession overlying the igneous rocks from the whole island as one group, the Lapithos Group, including the deposits from the independently developed Kyrenia Range. Later, detailed geological maps and studies were published for most areas of Cyprus in the Memoirs of the Geological Survey Department Cyprus. The southern flank of the Troodos Massif was covered by Wilson (1959), the south east by Pantazis (1967), the east by Bagnall (1960), the north east by Gass (1960), and the northern margin by Bear (1960). Pantazis (1967) proposed a change of the old name Lapithos Group for the marls and chalks around the Troodos Complex to Lefkara Formation because of significant differences in the setting between the sediments of the Kyrenia Range and the rest of the island. Further studies on the Lefkara Formation have been done by Kluyver (1969) in the western part of Cyprus including the Akamas peninsula, and by Cleintuar *et al.* (1977) as part of their more comprehensive study on the tectonic units of the island.

Although some detailed petrographic work on the sediments was carried out by previous authors (e.g. Bagnall, 1960), the first systematic studies of the Lefkara Formation including depositional and tectonic implications have been done by Robertson (1975) in the context of a PhD thesis. The research concerning the Lefkara Formation has concentrated on the cherts in the chalks (Robertson & Hudson, 1974; Robertson, 1977), and the Middle Lefkara chalk succession in which calciturbidites were first identified (Robertson, 1976). The interpretation of the basal marls of the Lower Lefkara and the underlying radiolarites and umbers to be deep-sea deposits (Robertson & Hudson, 1973, 1974) added to the revision of the previous shallow water interpretation for the basal part and the transgressive character of the formation.

Field guides describing important localities of the Lefkara Formation were published by Xenophontos *et al.* (1987) and Robertson (1978). A brief introduction to the general geological setting of Cyprus can be found in Panayiotou (1987).

1.5. LITHOSTRATIGRAPHY OF THE LEFKARA FORMATION

The Lefkara Formation is traditionally subdivided into the Lower, Middle, and Upper Lefkara (Fig.3). This points out the most apparent changes in the lithology from marly deposits (Lower Lefkara), to chalk-dominated sediments (Middle Lefkara), to marls (Upper Lefkara). For a more detailed description of the facies four lithological units can be recognised (Pantazis, 1967), which will be used in this work: the Lower Marl unit, the Chalk & Chert unit, the (chert-free) Chalk unit, and the Upper Marl unit, with the Chalk & Chert and the Chalk units together forming the Middle Lefkara Formation. Since these changes in facies are commonly observed to be gradual some confusion about the definition of the lithological units exists in the literature. This will be discussed when describing the individual units. As pointed out by Pantazis (1967) some authors defined the lithostratigraphical Lower Lefkara (Lapithos) Formation by its micropalaeontologically determined Maastrichtian age, thus mixing litho- and biostratigraphic definitions. The same inconsistency led to the inclusion of the chert-free chalks either into the Upper Lapithos (Bagnall, 1960; Bear, 1960) or into the Middle Lapithos (Wilson, 1959; Gass, 1960). To avoid any confusions in this work the pure lithological units will be used.

Comparing the publications of local mapping, significant lateral variations exist in the thickness of the units and not all units are present in all areas, depending on the palaeotopography and erosion which resulted in unconformities especially at the base and top of the formation. At the northern margin of the Troodos igneous complex the Lefkara Formation seems to be generally thin, condensed, and discontinuous, either due to a reduced sedimentation rate and/or to erosion (Bear, 1960; Robertson, 1975).

In the following, the most obvious facies characteristics of all lithological units will be described on the basis of the references given above and which were used when logging for the present study. Here also, the definitions for the units followed in this work will be specified. The thicknesses of the lithological units are the summary of ranges given in the publications cited.

Lower Marl unit:

The oldest sediments of the Lefkara Formation are typically grey or pinkish-brownish, thin-bedded marls with fine lamination occasionally observed (Robertson, 1978). The sediments of the Lower Marl unit are deposited in the uppermost part of already almost filled hollows in the lava surface and are therefore laterally discontinuous (Robertson & Hudson, 1974). Thickness estimates vary between maxima of 25m and 100m.

Apart from the discussed biostratigraphical definition of the lithological unit, further inconsistencies about defining the Lower Marl unit exist. Robertson & Hudson (1974) described the Lower Lefkara to be chert-free, not tuffaceous (Robertson, 1978) and exclusively consisting of marls. Other authors include strata that contain nodular or bedded coloured cherts, chalky marls and thin chalk beds towards the top of the unit, and occasional tuffaceous limestones or siltstones (e.g. Pantazis, 1967; Wilson, 1959). In this work the upper boundary of the Lower Marl sediments is defined at the start of pure white chalks because this is the only change in the lithology that can be clearly seen in the field which is not confused by gradual transition. The start of the cherts is not considered to be a characteristic for a unit definition since these gradually increase in frequency and thickness in an otherwise unchanging marl-rich background sediment.

Chalk & Chert unit:

The Chalk & Chert unit, the lower part of the Middle Lefkara, consists of well bedded, pure, white chalks, greyish impure chalks, some pinkish chalks near the bottom of the unit, grey marls, and silicified strata. The latter ones are either yellowish, extremely hard chalk beds, granular or rarer vitreous nodules, or chert bands which are coloured near the base of the unit and grey higher up in the succession. In some localities the sediments show sedimentary structures of turbiditic origin (Robertson, 1976) which are extensively developed in the southeast of the island. Descriptions of tuffaceous, sandy limestones in the literature in most cases also point to a turbiditic rather than to a primary volcanic origin.

In the literature the thickness of the unit is usually given for the whole Middle Lefkara with values up to 500m, and variable estimates for the chert-bearing part of up to 300m. The Chalk & Chert unit at the northern margin of the massif is condensed, less than 10m thick, and in a patchy distribution (Bear, 1960; Robertson, 1978).

Chalk unit:

The upper part of the Middle Lefkara is the almost chert-free Chalk unit. The lithology is either described as being identical to the underlying unit and just lacking the chert, or consisting of thick bedded or massive appearing pure chalks. Towards the top of the unit the chalks become usually increasingly flaggy.

The thickness of the unit, if given separately for the Chalk unit, is estimated to be a maximum of 240m in the southeast of the island and up to 70m in the north.

Upper Marl unit:

The Upper Marl unit is most variable in the facies described in the literature. The most typical lithology is grey marl which is developed relatively homogeneously after a transitional zone of interbedded chalks at the boundary towards the underlying unit. Occasionally, thin calcarenitic limestone layers may be intercalated and the sediments may be stained with iron oxide or contain limonitic nodules. Other authors include the flaggy chalks or the transitional marl-chalk alternation into the Upper Marl unit. Mainly in the east of Cyprus black shales, pyrite nodules and current bedding (Bagnall, 1960), plant detritus (Robertson & Hudson, 1974), reef detritus (Cleintuar et al., 1977), and worm tubes are described. Prominent slumping is observed in the east and northeast of the Troodos Massif and hiatuses are occasionally present.

The thickness of the Upper Marl unit varies between 3m and 200m. The reef detrital Terra Limestone, previously considered as locally the top of the Lefkara Formation has recently been found to be part of the overlying Pakhna Formation (Follows & Robertson, 1990).

The transition of the Lefkara Formation to the Pakhna Formation is characterised by the onset of wavy bedded, sandy, occasionally limonitic, and flaggy marls and limestones with or without current structures. Authors who define the start of the Pakhna Formation biostratigraphically by its Middle Miocene age (Gass, 1960) naturally do not always find any change in lithology at the boundary. The contact of the formations, if exposed, is described to be gradual or sharp and commonly unconformities are observed.

1.6. FIELD AREA AND MATERIAL

During two field seasons, six sections through the Lefkara Formation have been logged and sampled. All sections lie in the south or the east of the Troodos Massif (Fig.5). Most sections include deposits of all lithological units and therefore reflect the whole succession from the contact with the volcanics to the top of the formation near the overlying Pakhna Formation. Nevertheless, none of the sections is a continuous profile of the whole stratigraphic column but all are composed of several separate outcrops which show a more or less clear relationship to each other in the field. The description of all sections follows in Chapter 3.1.

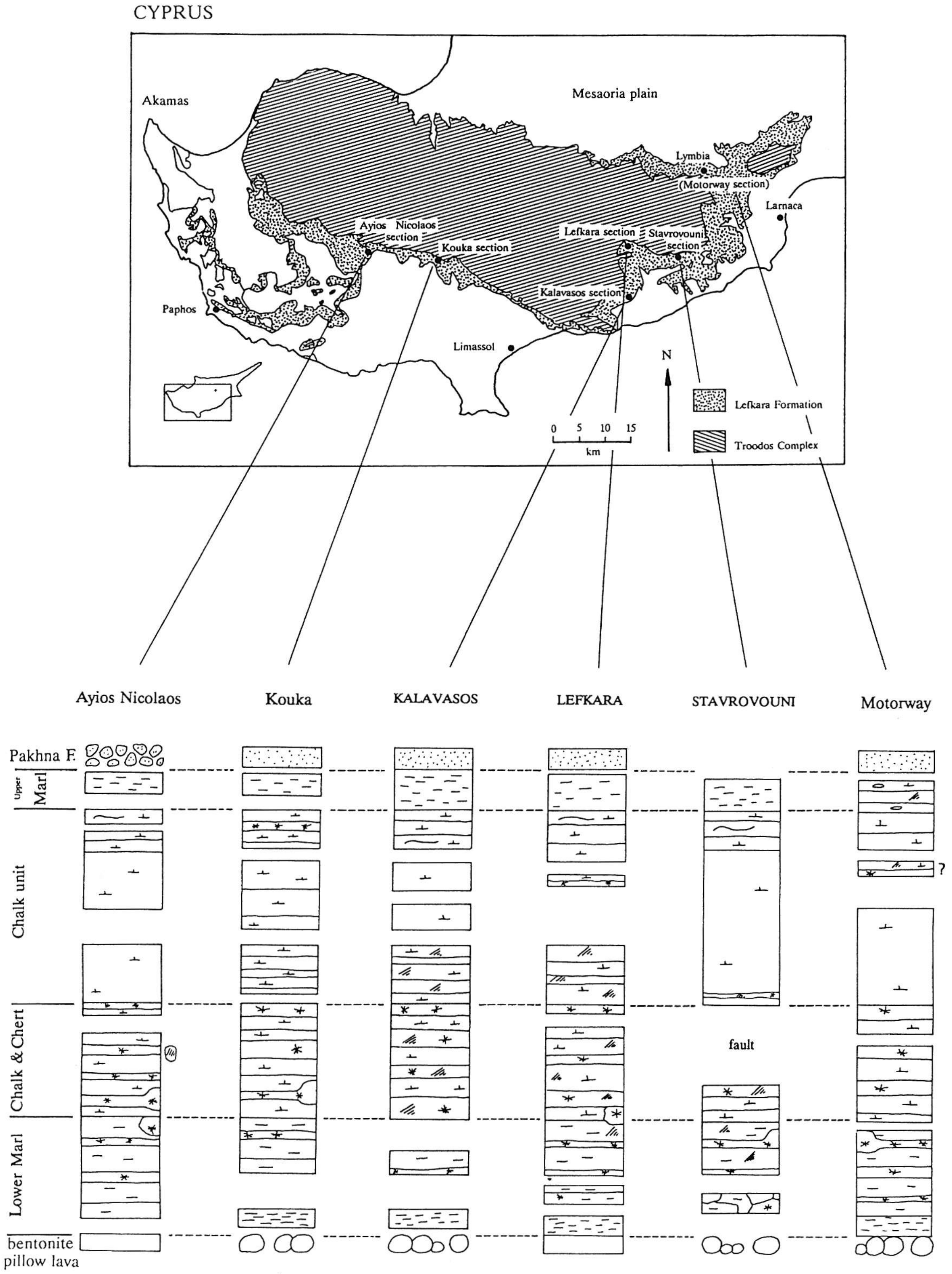


Fig.5. Location and facies of the six sections studied of the Lefkara Formation. Gaps in the stratigraphic column represent unexposed or inaccessible parts of the succession (not to scale, for legend see Fig.27).

CHAPTER 2
STRATIGRAPHY

2.1. MICROFOSSILS USED FOR RELATIVE DATING

2.1.1. CHOICE OF MICROFOSSIL GROUPS

Planktonic foraminifera are the dominant faunal components in most samples and only few samples were found to be barren. For this reason they have been chosen for establishing the biostratigraphy. Nevertheless, in the majority of samples strong diagenetic alteration has obscured diagnostic details of the tests. Consequently, in many cases no definite identification has been possible.

The second group of microfossils that is abundant to dominant in many samples, but completely absent in others, are radiolaria. The uncertainty of the stratigraphic position obtained by the planktonic foraminifera led to the decision to examine the radiolarian fauna in selected samples. The aim of the radiolarian study is (1) to gain further information from strata that do not contain indentifiable planktonic foraminifera, (2) to check an uncertain assigned biozone based on planktonic foraminifera, and (3) to give a more precise stratigraphic age for those samples where the foraminifera merely give a zone range (e.g. P10-12). If radiolarians are present, they are usually well preserved. Even strongly dissolved, very translucent specimens can often still be identified with certainty.

2.1.2. PLANKTONIC FORAMINIFERA TAXA

The identification of the planktonic foraminifera taxa is mainly based on the relevant works in 'Plankton Stratigraphy' published by Bolli *et al.* (1985) (papers by Toumarkine & Luterbacher, Bolli & Saunders, Iaccarino). Further important publications used for the classification are Blow & Banner (1962), Ellis *et al.* (1969), Stainforth *et al.* (1975), Blow (1979) and Kennett & Srinivasan (1983), besides several papers on local faunas and special phylogenetic lineages, of which Bolli & Saunders (1982) for the *Globorotalia mayeri/continuosa* group is the most important. For thin section investigations Postuma (1971), Sartorio & Venturini (1988) and

Tab.1. Planktonic foraminifera identified in the Lefkara Formation.

- Suborder Globigerinina
- Superfamily Globigerinacea
- Family Globigerinidae
- Subfamily Globigerininae
  - *Globigerina ampliapertura* (Bolli)
  - *G. angioporides* (Hornibrook)
  - *G. bollii lentiana* (Rögl)
  - *G. ciperoensis angustiumbilicata* (Bolli)
  - *G. ciperoensis ciperoensis* (Bolli)
  - *G. cyptomphala* (Glaessner)
  - *G. eocaena* (Guembel)
  - *G. euapertura* (Jenkins)
  - *G. falconensis* (Blow)
  - *G. gortanii* (Borsetti)
  - *G. hagni* (Gohrbandt)
  - *G. inaequispira* (Sabbotina)
  - *G. increbescens* (Bandy)
  - *G. juvenilis* (Bolli)
  - *G. linaperta* (Finlay)
  - *G. officinalis* (Subbotina)
  - *G. ouachitaensis gnaucki* (Blow & Banner)
  - *G. praebulloides leroyi* (Blow & Banner)
  - *G. praebulloides occlusa* (Blow & Banner)
  - *G. praebulloides praebulloides* (Blow)
  - *G. praeturrilina* (Blow & Banner)
  - *G. pseudovenezuelana* (Blow & Banner)
  - *G. sellii* (Borsetti)
  - *G. senni* (Beckmann)
  - *G. tapuriensis* (Blow & Banner)
  - *G. triloculinoides* (Plummer)
  - *G. tripartita* (Koch)
  - *G. velascoensis* (Cushman)
  - *G. venezuelana* (Hedberg)
  - *G. yeguaensis* (Weinzierl & Applin)

  - *Globigerinoides ruber* (d'Orbigny)
  - *G. trilobus immaturus* (LeRoy)

- Subfamily Porticulasphaerinae
  - *Globigerinatheka sp.* (Brönnimann)
  - *G. index rubriformis* (Sabbotina)

- Family Hastigerinidae
  - *'Hastigerina' cf. bolivariana* (Petters)

- Superfamily Globorotaliacea
- Family Globorotaliidae
  - *Globorotalia continuosa* (Blow)
  - *G. kugleri* (Bolli)
  - *G. mayeri* (Cushman & Elliser)
  - *T. obesa* (Bolli)
  - *G. opima nana* (Bolli)
  - *G. opima opima* (Bolli)
  - *G. opima nana / G. continuosa* transition
  - *G. scitula praescitula* (Blow)
  - *G. zealandica* (Hornibrook)

  - *Planorotalites australiformis* (Jenkins)
  - *P. chapmani* (Parr)
  - *P. pseudoscitula* (Glaessner)
  - *P. pusilla pusilla* (Bolli)

  - *Pseudohastigerina micra* (Cole)
  - *P. naguewichiensis* (Myatliuk)
  - *P. wilcoxensis* (Cushman & Ponton)

  - *Turborotalia cerroazulensis cerroazulensis* (Cole)
  - *T. c. cocoaensis* (Cushman)
  - *T. c. cunialensis* (Toumarkine & Bolli)
  - *T. c. frontosa* (Subbotinae)
  - *T. c. pomeroli* (Toumarkine & Bolli)
  - *T. c. possagnoensis* (Toumarkine & Bolli)
  - *T. permicra* (Blow & Banner)
  - *T. wilsoni* (Cole)

Tab.1. continued.

Family Truncorotaloididae

- *Acarinina broedermanni* (Cushman & Bermudez)
- *A. bullbrooki* (Bolli)
- *A. crassata* (Cushman)
- *A. mckannai* (White)
- *A. matthewsae* (Blow)
- *A. nitida* (Martin)
- *A. pentacamerata* (Subbotina)
- *A. primitiva* (Finlay)
- *A. soldadoensis sp.* (Brönnimann)
- *A. spinuloinflata* (Bandy)

- *Morozovella acuta* (Toulmin)
- *M. aequa* (Cushman & Renz)
- *M. angulata* (White)
- *M. aragonensis* (Nuttall)
- *M. conicotruncata* (Subbotina)
- *M. convexa* (Subbotina)
- *M. edgari* (Premoli Silva & Bolli)
- *M. formosa formosa* (Bolli)
- *M. formosa gracilis* (Bolli)
- *M. lensiformis* (Subbotina)
- *M. praecursoria* (Morozova)
- *M. pseudotopilensis* (Subbotina)
- *M. quetra* (Bolli)
- *M. spinulosa coronata* (Blow)
- *M. subbotinae* (Morozova)

- *Truncorotaloides collactea* (Finlay)
- *T. libyaensis* (El Khoudary)
- *T. rohri* (Brönnimann & Bermudez)
- *T. topilensis* (Cushman)

Family Catapsydracidae

- *Catapsydrax dissimilis* (Cushman & Bermudez)

- *Globoquadrina dehiscens* (Chapman, Parr & Collins)
- *G. altispira globosa* (Bolli)
- *G. altispira globulosa*

- *Globorotaloides carcoselleensis* (Toumarkine & Bolli)
- *G. hexagona* (Natland)
- *G. suteri* (Bolli)

Plate 1. Stratigraphically important planktonic foraminifera species.

- a *A. bullbrooki* (250x)
- b *A. broedermanni* (300x)
- c *A. soldadoensis* (200x)
- d *Globigerinatheka?* (200x)
- e *Globigerinoides sp.*, spiral view (200x)
- f *T. rohri* (300x)
- g *T. topilensis* (200x)
- h *C. dissimilis* (200x)
- i *P. micra* (300x)
- j *G. angustiumbilicata* (400x)
- k *G. praebulloides occlusa*? (200x)
- l *G. yeguaensis* (200x)
- m *G. venezuelana* (250x)
- n *G. euapertura* (200x)
- o *G. triloculinoides* (200x)
- p *G. obesa*? (200x)
- q *G. mayeri*, spiral view (200x)
- r *G. mayeri*, umbilical view (250x)
- s *G. opima opima/opima nana* transition (400x)
- t *G. opima nana/continuosa* transition (200x)
- u *G. carcoselleensis*? (300x)
- v *G. suteri* (300x)
- w *M. subbotinae* (200x)
- x *M .acuta* (200x)
- y *M acuta* (200x)
- z *M. formosa formosa* (150x)

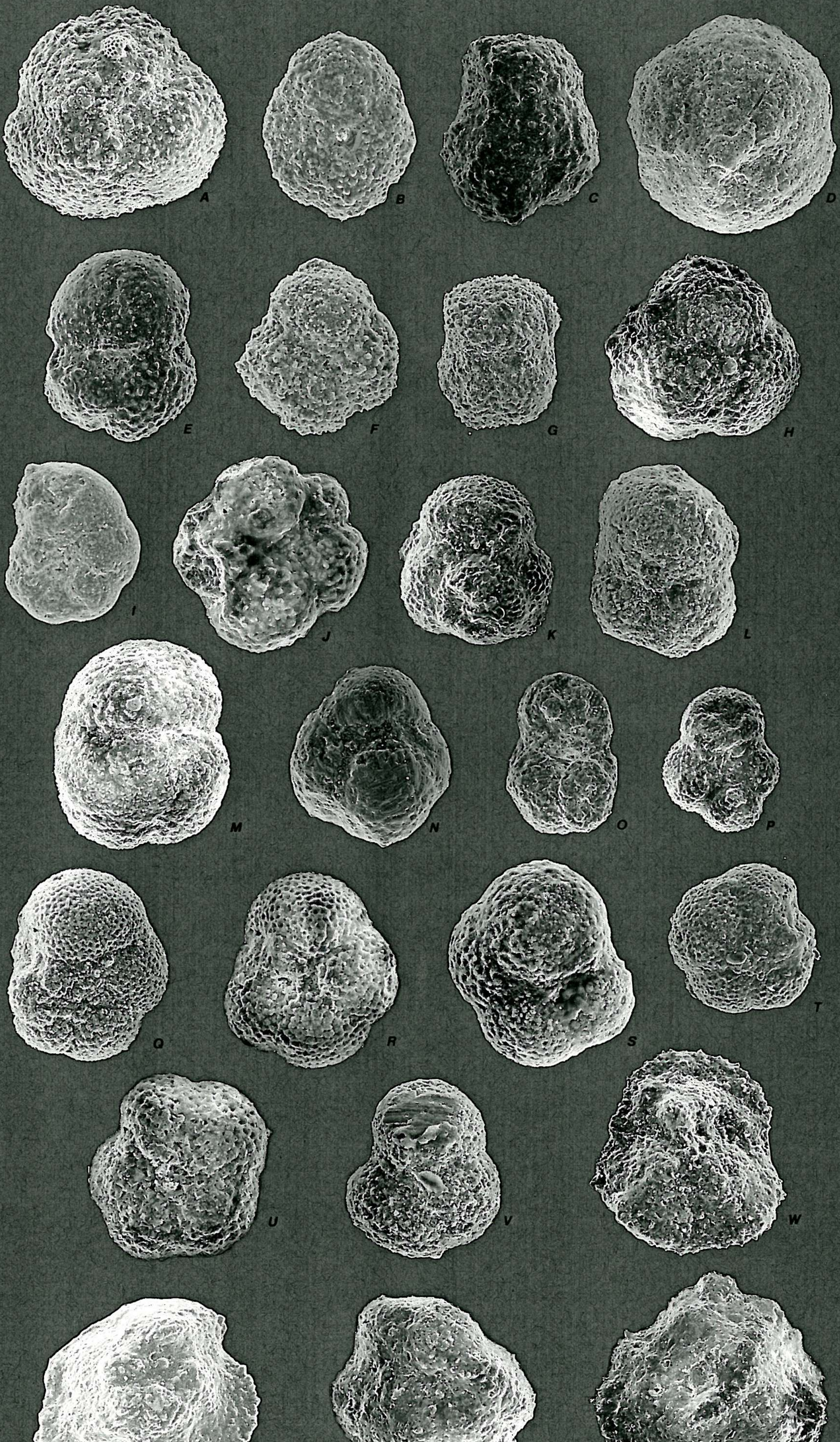
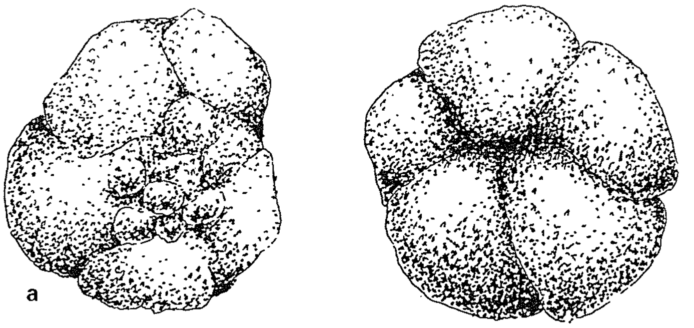
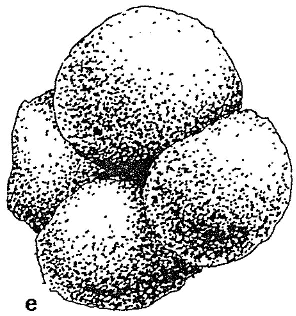
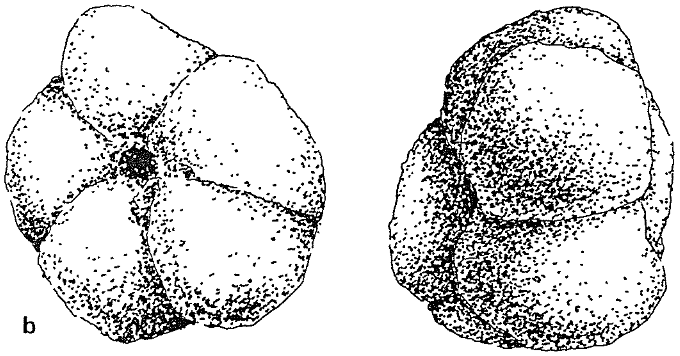

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z

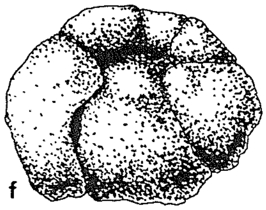
Plate 2. Planktonic foraminifera species continued.

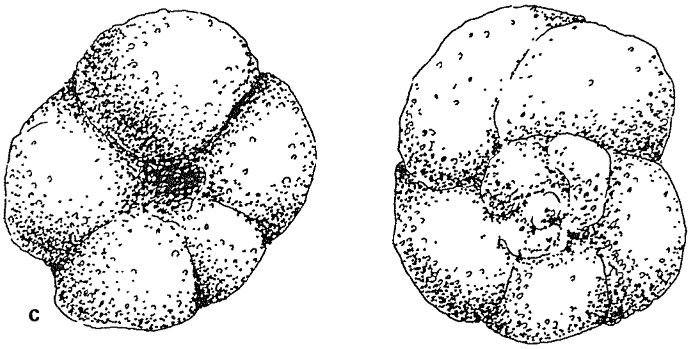
a *G. collactea* (spiral, umbilical view; 150µm)
b *A. mackannai* (umbilical, lateral view; 350µm)
c *A. pentacamerata* (umbilical, spiral view; 300µm)
d *A. bullbrooki* (umbilical, spiral view; 200µm)
e *G. hagni* (umbilical view; 250µm)
f *M. angulata* (lateral view; 200µm)
g *M. aragonensis* (lateral view; 250µm)

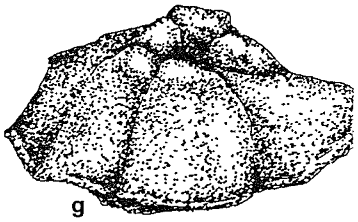

a

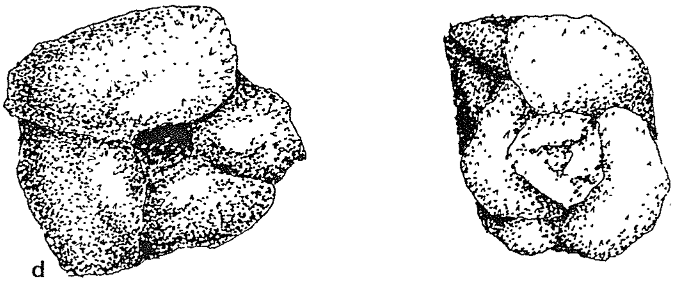

e


b


f


c


g


d

McGowran (1968) are additional sources.

For identification, foraminifera specimens were picked from the >63μm washed residue (for technique see Appendix A.1). Thin sections (TS) were used in addition, since especially small, fragile taxa, such as *Planorotalites* or spinose forms, are much better seen in thin sections where they are not destroyed during sample preparation.

A total of 95 planktonic foraminifera species and morphotypes picked from 74 samples are distinguished. A summary of the species identified is given in Table 1 and some species shown in Plate 1, 2 and 3. Here again it has to be underlined that the preservation of the foraminifera tests in the majority of the samples is extremely poor. Often the shape of the test is the only diagnostic feature of a specimen. This seems to be more reliable for Early and Middle Eocene taxa since test proportions are significant amongst the morozovellids and acarininids. For the late Palaeogene and early Neogene taxa identification becomes more difficult (and possibly less reliable). Here globigerinids dominate the fauna and their classification needs more details like the exact position of the aperture, lips or wall textures.

2.1.3. RADIOLARIAN TAXA

Of the radiolarian fauna present in the Lefkara sediments with few exceptions only representatives of the nasselarian suborder *Cyrtida* were identified and used for dating. Most spumellarians, spyrids and the genus *Lychnocanoma* of the theoperids were usually not considered even if they appeared in the material frequently.

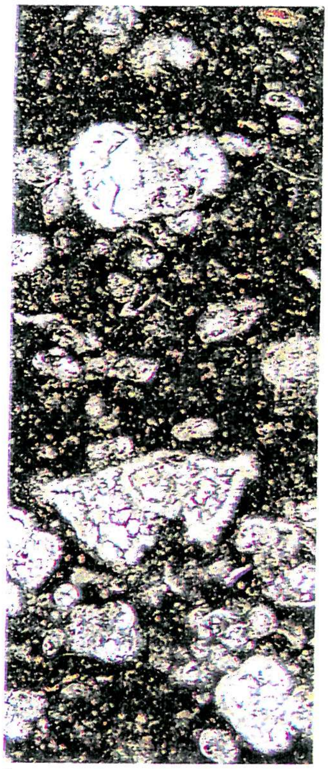
For identification, a big range of publications was used. As the basic work, the paper of Sanfilippo, Westberg-Smith & Riedel in Bolli *et al.* (1985) was used for the most important and most common taxa. For more detailed and partly original descriptions, better figures and a comprehension of the fauna for special time intervals, publications such as Foreman (1973), Nigrini (1977), Petrushevskaya & Kozlova (1972), Sanfilippo & Riedel (1973, 1989), and Riedel & Sanfilippo (1970, 1978) were used amongst others.

In contrast to the planktonic foraminifera, the radiolarian specimens are usually well preserved when they occur. Forty two samples were examined for the HCl-insoluble residue which was embedded in Canada Balsam (Appendix A.1). Fifty nine species or subspecies were recognised, mostly from the fraction 63-125μm. In some samples, specimens of larger size were

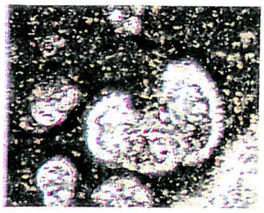
Plate 3. (1-5) Planktonic foraminifera in thin sections, (6-11) Radiolarian species.

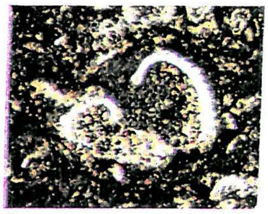
1 top *A. soldadoensis* (?), bottom *M. formosa gracilis*
2 top *A. bullbrooki*, bottom *T. rohri*
3 *T. topilensis*
4 *A. soldadoensis*
5 *T. cerroazulensis pomeroli*

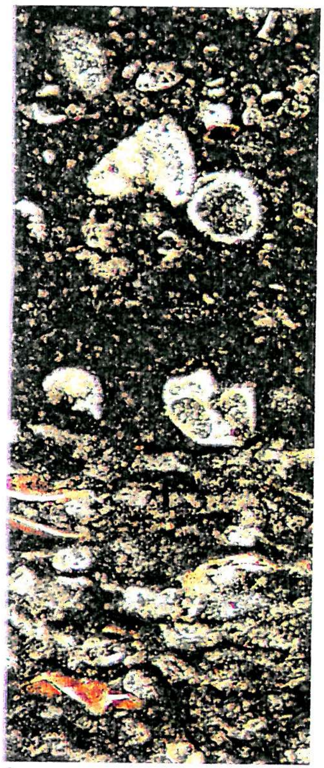
6 *P. sinuosa* (SEM photograph)
7 *S. triconiscus*
8 *D. mongolfieri*
9 *T. triacantha*
10 *P. sinuosa*
11 *P. ampla* (?)

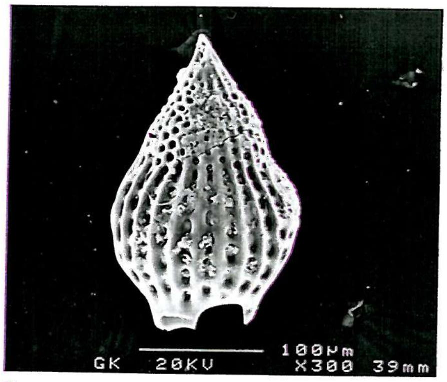

1


3

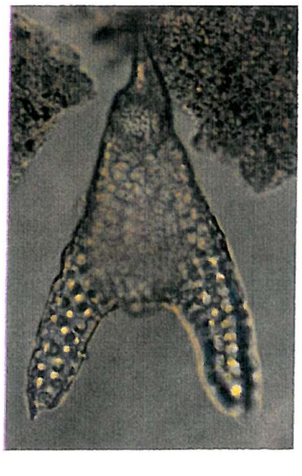

4

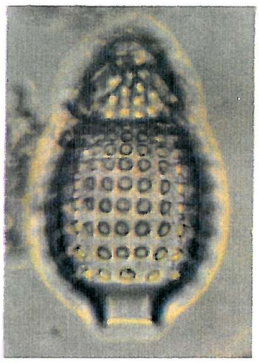

5

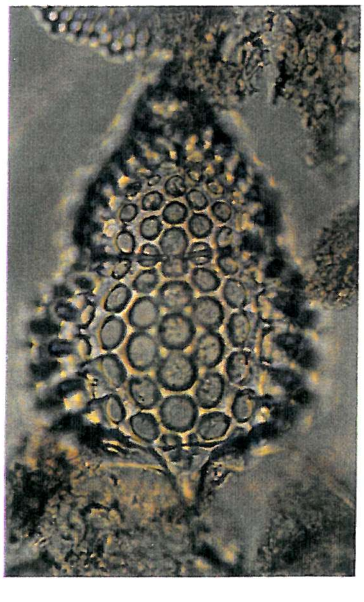

2

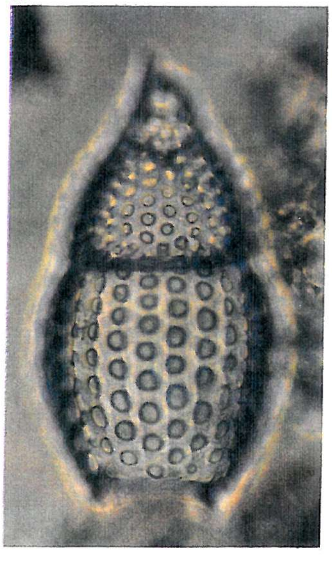


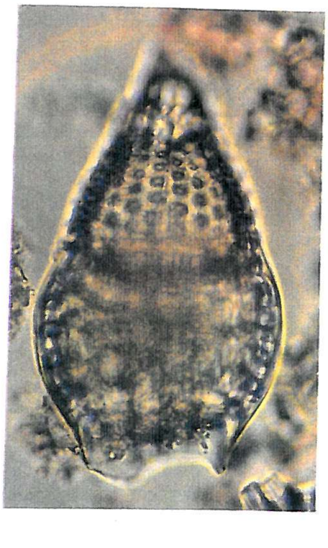
6


7


8


9


10


11

Tab.2. Radiolarian species identified in the sediments of the Lefkara Formation.

- Order Spumellaria
- Family Actinommidae
  - *Spongatractus pachystylus* (Ehrenberg)
- Family Coccodiscidae
- Subfamily Coccodiscinae
  - *Lithocyclia aristotelis* (Ehrenberg)

- Order Nassellaria
- Suborder Spyrida
- Family Acanthodesmiidae
  - *Dendrospyris fragoides* (Sanfilippo & Riedel)
  - *Rhabdolithis pipa* (Ehrenberg)
- Family Triospyridea
  - *Patagospyris pentas* (Ehrenberg)

- Suborder Cyrtida
- Family Theoperidae
  - *Buryella clinata* (Foreman)
  - *Buryella tetradica* (Foreman)
  - *Calocyclas hispida* (Ehrenberg)
  - *Calocyclas turris* (Ehrenberg)
  - *Calocycloma ampulla* (Ehrenberg)
  - *Calocycloma castum* (Haeckel)
  - *Eusyringium fistuligerum* (Ehrenberg)
  - *Eusyringium lagena* (Ehrenberg)
  - *Lithapium (?) plegmacantum* (Riedel & Sanfilippo)
  - *Lithochytris archaea* (Riedel & Sanfilippo)
  - *Lithochytris vespertilio* (Ehrenberg)
  - *Lithochytris (Lithochytrodes) sp.O* (Petrushevskaya & Kozlova)
  - *Phormocyrtis striata exquisita* (Kozlova)
  - *Phormocyrtis striata striata* (Brandt)
  - *Rhopalocanium ornatum* (Ehrenberg)
  - *Sethochytris babylonis* (Clark & Campbell)
  - *Sethochytris triconiscus* (Haeckel)
  - *Theocorys acroria* (Foreman)
  - *Theocorys anaclasta* (Riedel & Sanfilippo)
  - *Theocorys anapographa* (Riedel & Sanfilippo)
  - *Theocotyle cryptocephala* (Ehrenberg)
  - *Theocotyle nigrinae* (Riedel & Sanfilippo)
  - *Theocotylissa ficus* (Ehrenberg)
  - *Thyrsocyrtis (Thyrsocyrtis) bromia* (Ehrenberg)
  - *Thyrsocyrtis (Thyrsocyrtis) hirsuta hirsuta* (Krasheninnikov)
  - *Thyrsocyrtis (Thyrsocyrtis) rhizodon* (Ehrenberg)
  - *Thyrsocyrtis (Pentalacorys) lochites* (Sanfilippo & Riedel)
  - *Thyrsocyrtis (Pentalacorys) tensa* (Foreman)
  - *Thyrsocyrtis (Pentalacorys) tetracantha* (Ehrenberg)
  - *Thyrsocyrtis (Pentalacorys) triacantha* (Ehrenberg)

- Family Carpocaniidae
  - *'Carpocanistrum' azyx* (Sanfilippo & Riedel)

- Family Pterocorythidae
  - *Podocyrtis (Podocyrtis) ampla* (Ehrenberg)
  - *Podocyrtis (Podocyrtis) diamesa* (Riedel & Sanfilippo)
  - *Podocyrtis (Podocyrtis) dorus* (Sanfilippo & Riedel)
  - *Podocyrtis (Podocyrtis)papalis* (Ehrenberg)
  - *Podocyrtis (Lampterium) aphorma* (Riedel & Sanfilippo)
  - *Podocyrtis (Lampterium) chalara* (Riedel & Sanfilippo)
  - *Podocyrtis (Lampterium) fasciolata* (Nigrini)
  - *Podocyrtis (Lampterium) helenae* (Nigrini)
  - *Podocyrtis (Lampterium) mitra* (Ehrenberg)
  - *Podocyrtis (Lampterium) sinuosa* (Ehrenberg)
  - *Theocyrtis tuberosa* (Riedel)

- Family Artostrobiidae
  - *Dictyoprora amphora* (Haeckel)
  - *Dictyoprora mongolfieri* (Ehrenberg)
  - *Dictyoprora ovata* (Haeckel)
  - *Dictyoprora pirium* (Ehrenberg)
  - *Dictyoprora urceolus* (Haeckel)
  - *Siphocampe acephala* (Ehrenberg)
  - *Siphocampe elizabethae* (Clark & Campbell)
  - *Siphocampe lineata* (Ehrenberg)
  - *Siphocampe nodosaria* (Haeckel)

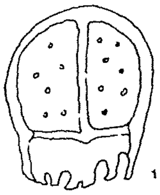
- Family Amphipyndacidea
  - *Amphipternis clava* (Ehrenberg)

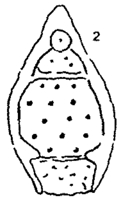
- Incertae sedis
  - *Lophocyrtis biaurita* (Ehrenberg)

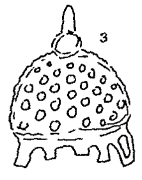
found preferentially in the fraction larger than 125μm but commonly the whole faunal assemblage was present in the smaller one. A list of all species identified is shown in Table 2 and important species illustrated in Plates 3, 4 and 5. The radiolarian content varies strongly from sample to sample, from completely barren to packed with shells. Commonly only a rudimentary fauna was found with the silica walls strongly corroded and dissolved. At the bottom and the top of the succession no radiolarians are preserved at all.

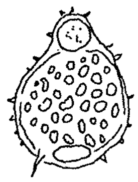
Plate 4. Stratigraphically important radiolarian species (not in scale).

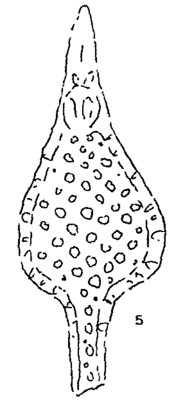
1 *D. fragoides*
2 *B. clinata*
3 *C. turris*
4 *C. ampulla*
5 *E. fistuligerum*
6 *E. lagena*
7 *L. vespertilio*
8 *P. striata striata*
9 *R. ornatum*
10 *S. babylonis* (3 morphotypes)
11 *T. anaclasta*
12 *T. anapographa*
13 *T. cryptocephala*
14 *T. ficus*
15 *T. bromia*
16 *T. rhizodon*
17 *T. tetracantha*
18 *'C' azyx* (?)

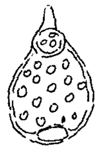

1

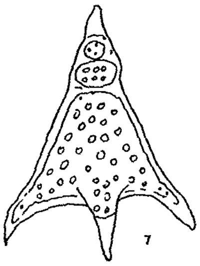

2

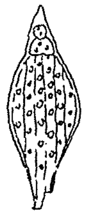

3

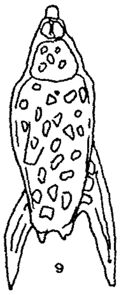

4

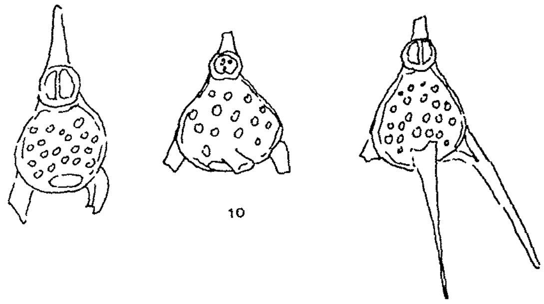

5

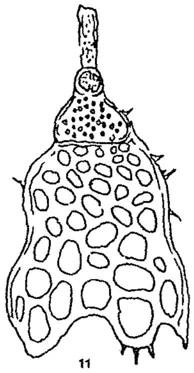

6

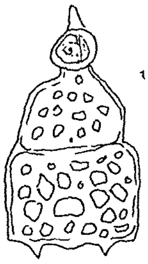

7

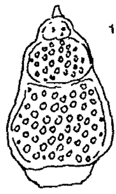

8

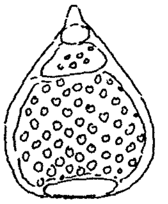

9

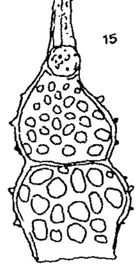

10

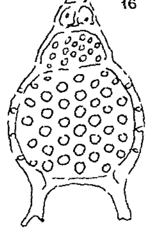

11

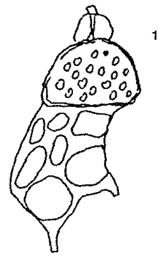

12


13


14


15


16


17

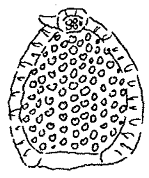
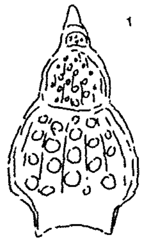
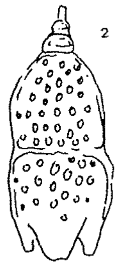
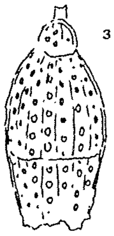

18

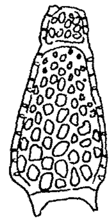
Plate 5. Radiolarian species continued.

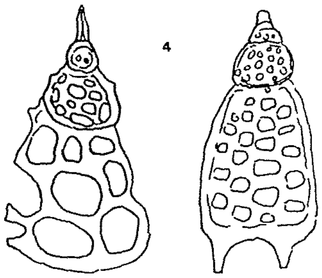
1 *P. ampla*
2 *P. diamesa*
3 *P. papalis*
4 *P. chalara* (two morphotypes)
5 *P. helenae* (broken specimen)
6 *D. amphora*
7 *D. ovata*
8 *D. urceolus*
9 *D. pirium*
10 *S. acephala*
11 *S. elizabethae*
12 *S. lineata*
13 *S. nodosaria* (?)
14 *A. clava*
15 *L. biaurita*

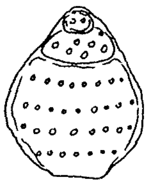

1

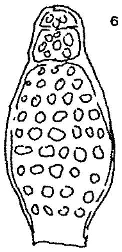

2

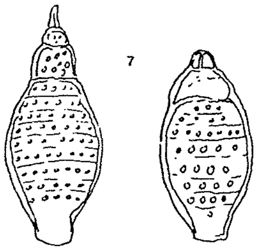

3

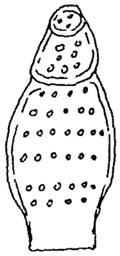

5

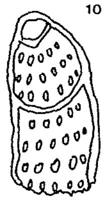

4

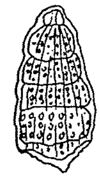

9

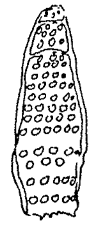

6

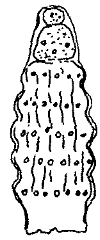

7

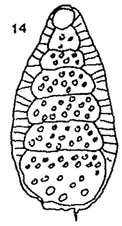

8

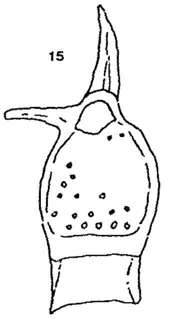

10


11


12


13


14


15

2.2. SAMPLE DATING

2.2.1. FORAMINIFERAL BIOZONES

As far as possible, the biozonal schemes that have been used in this study are of Toumarkine & Luterbacher (1985) for the Palaeocene to Eocene (emended from Premoli Silva & Bolli, 1973), Bolli & Premoli Silva (1973) for the Oligocene, and Iaccarino (1985) (emended from Iaccarino & Salvatorini, 1982) for the Mediterranean Neogene. Applying these schemes appears to be difficult in many samples of the Lefkara sediments. Many of the zonal markers are absent or rare. This is most probably due to bad preservation and selective dissolution. It is not possible to rely on first and last occurrences of species if they are not common in the sediment and most of the marker species were not found in any of the samples. Therefore biozones could not be defined in the established way. Instead, the whole set of species had to be considered to estimate the age. Since time ranges of species (especially non-marker species) differ locally (Blow, 1979, Bolli & Krashenninikov, 1977) the ranges given in the literature do not necessarily give exact data for the Cyprus area. For this reason the resolution of the dating in this work is comparatively low. Differential dissolution and reworking may have altered the species proportions and faunal composition in the Cyprus assemblages and this limits comparison with the typical assemblages of biozones as given in Toumarkine & Luterbacher (1985) (Appendix A.2).

For convenience of brevity zone numbers have been used. These were first introduced by Blow (1969), modified for the Palaeogene by Berggren & van Couvering (1974), and are summarised in Figure 6 from Bolli *et al.* (1985, Chapter 3).

The zonal scheme used was originally erected on data from low latitudes but it has been successfully applied in the Mediterranean area for much of the Palaeogene (Palaeocene to Eocene; Bolli *et al.* 1985, Chapter 3). Due to the isolation of the Mediterranean Sea from the Indian Ocean, an independent zonal scheme and different species ranges have to be adopted for sediments starting with the Oligocene.

The time ranges for the species identified are shown in Figure 7 and are taken mainly from Bolli *et al.* (1985, Chapters 5, 6, 8). A list of all specimens identified in each sample, including a discussion and details of dating, is presented in Appendix A.3. Figures 8-13 show these data summarised, together with the position of the samples in the stratigraphic columns. The bad state of preservation made it impossible to give a reliable description of the whole faunal composition of each foraminifera zone identified in the Lefkara Formation. Therefore only the species actually used for determining the zones are discussed below.

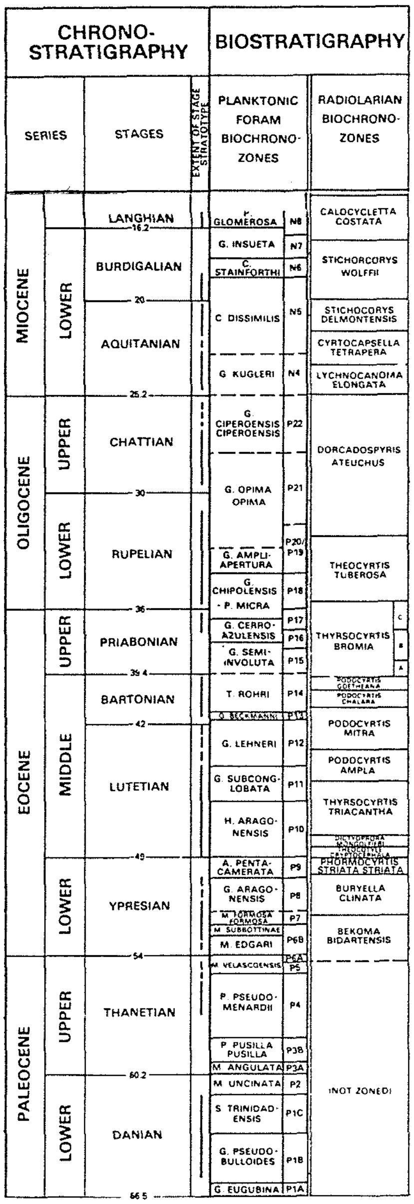


Fig.6. Correlation of biostratigraphic zonal schemes for planktonic foraminifera and radiolarians (from Bolli *et al.*, 1985; Haq *et al.*, 1987).

P3-4 are the oldest foraminifera biozones determined. No species were present to give a more exact resolution and they only occur as reworked material in younger strata. The most reliable indicators for this zone range are *Morozovella angulata* and *Morozovella conicotruncata* together with the rather uncertain species *Planorotalites pusilla pusilla* and *Globigerina triloculinoides*.

P5: There is no clear evidence existing for P5. The coexistence of *A. mckannai* and *A. soldadoensis* suggests biozone P5 in one sample (18/1).

P6 is clearly represented by two samples. It is defined by the overlap of *Morozovella formosa gracilis* and *M. formosa formosa* which start with P6 and *Morozovella acuta*, *Morozovella aequa*, *Planorotalites chapmani* and *Globigerina velascoensis*? whose ranges end with this zone.

P7 was found only in one sample (15/52) and is defined here by the overlap of the species *M. formosa gracilis* and *Planorotalites pseudoscitula*.

P8 was definitely detected in the Kouka section and less certainly in others as well. It is defined by the cooccurrence of *M. formosa formosa*, which has its last appearance in P8, and *Acarinina pentacamerata*, starting with P8. In some samples the earliest *Truncorotaloides collactea* were recognised.

P9 is a very frequently identified zone in all sections except Kouka. Here the first representatives of the typical Middle Eocene fauna such as the *Acarinina bullbrooki* group and several *Truncorotaloides* species, overlap with *Acarinina soldadoensis* and in some cases *Morozovella quetra*.

P10-12 were not definitely identified in any sample. No diagnostic species and zonal markers were found so that usually only a zone range could be determined. In sample 21/9 the mixture of zone P11 and P12 could be worked out because of the co-occurrence of *Morozovella aragonensis* (last occurrence in P11) and *Catapsydrax dissimilis* (first occurrence in P12) and *A. pentacamerata* (last occurrence in P12).

P13 is defined in one sample (30/4) by the overlap of *Acarinina primitiva*, ending with P13, and *Globigerina pseudovenezuelana*?, starting with P13. The definite identification of *Globigerina praebulloides occlusa* might indicate P13 as well. In sample 24/4 only the range of the biozones P13-14 can be fixed. The absence of *Globorotalia opima nana* suggests an age of P13.

P14 could be recognised in sample 30/104 containing *Planorotalites pseudoscitula*, *Truncorotaloides libyaensis?* and *T. collactea*? together with *Turborotalia cerroazulensis cocoaensis* and *G. opima nana*?.

P15 was not found in any sample and can possibly not be resolved with the present data set.

P16 and P17 may have to be treated as one biozone as has been (partly) done in the zonal scheme of Toumarkine & Luterbacher (1985). In sample 31/5 biozone P17 could be determined for sure by the overlap of *T. cerroazulensis cerroazulensis* and *Globigerina outachitaensis gnaucki*. In the suggested Late Eocene sample 33/1 *Pseudohastigerina naguewichitaensis*? sets the lower boundary for this sample to P16. In all samples attributed to this zone the genera *Acarinina*, *Morozovella* and *Truncorotaloides* are absent.

P18/19 and N1 was determined in sample 49/5 by the group of *Globigerina eocena*, *G. pseudovenezuelana*, and *Globorotalia increbescens,* cooccurring with *Globigerina sellii*. The *G. cerroazulensis* lineage is absent. *G. venezuelana* has its first occurrence in this sample as well since the Mediterranean *G.ampliapertura* - *G. euapertura* zone includes parts of N1.

N1, as mentioned, is partly included in P18/19 according to the Mediterranean zonal scheme. Sample 21/50 (and possibly 24/5) leads to an age of N1 because of the overlap of *G. venezuelana*, *G. yeguaensis*, and *G. ampliapertura*.

P21/N2 is not identified for certain in the Lefkara Formation. It is defined by the total range of *Globorotalia opima opima* and so includes N2 in the dating of sample 21/50.

P22/N3 is recognised by the first occurrence of *Globorotalia mayeri* and the last occurrence of *G. opima nana* in sample 49/16.
N4/6 is a combined zone due to a low resolution of species in the Mediterranean area. In the Lefkara material, the zone is indicated by the overlap of *C. dissimilis* and the *Globorotalia opima nana/continuosa* transition with *Turborotalia obesa* and *Globoquadrina dehiscens* (15/Q), or of *C. dissimilis* with *G. continuosa* (28/1).

N6/7 boundary indicates samples that contain a fauna typical for N4/6 (usually including *C. dissimilis*) but also contain *Globorotalia scitula praescitula* (15/100, 28/B) or in sample 21/77 *Globorotaloides hexagona*?.

biozone	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18/	N1/	N2/	N3/	N4/	N7
G. triloculinoides	o	o	o	o																			
M. praecursoria		o	o																				
M. conicotruncata			o	o																			
M. angulata			o	o																			
P. pusilla pusilla			o	o																			
A. mckannai			o	o	o																		
P. chapmani			o	o	o	o																	
M. convexa			o	o	o	o																	
M. acuta			o	o	o	o																	
G. velascoensis			o	o	o	o																	
A. primitiva			o	o	o	o	o	o	o	o	o	o	o										
M. aequa				o	o	o																	
A. nitida				o	o	o	o																
G. linaperta				o	o	o	o	o	o	o	o	o	o	o	o	o	o						
M. edgari					o	o																	
M. subbotinae					o	o	o	o															
M. quetra					o	o	o	o	o														
A. soldadoensis					o	o	o	o	o														
P. wilcoxensis					o	o	o	o	o	o	o	o											
M. formosa gracilis						o	o																
M. formosa formosa						o	o	o															
M. lensiformis						o	o	o															
M. pseudotopilensis						o	o	o	o	o													
P. austaliformis						o	o	o	o	o													
M. aragonensis							o	o	o	o	o												
P. pseudoscitula							o	o	o	o	o	o	o	o									
A. broedermanni								o	o	o	o	o											
A. pentacamerata								o	o	o	o	o											
G. inaequispira								o	o	o	o	o											
T. collactea								o	o	o	o	o	o	o									
G. senni								o	o	o	o	o	o	o									
P. micra								o	o	o	o	o	o	o	o	o	o	o					
T. wilsoni									o	o	o	o											
T. cerro. fronsosa									o	o	o	o											
A. bullbrooki									o	o	o	o	o	o									
A. mattewsae									o	o	o	o	o	o									
A. spinuloinflata									o	o	o	o	o	o									

Fig.7. Range chart for all planktonic foraminifera species identified, from Bolli *et al.* (1985).

biozone	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18/	N1/	N2/	N3/	N4/	N7
A. crassata									o	o	o	o	o	o									
M. spinulosa									o	o	o	o	o	o									
T. toplensis									o	o	o	o	o	o									
T. rohri									o	o	o	o	o	o									
G. hagni									o	o	o	o	o	o	o	o							
Globigerinatheka sp.									o	o	o	o	o	o	o	o	o						
G. cryptomphala									o	o	o	o	o	o	o	o	o						
G. eocaena									o	o	o	o	o	o	o	o	o	o					
T.c.possagnoensis										o	o	o											
"H."cf.bolivariana										o	o	o	o	o									
T. libyaensis										o	o	o	o	o									
G. angioporides										o	o	o	o	o	o	o	o	o	o	o			
G. index rubriformis											o	o	o	o	o	o							
G. carcoselleensis											o	o	o	o	o	o							
T. cerro. pomeroli											o	o	o	o	o	o	o						
T. c. cerroazulensis												o	o	o	o	o	o						
C. dissimilis												o	o	o	o	o	o	o	o	o	o	o	
G. pseudovenezuelana													o	o	o	o	o	o					
G. yeguaensis													o	o	o	o	o	o	o				
G. officinalis													o	o	o	o	o	o	o				
G. suteri													o	o	o	o	o	o	o	o	o	o	o
G. praebull. occlusa													o	o	o	o	o	o	o	o	o	o	o
G. praeturrilina														o	o	o	o						
G. c. cocoaensis														o	o	o	o						
G. tripartita														o	o	o	o	o	o	o	o		
G. opima nana														o	o	o	o	o	o	o	o		
G. increbescens															o	o	o	o					
G. p. leroyi															o	o	o	o	o	o	o	o	o
G. p. praebulloides															o	o	o	o	o	o	o	o	o
P. naguewichiensis																o	o	o					
G. ampliapertura																	o	o	o				
G. permicra																	o	o	o				
G. o. gnaucki																	o	o	o				
G. c. angustiumbilicata																	o	o	o	o	o	o	
G. euapertura																	o	o	o	o	o	o	o
G. tapuriensis																		o					
G. gortanii																		o	o	o			
G. sellii																		o	o	o	o		

Fig.7. continued.

biozone	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18/	N1/	N2/	N3/	N4/	N7
G. juvenilis																		o	o	o	o	o	o
G. c. ciperoensis																			o	o	o	o	o
G. venezuelana																			o	o	o	o	o
G. opima opima																				o			
G. altisp. globularis																				o	o	o	
G. woodi connecta																					o		
G. kugleri																					o	o	
Globigerinoides sp.																					o	o	o
nana/continuosa trans.																					o	o	
G. bollii lentiana																					o	o	o
G. mayeri																					o	o	o
G. falconensis																					o	o	o
G. zealandica																						o	o
G. tr. immaturus																						o	o
T. obesa																						o	o
G. altispira globosa																						o	o
G. dehiscens																						o	o
G. ruber																						o	o
G. continuosa																						o	o
G. p. praescitula																							o
G. hexagona																							o

Fig.7. continued.

An attempt was made to examine the whole fauna identified by comparing the assemblages of the six sections. It reveals a consistent development of the foraminifera faunas through the epochs:

Palaeocene planktonic foraminifera were found only as reworked specimens in younger strata. These are mainly of Middle Palaeocene age. The most common species are *Morozovella angulata*, *Morozovella conicotruncata*, and *Globigerina triloculinoides*.

The **Lower Eocene** is the first datable part of the section. The planktonic foraminifera content of the oldest sediments (P6-7) consists of various species of the genera *Morozovella* and *Acarinina* such as *Morozovella acuta*, *Morozovella formosa*, *Morozovella subbotinae* and *Acarinina soldadoensis*. *Planorotalites chapmani*, *Planorotalites pseudoscitula* and *Pseudohastigerina sp.* are often present. The second half of the Lower Eocene (P8-9) is dominated by large acarinids such as *Acarinina pentacamerata* and *A. soldadoensis*. An often repeating assemblage was found in the uppermost Lower Eocene near the transition to the Middle Eocene (P9). Here, a consistent cooccurrence of *A. soldadoensis* (sometimes questionable) and the commonly dominant *A. pentacamerata* together with early members of the typical Middle Eocene fauna seems to exist.

The **Middle Eocene** is characterised by a typical assemblage composed of the *Acarinina bullbrooki*-group (*A. bullbrooki*, *Acarinina matthewsae*, *Acarinina spinuloinflata*), various members of the genus *Truncorotaloides* and typically *Pseudohastigerina sp.*, *P. pseudoscitula* and *Morozovella spinulosa*. *A. soldadoensis* is absent. In the first half of the Middle Eocene, *Acarinina broedermanni*, *A. pentacamerata* and *Morozovella aragonensis* occur. Later in the Middle Eocene (varying in the sections but starting possibly with P11) big globigerinids increase in number and *Globigerinatheka* (?), and the *Globigerina praebulloides*-group starts. The stratigraphically important *Turborotalia cerroazulensis* lineage starts in the Middle Eocene but increases in number towards the end.

The **Upper Eocene** is significantly marked by the absence of the genera *Acarinina*, *Morozovella* and *Truncorotaloides*. The fauna is diverse, containing many species of globigerinids. Characteristic is the start of the often frequent *Catapsydrax dissimilis* and of the *Globorotalia opima nana*-group, while the latter already appears in some sections in P14. The *T. cerroazulensis* lineage, which is characteristic for the Upper Eocene, is developed in the Cyprus area but is rather rare.

With the beginning of the **Oligocene**, in some sections the fauna becomes monotonous with rare globigerinids, but in some this cannot be observed. *T. cerroazulensis* and *P. pseudoscitula* are absent. The assemblage consists typically of *the G. opima*-group, *C. dissimilis* and globigerinids such as *Globigerina euapertura*, *Globigerina pseudovenezuelana* and *Globigerina yeguaensis*. *Globigerina mayeri* starts towards the top of the stage.

In the **Early Miocene**, the fauna is diverse and commonly contains globigerinids, namely *Globigerina ciperoensis*, *G. euapertura*, *G. praebulloides*, *Globigerina venezuelana*. *C. dissmilis*, *G. mayeri*, the *Globorotalia opima nana-continuosa* group, possibly *Globigerinoides sp.* and more rarely *Globorotalia scitula praescitula* are present. *Globorotaloides suteri* occurs in most samples and already appears in some sections in N3.

The comparison of assemblages gives evidence for a slightly different range of some species compared to the literature. The *Globigerina praebulloides* group (including *Globigerina officinalis*) was found as weakly developed specimens in some assemblages of biozone P10, but it certainly occurred starting at zone P12. The literature gives a first occurrence in P13. *C. dissimilis* starts, according to Toumarkine & Luterbacher (1985), in zone P12. It is a common species in all samples in the Lefkara sediments starting approximately at zone P17. There is one exception in sample 21/9 where *C. dissimilis* was found at the boundary P11/12, but all following samples in that succession older than zone N1/1 do not contain the species. This shows that *C. dissimilis* is a common and reliable taxon only from Late Eocene onwards in the Lefkara Formation. A possibly less significant discovery of one single specimen of *Globigerinoides ruber* in a sample dated to zone N4/6 should be mentioned as well since this species usually first starts at zone N18 in the Mediterranean area.

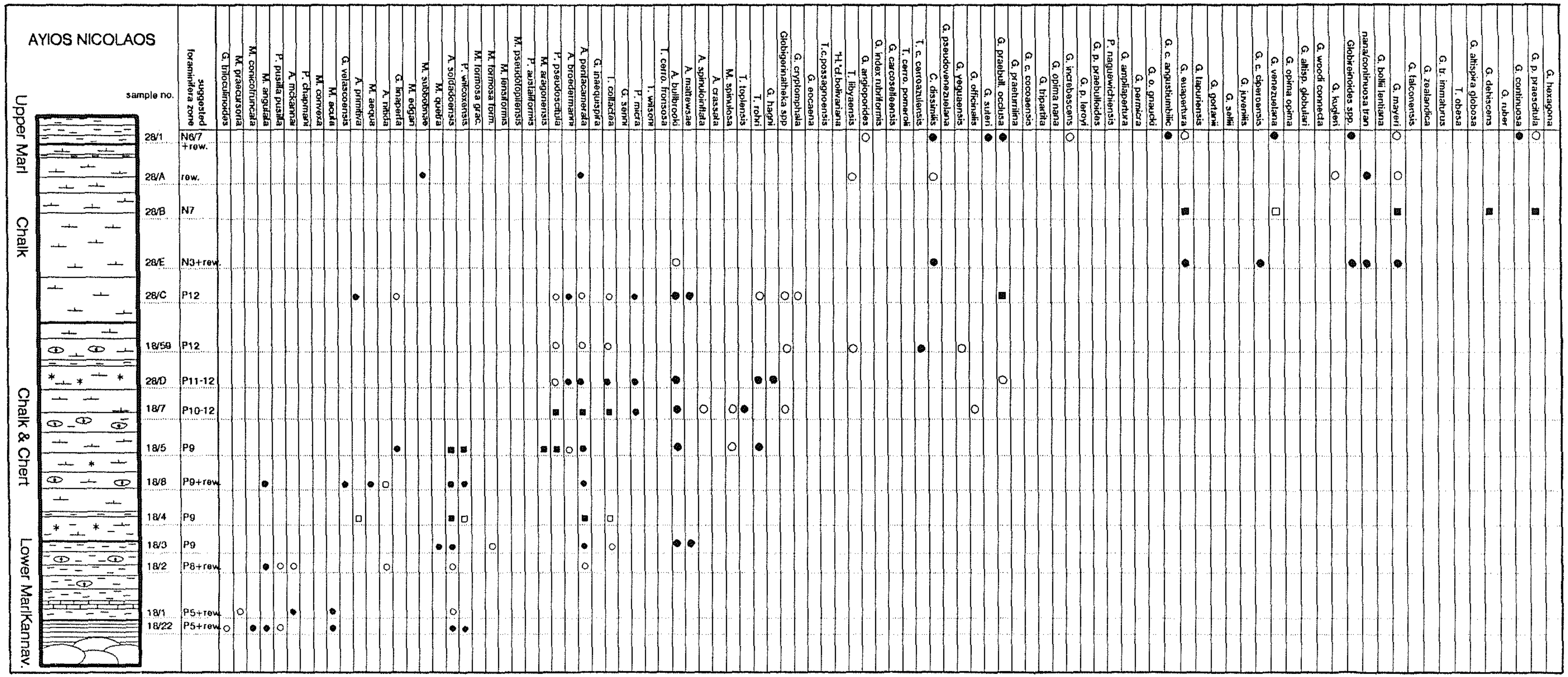


Fig.8. Planktonic foraminifera assemblage of each sample, Ayios Nicolaos section. Approximate sample position in the stratigraphic columns marked on the left. Circles: identification as whole specimens; squares: identification in thin sections; solid symbols: definite identification; hollow symbols: questionable occurrence.

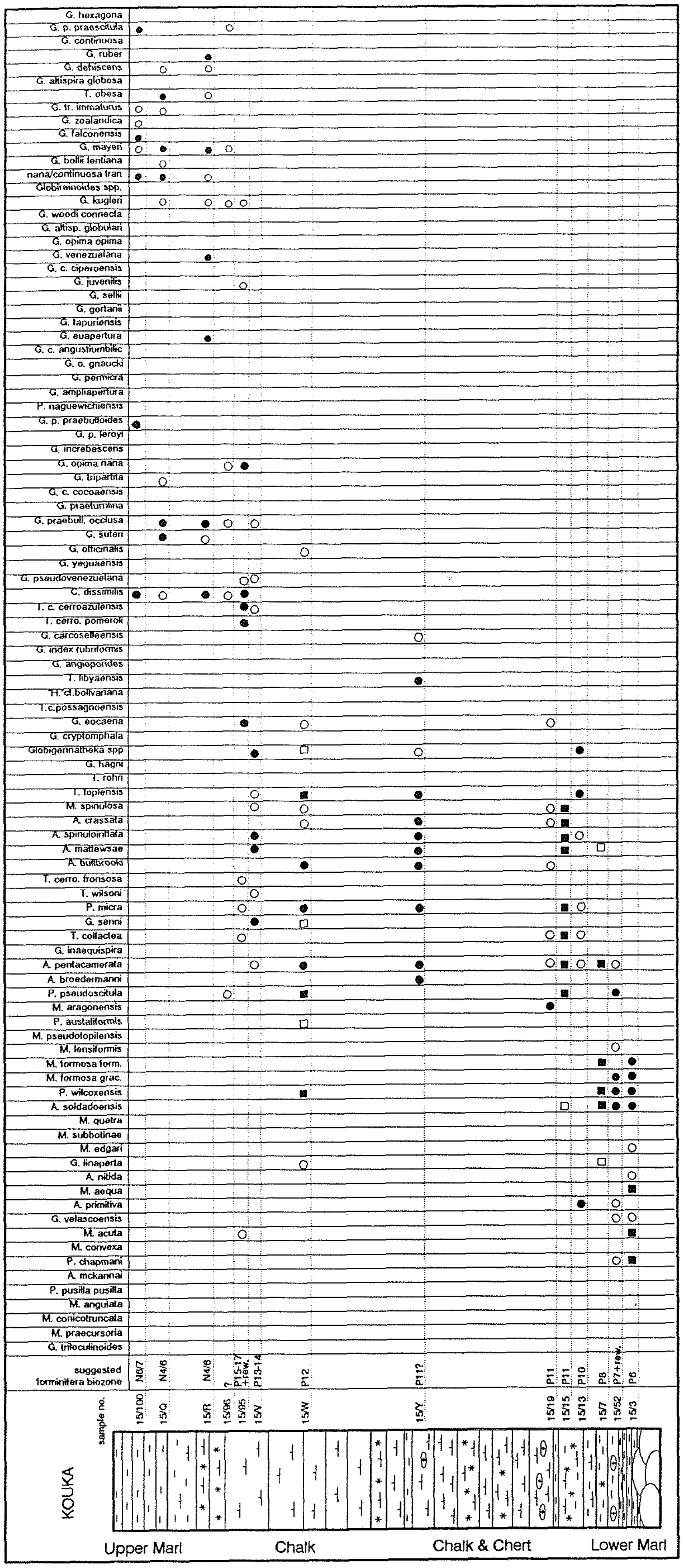


Fig.9. Planktonic foraminifera assemblage of each sample, Kouka section. For explanation see Fig.8.

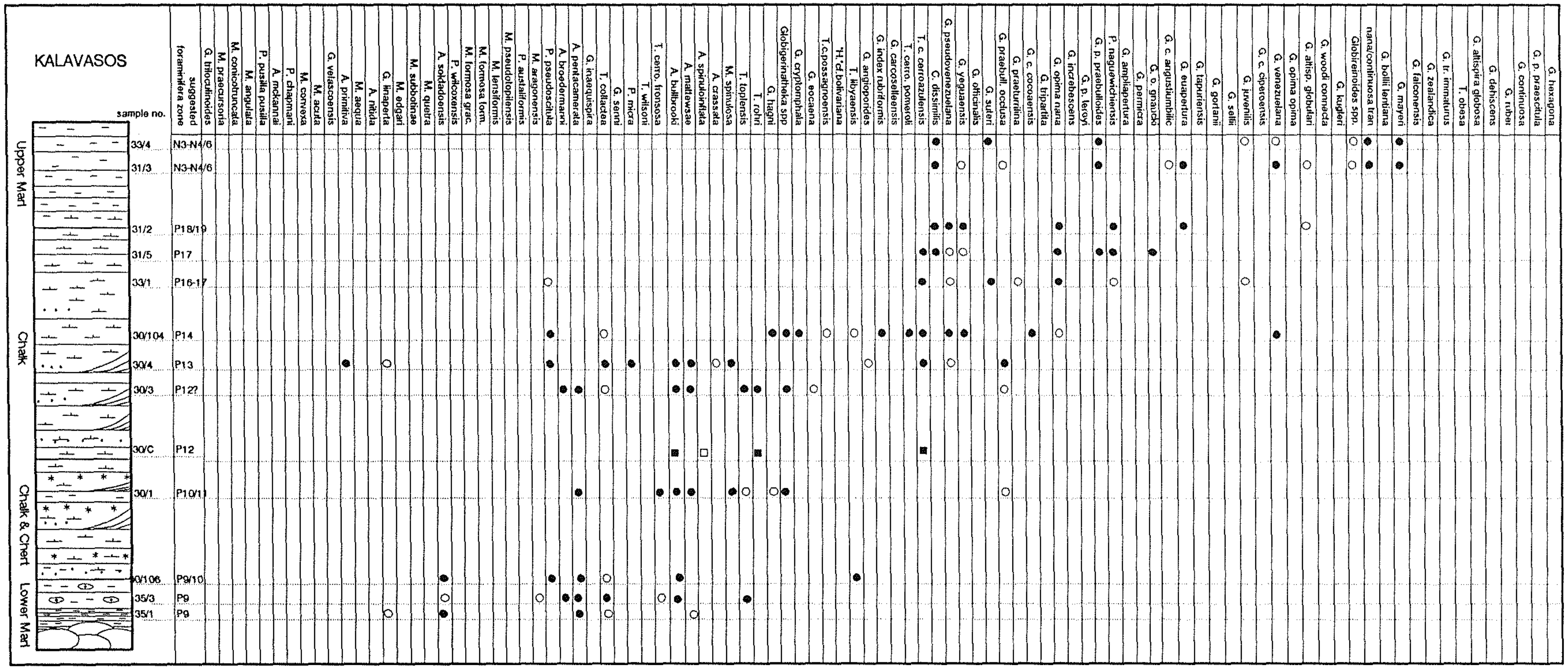


Fig.10. Planktonic foraminifera assemblage of each sample, Kalavasos section. For explanation see Fig.8.

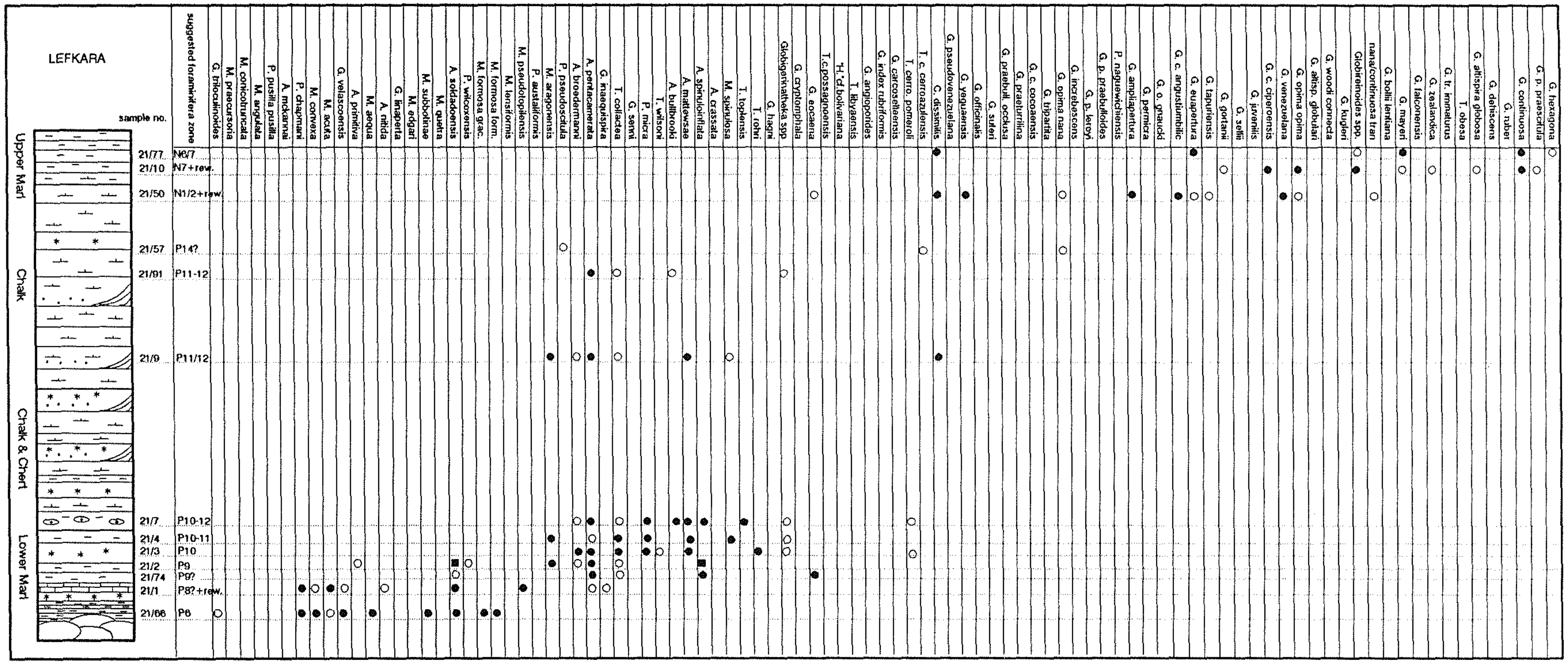


Fig.11. Planktonic foraminifera assemblage of each sample, Lefkara section. For explanation see Fig.8.

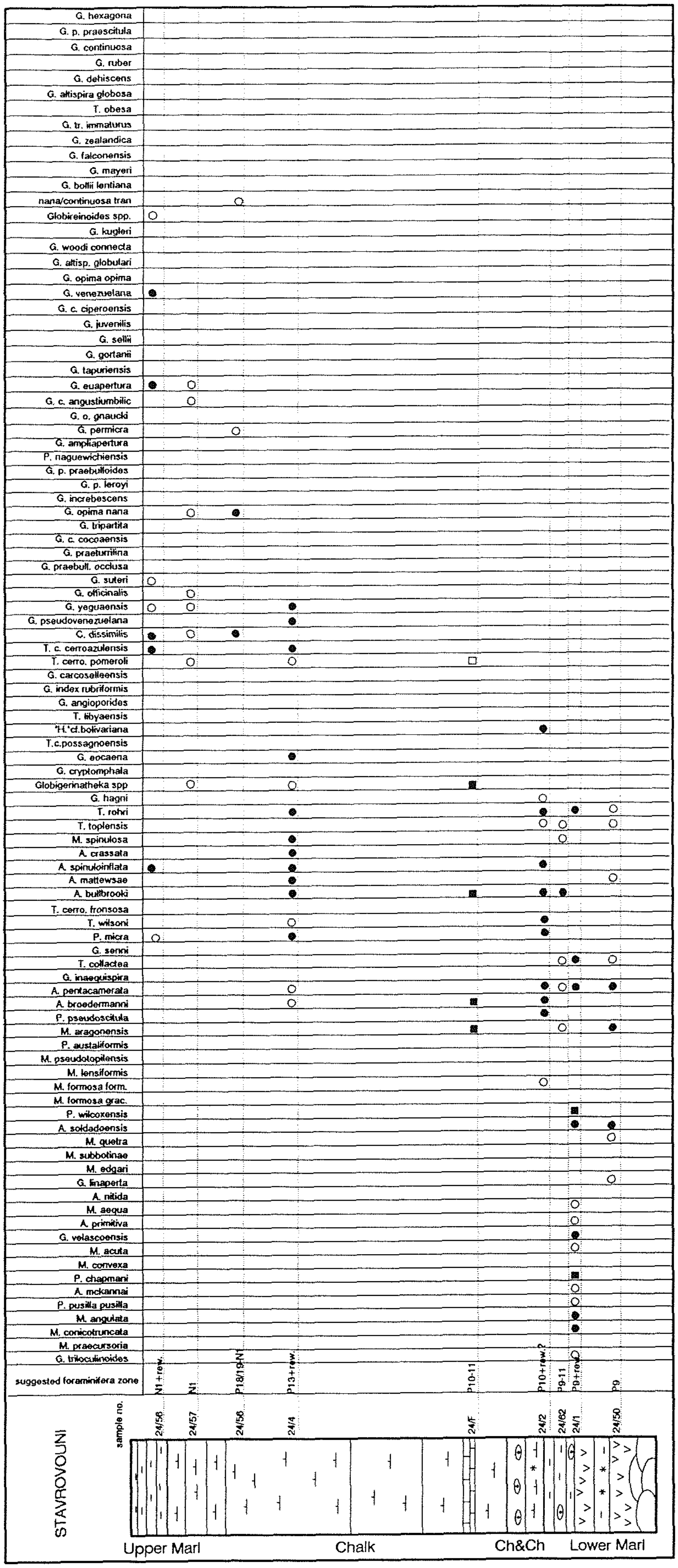


Fig.12. Planktonic foraminifera assemblage of each sample, Stavrovouni section. For explanation see Fig.8.

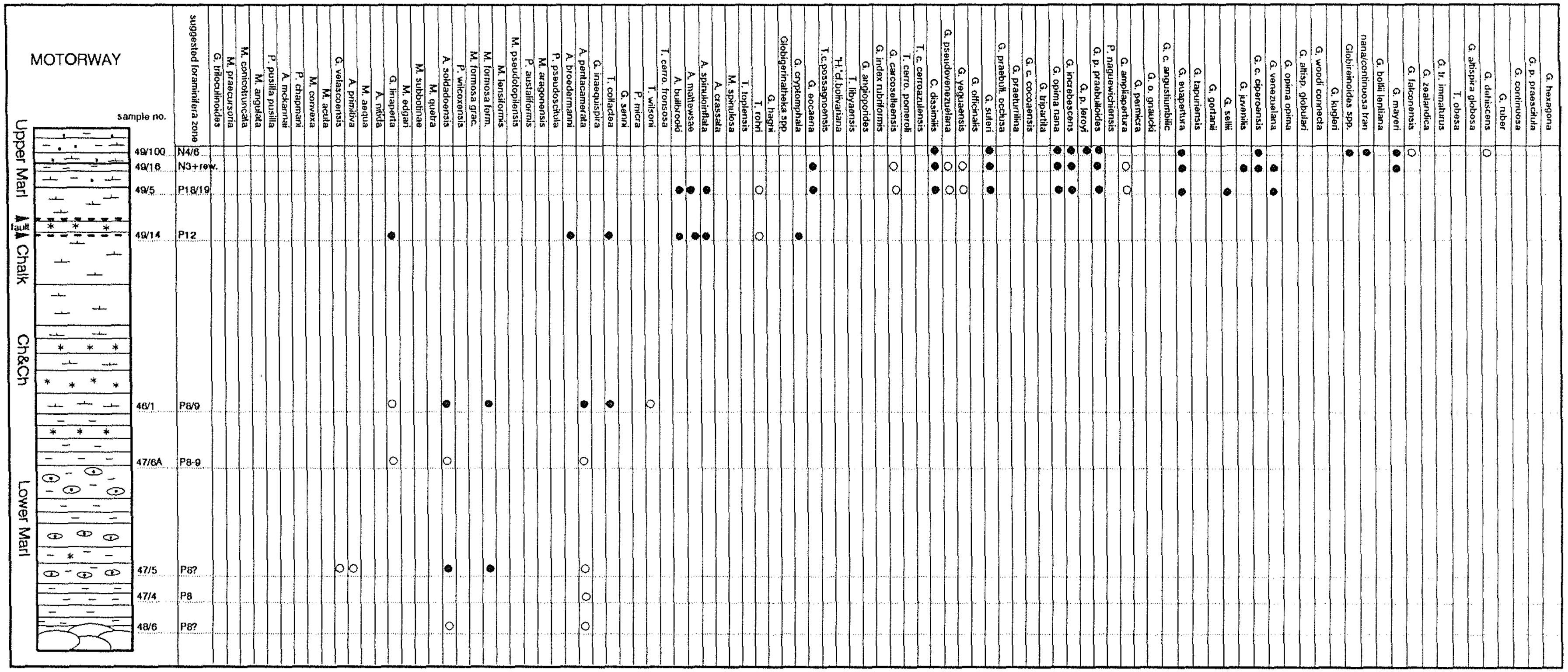


Fig.13. Planktonic foraminifera assemblage of each sample, Motorway section. For explanation see Fig.8.

2.2.2. RADIOLARIAN BIOZONES

The low latitude radiolarian zones summarised in Sanfilippo, Westberg-Smith & Riedel (1985) appeared to be well applicable to the Cyprus sediments. Species ranges are given in Figure 14. With two exceptions, all zones between the *Buryella clinata* zone and the *Thyrsocyrtis bromia* zone were recognised. In most cases the zone definitions and characteristics given in this paper could be used. If, in sparse faunas, the diagnostic taxa were absent, the overlap of species ranges from the literature were used to estimate the biozone as described in the section 2.2.1..

Most samples showing a rich radiolarian fauna can be used to establish a biozone. A poor fauna led to a low resolution range of zones. In the following, the characteristics and typical assemblages of the zones recognised are described. This may not always be fully representative for a time in the studied area since sometimes only one or two samples were recovered from one biozone. All radiolarians found in each sample are listed in Figures 15-20 (Appendix A.3), again showing the sample position next to a simplified log.

***Buryella clinata* zone** (2 samples): *Phormocyrtis striata exquisita* and *Siphocampe elizabethae* are present. The zonal marker and *Theocotyle nigrinae* were not found. *Buryella tetradica*, *Lophocyrtis biaurita*, *Theocorys acroria* and *Thyrsocyrtis hirsuta* occur sporadically.

***Phormocyrtis striata striata* zone** (2 samples): *Phormocyrtis striata striata* is present. *B. clinata*, *Lithochytris archaea* and *Rhopalocanium ornatum* may occur. *Dictyoprora amphora*, *Dictyoprora mongolfieri*, *P. striata exquisita*, *Theocorys anaclasta*, *T. nigrinae* and *T. rhizodon* are absent in this zone.

T. cryptocephala zone: This zone is not represented in the studied samples.

***Dictyoprora mongolfieri* zone** (1 sample): The nominate species and *Calocycloma ampulla*, *L. archaea*, *L. biaurita*, *P. striata striata*, *Podocyrtis aphorma*, *Podocyrtis sinuosa*, *R. ornatum*, *T. anaclasta*, *Theocotyle cryptocephala*, *Theocotylissa ficus*, *Thyrsocyrtis hirsuta*, *T. rhizodon* and *Thyrsocyrtis tensa*? are present. *Eusyringium lagena* is absent.

***Thyrsocyrtis triacantha* zone** (4 samples): The zonal marker, together with *Eusyringium fistuligerum*, *E. lagena*, *L. biaurita*, *P. striata striata* and *T. rhizodon* are present in most samples. *Amphipternis clava*, *Lithochytris vespertilio*, *Podocyrtis diamesa*, *P. sinuosa*, *R. ornatum*, *Siphocampe lineata* and *T. ficus*, may occur. *Podocyrtis ampla*, *T. nigrinae* and *T. hirsuta* are consistently absent.

***Podocyrtis ampla* zone** (4 samples): The only species that occurs in all samples of this zone is the zonal marker. In some of the samples *E. fistuligerum*, *E. lagena*, *L. biaurita*, *P. striata striata*, *R. ornatum*, *S. elizabethae*, *T. rhizodon* and *Thyrsocyrtis triacantha* were present. *Podocyrtis mitra* and *P. sinuosa* were not found.

	unzoned	bidartensis	clinata	striata	cryptocephala	mongolfieri	triacantha	ampla	mitra	chalara	goetheana	bromia
Buryella tetradica	o	o	o									
Theocorys acroria	o	o	o									
P.striata exquisita	o	o	o									
Dendrospyris fragoides	o	o	o	o	o	o						
Calocycloma ampulla	o	o	o	o	o	o	o	o	o	o	o	o
Patagospyris pentas	o	o	o	o	o	o	o	o	o	o	o	
Sethocyrtis babylonis	o	o	o	o	o	o	o	o	o	o	o	o
Podocyrtis papalis	o	o	o	o	o	o	o	o	o	o	o	o
Calocycloma castum		o	o	o	o							
Buryella clinata			o	o								
Lithochytris archaea			o	o	o	o						
Theocotyle nigrinae			o	o	o	o	o					
Thyrsocyrtis hirsuta			o	o	o	o	o					
Amphipternis clava			o	o	o	o	o	o				
Lophocyrtis biaurita			o	o	o	o	o	o	o			
Rhabdolithis pipa			o	o	o	o	o	o	o	o		
Theocotylissa ficus			o	o	o	o	o	o	o	o	o	
Thyrsocyrtis tensa			o	o	o	o						
Dictyoprora urceolus			o	o	o	o	o					
Calocyclas hispida			o	o	o	o	o	o	o	o	o	o
Siphocampe elizabethae			o	o	o	o	o	o				
Podocyrtis aphorma				o	o							
Theocorys anaclasta				o	o	o	o					
Podocyrtis diamesa				o	o	o	o					
Theocorys anapographa				o	o	o	o	o				
Phormocy.str.striata				o	o	o	o	o	o			
Rhopalocanium ornatum				o	o	o	o	o	o			
Dictyoprora amphora				o	o	o	o	o	o	o	o	o
Siphocampe lineata				o	o	o	o	o	o	o	o	o
Spongatr.pachystylus				o	o	o	o	o	o	o	o	
Thyrsocyrtis rhizodon				o	o	o	o	o	o	o	o	o
Siphocampe acephala				o	o	o	o	o	o	o	o	o
Theocot.cryptocephala					o	o						
Lithochy.vespertilium					o	o	o	o	o	o		
Podocyrtis sinuosa					o	o	o	o				
Lithapium plegmacantum						o	o	o	o			
Dictyoprora mongolfieri						o	o	o	o	o	o	o
Podocyrtis dorus						o	o	o				
Eusyringium lagena							o	o	o			
Thyrsocyrtis triacantha							o	o	o	o	o	o
Siphocampe nodosaria							o	o	o	o	o	o
Eusyr.fistuligerum							o	o	o	o	o	o
Podocyrtis ampla								o	o			
Podocyrtis fasciolata								o	o			
Podocyrtis helenae								o	o			
Podocyrtis mitra									o			
Sethocyrtis triconiscus									o	o	o	
Thyrsocyrtis lochites									o	o	o	o
Podocyrtis chalara										o		
Lithochytris sp.0										o	o	o
Lithocyclia aristotelis											o	o
Dictyoprora pirium											o	o
Thyrsocyrtis tetracantha											o	o
Thyrsocyrtis bromia												o
Calocyclas turris												o
Carpocanistrum azyx												o
Dictyoprora ovata												o
Theocyrtis tuberosa												o

Fig.14. Range chart for all radiolarian species identified, times of occurrences adopted from publications cited in the text.

***Podocyrtis mitra* zone** (5 samples): The species *E. fistuligerum*, *P. striata striata*, *Setochytris triconioscus*, *T. rhizodon* and *T. triacantha* are present in most of the samples. *P. mitra* is present occasionally. *P. ampla*, *Podocyrtis chalara* and *S. elizabethae* are absent.

***Podocyrtis chalara* zone** (3 samples): All samples have the occurrence of the nominate species in common. Additionally *E. fistuligerum*, *T. rhizodon* and *T. triacantha*? may be present. *P. striata striata*, *Podocyrtis goetheana* and *S. triconiscus* were not found.

***Podocyrtis goetheana* zone**: No sample of this zone was found.

***Thyrsocyrtis bromia* zone** (4 samples): Most samples contained specimens of *Calocyclas turris*, *Thyrsocyrtis bromia* and *Thyrsocyrtis tetracantha*. Sometimes *'Carpocanistrum' azyx*, *Dictyoprora ovata*, *Dictyoprora pirium*, *E. fistuligerum*, *Lithocyclia aristotelis*, *Lychnocanium amphitrite* occurred. *P. chalara* and *T. triacantha* were not present.

The reliability of the absence or presence of a species varies significantly. The most common, and consequently most reliable stratigraphic important taxa in all samples, are *C. turris*, *D. mongolfieri*, *E. fistuligerum*, *E. lagena*, *P. striata striata*, *P. chalara*, *S. acephala*, *S. elizabethae* and *T. rhizodon*. Nevertheless, climatic factors and preferential dissolution may have an influence on the presence of a species and the faunal composition as well. The diagnostic species *L. aristotelis*, *P. sinuosa*, *T. anaclasta*, *T. anporapha* and *T. nigrinae* are generally rare in the Lefkara sediments. The ranges of some common species appears to be shorter in the studied material than in the low latitude scheme. *P. ampla*, for example, was observed only in the *P. ampla* zone and never extended into the *P. mitra* zone. *S. triconiscus* was found in all samples of the *P. mitra* one but never in younger material.

2.2.3. COMPOSITE BIOSTRATIGRAPHY

A summary of all samples dated using planktonic foraminifera and radiolarians is given in Table 3. Most results obtained from both microfossil groups reveal a good agreement, but in other cases they show significant differences. Before going into details of comparing and interpreting the dating some general observations will be discussed.

(1) The two microfossil groups will be looked at separately to examine the logic of the dating.
(2) The method of integrating the results of both zonations will be described.
(3) The final stratigraphy for all sections will be discussed individually.

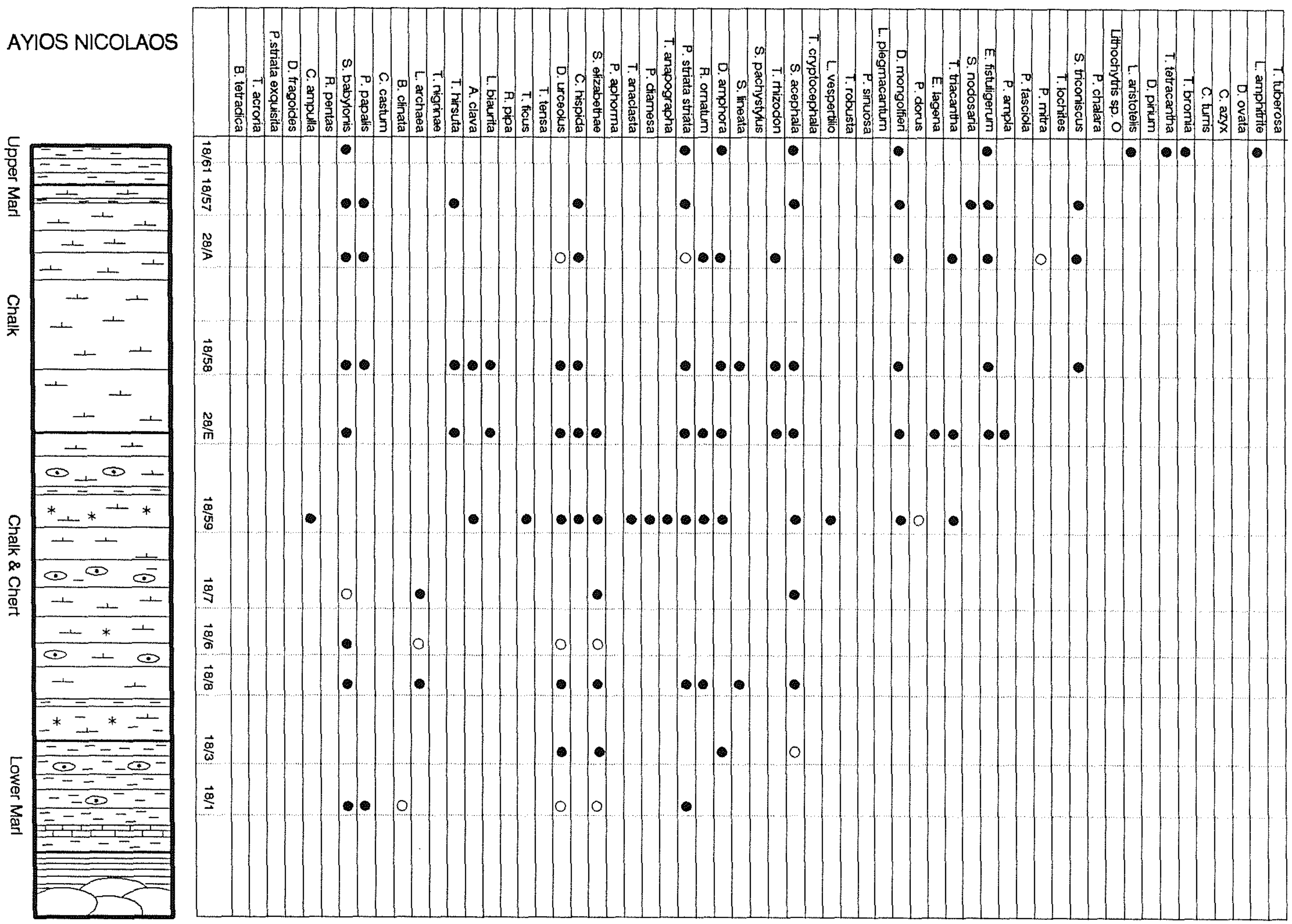


Fig.15. Radiolarian assemblage of each sample, Ayios Nicolaos section; solid symbols: definite identification; hollow symbols: questionable occurrence.

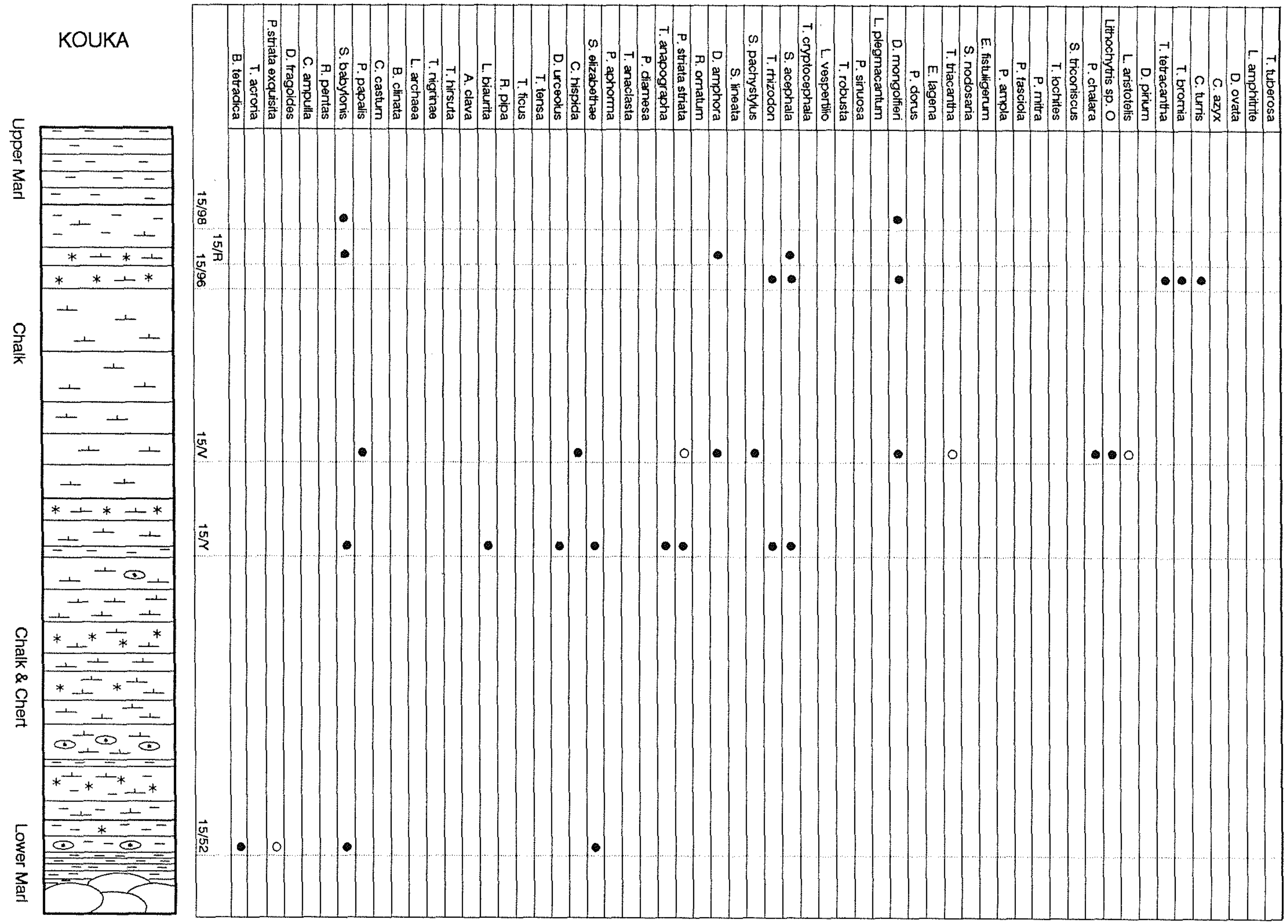


Fig.16. Radiolarian assemblage of each sample, Kouka section. For explanation see Fig.15.

T. tuberosa					
L. amphitrite					
D. ovata	●				
C. azyx	●				
C. turris	●				
T. bromia					
T. tetracantha					
D. pirium	●				
L. aristotelis					
Lithochytris sp. O					
P. chalara		●			
S. triconiscus					
T. lochites					
P. mitra					
P. fasciola					
P. ampla			●	●	
E. fistuligerum		●	●		
S. nodosaria					
T. triacantha		○	●		
E. lagena				●	
P. dorus					
D. mongolfieri	●	●	●	●	
L. plegmacantum					
P. sinuosa					
T. robusta					
L. vespertilio					
T. cryptocephala					
S. acephala		●			
T. rhizodon		●	●	●	
S. pachystylus					
S. lineata		●			
D. amphora	●	●	●	●	
R. ornatum			●		
P. striata striata			●		
T. anapographa					
P. diamesa					
T. anaclasta					
P. aphorma					
S. elizabethae				●	●
C. hispida		●	●		
D. urceolus		●	●		
T. tensa					
T. ficus					
R. pipa			●		
L. biaurita			●		
A. clava					
T. hirsuta					
T. nigrinae					
L. arcaea					
B. clinata					
C. castum					
P. papalis	●	●			
S. babylonis	●		●	●	○
R. pentas					
C. ampulla					
D. fragoides					
P.striata exquisita					
T. acroria					
B. tetradica					
	33/1	30/104	30/4	30/2	30/106

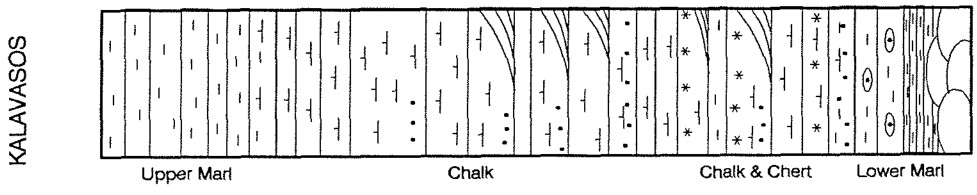


Fig.17. Radiolarian assemblage of each sample, Kalavasos section. For explanation see Fig.15.

	21/57	21/91	21/8	21/7	21/3	21/2	21/1	21/68
T. tuberosa								
L. amphitrite								
D. ovata								
C. azyx								
C. turris								
T. bromia								
T. tetracantha								
D. pirium								
L. aristotelis								
Lithochytris sp. O								
P. chalara								
S. triconiscus								
T. lochites								
P. mitra								
P. fasciola								
P. ampla		●						
E. fistuligerum								
S. nodosaria	●	●						
T. triacantha								
E. lagena		●						
P. dorus	●	●						
D. mongolfieri								
L. plegmacantum	●	●						
P. sinuosa		●						
T. robusta								
L. vespertilio								
T. cryptocephala								
S. acephala	●	●	●					●
T. rhizodon	●	●						
S. pachystylus								
S. lineata	●							
D. amphora	●	●	●			●		
R. ornatum	●							
P. striata striata	●	●	●	●				
T. anapographa			○					
P. diamesa	●			●				
T. anaclasta								
P. aphorma		●	●					
S. elizabethae	●	●	●	●	●		●	
C. hispida	●	●						
D. urceolus	●	●	●	●				●
T. tensa								
T. ficus								
R. pipa								
L. biaurita	●	●	●					
A. clava		●						
T. hirsuta			●	●	●			
T. nigrinae				○				
L. archaea			●	●				
B. clinata				●	●		○	
C. castum				●				
P. papalis	●	●	●					
S. babylonis	●	●	●	●				
R. pentas								
C. ampulla							●	
D. fragoides		●			●			○
P.striata exquisita			●	●				
T. acroria								
B. tetradica								

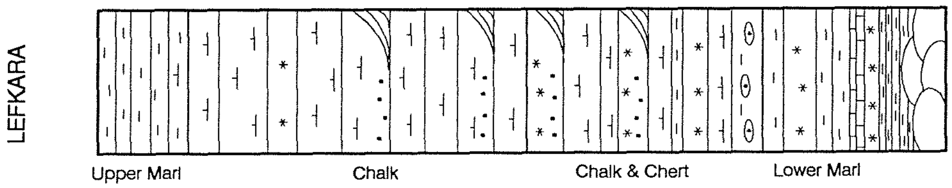


Fig.18. Radiolarian assemblage of each sample, Lefkara section. For explanation see Fig.15.

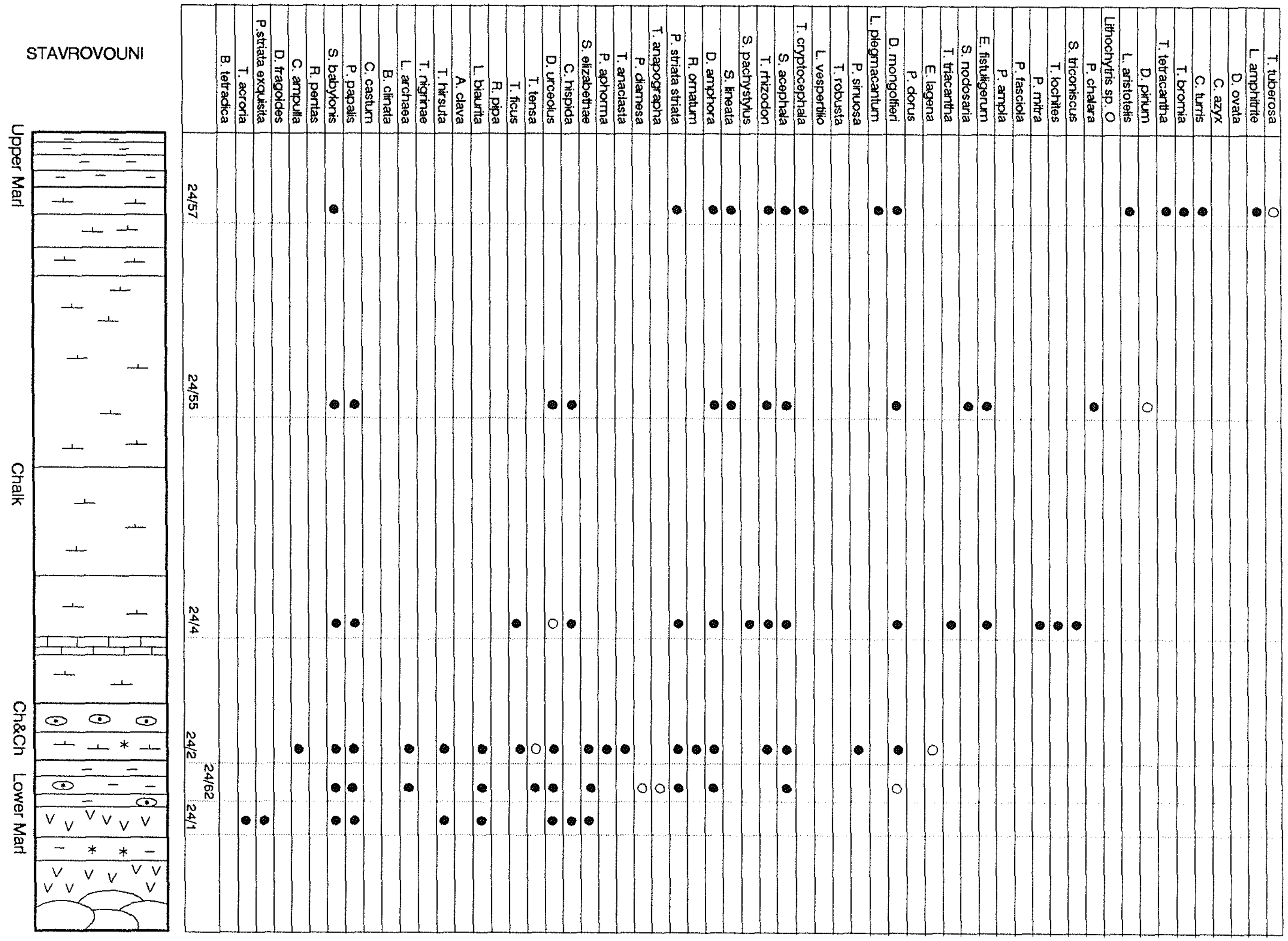


Fig.19. Radiolarian assemblage of each sample, Stavrovouni section. For explanation see Fig.15.

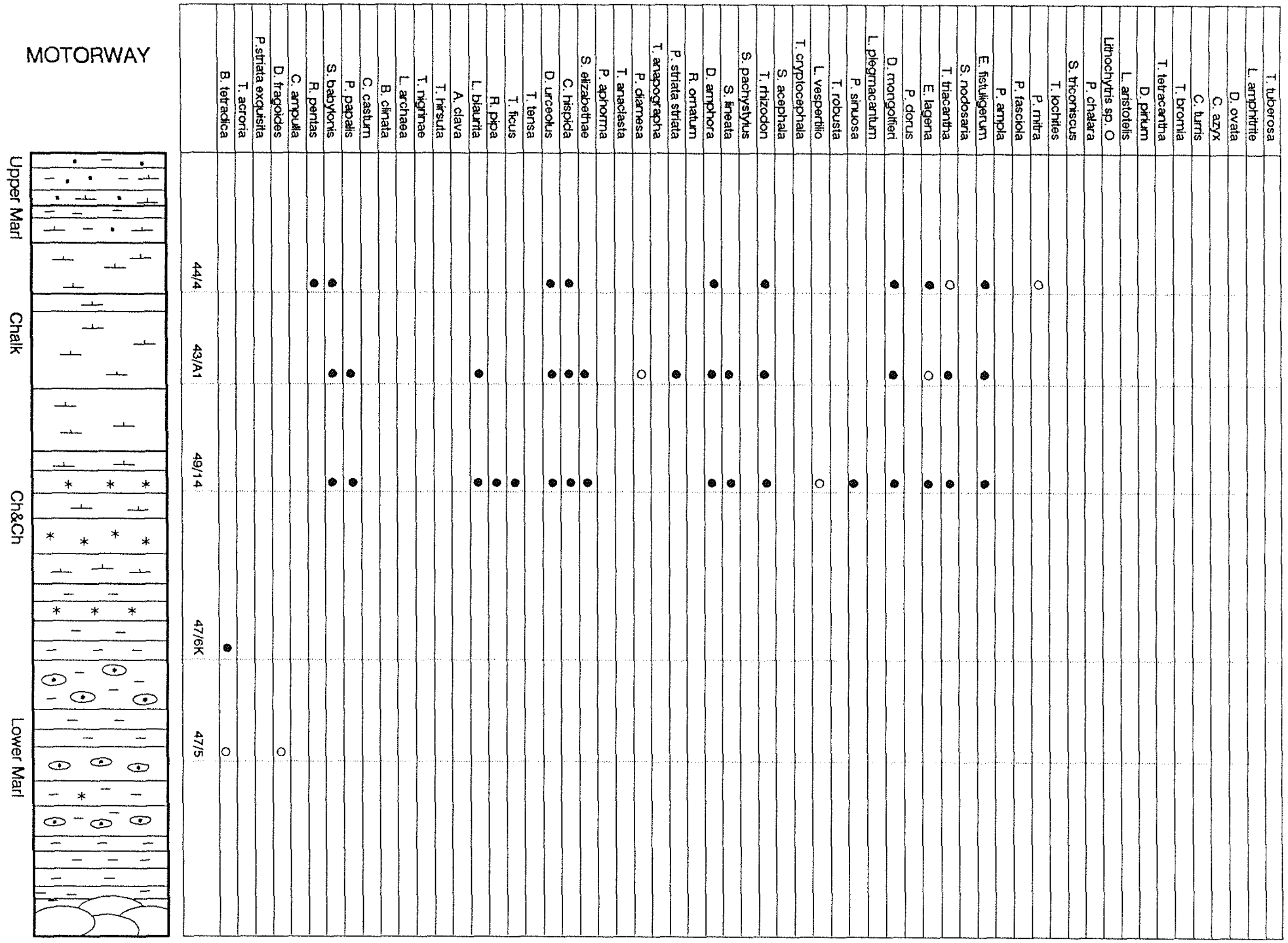


Fig.20. Radiolarian assemblage of each sample, Motorway section. For explanation see Fig.15.

Tab.3. Summary of biozones established. Column 1: sample number (compare also Fig.24-29); Column 2: biozone resulting from foraminifera identification; Column 3: logical foraminifera zone in respect to over- and underlying samples; Column 4: radiolarian zone; Column 5: radiolarian zone of the sample correlated to the N/P zonal scheme; Column 6: approximate abundance of radiolarians in a sample; Column 7: final biozone assignment from combined foraminifera and radiolarian data.

AYIOS NICOLAOS

	sample no	foraminifera zone (range)	suggested logical zone(s)	radiolarian zone	approx. corr. radiol. zone	radiolarian abundance	composite zone
Upper Marl	18/56	---	---	barren	---	absent	---
	28/1	N6 + P15-18/19	boundary N6/7 + rew.	---	---	---	boundary N6/7
Chalk	18/61	---	---	T. bromia zone + rew	P15-18	present	rew.
	18/57	---	---	P. mitra zone + rew.	P12-14	present	rew.
	28/A	N3-4 + Middle Eocene	reworked	P. mitra zone	P12-14	rare	rew.
	28/B	N7	N7	---	---	---	boundary N6/7
	18/58	---	---	P. mitra zone + rew.	P12-14	frequent	rew.
	28/E	N3+rew.M'Eocene?	N3 + rew.	P. ampla zone + rew.	P11-12	frequent	N3
	28/C	P9-12	P12	---	---	---	P12
Chalk & Chert	18/59	P12-14	P12	T. triacantha zone	P10-11	frequent	P11
	28/D	P9-12	P11-12	---	---	---	P11
	18/7	P9-12	P10-12	P.striata-D.mongolfieri zone	P9-10	present	P10
	18/6	---	---	B.clinate-D.mongolfieri? zone	P7-10?	---	P9-10?
	18/5	P9	P9	---	---	---	P9
	18/8	P8-9 +P4	P9 + rew.	P.striata-D.mongolfieri zone	P9-10	rare	P9
	18/4	P8-9	P9	---	---	---	P9
Lower Marl	18/3	P9	P9	P.striata-T.triacantha zone	P9-11	present	P9
	18/2	P3-4 + P8?	P8 + rew.?	barren	---	absent	rew.
	18/1	P3-5	P5 + rew.	P.striata striata zone	P9	present	P9
	18/22	P5-6 + rew. P3-4	P5 + rew.	---	---	---	P5

KOUKA

	sample no	foraminifera zone (range)	suggested logical zone(s)	radiolarian zone	approx. corr. radiol. zone	radiolarian abundance	composite zone
Upper Marl	15/100	N6+7	boundary N6/7	---	---	---	boundary N6/7
	15/Q	N5-6	N4/6	barren	---	absent	N4/6
Chalk	15/98	---	---	D.mongolfieri-T.bromia zone	P10-18	present	rew.
	15/R	N5-6	N4/6	P.striata-T.bromia zone	P9-18? (P11-13?)	present	N4/6
	15/96	?	no Middle Eocene	T. bromia zone	P15-18	rare	P15-18
	15/95	P14-17 + rew.?	P15-17 + rew.?	barren	---	absent	P15-17
	15/V	P9-14	P13-14	P. chalara zone	P14	rare	P14
	15/W	P9-12	P12	---	---	---	P12
Chalk & Chert	15/Y	P10-12	P11?	P.striata-T.triacantha zone	P9-11	present	P11?
	15/19	P9-11	P11	---	---	---	P11
	15/15	P9-12	P11	---	---	---	P11
Lower Marl	15/13	P9-13	P10	---	---	---	P10
	15/7	P8	P8	---	---	---	P8
	15/52	P7 + rew. P3-6?	P7 + rew.?	B. clinata zone	P7-8	present	P7
	15/3	P6	P6	---	---	---	P6
	15/103	---	---	no identification possible	---	frequent	---
	15/102	no id	no id	barren	---	absent	---

Tab.3 continued.

KALAVASOS

		sample no	foram zone (range)	suggest.logical zone	radiolarian zone	approx.radio.zone	radiolarian abundance	composite zone
	Upper Marl	33/4	N3-6	N3-N4/6	barren	---	---	N3-4/6
		31/1	N3-6	N3-N4/6	barren	---	absent	N3-4/6
transitional lithology	Chalk	31/2	P17-18/19	P18/19	barren	---	absent	P18/19
		31/5 + 33/2	P16-17	P17	barren	---	absent	P17
		33/1	P14-17	P16-17	T. bromia zone	P15-18	frequent	P16/17
		30/104	P14	P14	P. chalara zone	P14	frequent	P14
		30/4	P13	P13	P.ampla+P.mitra zone	P11-12+P13-14	frequent	P13
		30/3	P9-12	P12?	---	---	---	P12
	transitional lithology	30/2	---	---	P. ampla zone	P11-12	frequent	P12
		30/C	P12-14	P12	---	---	---	P12
		30/1	P9-12	P10-11	---	---	---	P10-11
Chalk & Chert		30/106	P9+10	boundary P9/10	B.clinata-P.ampla zone	P7-12	present	boundary P9/10
	Lower Marl	35/3	P9-12	P9	barren	---	absent	P9
		35/1	P8-9	P9	---	---	---	P9
		35/2	barren	barren	barren	---	absent	---

LEFKARA

	sample no	foraminifera zone (range)	suggested logical zone(s)	radiolarian zone	approx. corr. radiol. zone	radiolarian abundance	composite zone
Upper Marl	21/77	N4-6	boundary 6/7	---	---	---	boundary N6/7
	21/50	N1+N2 + rew.P18/19?	reworked	barren	---	absent	reworked
Chalk	21/51	---	---	barren	---	absent	---
	21/10	N6-7 + N2	N7 + rew.	P.striata-P.ampla zone	P9-12	present	boundary N6/7
	21/57	?	P14?	T. triacantha zone	P10-11	frequent	tectonic dist., P14?
	21/91	P9-12	P11-12	P. ampla zone	P11-12	frequent	base P12
	21/9	P11+12	boundary P11/12	---	---	---	boundary P11/12
Chalk & Chert	21/8	---	---	B.clinata-P.striata zone	P8+P9 (P9?)	rare	reworked
	21/7	P9-12	P10-12	B.clinata+P.striata zone	P8+9	frequent	P10-12
Lower Marl	21/4	P9-11	P10-11	---	---	---	P10-11
	21/3	P9-12	P10	B.clinata-P.striata zone	P7-9	present	P10
	21/2	P9	P9	P.striata-T.bromia zone	P9-18	present	P9
	21/74	P9-12	P9?	---	---	---	P9
	21/1	P6+8?	P8?+rew.?	B.clinata+P.striata zone	P8+9	present	boundary P8/9
	21/68	---	---	P.striata-T.triacantha zone	P9-11	present	P9
	21/66	P6	P6	barren	---	rare	P6
	21/Z	---	---	barren	---	absent	---

Tab.3 continued.

STAVROVOUNI

	sample no	foraminifera zone (range)	suggested logical zone(s)	radiolarian zone	approx. corr. radiol. zone	radiolarian abundance	composite zone
Upper Marl	24/60	---	---	barren	---	absent	---
	24/5	N1-6 + P12-14	N1 + rew.	---	---	---	N1
Chalk	24/57	N1?	N1	T.bromia zone + rew.	P15-18	rare	P18/19
	24/56	P17-N1?	P18/19-N1	---	---	---	P18/19
	24/55	barren	---	P.chalara zone+rew.	P14	frequent	P14
	24/4	P13-14 + rew.P9-12	P13 + rew.	P. mitra zone	P12-14	frequent	P13
	24/A	---	---	barren	---	absent	---
	24/F	P9-11	P10-11	---	---	---	P10-11
Chalk & Chert	24/2	P9-12	P10 + rew.?	D.mongolfieri zone	P10	frequent	P10
Lower Marl	24/62	P9-14	P9-10	T.cryptocephala- D.mongolfieri zone	P9-10	present	P9-10
	24/1	P9 + P3-4	base P9 + rew.	B.clinata zone	P7-8	rare	boundary P8/9
	24/50	P8-9	P9	---	---	---	boundary P8/9
	24/51	barren	---	barren	---	absent	---

MOTORWAY

	sample no	foraminifera zone (range)	suggested logical zone(s)	radiolarian zone	approx. corr. radiol. zone	radiolarian abundance	composite zone
Upper Marl	49/100	N3-6	N4/6	---	---	---	N4/6
	49/101	---	---	barren	---	absent	---
transitional lithology Chalk	49/16	N3 + rew.Late Eocene	N3 + rew.	---	---	---	N3
	49/8	---	---	barren	---	absent	---
	49/5	P18/19 + N1?	P18/19	barren	---	absent	P18/19
	44/4	---	---	P. mitra zone	P12-14	frequent	top P12
	43/A1	barren	barren	T. triacantha zone	P10-11	frequent	top P10
Chalk & Chert	49/14	P9-12	P12	T. triacantha zone	P10-11	frequent	P10-11 tectonically disrupted
	46/1	P8+9	boundary P8/9	---	---	---	boundary P8/9
Lower Marl	47/6A	?	P8-9	barren	---	absent	P8-9
	47/6K	---	---	unzoned- B. bidartensis zone	P1-7	present	rew.
	47/5	P6-8	P8?	B. bidartensis- B.clinata? zone	P5-8?	present	P8?
	47/4	Early Eocene	P8	barren	---	absent	P8?
	48/6	?	P8?	barren	---	absent	P8?
	48/3	barren	---	---	---	---	---

In general, the **planktonic foraminifera** zones determined show a consistent (but not continuous) order in all sections. The oldest sample dated in the Lefkara Formation is from biozone P5 or P6, Late Palaeocene, the youngest one from the boundary N6/7 in the Early Miocene. Table 3 shows the uninterpreted biozone results in the first column for each section. The second column lists the most likely zone of the original low resolution range of zones after considering the whole foraminiferal assemblage (see Appendix A.3, suggested biozone).

All planktonic foraminifera (and radiolarian) species found in a sample indicating an older age than the youngest definitely identified taxon are considered to be reworked. Since the sediment analysis clearly shows strong reworking in many sections, age mixture in the assemblages is an expected phenomenon. If reworking is extremely strong, a sample may contain only allochthonous material and no specimens are preserved to show the real age of deposition. This leads to a too old biozone in the dated succession and so to an inconsistency in the stratigraphic column. For the planktonic foraminifera biozones, this is the case only once, in sample 28/A. Hence, these have to be considered to be completely reworked.

All dated **radiolarian** samples are also summarised in Table 3. Many of the samples contain solely reworked material. However, inconsistencies in the order of the radiolarian biozones can only be seen in two samples (21/57 and 49/14).

A general feature seen in the radiolarian samples is a decrease or even absence of siliceous microfossils near the bottom and the top of the succession in all sections. This in illustrated in Table 3 in the column 'radiolarian abundance'. The number of specimens is important to estimate the reliability of a sample dating, since a poor fauna will lead to a lower confidence and resolution of the biozone. The complete absence of radiolarians at the top of the succession is very clear in the Kalavasos and Motorway sections. Reworking seems to be more important in the radiolarian content and, more often than in the foraminifera fauna, stratigraphically older radiolarians are redeposited into strata that do not contain any contemporaneous radiolarians. This is the only explanation for several inconsistencies in the stratigraphic order and correlation to the foraminifera zones towards the top of the formation, e.g. in the Lefkara and Ayios Nicolaos sections. This will be discussed in detail in Chapter 5.2.. Reworking might not have been detected in samples with a poor fauna and a low resolution dating. An interesting fact is that, in Kalavasos, no reworking of microfossils can be seen at all although the sediments consist of thick turbiditic cycles. In contrast, in the sediments of the Ayios Nicolaos section, only few sedimentary structures can be seen in the field but the microfauna is strongly redeposited.

In summary, the examination of the radiolarian fauna leads to 'ages' for the Lefkara Formation between the *B. clinata* zone and *T. bromia* zone. No material younger than Early Oligocene age was found. That suggests that no siliceous microfossils are preserved from the upper part of the succession, which are the strata where the foraminifera do not provide reliable dates as well.

When comparing the foraminifera and radiolarian zones, only in a few cases both groups lead to exactly the same zone or zone range definition. Commonly, one or both of the two groups, show a low resolution range of zones. Then the overlap was taken to decide the final zone, using the correlation chart of both zonal schemes from Bolli *et al.* (1985) (Fig.6). If there is a disagreement in zones between foraminifera and radiolarians, all information such as the additional assemblage characteristics, reliability of identifications, number of specimens in a sample and the whole stratigraphic context, is used to determine the biozone. Samples that were only examined for foraminifera are dated according to the suggested biozone.

Apart from the comparatively low accuracy in biozone determination, most samples show a good agreement in dating of both fossil groups. The most consistent results are obtained in the sections which show the smallest indications of reworking in the microfossil assemblages, in the Kalavasos, Kouka and Motorway sections.

In Kalavasos, where no redeposition was detected at all, all datings fit very well. The combined foraminifera-radiolarian stratigraphy leads to a comparatively continuous time scale for the whole succession starting with the late Lower Eocene.

The Motorway section gives a not as complete but also continuous succession of biozone datings. The only sample that does not fit is 49/14 which shows a definitely too-old age in the radiolarian fauna. Although the suggested foraminifera dating of this sample would fit, the definite foraminifera identifications also include older zones as do the radiolarians. This section is strongly faulted and folded and the sample is taken from a separate outcrop that is not in a direct contact with the preceding and following ones. Therefore, a tectonic disturbance has to be assumed and these strata are originally part of the Chalk & Chert unit.

In Kouka, an inconsistent order in dating starts with the samples dated to Early Miocene using planktonic foraminifera. Samples 15/R and 15/98 which show too-old radiolarian ages compared to the calcareous plankton, both contain very few specimens. These are most likely redeposited.

In the other three sections, Stavrovouni, Ayios Nicolaos and Lefkara, much stronger reworking in the foraminiferal as well as in some of the radiolarian assemblages is seen. Nevertheless, Stavrovouni shows good agreement in dating of both fossil groups. It also has a continuous coverage of samples throughout the succession, namely in the Eocene. Only one inconsistency in the foraminifera and radiolarian datings exist in sample 24/57. Here no definite identification of foraminifera could be made but the radiolarians show a diverse and typical fauna of the *Thyrsocyrtis bromia* zone. Therefore the latter one seems to give a more reliable result.

The final two sections (Ayios Nicolaos and Lefkara) show much bigger discrepancies in the dating between foraminifera and radiolarians than the previous ones. In the Lefkara section there is disagreement in samples 21/3, 21/7 and 21/8. Here the foraminifera fauna suggests a zone younger P9 whereas the radiolarians indicate *B. clinata* and/or *P. striata striata* zone, correlated to P8 and P9. The two younger samples are reliable in the radiolarian content since they contain high specimen numbers. Nevertheless, although the foraminifera ranges of the definitely identified species in the samples include P9 as well, the assemblages are not typical for the late Early Eocene at all. Although no reworking was detected in the microfossils assemblages of any of these samples, the Lefkara section shows clear evidence of turbiditic activity. Radiolarians appear to be redeposited easily in much of the material. Although every decision is unsatisfactory, in this case the suggested zones of the foraminifera are used, and reworking is assumed for the radiolarian fauna. The radiolarian dating of sample 21/57 is too old as well, compared to the closely positioned underlying sample 21/91. Both radiolarian faunas are rich and therefore reliable. The inconsistency might be explained most plausibly by a tectonic disruption. The rocks dip very steeply and are faulted near the position of sample 21/57. Another possible explanation is an allochthony only of the radiolarians in sample 21/57. The foraminifera fauna indicates a very uncertain, younger age (zone P14) which would fit into the system.

In Ayios Nicolaos, the biozones derived from the foraminifera and radiolaria commonly differ strongly. The comparatively old age of the base of the section (sample 18/22), obtained from foraminifera, is questionable since the radiolarians give an age of *Phormocyrtis striata striata* zone for sample 18/1. Since sample 18/22 is about at the same level as 18/1 in the stratigraphic column, it may be that the foraminifera are reworked in both samples, but there is no proof for this in the present data and sedimentation rates may be low. In sample 18/59, only the presence of *T. cerroazulensis cerroaculensis* indicates a zone not older than P12. The rest of the fauna is badly preserved and all identifications are questionable. The radiolarian fauna is well preserved and diverse which makes this result more reliable. All following younger samples show an older radiolarian age than the foraminifera equivalents. This is similar to the samples interpreted as being post-Eocene in the Kouka and Lefkara sections but more difficult to explain in Ayios

Nicolaos because the radiolarian fauna is well developed and the zonal assignments are definite. In contrast, the identifications of the foraminifera are often doubtful. Nevertheless, it is relatively certain that the foraminifera samples 28/E to 18/61 are not of Middle Eocene age as the radiolarians indicate. Consequently, reworking has to be accepted for all these radiolarian samples.

In summary, the result of the biostratigraphic analysis shows that the sediments of the six sections examined range in time from foraminifera zone P5 to the boundary N6/7. The best resolution in dating for the whole Eocene was obtained in the Kouka section (and Kalavasos section) which was sampled comparatively continuously starting with foraminifera zone P9.

The radiolarians are a useful tool for the stratigraphy for the Palaeogene. In the higher Oligocene and in the Early Miocene, they are absent in the sediments of the Lefkara Formation. Consequently they are of no help confirming the foraminifera datings in the upper part of the succession where diagnostic planktonic foraminifera are also rare. Radiolarians are easily reworked either from various older zones or from only one radiolarian zone. In some cases, the reworked microfossils provide evidence that deposition took place also during time periods from which no autochthonous sediment is preserved or from which no samples have been recovered. The oldest reworked foraminifera, for example, are from the biozone P3-4 while the oldest dated sample is from P5 or P6. Similarly in Ayios Nicolaos no higher Eocene samples were found in the succession but redeposited radiolarians are from the *Podocyrtis mitra* and *Thyrsocyrtis bromia* zones.

2.3. THE AGES OF THE LITHOLOGICAL UNITS OF THE LEFKARA FORMATION

2.3.1. REVISED DATING OF THE LITHOLOGICAL UNITS

The biostratigraphic results enable a comparison to be made between the ages of the lithological units of the Lefkara Formation in the six sections, to check whether their duration is of equal length and whether any diachrony can be seen. To obtain the age of the beginning and end of each lithological unit in most cases samples from their boundaries were dated. This was not necessary if there was a long period of deposition during one biozone which crosses the lithological boundary. The duration of the lithological units is plotted in Figure 21. The difficulties in defining the lithology of the Lower Marl and sometimes the Upper Marl (Motorway section) have already been discussed in Chapter 1.5. (see also Chapter 3.1.2.). This problem in defining the boundaries between the units directly affects their dating. In many cases it could not be definitely detected since gradual rather than abrupt changes in the macrofacies are characteristic for the whole succession.

The base of the **Lower Marl** could not be dated anywhere because no planktonic foraminifera or radiolarians could be found or identified respectively. In the Ayios Nicolaos and the Motorway sections, the oldest samples which could be dated were recovered just a few metres above the contact with the pillow lava. They possibly date the base of the succession to foraminifera zone P5 in Ayios Nicolaos and to a questionable P8 in the Motorway section. The oldest sample in the Stavrovouni section is from near the pillow lava contact too but here only very small patches of the Lower Marl crop out and they appear to be brecciated and disturbed. In Kalavasos, Kouka and Lefkara the direct contact of the Lefkara Formation with the pillow lava is barren in microfossils and outcrops of the lower part of the Lower Marl are missing. The most reliable first ages for the Lower Marl for these sections are from the base of the Early Eocene with the Kalavasos section not being sampled. In most sections the Lower Marl ends with biozone P9 or P10. Only in the Motorway section it might terminate slightly earlier with the boundary P8/9.

The **Chalk & Chert** unit was generally deposited during early Middle Eocene time. In some sections it starts with biozone P9 (Ayios Nicolaos, Kouka, Motorway sections), most include P10 and often P11 as well. The Chalk & Chert in Lefkara and Kalavasos possibly extends to P12. This might be caused by a low resolution in the dating for the Lefkara section. The samples from biozone P12 from the Kalavasos section are all from a transitional zone between the Chalk &

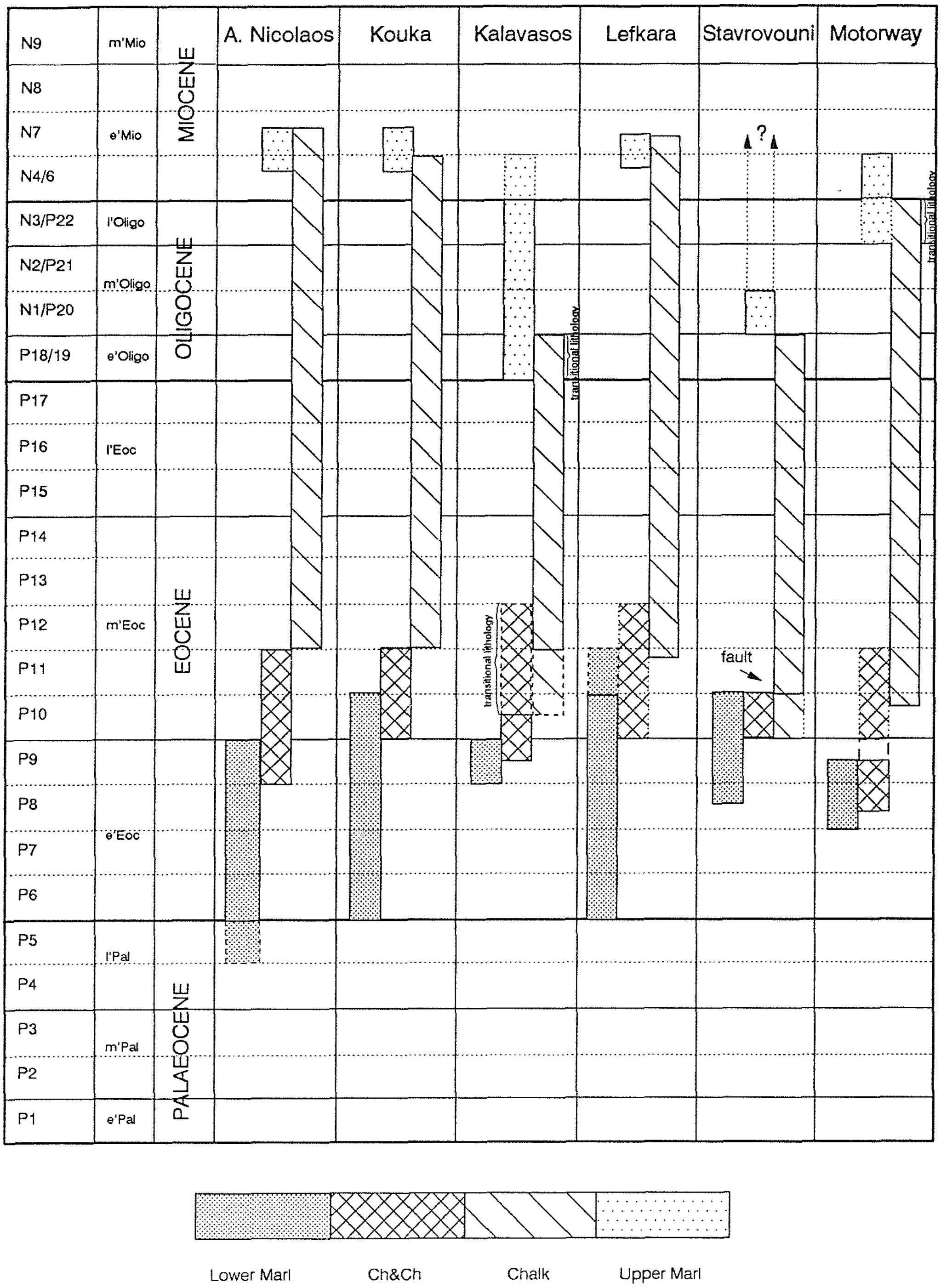


Fig.21. Duration of the lithological units of the Lefkara Formation using the new dating. Solid rim: definite age of a unit; broken rim: inclusion of biozone(s) is possible due to low accuracy in dating; dotted rim: low resolution range of biozones.

Chert and the overlying Chalk unit. In the Motorway section no samples are dated from the top of the Chalk & Chert unit. The only sample of the unit was taken near the bottom of the succession and dated to the boundary between biozones P8/9.

The chert-free **Chalk** unit shows by far the longest duration of deposition. It starts with the Middle Eocene with P12 in the Ayios Nicolaos, Kouka, and possibly slightly earlier in the Lefkara sections. In the Kalavasos section samples taken from a transitional zone between the Chalk & Chert and Chalk units range from biozones P10-P12 but the first definite samples from the Chalk unit are also of biozone P12. In the Stavrovouni section a fault lies between the two units, truncating most likely the top of the Chalk & Chert unit. The assumed base of the Chalk unit here is dated to the slightly younger biozone P10 or P11. For the Motorway section unfortunately no age was obtained directly from the base of the unit but the samples dated to the top of P10 originate from the lower part of the Chalk unit and may be therefore representative. The top age of the Chalk unit is very variable in the different localities, between Early Oligocene (P18/19: Kalavasos and Stavrovouni), Late Oligocene (N3: Motorway), and Early Miocene (N4/6 or the boundary to N7: Ayios Nicolaos, Kouka, and Lefkara).

Consequently, in some sections the **Upper Marl** starts in the early Oligocene (P18/19: Kalavasos) whereas in others during the Oligocene (Stavrovouni, Motorway) or at the beginning of the Early Miocene (Ayios Nicolaos, Kouka, Lefkara). The top of the Upper Marl is dated relatively uniformly to biozone N4/6, in the Ayios Nicolaos, Kouka and Lefkara sections possibly to the boundary towards N7. In Kalavasos, Lefkara and possibly Kouka the top of the Upper Marl was sampled directly at the (transitional) contact to the Pakhna Formation. Therefore these ages can be seen as the top of the Lefkara Formation. The other sections were sampled near the top of the Upper Marl as well, but in Stavrovouni the unit is strongly eroded.

Comparing the dating of the lithological units from west to east, a division of the sections into two groups is possible, although not strictly west-east related. These are Ayios Nicolaos, Kouka and Lefkara, on the one hand, and Kalavasos, Stavrovouni and the Motorway section on the other. The first three sections show a relatively good agreement in the duration of the units. In all of them the Lower Marl starts early in P6 or in P5 in Ayios Nicolaos, with only Kouka not being dated near the base of the succession. The Chalk unit ranges up to the early Miocene in all three sections. The Upper Marl is consequently of short duration only near the boundary of the foraminifera zones N4/6 and N7.

In contrast to these three sections, the Kalavasos, Stavrovouni and the Motorway sections show a similar agreement. In all of them, the first possible dating of the Lower Marl is comparatively young, zones P8 or P9. The Chalk unit in the Kalavasos and Stavrovouni sections ends in Late Eocene or Early Oligocene while in the Motorway section a sequence of a transitional lithology towards the Upper Marl unit is dated to Late Oligocene. The underlying undated sediments in the latter section are only a few metres thick and the uppermost chalks of the Chalk unit are dated to Early Oligocene which indicates a low accumulation rate. The situation of a transitional zone in the lithology adjacent to a low rate in sedimentation is very similar to the one in Kalavasos but there the oldest Upper Marl sample, at the transition from the underlying Chalk unit, is of Early Oligocene age. The early termination of the Chalk in the Kalavasos, Stavrovouni and, less significant, in the Motorway sections leads to an early start of the Upper Marl with early or early Middle or Upper Oligocene respectively. Since in all six sections the Lefkara Formation has an almost contemporaneous end in the Early Miocene, the Upper Marl in the eastern sections has a much longer duration. This is most likely true for the Stavrovouni section as well but here the top of the lithological unit has been lost by erosion. The top of the Upper Marl in the Kalavasos and Motorway section seems to be slightly older than in the western sections since no indication of zone N7 was found.

Comparing the map (Fig.5), the subdivision of the sections into two groups follows a southwest-northeast directed line in the east of the Troodos Massif. The Lefkara section is positioned near the boundary of this division but shows the characteristics of the western group. The reasons for the differences in the lithology during corresponding times will be discussed in the Chapters 4 and 5.

2.3.2. COMPARISON AND DISCUSSION OF THE NEW DATINGS WITH THE ESTABLISHED STRATIGRAPHY IN CYPRUS

Mantis (1970):
The stratigraphy in most papers concerning the Lefkara Formation and published after 1970 is based on the datings of Mantis (1970). It is the latest and most systematic stratigraphical analysis of the area, in which benthic foraminifera, planktonic foraminifera and radiolarians were used for dating.

Three main difficulties arise when comparing the previous dating with the results of this study. Firstly, Mantis did not illustrate any of the foraminifera or radiolaria identified which makes it difficult to explain significant discrepancies in identification. Secondly, only a summary of the ages of the lithological units is presented. The microfossil assemblages and the resulting dates are not listed for the different areas studied. Therefore any diachrony across the Cyprus area cannot be detected and Mantis did not subdivide local differences. Thirdly, the state of preservation of the microfossil content for the planktonic foraminifera in particular is not mentioned. Mantis describes the results as 'exact age determinations' and does not mention the bad preservation of the calcareous fauna which led to major uncertainties in this study. Additionally, a radiolarian fauna is only identified from the Chalk unit whereas in this work radiolarians were found in the Lower Marl and the Chalk & Chert unit as well.

In brief, Mantis' age determinations are a Maastrichtian age for the Lower Marl, a Palaeocene to Lower Eocene age for the Chalk & Chert unit, a Middle to Upper Eocene age for the chert-free Chalk unit, and an Oligocene to Lower Miocene age for the Upper Marl (Tab.4). The inconsistencies in dating compared to the present study and the foraminiferal content will be examined now. The radiolarian fauna will not be considered since mainly spumellarians, not identified in this work, and only few nassellarians, which were not found in the material of the recent work, were identified by Mantis.

The Lower Marl has been dated by Mantis to Maastrichtian time. It seems apparent that the reason for the disagreement in age is due to an inconsistent definition of the lithological units (see Chapter 1.5.). Mantis excludes all chert-bearing strata from the Lower Marl. Since in this work another definition was followed it means that the upper part of the Lower Marl, which contains chert strata, is included in the Chalk & Chert unit by Mantis. Consequently, the Lower Marl in Mantis' work is older and the Chalk & Chert unit starts earlier. In the six sections of the present study no sediments of the patchily distributed Maastrichtian sediments were present.

The Chalk & Chert unit, according to Mantis' dating, is restricted to the Upper Palaeocene and Early Eocene while it ranges from the upper part of the Early Eocene clearly into the Middle Eocene according to the present study. The planktonic foraminifera fauna described for the Chalk & Chert unit by Mantis is largely consistent with the one of this work for the Lower Marl. The previous paragraph seems to explain this. Some species are attributed to slightly different times of occurrence. *A. bullbrooki* for instance, one of the most important diagnostic species in the Chalk & Chert unit, was found only in the Massive Chalk by Mantis.

The chert-free Chalk has a basal age of Middle Eocene in both studies, but in the present one it does not start at the base but higher up in the Middle Eocene. There is an agreement for the top of the unit with the end of the Eocene in the Kalavasos section. In all other localities the unit ranges higher in time according to the present study. The fauna Mantis found in the lower part of the Middle Eocene is comparatively poor. Except *Acarinina bullbrooki* it consists of species that were not identified in this study. This is difficult to explain since the Middle Eocene fauna was often found to be the best preserved and most diverse one in the Lefkara succession. The fauna of the upper half of the Massive Chalk is characterised mainly by various *Globigerinita* and *Hantkenina* species. In this study members of the latter genus were not found at all in the Lefkara Formation. Other species Mantis used to restrict the age of the upper part of the Chalk to the Upper Eocene have a longer range of occurrence according to the recent literature. Most of the species listed by Mantis and related only to the Late Eocene in fact start in the Middle Eocene. In this case this does not change the result of the dating of the unit (since it ranges in the Middle Eocene as well) but it shows the general problem: Occurrences used to argue for a biozone often have longer total ranges than shown in Mantis' range chart.

The Upper Marl shows a summarising age from Oligocene to Lower Miocene in both works. According to the present work that is right only for most of the sections in the east of the Troodos Massif. Mantis did not subdivide or point out localities where the Upper Marl started later with the Lower Miocene. With few exceptions there is a good agreement in the identified fauna for this time in both works.

The comparison of Mantis' and this study shows that there are many agreements in dating the lithological units of the Lefkara Formation. Discrepancies in the lower part of the succession are mainly due to the definition of the lithology in the Lower Marl and Chalk & Chert unit. Why Mantis found hardly any Middle Eocene species in the Chalk & Chert unit cannot be explained. The dating of the Chalk and Upper Marl is consistent in some places, but not in others due to a diachrony between sections. Mantis did not mention any indications for diachronous sedimentation.

Cockbain (1961):

Previous to Mantis, Cockbain (1961) reviewed the foraminifera content of the Lefkara Formation, then still called Lapithos Group. The subdivisions of the Group into Lower, Middle, and Upper Lapithos Formation are purely biostratigraphical ones and are not based on the lithology, as in the subdivisions of the Lefkara units used in the present study. The Lower Lapithos lithology roughly corresponds to the Lower Marl definition used in this work, being composed of chalk, marly chalk and rare chert. The Middle Lapithos consists mainly of the chalk and chert sequence, but includes locally massive chalks as well. The Upper Lapithos Formation is described as containing bedded chalks and occasional marl.

The dating of Cockbain only gives a time resolution to epoch level. In some cases it was tried to define assemblages to subdivide the epoch, but these were not correlated to established biozones or an absolute age. For most listed assemblages localities were given so that the results could be compared, although this is difficult because of the different nomenclature and definitions of the formation. Planktonic and benthic foraminifera were examined by Cockbain but here only the planktonic fauna are considered. Since no exact sample positions in relation to the whole succession were given, it is difficult to judge whether the age of a whole lithological unit was dated. If only scattered samples within the lithologies were studied, this might not reveal the whole age of a lithological unit if the boundaries were not dated.

The Lower Lapithos Formation is defined by its Maastrichtian age. This is based on planktonic and benthonic foraminifera. The lithology is described similar to the Lower Marl definition used in this work. All localities indicate a Maastrichtian age, as do the results of other cited authors. Since some of the mentioned outcrops have been examined also in this study (Ayios Nicolaos, Lymbia) it has to be assumed that locally a Maastrichtian fauna can be detected but the samples of the strata collected for this study were barren of Cretaceous planktonic foraminifera.

According to Cockbain, the Middle Lapithos Formation starts above the Cretaceous-Tertiary boundary in Danian time and includes the whole Eocene. The lithological descriptions corresponds to the Chalk & Chert unit in this work, including parts of the chert-free Chalk. The oldest assemblage detected is of Danian to Lower Palaeocene age and contains *Globorotalia pseudobulloides*. It is rare and found only in a patchy distribution and not detected in this work. The younger *'Truncorotalia'* assemblage, containing *M. velascoensis*, *M. quetra*, *A. soldadoensis*, *M. aragonensis* and other species, indicates an age of Palaeocene to Middle Eocene and was found commonly. This assemblage corresponds partly to the fauna of the Chalk & Chert unit in this study. The species Cockbain listed all indicate rather a Palaeocene to Early Eocene age. The youngest two assemblages of the Middle Lapithos were only found regionally and contain *Hantkenina* and *Globigerapsis* species which indicate a Middle Eocene and possibly Upper Eocene age. These species could not be found or definitely identified in any of the six sections of this study. In contrast, the species used to determine the Upper Eocene in this work were mostly not identified by Cockbain. The *Hantkenina* species are described being in an assemblage together with *M. aragonensis*, *T. cf. cerroazonensis pomeroli*, *A. cf. bullbrooki* and even *A. cf. soldadoensis, and M. quetra*. This strongly suggests an age of the earlier part of the Middle Eocene, clearly excluding the Upper Eocene. No lithological description was given but from the context it can be assumed that it belongs to the chalk and chert sequence. Consequently it can be concluded that the Chalk & Chert unit was locally dated to the Middle Eocene as has been done in the present study. The *Globigerapsis* species, that indicate a Middle Eocene and possibly, but not necessarily, a Late Eocene age, were found only in massive chalks. Correlated to the present study this chalk section belongs to the chert-free Chalk unit and is consequently dated here to the Middle Eocene in its lower part of the succession.

According to Cockbain, the Upper Lapithos Formation ranges from Oligocene to Lower Miocene although several Oligocene species listed are not restricted to this epoch but have longer ranges. Compared to the lithological units the formation includes partly the Chalk unit and the Upper Marl. Many of the species identified by Cockbain are in agreement with this work, partly indicating a slightly different species range. The presence of *Orbulina universa*, *Orbulina suturalis* and *Globorotalia menardii* indicates that Middle Miocene sediments are included in the Lapithos Group. These might belong to the overlying Pakhna Formation, since the lithologies grade into each other.

Relating the datings of the Lapithos Group to the lithological units of the Lefkara Formation, the Lower Marl is of Maastrichtian age, the Chalk & Chert unit is of Palaeocene to Middle Eocene age, and the Chalk unit starts with Middle Eocene and includes possibly the Upper Eocene. No lithological evidence has been given for an increase in the marl content in the Upper Lapithos Formation so that no age correlation can be reconstructed for the Upper Marl. The end of the formation is dated to Early Miocene, while some early Middle Miocene species must have been taken from the Pakhna Formation.

The comparison shows a definite discrepancy for the age of the Lower Marl, which can only be explained by the missing of appropriate samples in this study. The explanation for the old base of the Chalk & Chert unit, compared to the present study, of Palaeocene, might be that parts of the Lower Marl, as defined in this work, are included in the Chalk & Chert unit. Otherwise the age of the Chalk & Chert unit shows a good agreement, so does the starting age of the Chalk unit. The problem of the absence of the *Hantkenina* and the *Globigerapsis* species in this study, which could not be explained when comparing to Mantis' work, seems now to be solved since these assemblages are found to have restricted local occurrences. No comparison of the age for the younger part of the succession is possible, except for the top of the Formation, which is consistently of Early Miocene age.

Henson *et al.* (1949):

The first attempt dating the Lefkara Formation using foraminifera was done by Henson *et al.* (1949) who examined the fauna found in the sediments near the Ayios Nicolaos section. Only few planktonic foraminifera were identified from the Tertiary, with some Palaeocene species being referred to as Upper Cretaceous forms. Altogether only 9 species were found. Nevertheless, datings based on benthic foraminifera led to the age of the Lapithos Group from

Maastrichtian to Oligocene time.

Memoirs of the Geological Survey Department:

Other work on the stratigraphy of the Lefkara Formation have been published in the Memoirs of the Geological Survey Department of Cyprus. Planktonic foraminifera biozone results were given in Bagnall (1960, datings by Cockbain), Gass (1960) and Pantazis (1967, datings by Mantis, Thallmann, Allen; compare also Allen, 1966). All works state a Maastrichtian age for the Lower Marl, based on planktonic and benthonic foraminifera. In Gass, the Chalk & Chert unit is dated to Lower to Middle Eocene time, as in this work. In Pantazis, Mantis' ages for the Chalk & Chert unit were published. In Bagnall, the unit is dated to Oligocene but tectonic disturbance is mentioned for the examined outcrop. For the Chalk unit he gives an Early Miocene age which is partly but not exclusively consistent with this work. According to Gass the Chalk unit has a Middle to Upper Eocene age. It might even include the Oligocene to Lower Miocene since in the sections studied in the north of the Troodos Massif the Upper Marl is not developed typically as in the south, and so the problems in defining the units occur here again. This time range for the Chalk unit would be most consistent to the present work. In Pantazis, the chert-free Chalk was dated as Upper Eocene to Lower Miocene near and west of Kalavasos with the Upper Marl not being present. Here again the lithological definitions must have led to the discrepancies in dating.

Tab.4. Stratigraphy of the Lefkara Formation from previous works.

	Bagnall (1960)	Gass (1960)	Cockbain (1961)	Pantazis (1967)	Mantis (1970)	present work
Upper Marl unit	not present	Oligocene - Early Miocene (overlap in lithology)	not distinguished	not present	Oligocene - Early Miocene	a) Early Miocene b) Oligocene - Early Miocene
Chalk unit	Early Miocene	Middle Eocene - Later Eocene	Middle Eocene - Early Miocene	a) Late Eocene (dating by Mantis) b) Late Eocene - Early Miocene (dating by Thalmann)	Middle Eocene - Upper Eocene	Middle Eocene - a) Early Miocene b) Oligocene
Chalk & Chert unit	Oligocene? tectonic disturbance	Early Eocene - Middle Eocene	Danian - Middle Eocene	(dating see Mantis, 1970)	Late Palaeocene - Early Eocene	Early Eocene - Middle Eocene
Lower Marl unit	Maastrichtian	Maastrichtian	Maastrichtian	Maastrichtian	Maastrichtian	Late Palaeocene - early Middle Eocene

Summarising, the datings of the Lefkara Formation led to a general agreements in ages between previous and the recent works (Tab.4). The reason for the consistent dating of the Lower Marl (Lower Lefkara/Lapithos) to Maastrichtian age by all previous authors lies in the chronostratigraphic subdivision of the Formation rather than a lithostratigraphic definition as adopted in this study. The Chalk & Chert unit consequently included older strata but was otherwise dated to a comparable age by most authors including the recent study. Mantis was an exception since he found an earlier termination for the unit with Early Eocene. Palaeocene samples were found to be generally rare. The strong time transgressive character of the Chalk unit was first specified in the present work. Although it was not considered by the summarising study of Mantis, the comparison of the different localities on the island (Memoirs of the Geological Survey Department Cyprus, Cockbain, 1961) pointed to this diachrony. The top of the Lefkara Formation was consistently dated to Early Miocene by all authors. None of the previous stratigraphic investigations resolved the datings to the level of the modern standard biozonation (Bolli *et al.*, 1985) and no detailed radiolarian zonation was established for the Tertiary Lefkara Formation so far. The benthic foraminifera, used in several studies, were not judged for their stratigraphic value here.

2.3.3. ABSOLUTE AGES OF THE BIOSTRATIGRAPHICALLY DATED SAMPLES

Correlation of the biozones, obtained for the Lefkara Formation, with the chronostratigraphic time scale was done on the basis of Berggren *et al.* (1985) for the Palaeogene and Neogene. The ages proposed in these papers for the base of each foraminifera zone are listed in Table 5. Where applied to the present work the ages are rounded to whole million years. The composite biozones (Tab.3) from this study are used to correlate the relative datings with absolute ages. If the result of a microfossil dating is only a low resolution biozone range, that zone is chosen which results in the most even spacing between the preceding and following samples (e.g. for the range P10-12, P11 is chosen).

Plotting the samples against years (Fig.22) the time-continuity of samples dated becomes apparent, independently from the sample spacing in the succession. The accumulation of samples of the same age in the older part of some sections (e.g. Ayios Nicolaos, Lefkara) is due to a higher density of dated samples here and shows the comparatively high time resolution. The detailed relationship between sample position in the succession and the age will be shown later in this chapter (2.3.4.) when discussing the sedimentation rates. Here the emphasis is on checking whether the samples are dated in a continuous time spacing throughout the sections or whether

Tab.5. Chronostratigraphy of N/P zones and epochs (after Berggren *et al.*, 1985).

N/P zone	age (Ma)	
N8	16.6	EARLY MIOCENE
N7	17.6	
N4/6	23.4	
N3/P22	28.2	LATE OLIGOCENE
N2/P21	31.6	
N1/P20	34.0	EARLY OLIGOCENE
P18/19	36.3	
P17	37.3	LATE EOCENE
P16	38.1	
P15	40.2	
P14	42.6	MIDDLE EOCENE
P13	43.0	
P12	46.0	
P11	49.0	
P10	52.0	
P9	53.4	EARLY EOCENE
P8	55.2	
P7	56.1	
P6	58.2	
P5	58.8	LATE PALAEOCENE
P4	61.0	
P3	62.3	
P2	63.0	EARLY PALAEOCENE
P1	66.4	

gaps are due to a significant decrease in sedimentation (see also Appendix B).

In the Ayios Nicolaos section two time gaps become visible in an otherwise relatively continuous succession, one between 43Ma and 28Ma, the other one between 23Ma and 18Ma. The first might be caused by discontinuous sampling, whereas the second time gap near the top of the succession is better constrained and therefore clearly of sedimentary origin. The Kouka section shows a well supported continuous chronology throughout the succession, except for one time gap between 36Ma and 23Ma (samples 15/96 and 15/R). Although here the dating resolution is low, the samples are closely spaced and therefore a sedimentary reason for the discontinuity must be assumed. In the Lefkara section no samples are dated between 40Ma and 18Ma (samples 21/57 and 21/10). This huge time gap might be partly explained by a tectonic disturbance in this area and a consequent lack of part of the succession. However, the closeness of samples most likely indicates, at least additionally, a slow sedimentation rate. The Kalavasos

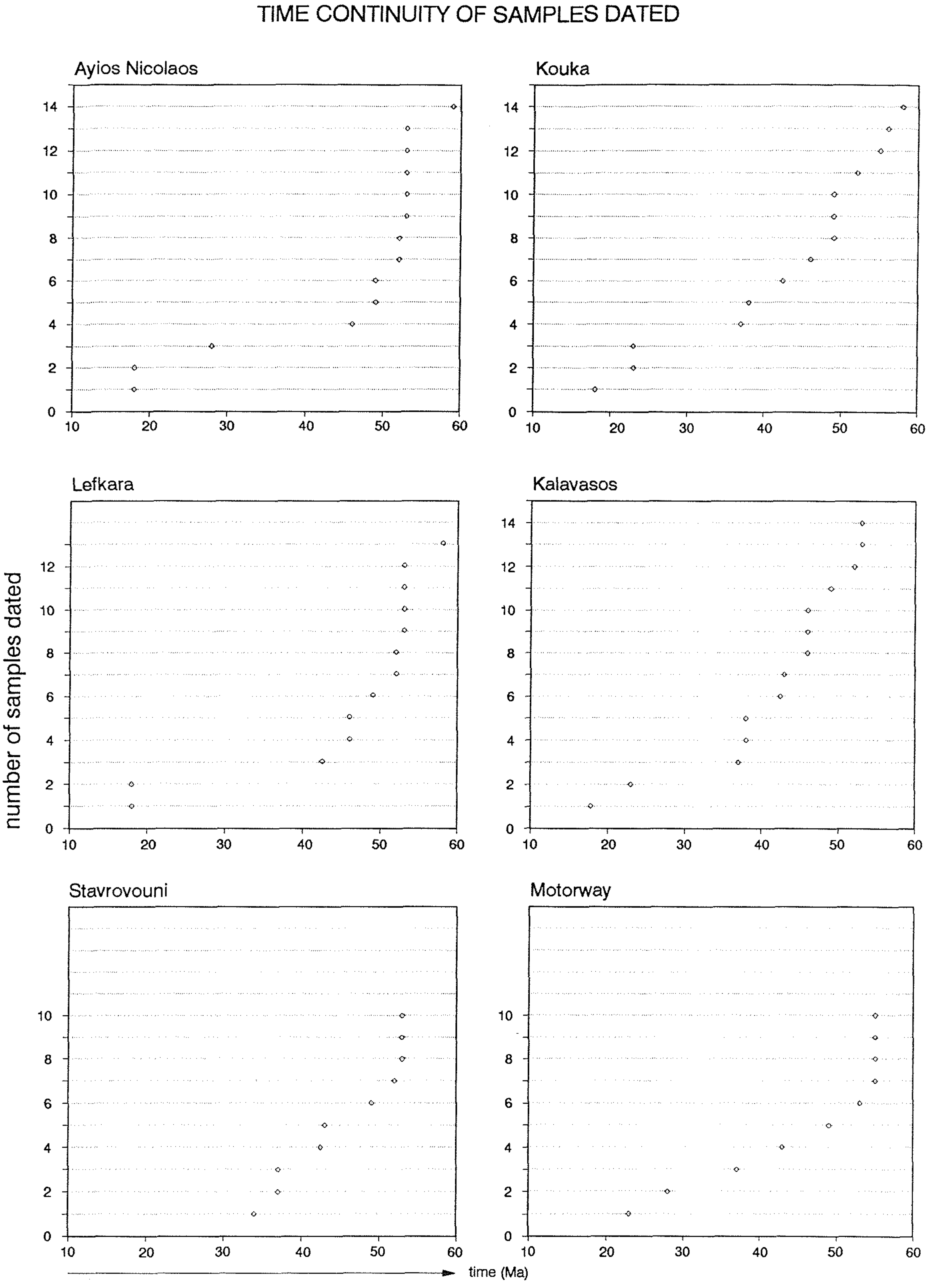


Fig.22. Absolute ages of all biostratigraphically dated samples. Gaps in time continuity are due to a low sample density or a low sedimentation rate (for distinction see text).

section does not show any dated samples between 34 and 23 Ma. Part of this gap in time might be artificial since sample 31/1 gave only a biozone range between N3 and N4/6. Accepting the younger age of the sample, the gap would be much shorter (34-28Ma), but still present. This is still significant since only a few metres of sediment lie between the relevant samples. The Stavrovouni section does not expose any obvious irregularities or breaks in dating but the youngest part of the succession was not sampled. The Motorway section shows quite a wide but regular spacing in the dating of the samples. Yet the relatively short break between 34Ma and 28Ma (samples 49/16 and 49/5) is significant because the samples are closely spaced here. Consequently a reduction in the sedimentation rate must be assumed.

Summarising, in most sections time gaps in the record occur between 34Ma and 23Ma. These cannot be explained by discontinuous dating or solely tectonic cause and so must reflect reduced or zero sedimentation.

Absolute ages of intermediate samples:

To work with a series of samples it is necessary to have continuity in the sequence. If succeeding samples were dated to the same biozone or if samples studied for the lithology are not biostratigraphically dated but lie between data points that were studied for the stratigraphy, the age of these samples had to be interpolated. If, as in the first case, several samples lay in one biozone, the oldest sample was dated chronostratigraphically to the basal age of the biozone. The ages of the following younger samples were then interpolated between this and the base of the overlying biozonal age. If samples were not dated biostratigraphically, the age was interpolated between the preceding and the following dated samples. If necessary, the position of the undated sample in the outcrop logged in relationship to the dated ones was considered, e.g. whether a sample lay near to a biostratigraphically dated one or half way between two.

No very accurate estimation of the age of the oldest samples of all sections, which are taken from near the contact to the pillow lava, can be made. Although no biozonal age was determined, no evidence for Upper Cretaceous, as given in the literature, is found in the studied sections. Therefore, in the following discussion of the sedimentation rates, the base of the succession is assumed to coincide with the base of the Tertiary, although, in places, it might in fact be younger or older.

2.3.4. SEDIMENTATION RATES

In the following section an attempt is made to calculate sedimentation rates using the new dates obtained from this study. First, the most commonly cited sediment thicknesses from the literature are applied and the resulting sedimentation rates discussed. Afterwards, local variations in unit thicknesses are considered. Finally, sedimentation rates using the short outcrop segments logged during this study are calculated, compared with the literature data, and analysed for breaks in sedimentation.

Sedimentation rates calculated using sediment thicknesses from the literature:

Robertson & Hudson (1974):
Since no systematic mapping has been done in the scope of the recent study, thicknesses of the whole units were difficult to estimate due to faults, folds, and incomplete successions. Therefore, in order to calculate sedimentation rates for the individual lithological units, sediment thicknesses are taken from Robertson & Hudson (1974). Excluding the northern condensed succession of the Lefkara Formation and the irregularly deposited sediments on top of the Mamonia nappes in the southwest, and not considering local variations, general maximal thicknesses for the lithological units in the south and southeast of the island are given as follows (Tab.6): 40m for the Lower Marl, 250m for the Chalk & Chert unit, 200m for the Chalk unit, and 200m for the Upper Marl.

Using these thicknesses and applying the new dates obtained from the present work (compare Chapter 2) average sedimentation rates are calculated (Tab.6). For the Lower Marl approximately 3m/Ma and for the Chalk & Chert unit 50m/Ma are determined. For the Chalk unit local variations of the duration of this unit lead to very different results in the sedimentation rates (compare Fig.21). In areas of long duration comparable to the localities of the Ayios Nicolaos, Kouka, Lefkara, and possibly the Motorway sections, where the sedimentation of the chalk facies ranges up to the Early Miocene, sedimentation rates are relatively low, *i.e.* 7m/Ma. Using the same sediment thickness to calculate the sedimentation rates for the areas of the sections with a short duration of the Chalk unit up to Early Oligocene (as for the Kalavasos and Stavrovouni sections) leads to higher sedimentation rates of 17m/Ma. Similar variations of the sedimentation rates are found for the Upper Marl unit, again due to the average thickness used. Consequently, localities starting early in Oligocene time and ranging up to Early Miocene show lower sedimentation rates (13m/Ma) than the sections mainly being deposited during biozone N4/6 (40m/Ma). However, the latter result seems to be too high a value and is discussed below.

Tab.6. Sedimentation rates for the individual lithological units, (a) calculated using sediment thicknesses from Robertson & Hudson (1974) and the new dating from this study; for comparison thicknesses from other publications are given below, and (b) calculated from short logs measured and dated in this study.

SEDIMENTATION RATES

			Lower Marl	Chalk&Chert	Chalk	Upper Marl
Ⓐ Robertson & Hudson 1974	thickness of unit		max.40m	max.250m	max.200m	max.200m
	duration (Ma), new datings		a)15Ma (start Maast) b)8Ma (start Pal)	5Ma	a)28Ma b)12Ma	a)5Ma b)16Ma
	sedimentation rate (for maximal thickness, duration from this study)		a)2.7m/Ma b)5m/Ma	50m/Ma	a)7m/Ma b)17m/Ma	a)40m/Ma b)13m/Ma
	Wilson, 1959	thickness of unit (maxima)	100m	330m		80m
	Gass, 1960		15m	270m	33m	50m
	Pantazis, 1967		15m	300m	230m	-
	Bagnall, 1960		40m	280m	240m	40m
Ⓑ this study	thickness of unit (where complete)		Motorway:20-40m	Kouka:20m	-	Kalavasos:20m
	sedimentation rates		Kouka:0.4m/Ma Stavrovouni:3m/Ma Motorway:10-20m/Ma	Kouka:5m/Ma Kalavasos:2m/Ma Lefkara:>4.3m/Ma	Kalavasos:5m/Ma Stavrovouni:5.5m/Ma near top of unit: A.Nicolaos:0.2m/Ma Kouka:0.3m/Ma Motorway:0.6m/Ma	Kalavasos:1m/Ma

For sedimentation rates calculated for the Lower Marl the age of the base of Tertiary for the start of the unit is adopted. As mentioned by various authors and also found in the present work, in many localities the Lower Marl unit, in fact, starts later in the Palaeocene. The shorter duration of deposition (start with P5) of the same sediment thickness leads to a slightly higher sedimentation rate of 5m/Ma, but still remains in the same order of magnitude. It is not clear whether the later start is related to a thinner unit. Compared to the high rates of 50m/Ma of the Chalk & Chert unit, the low values for the Lower Marl are consistent since carbonate dissolution may be present (see Chapter 4.3.1.1.). In addition, the high values of the Chalk & Chert unit are easily explained by rapid deposition from turbidity currents. Additionally, the chert-bearing unit is comparatively less compacted as a whole and therefore more closely approximates to the original sediment thickness at least in the chert layers.

The bimodal sedimentation rate of the Chalk unit (7m/Ma and 17m/Ma) cannot be related to differences in turbidite deposition since the diachronous Kalavasos and Lefkara sections both show these strong differences in the rate of deposition although both are turbidite dominated and from the same area (Fig.21). Nevertheless, the sections showing a more distal turbidite facies (see Chapter 3.1, Ayios Nicolaos and Kouka sections) consistently show low sedimentation rates. The significantly lower sedimentation rate in the Chalk unit than in the Chalk & Chert unit can easily be explained by stronger post-depositional compaction due to the absence of chert and less dominant turbidites in this unit. As a consequence of the different timing for the end of the Chalk unit in different areas, the Upper Marl has a similar variable length of duration and bimodal sedimentation rate (40m/Ma, 13m/Ma).

Geological Survey Department Memoirs:
Since local variations of sediment thickness of the lithological units are characteristic for the Lefkara Formation, estimations for the different areas by other authors are compared (Tab.6). Although values given for the Lower Marl unit varied significantly, which is additionally influenced by the previously discussed problems of unit definition, an average thickness of 40m seems to be most common. Nevertheless, sedimentation rates calculated from the different thicknesses and durations of the Lower Marl unit taken from the literature led to a large range between 1m/Ma and 13m/Ma.

The Chalk & Chert and the Chalk units are relative consistently estimated by all authors to be between 200m to 300m thick each. Only the values given by Wilson (1959) for the southern Troodos margin are lower, *i.e.* 330m for the whole Middle Lefkara which might indicate a lower sedimentation rate for the areas of distal turbidite deposition.

Using the maximal sediment thicknesses of the whole Middle Lefkara (Chalk & Chert and Chalk units) given for the different areas and applying the dates from the present work for the appropriate localities, sedimentation rates for the Troodos area (Wilson, 1959), for the Lefkara area (Bagnall, 1960), and for the Kalavasos area (Pantazis, 1967)) are obtained with resulting values of 10m/Ma for the western localities, and 17m/Ma and 29m/Ma for the eastern localities. This shows a slight decrease in the sedimentation rate from east to west.

The maximal thickness for the Upper Marl unit given by Robertson & Hudson (1974) is higher than given in any of the other publications, with an average being about 45m. This results in a sedimentation rate of 3m/Ma to 10m/Ma, depending on the duration of the unit due to the diachrony. These values are more comparable to the thickness measured for the complete Upper Marl succession in the Kalavasos section in the present study, *i.e.* about 20m.

Sedimentation rates and hiatuses based on this study:

Although no complete sediment thicknesses could be obtained from the six sections studied for the present work the resolution of dating in some outcrops are high enough to estimate sedimentation rates (Tab.6). This allows comparison with the previous work and gives some insight in the continuity of deposition. The times of existing gaps in dating have been briefly discussed above (Fig.22). Times of obvious hiatuses are shown in Figure 23. A detailed description of the relative position of the samples dated in the outcrops in respect to the resulting sedimentation rates is given in Appendix B for all sections.

The sedimentation rate of almost the whole **Lower Marl** succession of the Motorway section can be calculated, indicating 10m to 20m of deposition per million years. For the chert-bearing part of the Lower Marl in the Kouka section a rate of 0.4m/Ma and in the (clearly turbidite related) Stavrovouni section 3m/Ma was obtained. This points to a higher sedimentation rate in the eastern sections and is highest for the turbiditic succession of the Lower Marl. Since the values given in the literature are maximal sedimentation rates the calculations of the recent work lead to results of the same order of magnitude (Tab.6).

The dating of the Lower Marl unit succession indicates the presence of hiatuses or, at least, periods of very slow sedimentation. This is inferred from the small distance between adjacent samples in the Ayios Nicolaos section between the biozones P5 and P9, and in the Lefkara section most likely between the zones P6 and P9. Slow but continuous sedimentation is resolved in the Kouka section, which might indicate that the same is true for the other two sections since the facies indicates similar sedimentological processes. A slow rate of deposition is plausible for the Lower Marl unit since carbonate dissolution at or near the calcite compensation depth (CCD) was likely in this time period (see Chapter 4.3.1.1.).

Sedimentation rates calculated from short successions of the **Chalk & Chert** unit led to values between 2m/Ma and 5m/Ma for three sections, with no differences found between the western 'distal' and eastern clearly turbiditic sections. For the Kouka section the sedimentation rate seems to be calculated for the complete thickness of the unit. These values are one order of magnitude lower than the rates calculated from sediment thicknesses given in the literature. The reason must lie in extensive local thickness variations of this facies. However, as for the sedimentation rates obtained from literature data, the values seem to be slightly higher than for the Lower Marl.

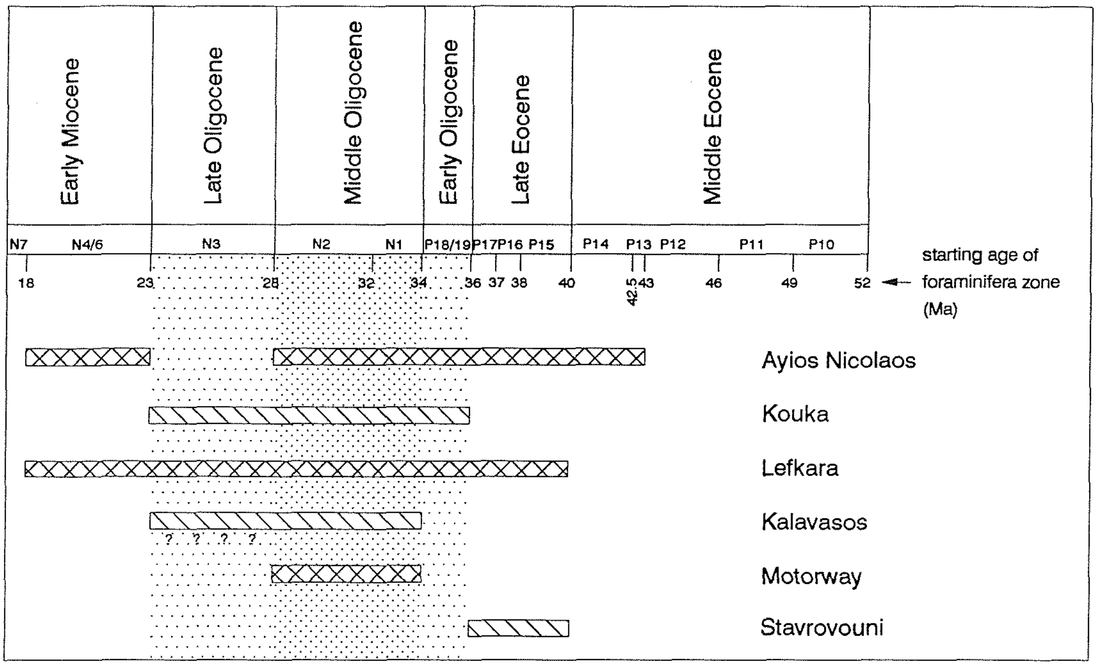


Fig.23. Times of hiatus occurrences in all sections. Horizontal bars represent times of slow or non-deposition. Note the time of maximum hiatuses in the Middle Oligocene (densely dotted background). The lack of sediments in the Ayios Nicolaos section in the Middle Eocene is most likely due to tectonic disruption.

Sedimentation rates of similar ancient calcareous-siliceous turbidite successions lie between 0.6m/Ma and 2m/Ma (Vecsei *et al.*, 1989; Garrison & Fischer, 1969) or range up to 10m/Ma (Stow *et al.*, 1984). The results of this study are therefore in the range observed for other localities while the value of 50m/Ma resulting from the literature data seems to be rather high.

The deposition of the sediments of the Chalk unit is most likely continuous in the lower part of the unit. A regular time succession is found for the Stavrovouni and possibly the Lefkara sections from biozone P11 or P12 respectively up to P14, for the Kalavasos and Motorway sections up to P18/19, and the Kouka section up to some time between P15 and P18/19. Sedimentation rates for this interval are obtained from the turbiditic deposits of the Kalavasos section (5m/Ma) and from the massive chalks of the Stavrovouni section (5.5m/Ma). Although the sediments of the latter area do not exhibit turbiditic structures the sedimentation rate is comparable to that for the turbiditic deposits, which might indicate the same origin. The sedimentation rates calculated lie in the order of magnitude of the values derived from the literature thicknesses for the long time of deposition (28Ma, case (a) in Tab.6). Again, differences in the sedimentation rates between the values obtained from the logs and the literature must be explained by local thickness variations which is due to a diachronous onset of the Upper Marl deposition.

Near the top of the Chalk unit, probable hiatuses are found in all sections except for the Kalavasos section (Fig.22, see section 2.3.3.). These lie between P12 and N3 in the Ayios Nicolaos section but here a tectonic cause for part of the apparent hiatus cannot be excluded. A definitely reduced sedimentation rate exists between N3 and the boundary between N6/7 with a calculated rate of 0.2m/Ma. In the Kouka section a similar low sedimentation rate is calculated between closely spaced samples of biozone P15-18 and N4/6 with 0.3m/Ma, and in the Motorway section the sedimentation rate is 0.6m/Ma between the two samples of P18/19 and N3. In the Lefkara section most likely a hiatus between P14 and N6/7 exists while it was definitely found between P14 and P18/19 in the Stavrovouni section. This reveals the start of very slow or discontinuous deposition at the beginning of Late Eocene and with a minimum rate deposition or complete hiatus in Middle Oligocene. At the top of the formation, Early Miocene samples are recovered from most sections which might indicate that higher rates of sedimentation were resumed.

The Upper Marl unit could not be sampled systematically enough to obtain any sedimentation rates except in the Kalavasos section. Here a sedimentation rate of 1m/Ma is calculated between the bottom and top samples of the unit, indicating a continuous but slow rate of sedimentation. This result is in significant contrast to the sedimentation rates calculates from the data taken from the literature (especially Robertson & Hudson, 1974) which show even higher rates than found for the Chalk unit. The average value of 200m of deposition might be an exceptionally high value, possibly a result of redeposition and slumping (Bagnall, 1960). The resulting sedimentation rates of 3-10m/Ma from other authors and areas might be more realistic values.

Comparing the lithologies of the onset of reduced sedimentation, the youngest clearly resolved gap in the Ayios Nicolaos section coincided with the start of thick marl layers in the chalks. In the Kouka section, the gap in dating is found where a chert-bearing interval at the top of the Chalk unit starts. Similarly, the time gap in the Lefkara section is found above chert-rich strata of assumed turbiditic origin. In the Motorway section the decreased sedimentation rate starts with first indications of contourites (see Chapter 4.3.2.7.). The rather short time gap in the Kalavasos section is limited to the lowest part of the Upper Marl unit. The Stavrovouni section is the only one where a sample is dated to N1 of the Middle Oligocene and no younger hiatus is resolved since higher samples are absent. This coincidence between the start of slow or possibly discontinuous sedimentation and the change in lithology is most likely causally related and is discussed in Chapter 5.2..

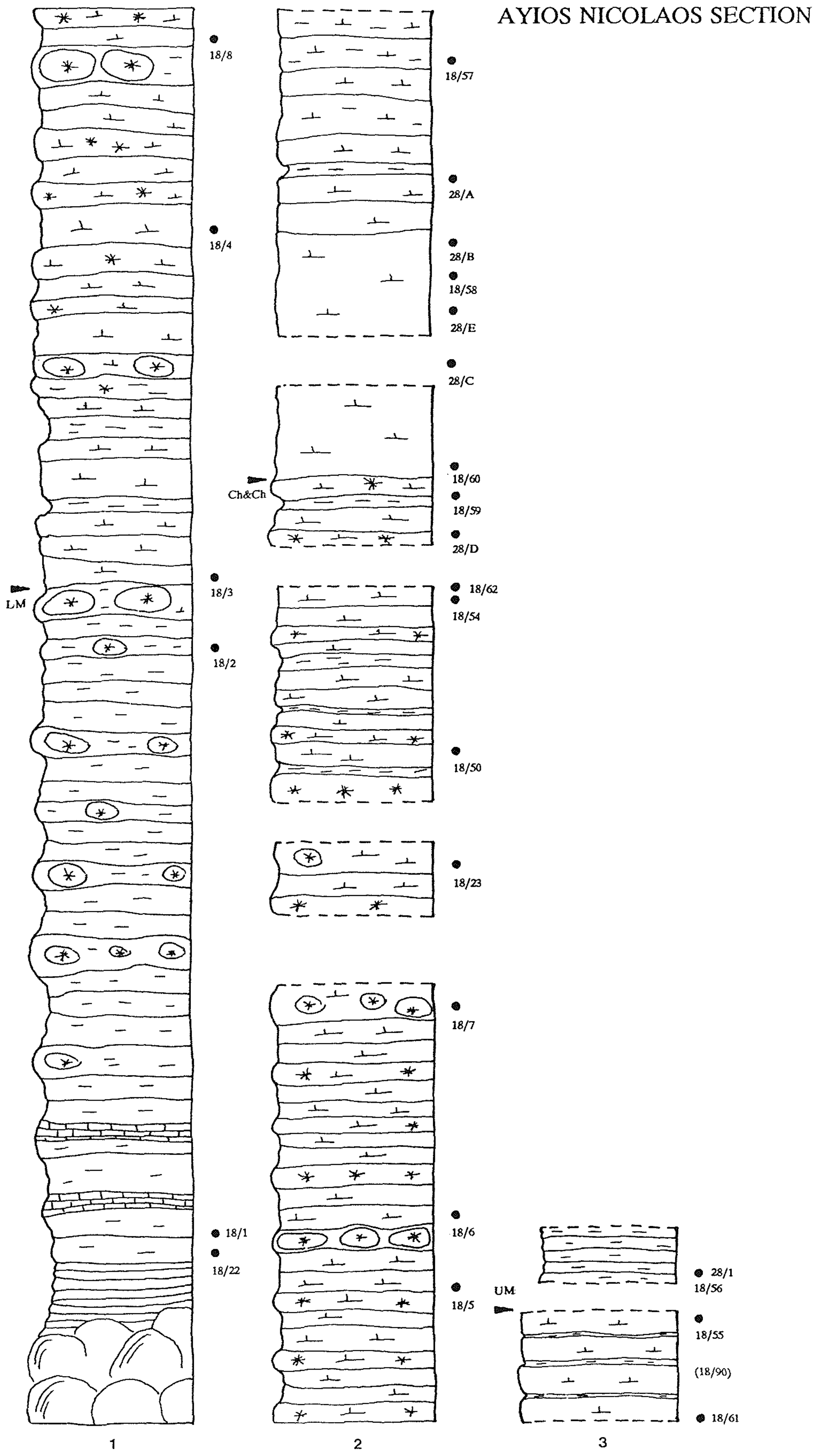


Fig.24. Simplified logs of the Ayios Nicolaos section, showing the measured parts of the outcrops. Unit boundaries and position of the samples analysed are added. For legend see Fig.27.

KOUKA SECTION

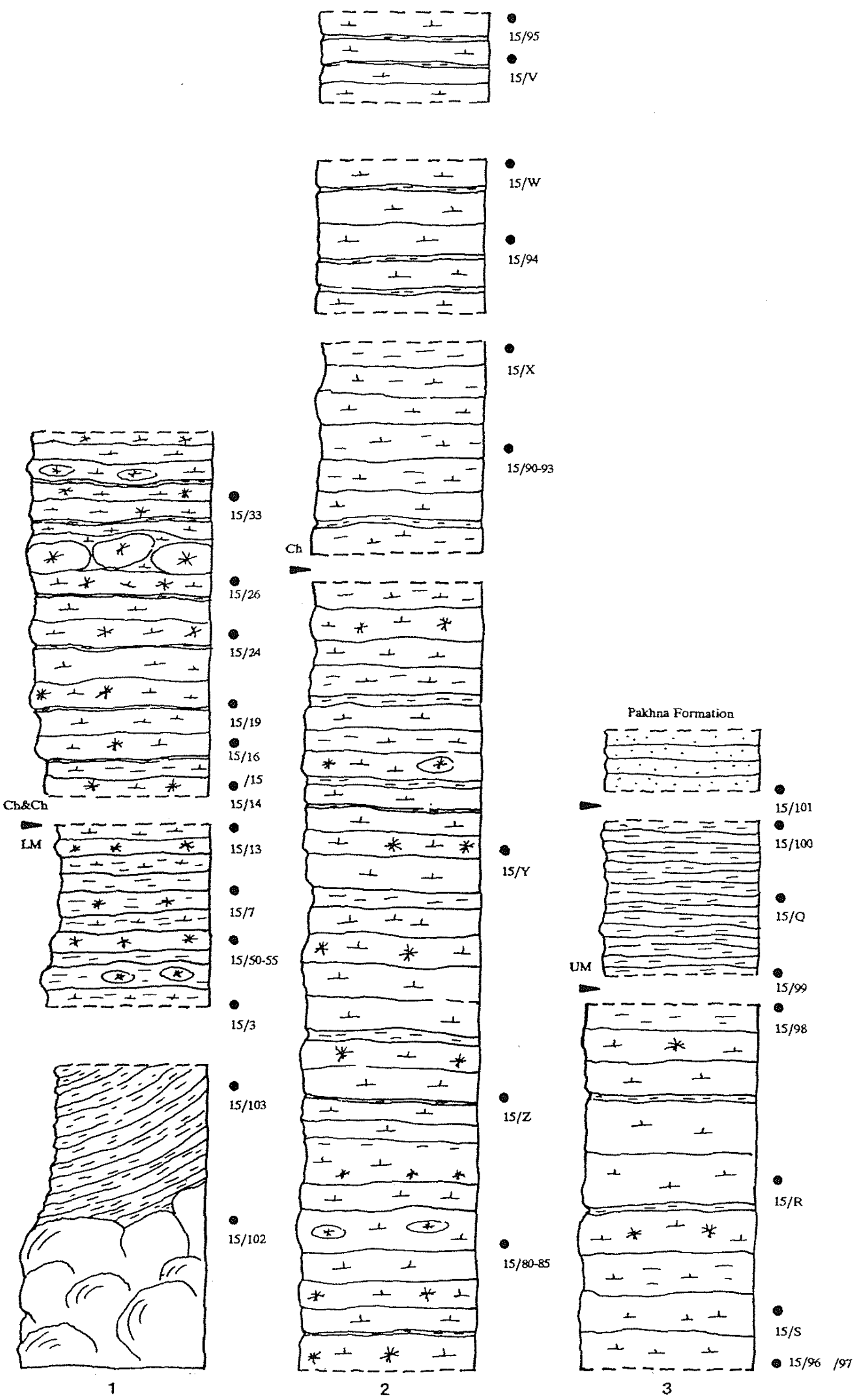


Fig.25. Simplified logs of the Kouka section; for explanation see Fig.24.

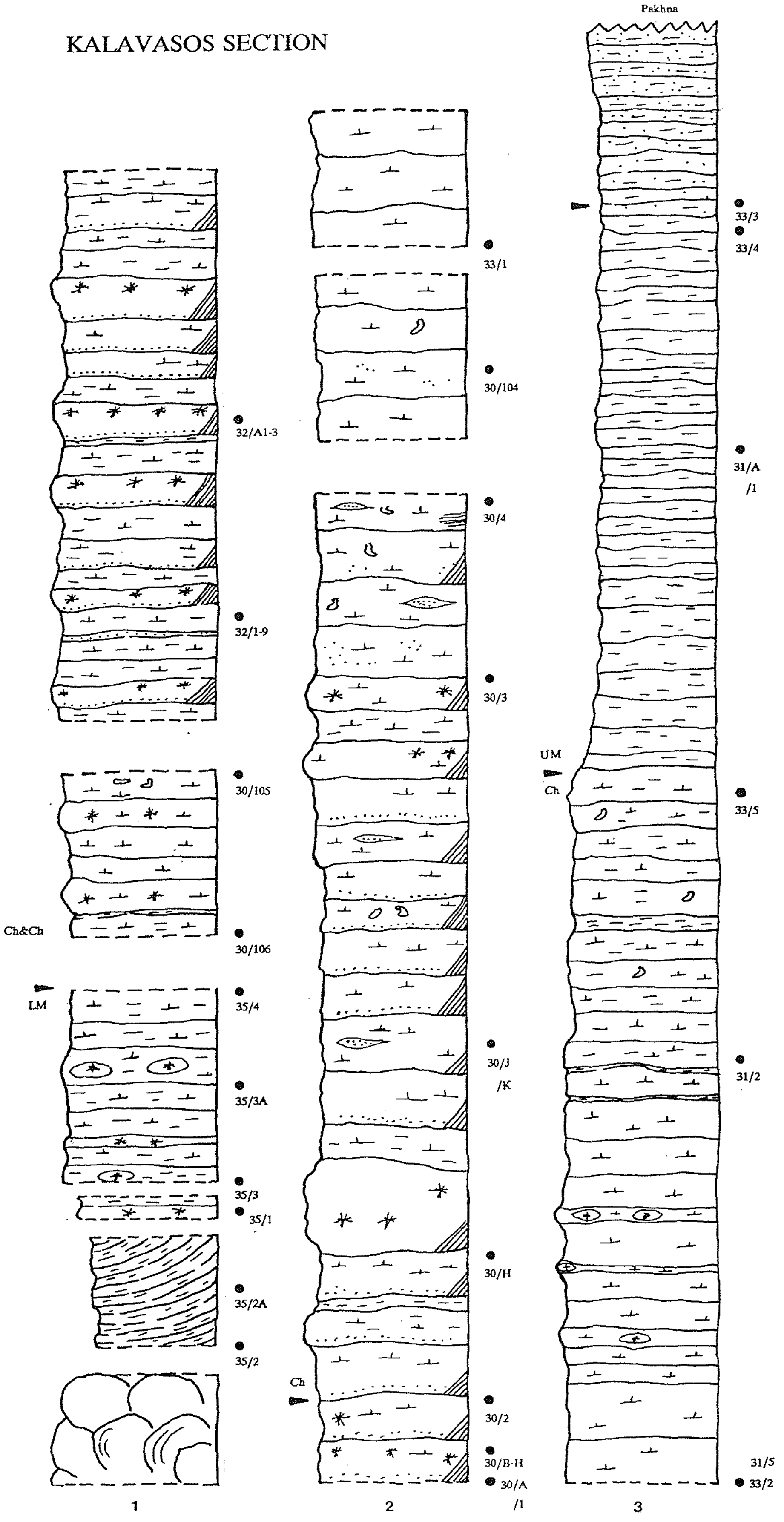


Fig.26. Simplified logs of the Kalavasos section; for explanation see Fig.24.

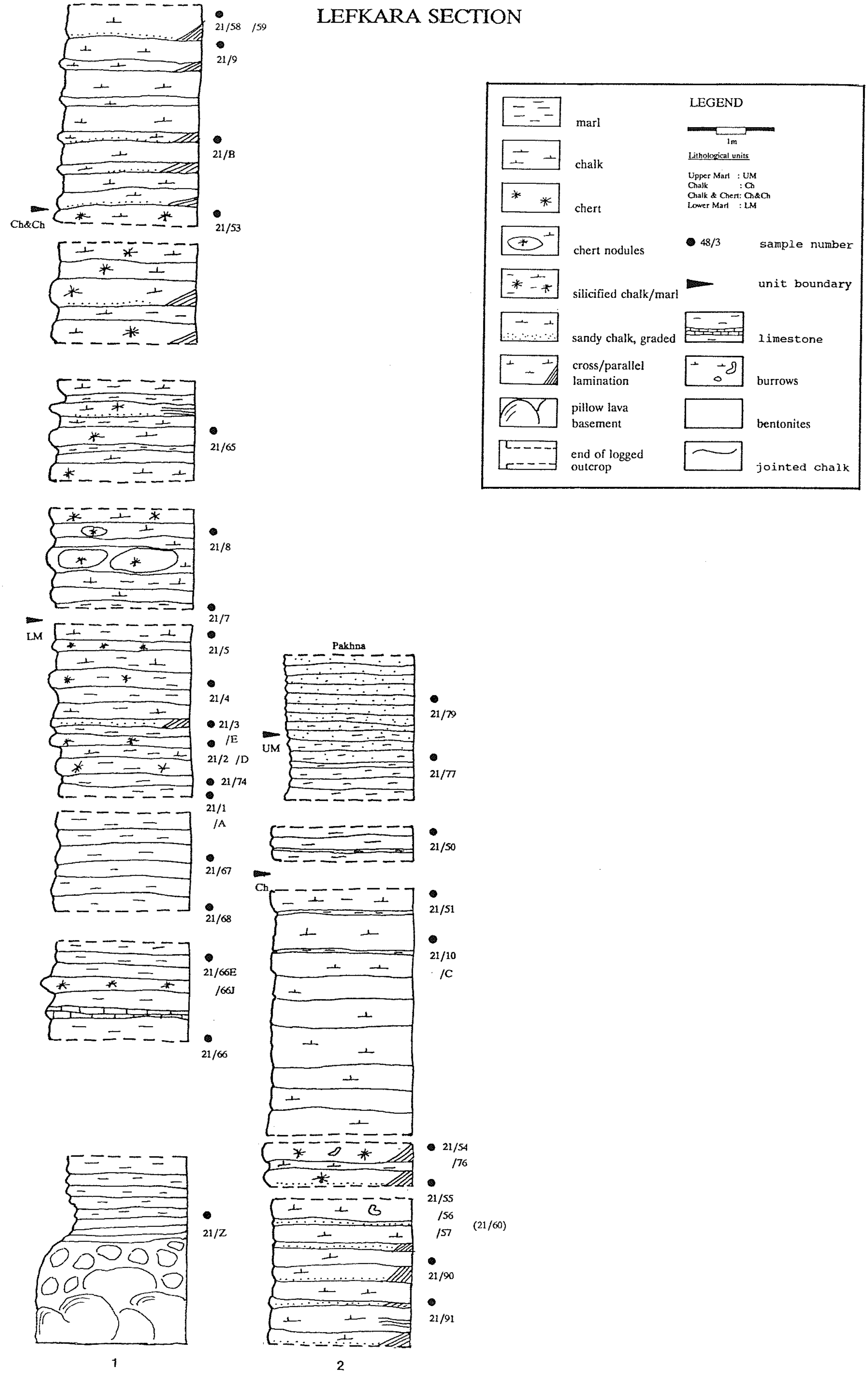


Fig.27. Simplified logs of the Lefkara section; for explanation see Fig.24.

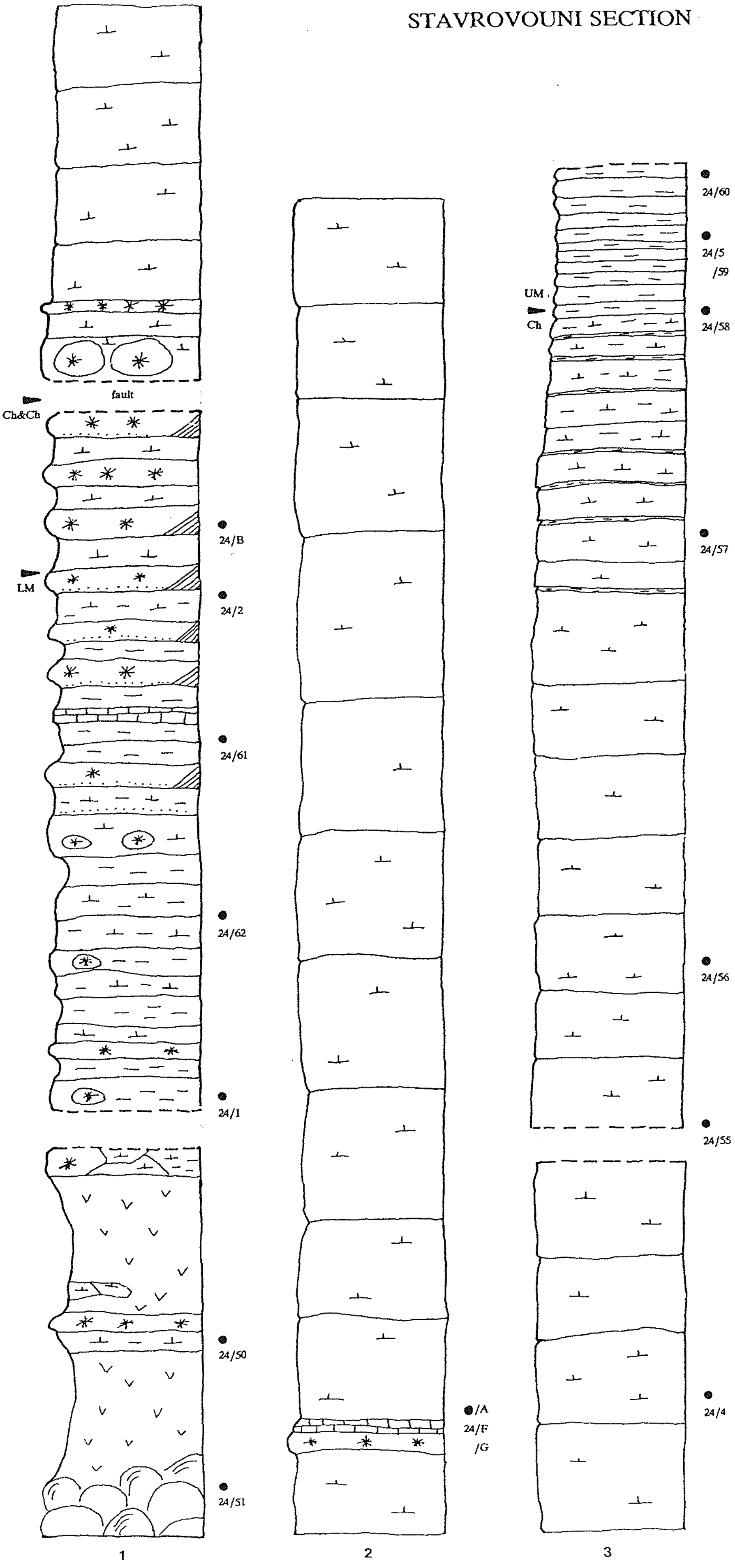


Fig.28. Simplified logs of the Stavrovouni section; for explanation see Fig.24.

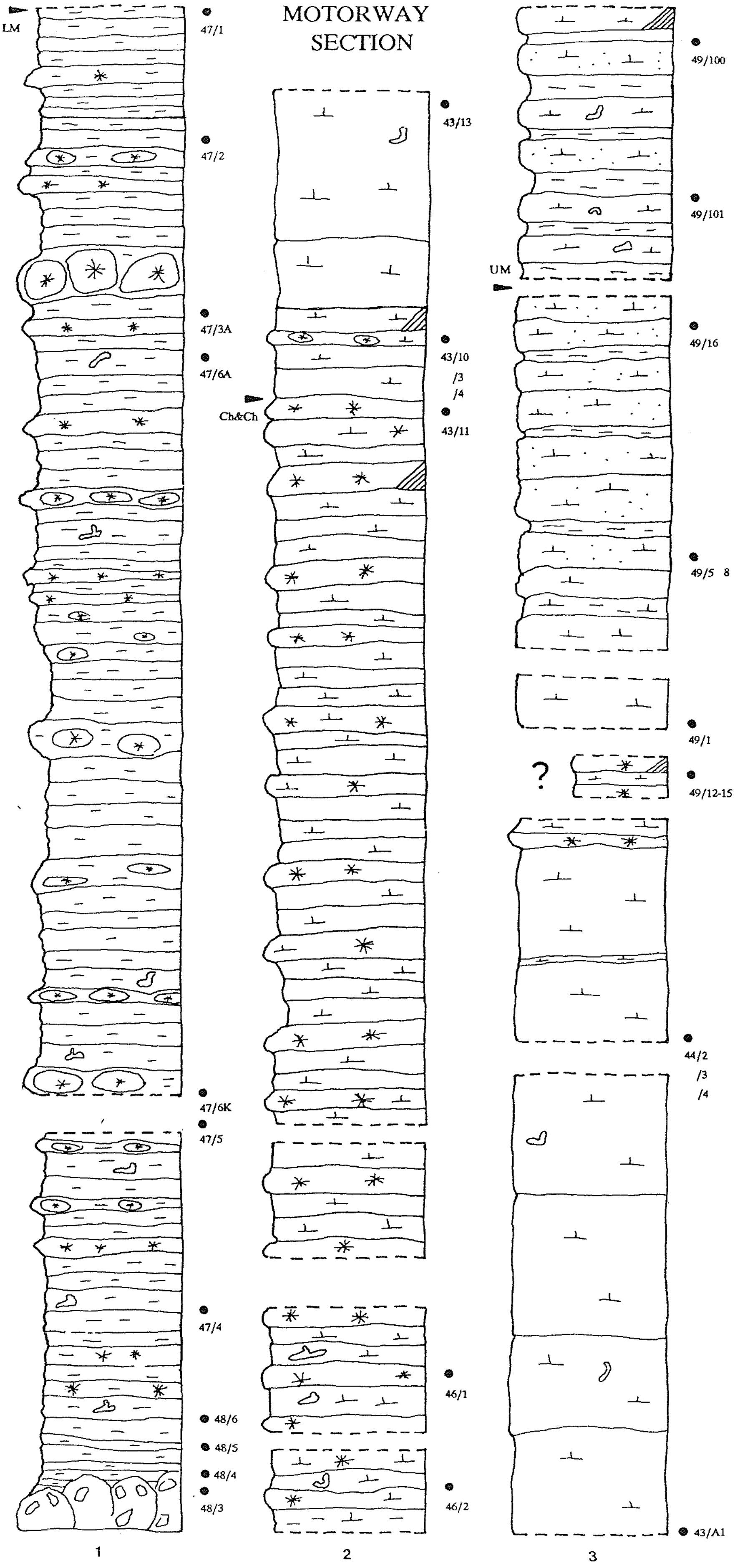


Fig.29. Simplified logs of the Motorway section; for explanation see Fig.24.

CHAPTER 3
RESULTS OF THE SEDIMENT STUDIES

3.1. FIELD DATA AND MACROFACIES

3.1.1. SECTIONS LOGGED

The approximate geographic position of the six sections on the island is shown in Figure 5. In the following, the exact localities, the characteristics of the sections, and simplified logs, highlighting the most important lithological variations (Figs.24-29), are presented.

Ayios Nicolaos section (Fig.24)

In the Ayios Nicolaos section all lithological units are well exposed along the road Ayios Nicolaos-Mandria (Figs.30-33). Nevertheless, most of the succession, especially the chert-free upper part of the formation, is strongly disturbed by tectonics. The basal Lower Marl strata of the Lefkara Formation are deposited on top of bentonites (Fig.32) which themselves overlie pillow lava. Due to faults the dip and strike measurements vary between 5/300 NW for the Chalk & Chert unit, 25/140 SE in the Chalk unit, and 70/240 SW in the Upper Marl. Further outcrops apart from the ones logged and described are found further along the road.

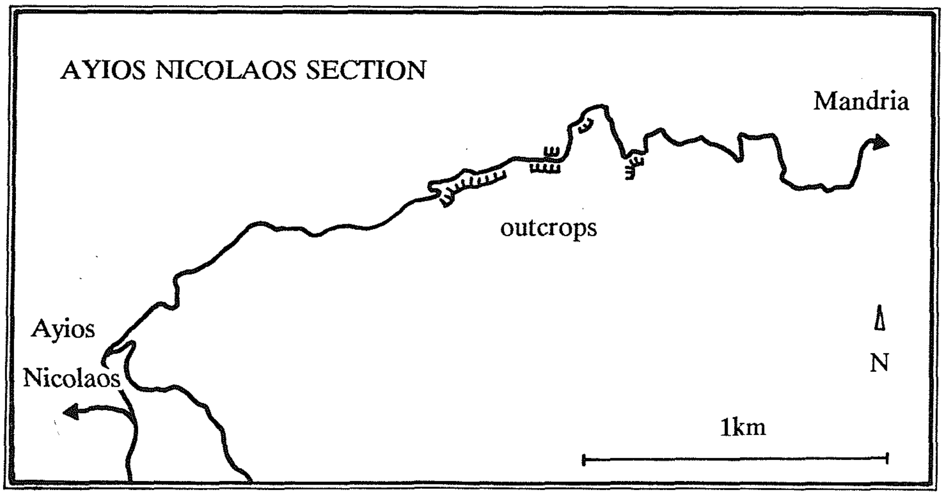


Fig.30. Locality map of outcrops studied in the Ayios Nicolaos section.

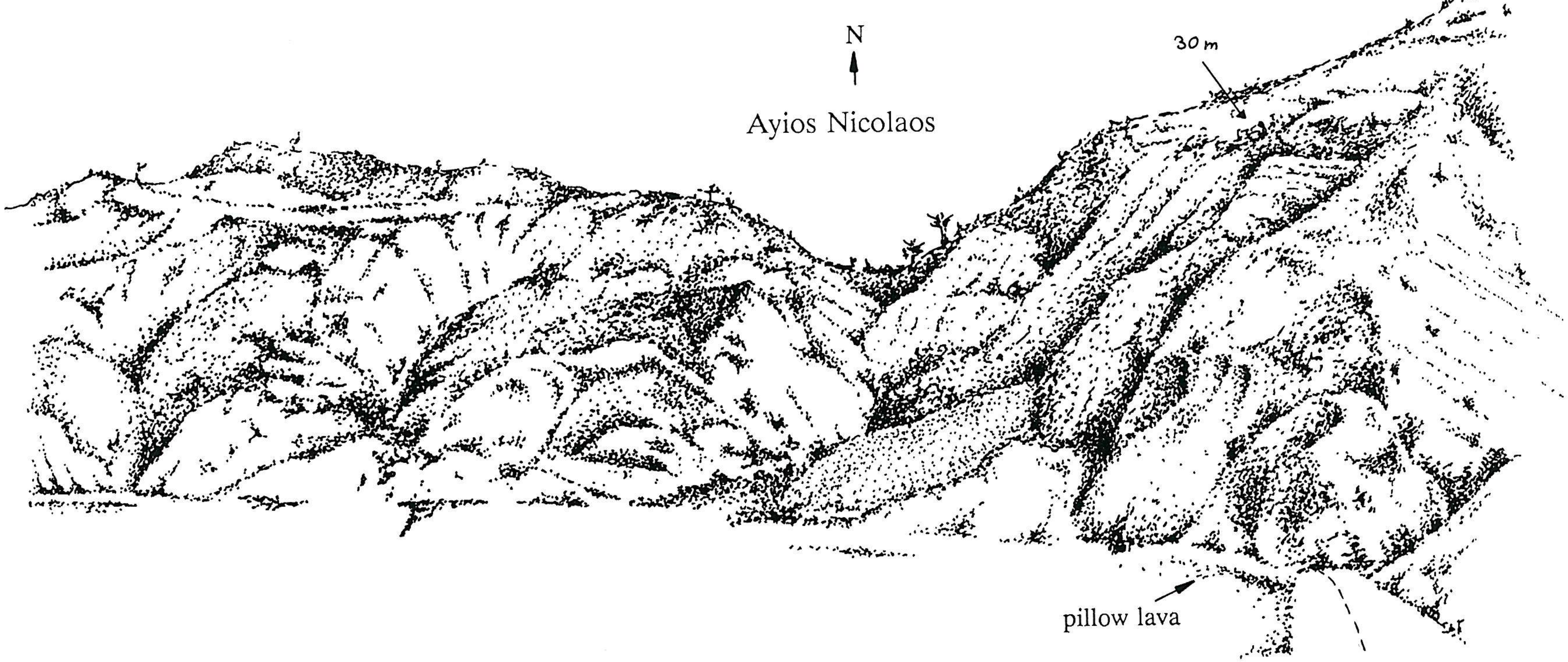


Fig.31. Panorama sketch with outcrops of the Lefkara Formation, Ayios Nicolaos-Mandria road.

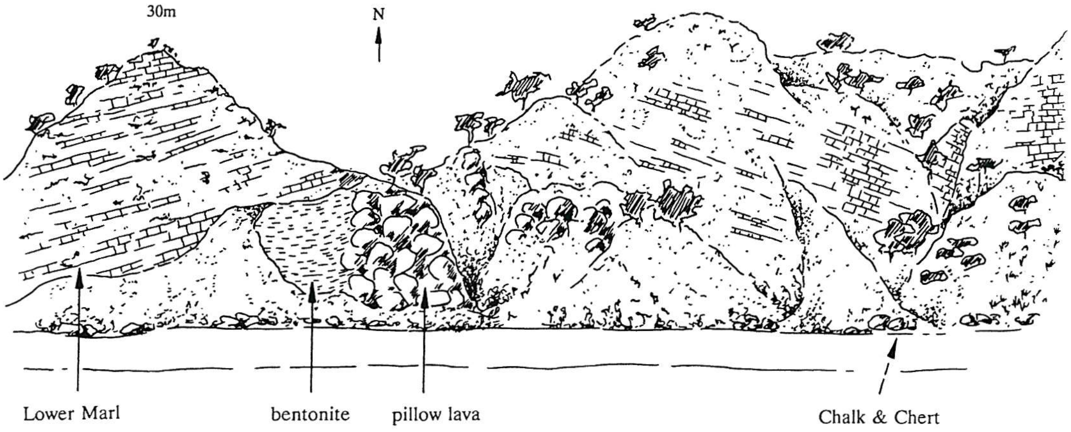


Fig.32. Detail of Fig.31. Contact of the Lefkara Formation with underlying pillow lava and bentonites and upward succession from bedded Lower Marl deposits into the Chalk & Chert unit, Ayios Nicolaos section.

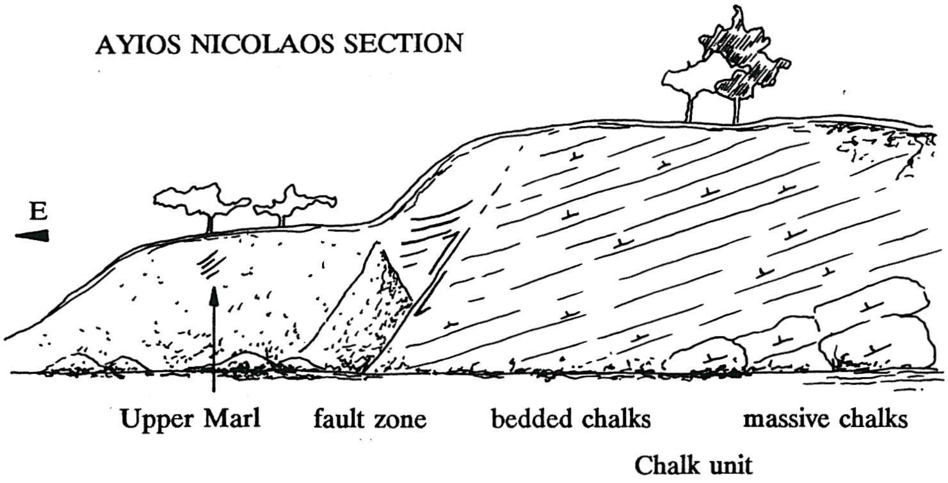


Fig.33. Outcrop of the Chalk and Upper Marl units in the Ayios Nicolaos section, including the transition in lithology from massive to well bedded chalks. The section is approximately 100m long.

Kouka section (Fig.25)

The outcrops of the Kouka section lie to the south of the small village Kouka at the southern margin of the Troodos Massif along the road between Kouka and Silicou (Fig.34). All lithological units of the Lefkara Formation are present in this section although the succession is not continuously exposed (Fig.35). The contact of the Lefkara Formation with the igneous basement is exposed a few hundred metres further north along the Perapedhi-Trimiklini road. Here, the varying dip of the Lower Marl sediments indicates deposition in a depression of the pillow lava surface (Fig.36). Small scale faulting in the chert-bearing layers and folding in the chert-free part of the succession is observed. The sediments of the Lower Marl unit show average dip and strike values of 20/185 SSE, the ones of the Chalk & Chert unit 20/190 SSW, and the Chalk unit (excluding a large fold) of 15/200 SW, whereas an interval of chert-bearing strata near the top of the Chalk unit shows strike-values between 200 and 270.

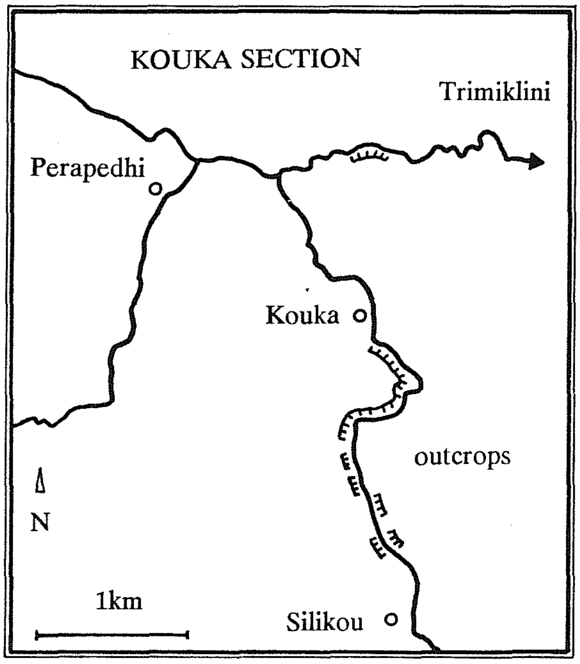


Fig.34. Locality map of outcrops studied in the Kouka section.

Fig.35. Examples of sediment successions from the Kouka section.

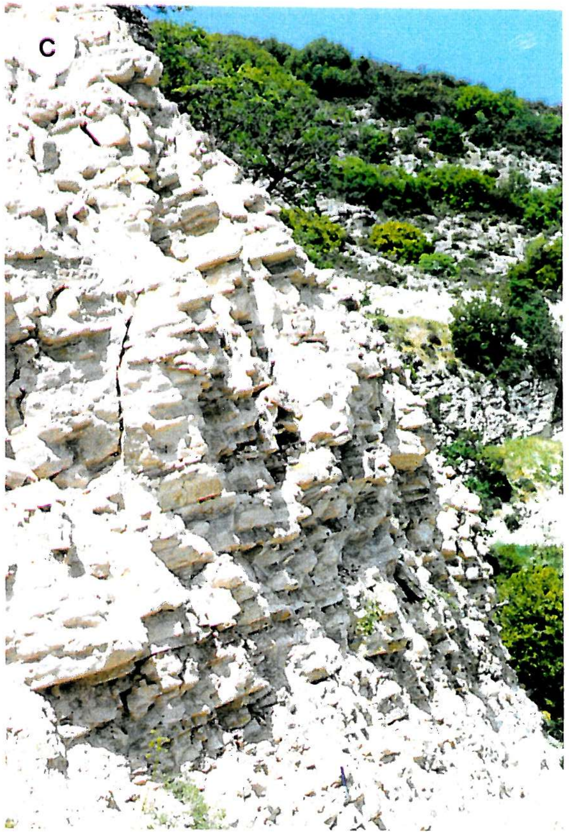
A Interval of well bedded, silicified carbonates near the top of the Chalk unit, interpreted as contourites (outcrop approximately 10m wide)

B Thick-bedded strata of the Chalk unit with faint changes in material visible

C Bedded Chalk & Chert unit


A


B


C

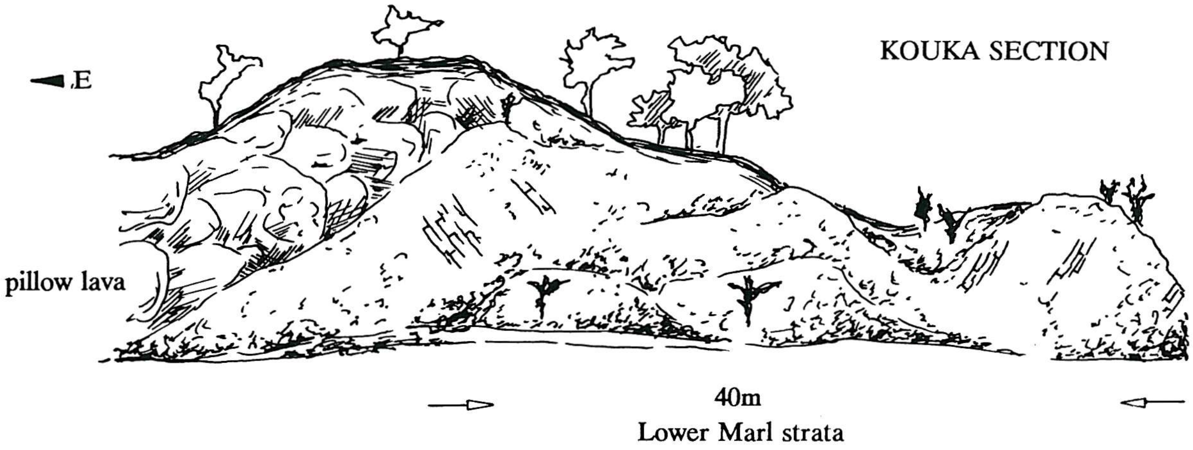


Fig.36. Outcrop containing the lowest strata of the Lefkara Formation in the Kouka section, with chert-free Lower Marl directly overlying pillow lava. The dip of the sediments indicates deposition in a hollow on an irregular sea floor.

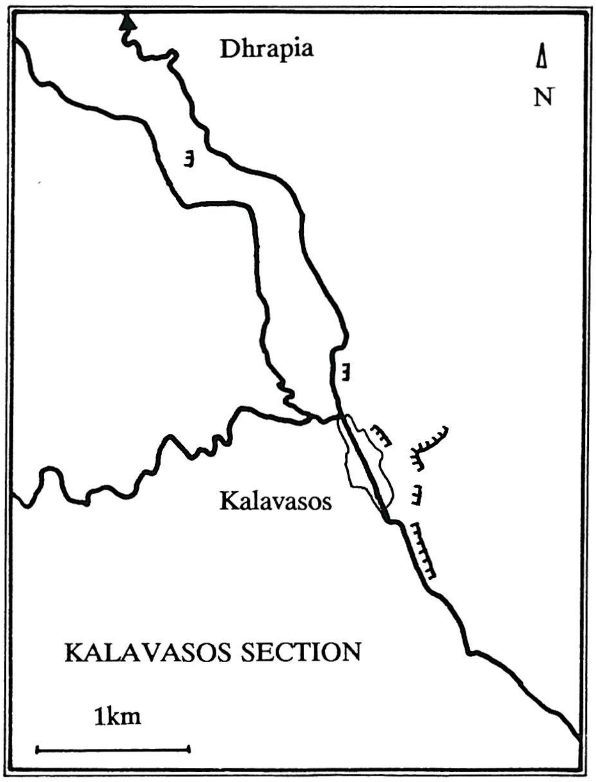


Fig.37. Locality map of the Kalavasos section. In the outcrop on the way to Dhrapia the contact of the Lower Marl with the volcanics is exposed.

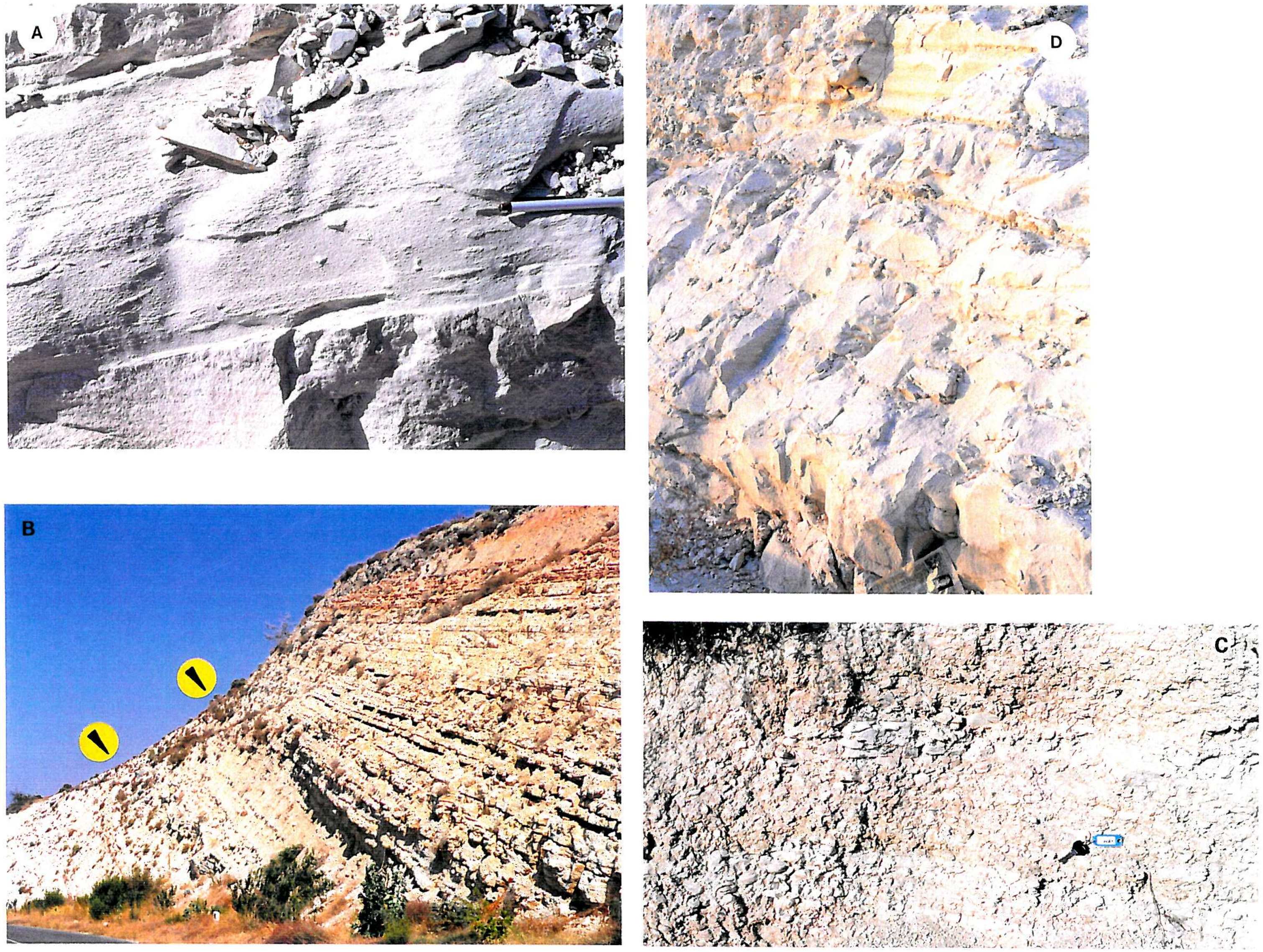
Fig.38. Exposures of the Kalavasos (A-C) and Motorway (D) sections.

A Uppermost part of the turbidite sequence (Chalk unit) with lamination and burrows visible.

B Outcrop containing the transition from the Chalk unit to the (thin developed) Upper Marl to the Pakhna Formation, as indicated by the arrows.

C Lower Marl lithology.

D Chalk unit of the Motorway section, faint bedding is possibly due to contour current influence.


A
D
B
C

Kalavasos section (Fig.26)

The Kalavasos section includes outcrops of the Lefkara Formation to the east and southeast of the village together with exposures of Lower Marl deposits in the valley to the northwest, where the contact with the pillow lava is found (Fig.37). All lithological units are recognised, with thick deposits of the turbidite-influenced Chalk & Chert and Chalk units and the exceptionally well exposed succession from the upper part of the Chalk unit into the Pakhna Formation (Fig.38 (A)-(C)). No indications of major tectonic disturbance of the sedimentary succession are observed. The dip and strike angles of all measured parts of the section except the basal sediments are consistent and vary between 15/150 SE and 10/165 SE.

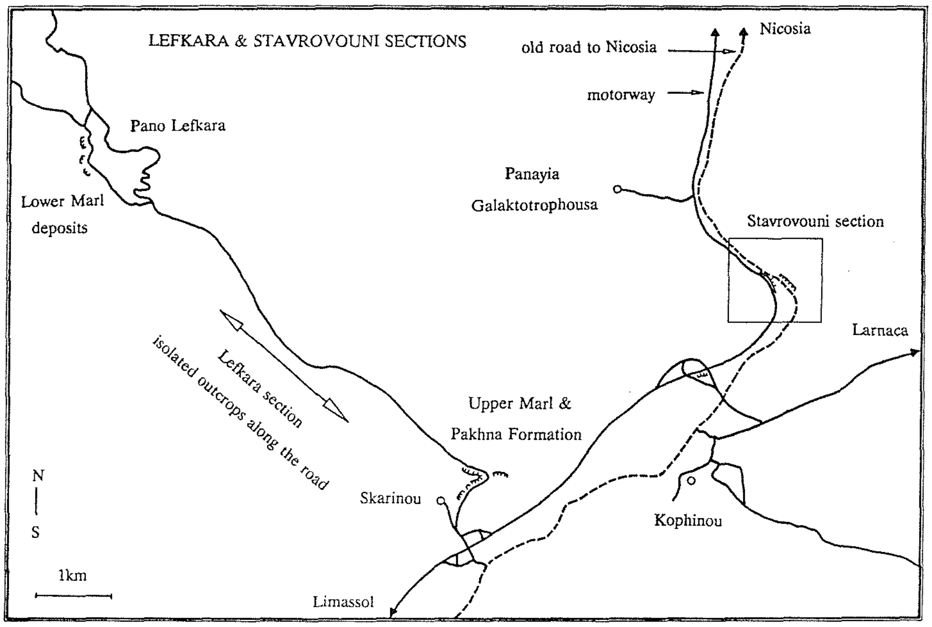


Fig.39. Locality map of the Lefkara and Stavrovouni sections. In the Lefkara section numerous outcrops of the Chalk & Chert and Chalk units are exposed along the whole length of the new road Skarinou-Pano Lefkara.

Fig.40. Lithologies of the Lefkara (A-E) and Stavrovouni (F) sections.

A Casts of burrows in a calcarenitic turbidite bed.

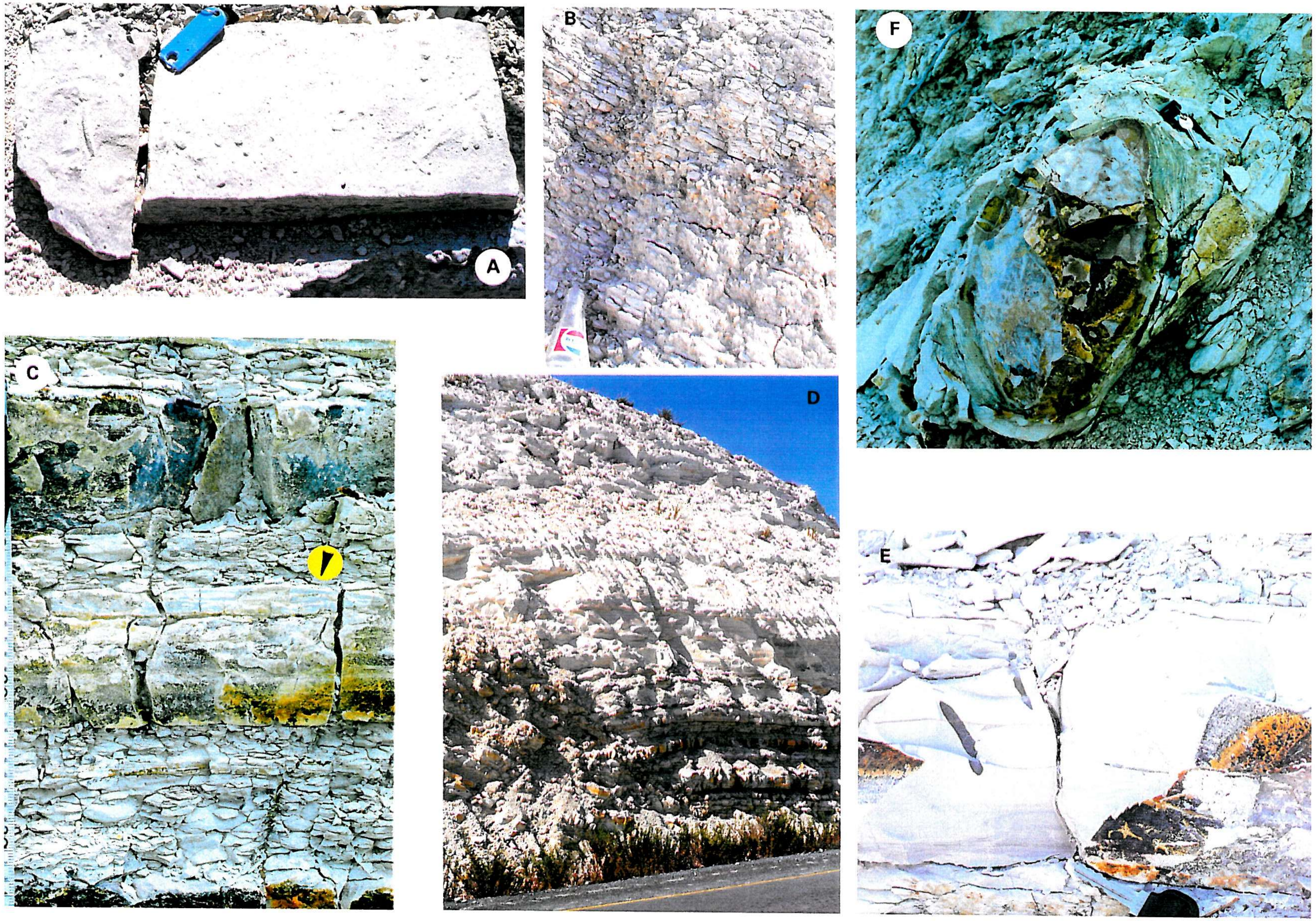
B Upper Marl facies.

C Succession in the Chalk & Chert unit with alternating marly chalks and silicified calciturbidites; arrow marks chertified cross laminae.

D Large fault in the Chalk & Chert unit, transition to chert-free chalks is exposed at the top of the outcrop.

E Chert-filled almost vertical or branched burrows (possibly *Thalassinoides*) reaching from structureless chalk into a cross-laminated turbidite.

F Large chert nodule from the Stavrovouni section, Chalk & Chert unit.


A
B
F
C
D
E

Lefkara section (Fig.27)

The Lefkara section is the type locality of the Lefkara Formation. The contact with the igneous basement is sampled at a distance of several km from the main outcrops exposed at the motorway. All main outcrops lie along the new road leading from the valley at the level of the motorway up to the village Pano Lefkara (Fig.39). The whole length of the road cuts through Lefkara sediments (Fig.40 (A)-(E)). The thickness of the succession is deceptive since the same strata outcrop at different altitudes of the road if the average dip of the sediments is parallel to the slope of the road. Nevertheless, the rocks have highly variable dip and strike values due to tectonic disturbances. Folds in the chert-free succession and block faults in all lithologies are common (Fig.40 (D)). Although the succession is several kilometre long only short logs of undisturbed sediments could be measured since the single outcrops could rarely be correlated. Nevertheless, all lithological units of the Lefkara Formation are present in the section.

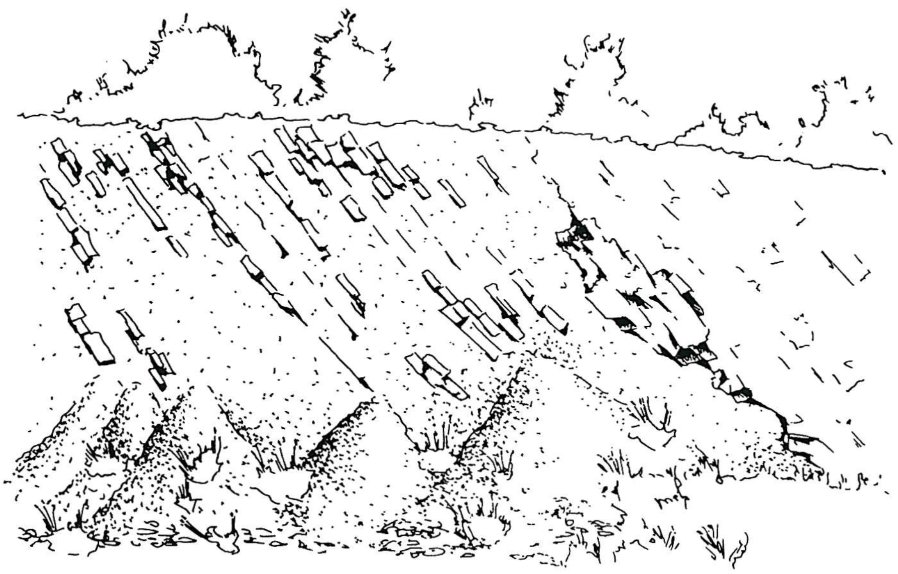


Fig.41. Outcrop of the Stavrovouni section, including a large fault with tectonic-related chert development (centre). To the right of the fault, strongly weathered Lower Marl and Chalk & Chert sediments; to the left, chert-free massive chalks. Outcrop approximately 5m high.

Stavrovouni section (Fig.28)

The Stavrovouni section is a small area of outcrops in the south of Stavrovouni Forest and in the north of Kophinou along the old road to Nicosia (Fig.39). The succession includes sediments from the upper part of the Lower Marl to the Upper Marl. Pakhna sediments were not found. Although the pillow lava outcrops at a distance of approximately 50m from the main section there are no clear Lower Marl sediments present from the lower part of the unit. However, small exposures of a limestone breccia contain silicified marls similar to those of the Lower Marl. The whole succession shows strong indications of tectonic disturbance with frequent faults present. The Chalk & Chert unit is represented only by few metres and is terminated at the top by a major fault (Figs.41, 40 (F)). It is possible that most of the upper part of the unit is tectonically truncated. The dip values vary strongly especially in the upper part of the Chalk unit with values between 25° and 55°. In contrast, the strike is comparatively constant around 150° SE.

Motorway section (Fig.29)

The Motorway section is a succession of outcrops all exposed along the new motorway connecting Nicosia and Larnaca. The Lefkara sediments outcrop between a few kilometres west of Lymbia and northwest of Aradhippou (Fig.42). All lithological units except typical Upper Marls are present and the succession starts in direct contact with the volcanic base (Fig.43 (A),(B)). The Upper Marl deposits are not developed in the same facies as in the other sections

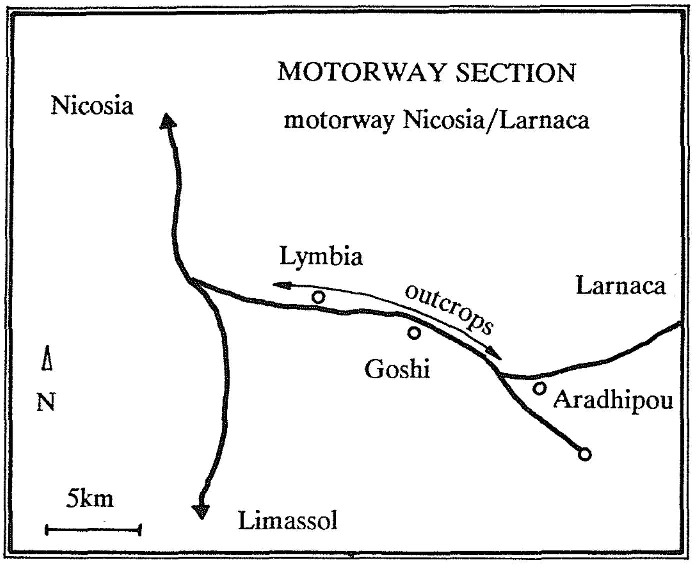


Fig.42. Locality map of the Motorway section. Isolated outcrops occur along the new Motorway between west of Lymbia and west of Aradhippou.

Fig.43. Exposures of the Lefkara Formation in the Motorway section.

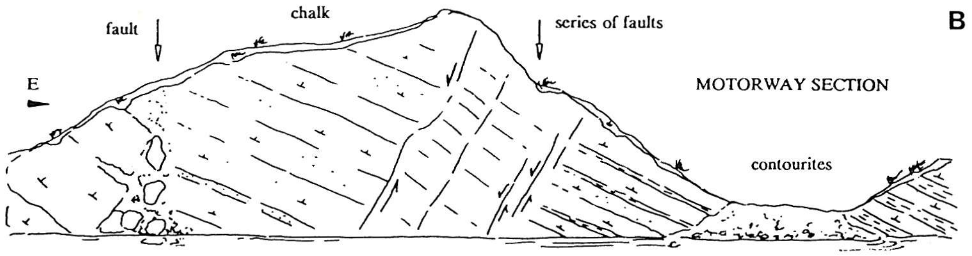
A Succession from pillow lava into overlying chert-poor pinkish Upper Marls.

B Detail from A, direct contact between altered lava and few cm of clay-rich marl, above: soft pinkish marl forms the base of the characteristic Lower Marl facies.

C Massive chalks from the Chalk unit with faint but laterally continuous bedding visible.

D Silicified brownish chalk from the base of the Chalk & Chert unit; in the silica-enriched base of the bed mottling is preserved.


A
C
B
D



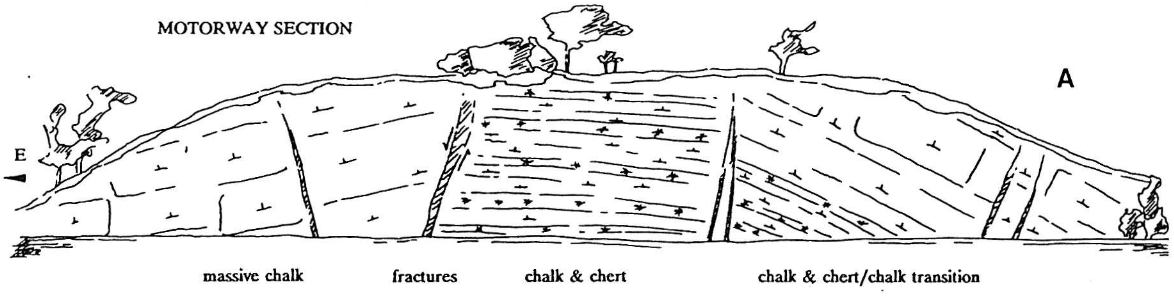


Fig.44. Outcrops from the Motorway section. **(A)** Strongly faulted succession containing blocks of massive chalk (Chalk unit), chalks with chert (Chalk & Chert unit) and the continuous transition from the Chalk & Chert unit into chert-free turbidites. Outcrop is approximately 500m long; **(B)** Faulted succession of the uppermost Chalk unit and the Upper Marl-equivalent contourites. Outcrop is approximately 350m long.

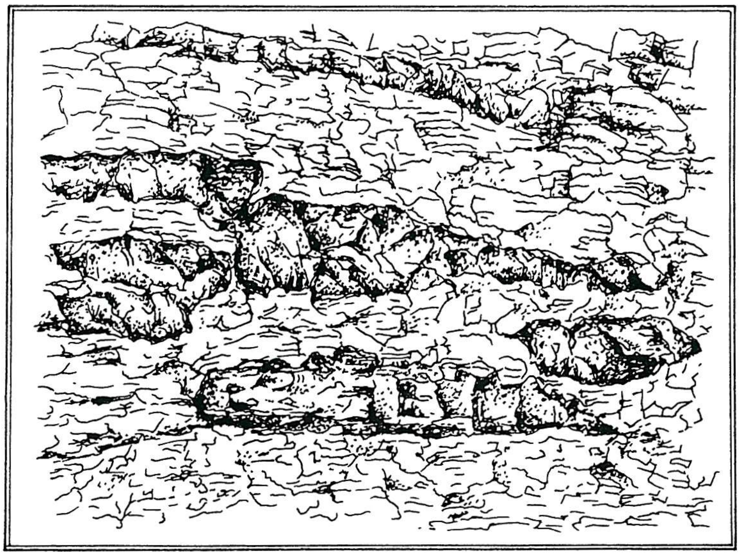


Fig.45. Faulted chert beds from the Chalk & Chert unit in the Motorway section. Chert strata are 20cm thick on average.

(Fig.44 (A)). Nevertheless, a change in material above the chalks indicates these sediments to be an equivalent to the marls. The Pakhna Formation was not found in direct contact with the uppermost Lefkara sediments but at a distance of some kilometres near the motorway junction at Aradhippou. Strong faulting was observed in most outcrops of the Motorway section (Fig.44) starting in the top-sediments of the Lower Marl unit. A major disturbance lies between a Chalk & Chert and Pakhna outcrop several kilometres south of Lymbia. A second large scale fault was found near the top of the Chalk unit where the Chalk & Chert unit outcrops. Microfossil dating shows that the cherts are older and not related to a change in facies and consequently must have been displaced. Due to tectonics the dip and strike values vary in the whole area. The base of the succession has an average strike of 240°SW with a dip of 15°, and the Upper Marl equivalent sediments of 15/110 ESE.

The detailed logging of all sections proved to be difficult in many cases which resulted in short logs. The reasons for this are: (1) the subhorizontal dip of many strata resulting in either a short vertical extent and/or poor accessibility of the outcrops, and (2) numerous faults coupled with the lack of marker beds which made it impossible to trace the lateral continuation of beds to another part of the area where the vertical section might have been extended (Fig.45).

Bed thickness measurements are rather vague since variations in composition are commonly faint, weathering obscures an existing bedding or chert accumulations mimic independent beds or reduce the original number of beds. The most common inaccuracy in the measurement of bed thicknesses is their common gradational contacts.

3.1.2. CHARACTERISTICS OF THE LITHOLOGICAL UNITS

Following the unit subdivisions of the Lefkara Formation as outlined in the introduction, the vertical facies variations are studied for the six sections. Many characteristics can be followed in all localities analysed, as shown in Figure 5 (see also Figs.24-29). Rather than giving a detailed description of every outcrop, in the following section the lithological units are described as they are observed in the field and the individual features of the single localities are compared. Bed thicknesses of logged outcrops are illustrated in Figure 46.

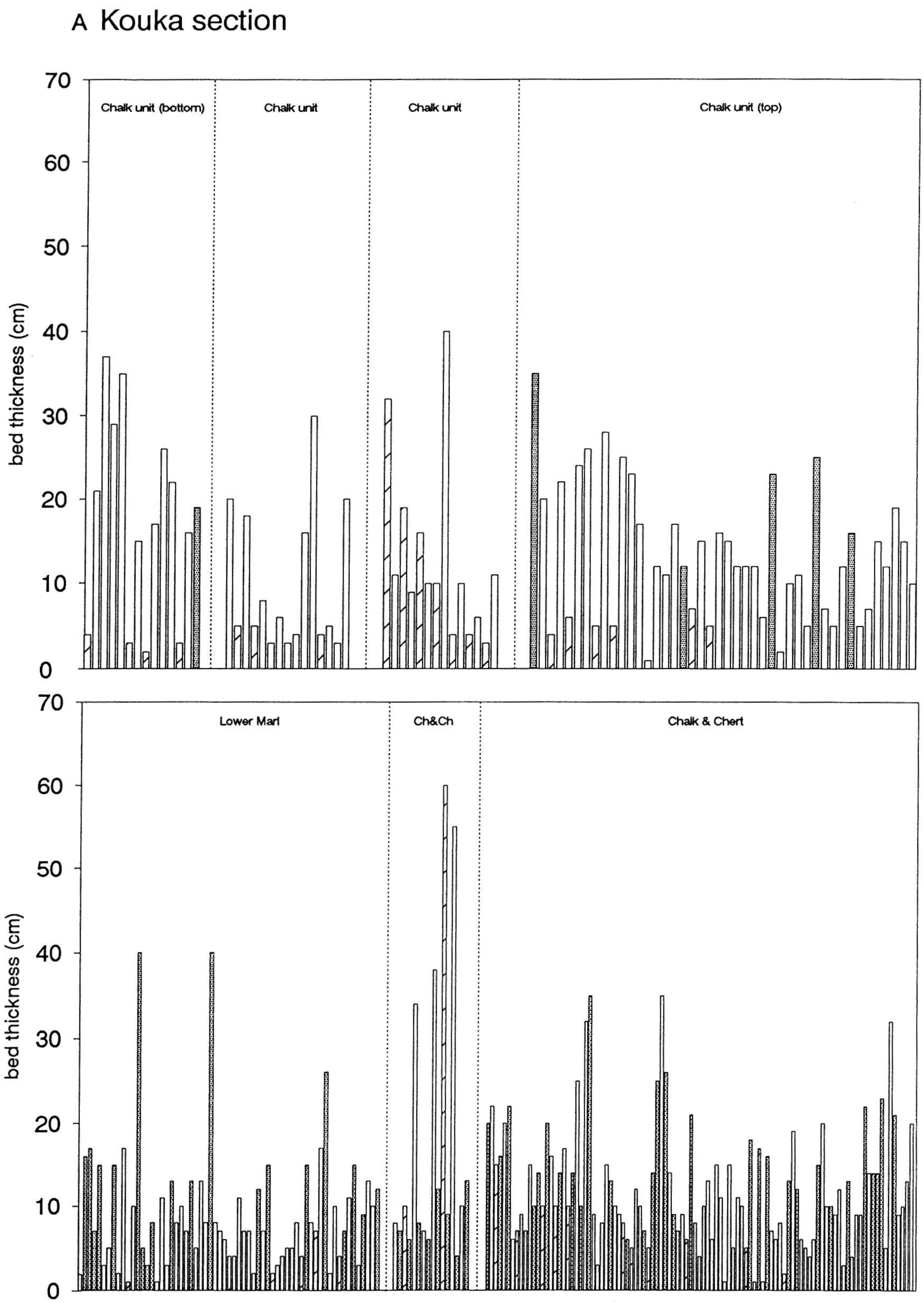


Fig.46. Bed thicknesses from logs measured in detail; gaps in logging are indicated by broken lines. For ornament see Lefkara section.

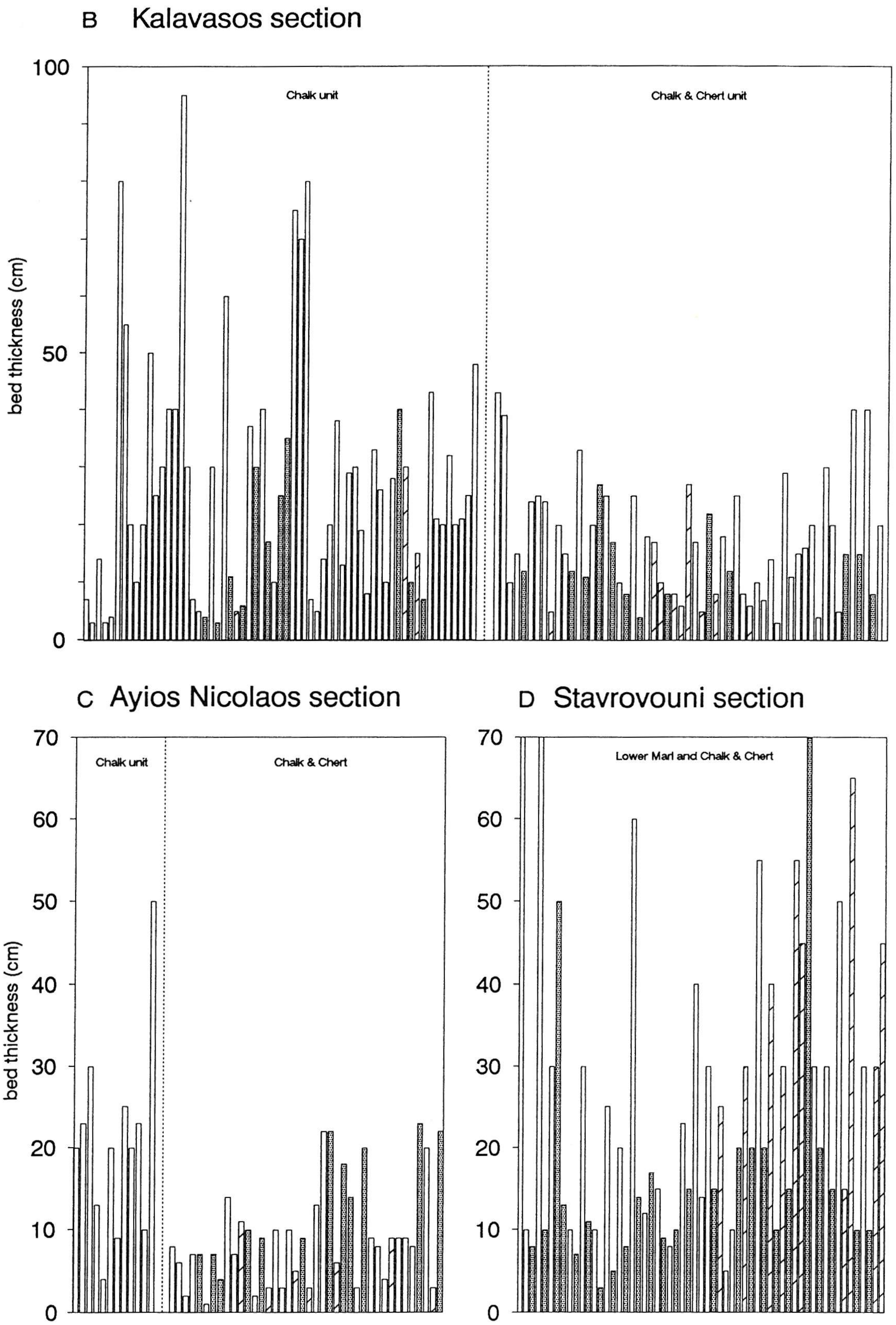


Fig.46 continued.

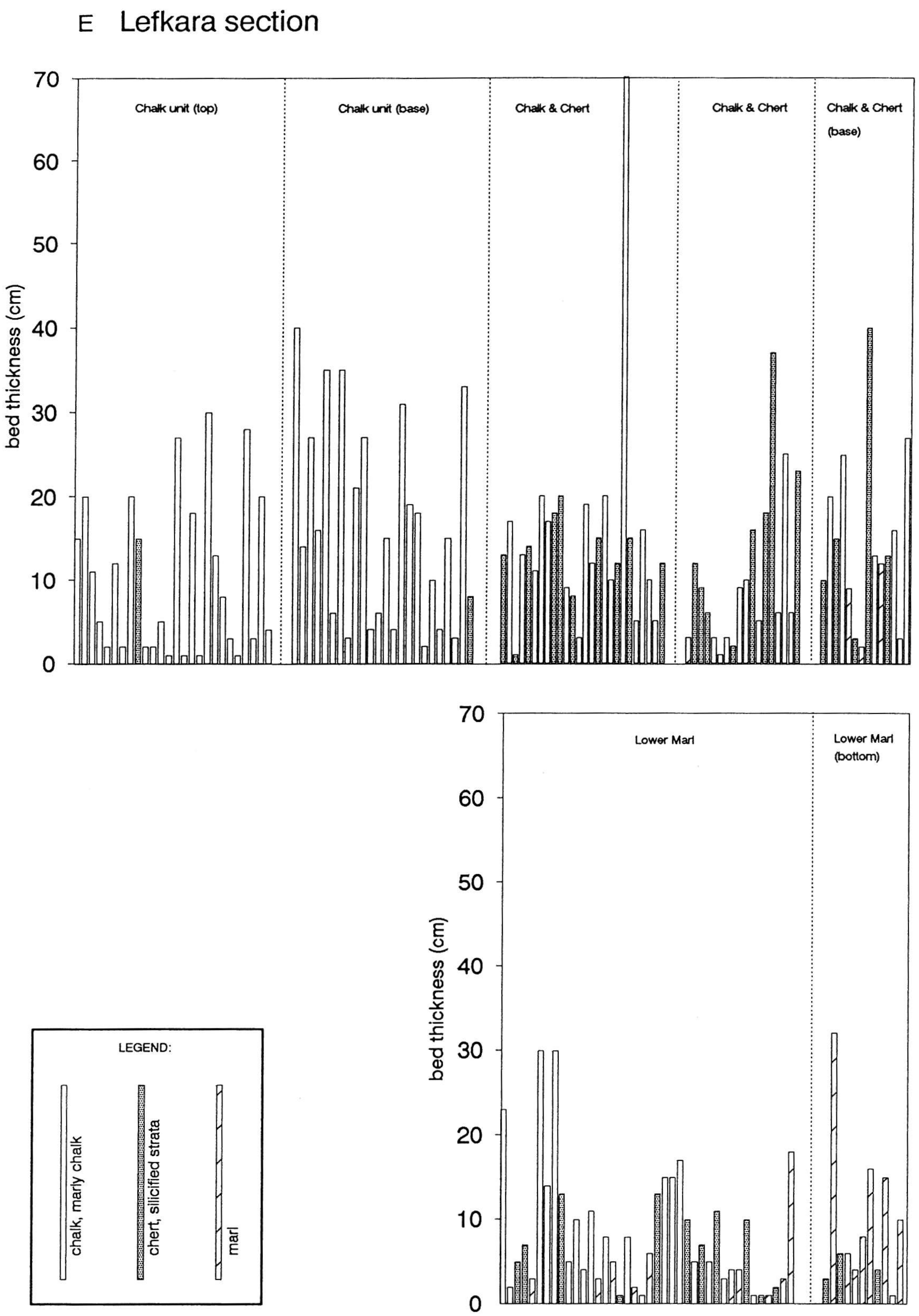
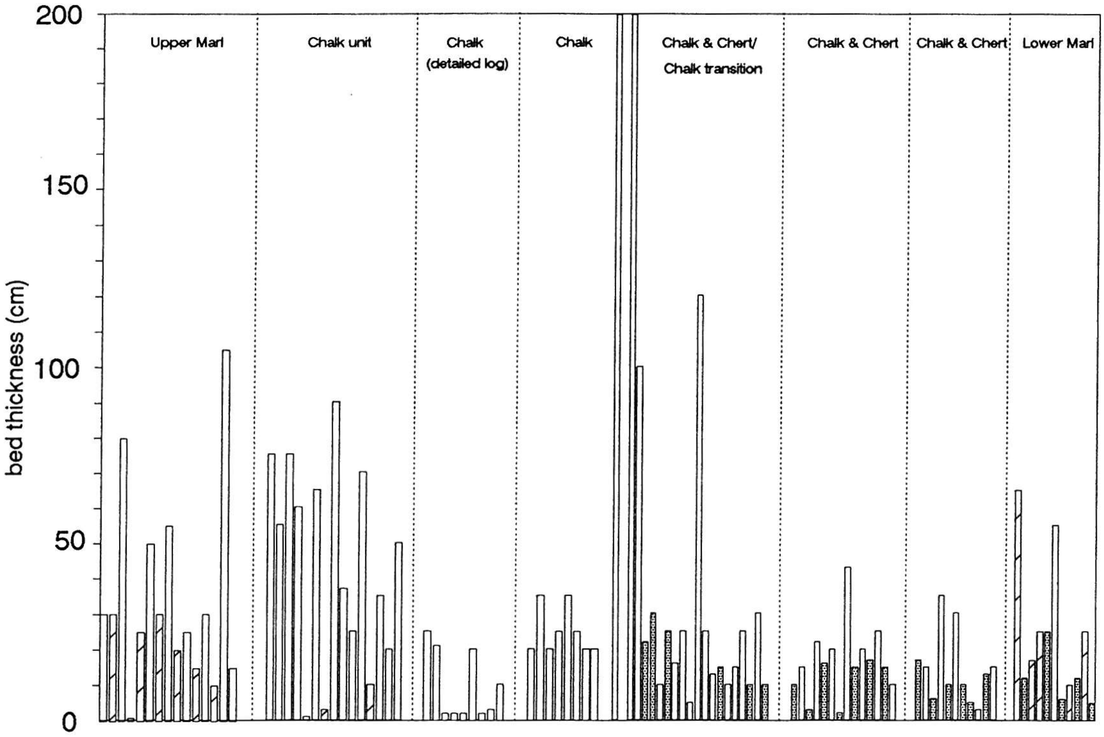


Fig.46 continued.

F Motorway section



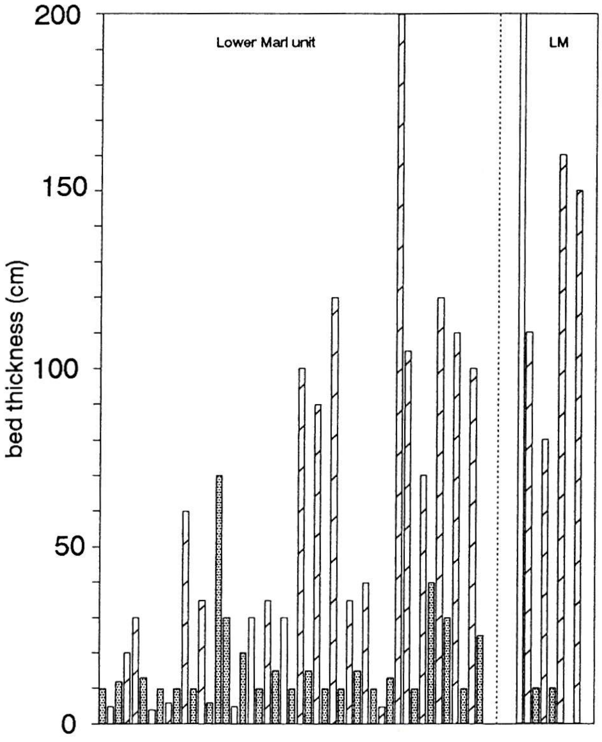


Fig.46 continued.

Lower Marl unit:

Lower part (chert-poor):
The chert-free basal part of the Lower Marl unit was found in all sections except Stavrovouni. Most of these outcrops are only thin relics which are protected by the underlying volcanic rocks from being weathered (Figs.36, 38 (C)). The higher, only rarely silicified strata are entirely eroded except in the Motorway section where the whole succession into the chalky top of the unit is more or less continuous. Here up to 150cm thick marl strata alternate with thin chert horizons (several cm; Fig.43 (A)). Another outcrop was found in Pano Lefkara where some isolated strata of the unit are preserved which must be located somewhere between the basal marls and the pinkish chert-rich marls at the top of the unit. These strata are thin (commonly below 10cm) with limestone beds and lamination visible. A clear and gradual decrease in bed thickness was observed in the Motorway section throughout the whole unit.

Upper part (chert-bearing):
The higher chert-bearing part of the Lower Marl unit is preserved in many localities. Most show a consistent average bed thickness around 20cm (Kouka, Ayios Nicolaos, Motorway sections). In the Lefkara section the beds are thinner, 8cm on average. In the whole upper part of the unit thick marl beds alternate with thinner chert strata. Many of the pinkish marls as well as the cherts are mottled or show clear lenticular burrows. Bioturbation is rare in the Stavrovouni section. An unusual feature is that the Lower Marl sediments of the Motorway section are frequently bioturbated throughout the whole unit starting with the lowermost strata near the pillow lava base. In all localities sedimentary structures are rare in the Lower Marl sediments except in the Stavrovouni and Lefkara sections where they show common turbidite structures. Extreme developments of dm thick chert nodules are common in most sections either in the uppermost part of the Lower Marl or near the bottom of the Chalk & Chert unit (Fig.40 (F)).

Chalk & Chert unit:

Lower part:
In the outcrops of the lower part of the Chalk & Chert unit the beds show a consistent average bed thickness of 9-15cm in the Kouka, Lefkara, Stavrovouni and Motorway sections (Figs.35 (C), 40 (C)). Compared to the upper strata of the Lower Marl, this shows a tendency towards slightly thinner beds. In Kouka and Lefkara the chert layers are of approximately the same thickness as the chalk beds while they are slightly thinner in the Stavrovouni and Motorway sections. Definite marl strata are almost absent in all successions examined but chalky marls are common. Indications of bioturbation are absent or rare in the Kouka and Stavrovouni sections, more

frequent in the Lefkara section and very abundant in the Motorway section (Fig.43 (D)). Sedimentary structures caused by turbidity currents are common in the Stavrovouni section and in the Lefkara section (Fig.40 (E)), where they increase gradually from the top of the Lower Marl towards the higher strata of the Chalk & Chert unit.

Upper part:
The higher part of the Chalk & Chert unit is characterised and dominated by turbiditic sedimentary structures in the Kalavasos and Lefkara sections. In the Stavrovouni section the higher part of the unit is either tectonically truncated, as indicated by a fault visible in the outcrop (Fig.41), or, less likely, the whole unit is condensed and only 3m thick. Nevertheless, the Chalk & Chert unit contains also frequent turbidites here. The western sections, Kouka and Ayios Nicolaos, do not show any clear sedimentary structures in the upper part of the Chalk & Chert unit except for a few laminae in the sediments of the Kouka section and an isolated structured hand specimen from the Ayios Nicolaos section. The Motorway section contains turbiditic strata which are weakly developed. There is an apparent increase in average thickness of beds from west to east. The thinnest beds are measured in the (western) Kouka and Ayios Nicolaos sections, being approximately 11cm on average. In the turbidite influenced sections the average is around 16cm, while in the Motorway section, farthest in the east, the average thickness is increased to 45cm due to the presence of several extremely thick chalk beds. Otherwise chalk and chert beds are of equal dimensions in all sections in the upper part of the unit.

Bioturbation is present occasionally in the highest divisions of the turbidite beds in the Kalavasos and Lefkara sections (Fig.40 (A)). It is rare in the Ayios Nicolaos and Motorway and apparently absent in the Kouka sections. Marl strata occasionally occur in the higher part of the Chalk & Chert unit, except in the Motorway and Lefkara sections. An interval of comparatively thick marl strata was found in the Kalavasos section and marl layers increase gradually towards the top of the Chalk & Chert succession in the Kouka section.

Chalk unit:

Lower part (massive chalks and/or turbidites):
The lower part of the Chalk unit is composed of massive chalks in the Ayios Nicolaos, the Motorway (Fig.43 (C)) and, assuming that the base of the succession is not truncated, in the Stavrovouni sections. The localities containing turbidites (Kalavasos and Lefkara) do not show an interruption in the turbiditic facies across the unit boundary except for the absence of chert. In the Lefkara section the bed thicknesses remain constant but decrease towards the higher part of the unit with abundant thin strata intercalated. In the Kalavasos section thicker beds increase

in quantity in the turbiditic part of the Chalk unit and become thin and more differentiated at the top of the outcrop (Fig.38 (A)). The Kouka section stands somewhat between the two groups of sections described above. Although it does not show any clear turbiditic facies in the field, the lower part of the Chalk unit is not massive but clearly bedded (Fig.35 (B)) with average bed thicknesses showing a slight decrease upwards from 13cm to 10cm. Bioturbated horizons are hardly ever found in the Kouka, Ayios Nicolaos and Stavrovouni sections. They are present in the Kalavasos and Lefkara sections and increase in frequency towards the top of the turbiditic successions. Individual bioturbated horizons and some laminae are observed in the massive chalks of the Motorway section (Fig.38 (D)).

Above the turbiditic, mainly chert-free chalks of the Kalavasos section the sediments become massive and structureless. This facies is very similar to the massive chalks of several of the logged sections described above.

Upper part (bedded and flaggy chalks):
The upper part of the Chalk unit is regularly bedded in all sections. In the Ayios Nicolaos, Kouka, and Motorway sections bed thicknesses lie around 21-25cm. They are slightly thinner in the Kouka section where a possibly equivalent short chert-bearing interval is logged (Fig.35 (A)). A bedded facies was also observed in the Stavrovouni, Kalavasos, and Lefkara sections and this facies exhibits a gradual decrease in bed thickness from 20-50cm chalk beds into the thin cm-bedded Upper Marl sediments (Figs.38 (B), 33). In this part of the succession in most sections (except for the Motorway section) common clay seams are found in the chalks ('flaggy chalks'). Below these an interval of intercalated cherts is present in the Kouka and the Lefkara sections (Fig.35 (A)). Except for few laminae observed in the Stavrovouni section only the deposits of the Motorway section show any sedimentary structures in the higher Chalk unit. The facies of the Motorway section is different from all other localities. Here the uppermost chalk beds have an average thickness of 37cm and become thinner upwards. Higher up the chalks become silty and are laminated and bioturbated (see Chapter 4.3.2.8., Fig.88). This increases significantly towards the top where these features are predominant and considered to be part of the Upper Marl. Additionally thick marl strata are interbedded with the chalks (Fig.44). Indications of bioturbation near the top of the Chalk unit are also present in the Kalavasos, Lefkara, and Ayios Nicolaos sections.

Upper Marl unit:

The Upper Marl sediments do not show significant variations between the sections except in the Motorway section described above. The cm-bedded marls (Fig.40 (B)) grade transitionally into the calcarenitic thin bedded marls of the Pakhna Formation.

3.1.3. LITHOFACIES TYPES

The Lefkara Formation is composed of chalks, marls, and cherts. These end member facies occur either isolated or in associations. The Chalks are the only definitely primarily deposited sediments while the cherts are entirely and the marls partly the result of diagenetic modification. Nevertheless, a primary difference in composition is responsible for the development of all three end members. Figure 47 shows the facies types and associations recognised in the sediments. For clarity, their occurrence in the different lithological units of the stratigraphic column is added. Where the facies has been found to contain turbiditic structures, this is indicated at the top of the diagrams in Figure 47.

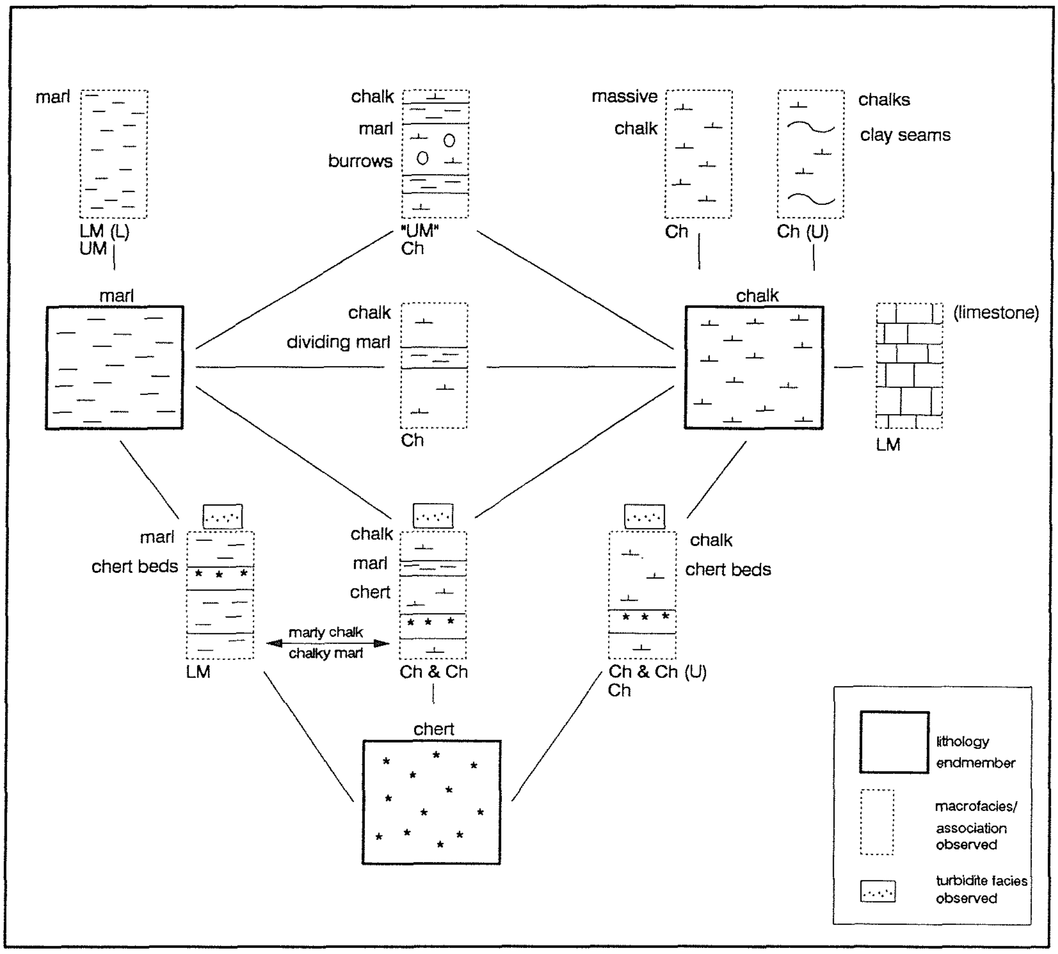


Fig.47. Macrofacies types observed in the Lefkara Formation. For legend see Fig.27, (L) = lower part of unit, (U) = upper part of unit.

Chalk:

The chalk facies varies between chalks which are (1) very soft, bright white, and pure, (2) soft, grey, marly chalks, (3) hard, strongly compacted chalks with or without clay seams in the matrix (flaggy, Fig.48 (E)), (4) slightly calcarenitic pure chalks, and all transitional stages. With the exception of fish teeth and trace fossils no macrofossils are present in the structureless facies. Even the calciturbidites, which will be described below when discussing the sedimentary structures in this chapter and the microfacies in Chapter 3.2., are free of macroscopic fossils. Depending on the position in the stratigraphic column, chalks are regularly bedded or massive.

Limestones:

Limestones are rare and occur mainly in thin cm-thick beds near the base of the succession. The microfacies analysis shows that these are in fact chalks with the microfossils being strongly recrystallised or infilled with silica.

Marl:

If not silicified, marls are soft and easily weathered. Burrows (Figs.48 (G), 49 (A)) or mottling are mainly preserved when the rocks are silicified or harder due to compaction or a higher chalk content. Marls either occur in monolithological strata with relics of cm-beds and wavy bedding planes visible (Fig.38 (C)) or they are in association with cherts, chalks and rarely limestones. Although they occasionally occur in dm-thick beds between the other facies, marls are most common as mm- to cm-thick dividing layers and show a gradual transition to chalk.

In the calcareous lithofacies, only the end members chalk and marl (and limestones) are clearly distinguishable while all transitional forms between these lithologies occur. A distinction between marly chalk or chalky marl respectively is not made here since no clear definition is possible in the macrofacies but these are integrated into the category of the pure chalks and marls respectively.

Amongst chalky marls and marls, variations in colour exist. This has not been added as a facies criteria but is consistent for all sections. In the monolithological lowermost part of the Lower Marl and Upper Marl units the marls are grey or brownish cream in colour. In the higher part of the Lower Marl the sediments become characteristically pinkish or brownish. Higher up in the succession marls and marly chalks are of variable lighter or darker grey. In some localities the Upper Marl rocks are stained reddish brown.

Chert:

In distinguishing facies types, chert is only considered as present or absent although, in fact, it occurs in very different appearances in the sediments. All forms are replacement cherts. It occurs as nodules (Fig.40 (F)), individual strata (Figs.40 (C), 35 (C)), layers integrated into a chalk or marl bed (Fig.40 (C)), or as chalk or marl strata completely penetrated with silica ('silicified chalk/marl', Figs.35 (A), 43 (D), 49 (D)) which might contain slightly silica-enriched areas. The silicified chalks are homogeneous, mainly structureless, of yellowish or pinkish colour and extremely hard. The chert nodules and beds are commonly highly concentrated chert accumulations, in the extreme case being of flint-like (vitreous) appearance but more often granular. A colour change can be observed in different parts of the stratigraphic column. In the lowest Lower Marl strata the cherts are dark and grey. In the higher part of the unit and extending into the lower part of the Chalk & Chert unit the cherts are always stained, being brown or sometimes red or green. Chert occurring in turbiditic strata are accumulated in the coarsest layers (Fig.49 (C)). Many examples are found where grey chert accumulates selectively in thin horizons and laminae (Fig.49 (B)). No distinction is made in the establishment of the macrofacies between different types of chert. However, it appears that the main differences are due to variations in the amount of silica that has accumulated diagenetically rather than to a more primary depositional cause. Evidence for this are chert beds which laterally develop into nodules, laterally discontinuous silica accumulations, or granular chert layers which become gradually vitreous or nodule-like towards the bottom of the bed.

Sedimentary structures:

In addition to the compositional variation, sedimentary structures are notable features of the sediments and therefore have to be considered when establishing the macrofacies. The main consistently occurring structures and their sequence are clearly turbiditic in origin (although some of the structures are produced by bottom currents). Characteristic structures observed include grading, parallel, cross, and rare convolute lamination (Fig.48 (A)), and few small scour marks (Fig.48 (D)). The beds exhibiting many sedimentary features are commonly silicified, and mostly show complete or base-cut Bouma sequences with a graded bed and sand-sized clasts at the bottom, parallel lamination above, followed by cross lamination, and fine-grained sediments. The interbedded chalks are commonly structureless with rare silt lenses or lamination. Bioturbation is rare in the chalk matrix but the bottom of sandy beds show casts of burrows which indicate bioturbation at the uppermost part of the underlying chalk.

Figures 48, 49 and 50 illustrate the structures of the different turbidite divisions observed mainly in hand specimens. These will be discussed in more detail in Chapter 3.2. on the microfacies. In the field, turbidite beds were recognised by generally being coarser grained (commonly sand-sized) and showing A, B, or C divisions. The thickness of each division varies from few millimetres to several decimetres although a cm-scale is the most common. These three coarsest divisions are commonly silicified in the Chalk & Chert unit and may contain small quantities of silica even in the 'chert-free' unit. The finer-grained and unsilicified strata of turbiditic deposits were difficult to observe and distinguish in the outcrops. Therefore, the study of the turbidite sequences in the field does not reveal the whole range of structural differences present in the lithology. Practical problems arising were: (1) faint material changes were in many cases not visible in outcrops because of weathering and irregular rock surfaces. Especially in chalks, structures were vague and can only be studied in the lab on cut rock surfaces treated with oil. (2) Silicified beds partly highlighted sedimentary structures as in cross-laminated strata when only the laminae were silicified. In other examples a strong enrichment in chert in a bed may have obscured all original structures, with only a homogeneous chert bed being visible. (3) Beds were identified as such and logged where they were characterised by a clear change in material rather than a change in the (faint) sedimentary structures. One chert bed may contain several turbidite divisions but was in many cases only logged as one bed. For these reasons, the field data do not contain all information present in the sediments.

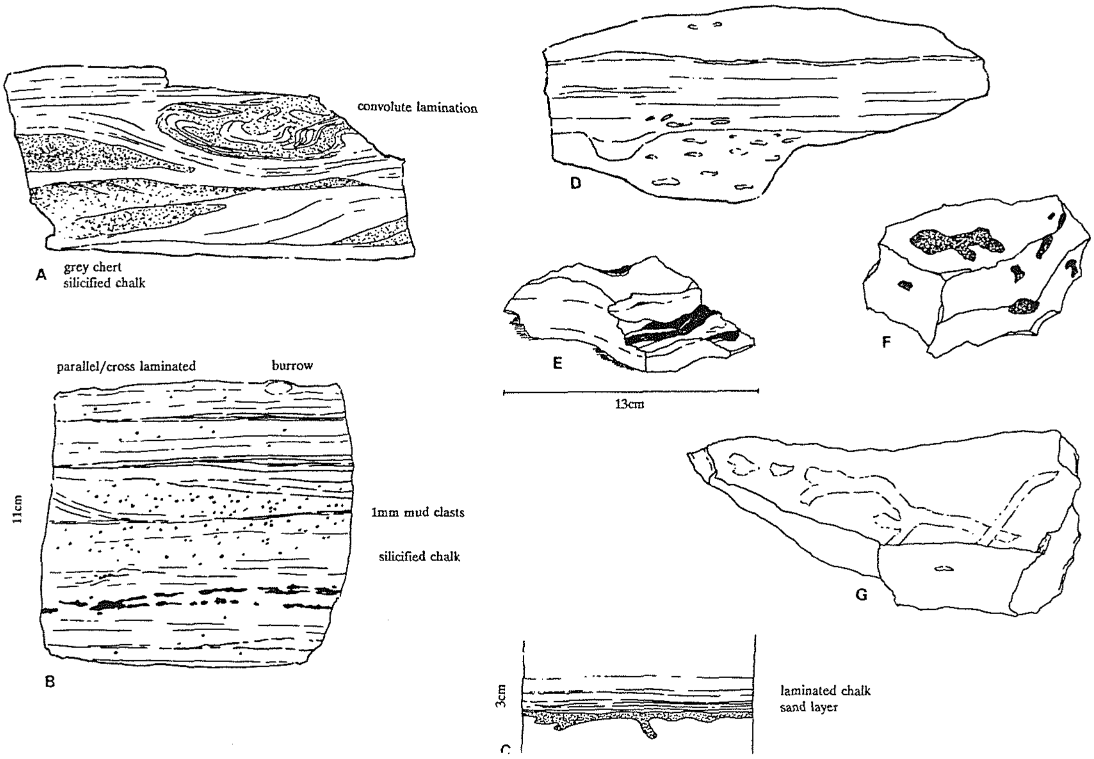


Fig.48. Examples of different macrofacies types and sedimentary structures. **(A)** Convolute laminated silicified chalk with chert areas (C-division, Lefkara section); **(B)** Highly silicified parallel- and cross-laminated chalk containing macroscopic mud clasts (C-division, Lefkara section); **(C)** Laminated chalk with calcarenitic base, deposited on top of bioturbated pure chalk (possibly C-division, Lefkara section); **(D)** Soft laminated and bioturbated chalk with small scale scour mark (F- and B-divisions, Lefkara section, hand specimen 15cm long); **(E)** "Flaggy" chalk with distinctive grey clay seams from the top of the Chalk unit (Ayios Nicolaos section); **(F)** White, hard chalk with chert-filled, branched burrows (specimen 10cm long, Lefkara section); **(G)** Pinkish, soft marl with flattened burrows (2-3mm in diameter) parallel to the bedding (Lefkara section).

Fig.49. Examples of different macrofacies types and sedimentary structures continued.

A Compacted, chalky marl with deformed light burrows, colour darkened due to oil treatment (Kouka section).

B Cross-laminated silicified chalk, laminae are traced by almost pure, grey chert (C-division, Kalavasos section).

C Turbidite bed with calcarenitic, mud clast-containing basal part, cross lamination and increasingly bioturbated top, higher turbidite divisions may be truncated by contour currents (Lefkara section).

D + E Extraordinarily thick chertified A-division of a turbidite with contact to underlying sequence, the whole division is massive and graded, the enlargement (E) shows several mm-sized carbonate mud clasts (Lefkara section).

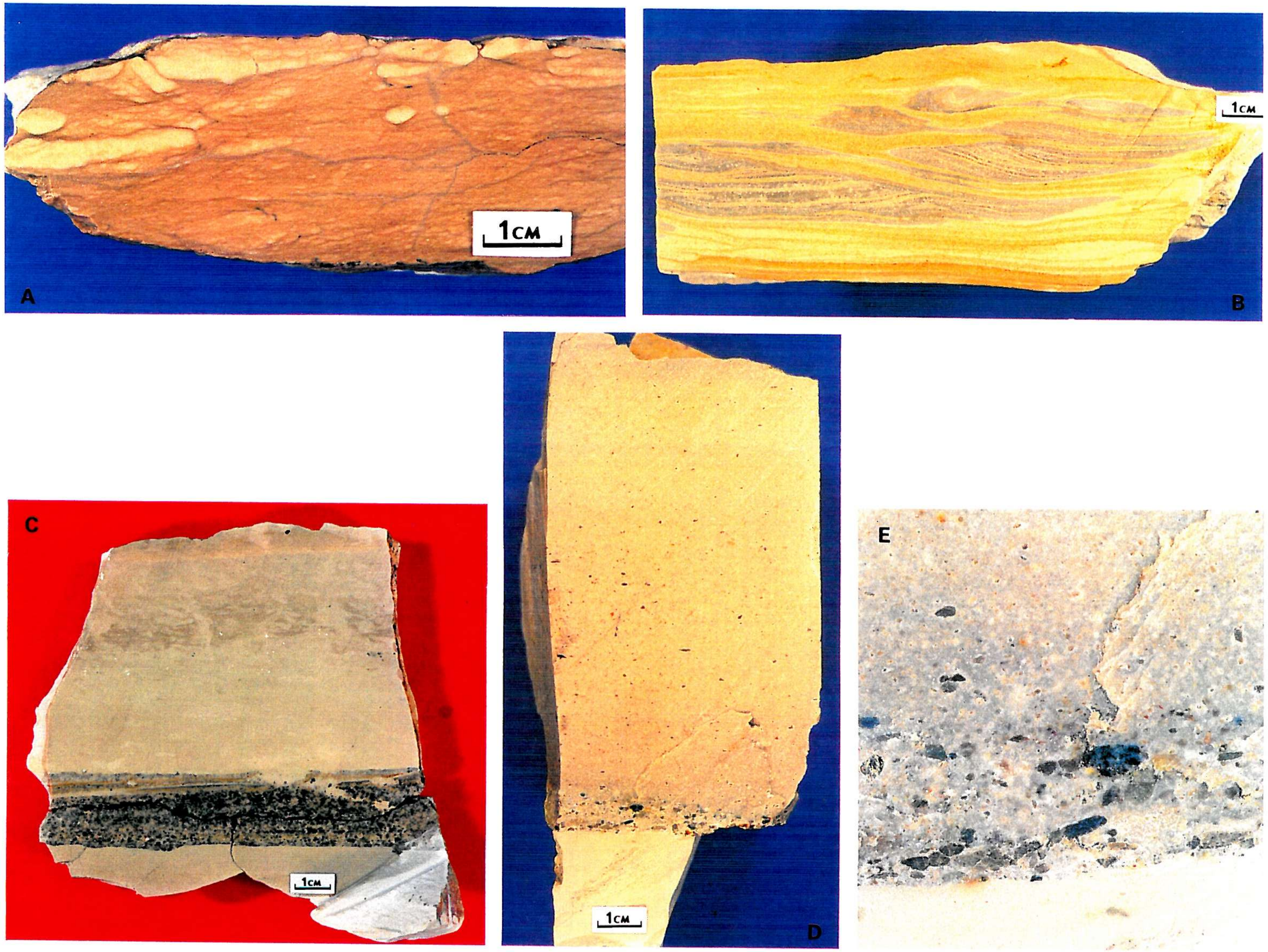

1CM
A
1CM
B
C
1CM
1CM
D
E

Fig.50. Examples of different macrofacies types and sedimentary structures continued.

A Burrowed B- and C-divisions of a fine-grained turbidite (Lefkara section).

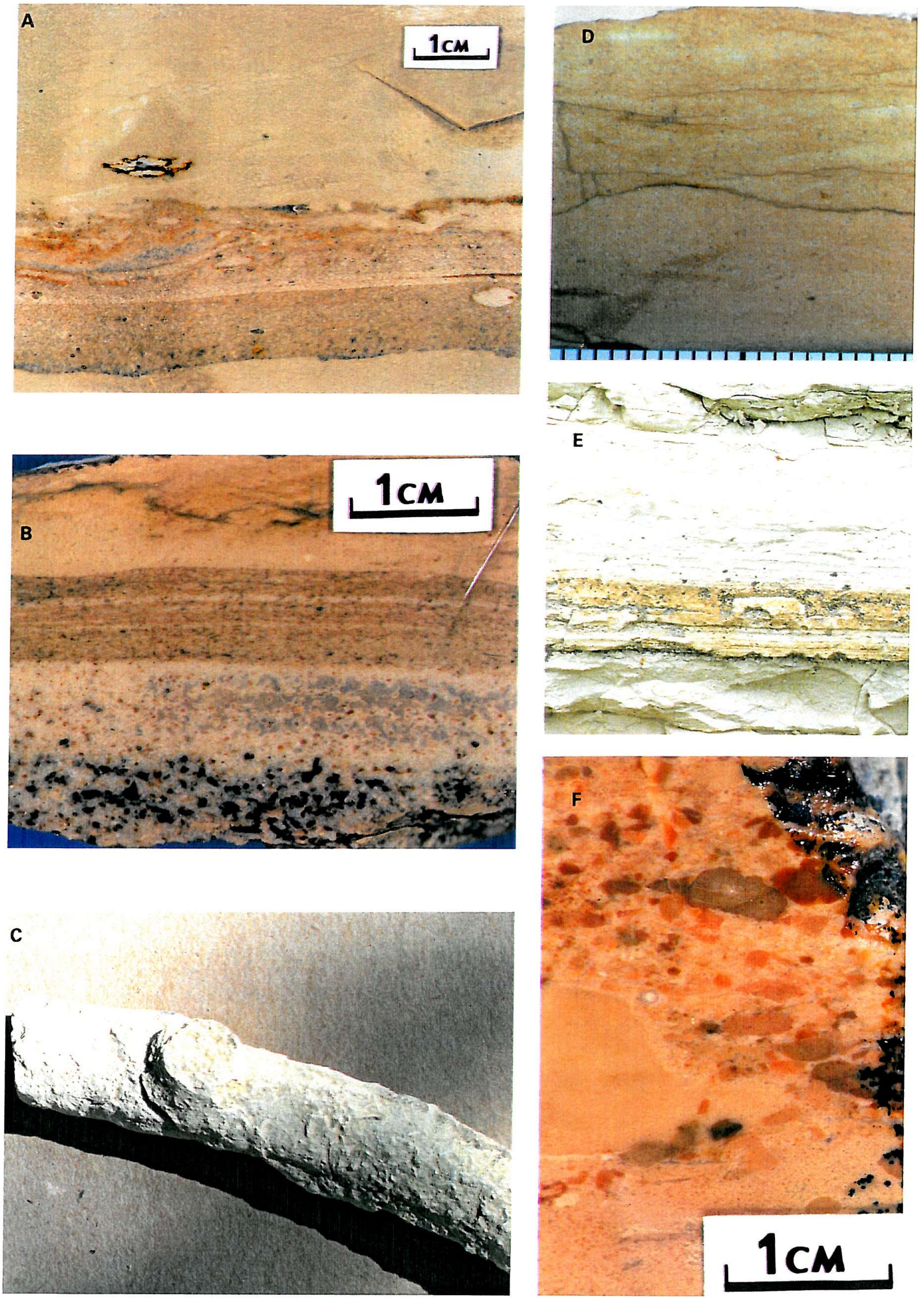
B Chertified A- and B-divisions, sequence possibly top-cut (Chalk & Chert unit, Kalavasos section).

C *Thalassinoides* tube from the Chalk unit of the Kalavasos section; total length approx.15cm.

D Bioturbated chalk, oil-treated (Chalk & Chert unit, Ayios Nicolaos section).

E Outcrop photograph of laminated, soft chalks from the top of the turbidite succession (D- to F-divisions, Chalk unit, Kalavasos section).

F Detail from an A-division of a coarse-grained turbidite, strongly silicified marl with up to several cm-sized intraclasts (Lower Marl unit, Lefkara section).


A
1CM
B
1CM
C
D
E
F
1CM

3.2. MICROFACIES

3.2.1. INTRODUCTION

Thin sections, partly polished for studies under the scanning electron microscope (SEM), were made from rock samples of all six logged sections. As far as possible at least one specimen was taken from each of the different lithological units and macrofacies types as seen in the field. Special attention was given to thin sections of hand specimens that showed any kind of sedimentary structure. The main work concentrated on studying thin sections under an Olympus BH-2 polarising microscope. More limited SEM studies were undertaken where further detailed identification was necessary.

In the following, the individual components of the chalks, marls and cherts are described as the basis for further interpretation. This includes a brief look at the intraparticle cements and fillings as far as it seems to be important for this study. Afterwards sedimentary and diagenetic structures will be examined. Altogether this will lead to the establishment of eight different microfacies types.

3.2.2. LIMESTONE CLASSIFICATION

In the first instance, all thin sections are classified after Folk (1962) into two broad categories in which almost all rocks of the Lefkara Formation can be grouped, including, in most cases, even the cherts. Further subdivision of the thin sections into eight microfacies was made after consideration of their composition, structure and fabric. All rocks possess a micritic matrix and are therefore micrites. The matrix may be more or less silicified but still shows clearly its micritic origin which allows classification of even the 'cherts' into the limestone categories. According to other limestone classification systems, the rocks may be classified as wacke- and packstones (Dunham, 1962), calcimudstones (Wright, 1992), or nannofossil-foraminifer chalk, nannofossil-radiolarian-foraminifer chalk and marly nannofossil-radiolarian-foraminifer chalk (Luyendyk & Sharman, 1979).

In the matrix a varying amount of allochems, mainly pelagic microfossils, of silt to sand size is present. Intraclasts are generally observed but remain below 25% of the total. Faecal pellets are not identified. Depending on the amount of bioclasts, which varies between 10% and 90%, it is possible to group the thin sections into either sparse (e.g. Fig.58 (C)) or packed (e.g. Fig.58 (F)) biomicrites, with 10-50% being sparse and >50% being packed.

3.2.3. MATRIX

The matrix of the Lefkara chalks and marls is micritic if examined in transmitted light. The crystal size is generally too small to distinguish individual grains. In both plain and crossed polarised light, the micrite is of dark brownish-grey which varies slightly between the specimens.

Using polished thin sections the micrites can be further studied under the SEM. The matrix appears to be an irregular patchwork of well defined lighter and darker areas (Fig.51). The lighter areas are dominated by calcium carbonate whereas the darker ones are rich in silica and contain small amounts of clay (Fig.52). Dolomite was found only in one sample from the top of the Kalavasos section. Here it forms idiomorphic crystals of few micron in size and has a composition of approximately 62% calcium and 35% magnesium.

As the x-ray diffraction (XRD) analysis reveals (Chapter 3.3.), clay is a significant constituent of the chalks as well as the marls. In many thin sections clay enriched areas in the micritic matrix are seen under the polarising microscope as darker seams. These will be more closely examined in the paragraph describing compaction. Under the SEM these seams are confirmed to be areas of clay enrichment and the single clay minerals can be detected in high magnification between the micrite crystals (Fig.53 (B)).

SEM studies of whole rock specimens reveal the matrix to be composed of rhombohedral calcite crystals of 2-3µm in size which are closely attached to each other (Fig.54 (F)). Coccoliths are present in the matrix but they are rare and definitely not as abundant as is common in soft chalks (e.g. 80%, Greensmith, 1989). Typically they are found attached to bioclasts (Fig.53 (D)) or in cavity fillings (Fig.53 (C)) and show a high degree of overgrowth or corrosion (Fig.53 (B)).

In transmitted light dark or brown isotropic particles of approximately 20-50µm in diameter are visible in the matrix of some thin sections. Similar spherical dark particles picked from the washed residue are of significantly larger size, 80-90µm in diameter, but most likely of the same origin. The SEM examination proves them to be framboidal pyrite particles with a pure composition of iron sulfide (FeS_2, Fig.53 (F)). Other particles picked from the residue are brown in colour. They are oxidised iron and most likely formed from pyrite during outcrop weathering.

Nevertheless, the proportions of iron compounds must be low since they are not detected in the XRD bulk mineral analysis.

Many of the micritic sediments contain patchy silica accumulations. Here the micrite is commonly totally replaced by quartz or chalcedony. The replacement cherts were studied in detail by Robertson & Hudson (1974; Robertson, 1975, 1977).

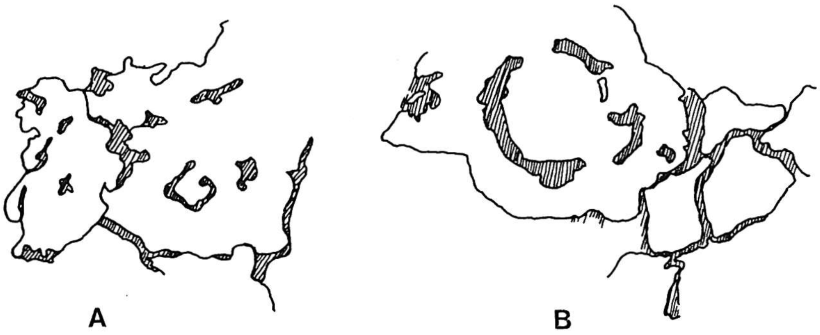


Fig.51. Micrite and foraminifera test as appearing in polished thin sections under the SEM. **(A)** Matrix with dark areas being silica and/or clay-dominated, the light carbonate-dominated; **(B)** Foraminifera chamber, walls are pure calcite.

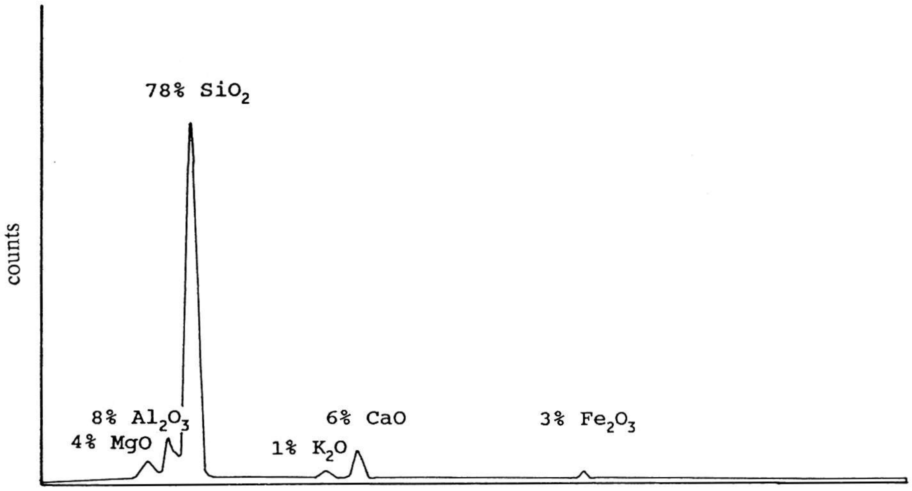


Fig.52. Composition of carbonate-poor matrix, SEM x-ray analysis.

Fig.53. Allochems present in the sediments.

A Corroded coccolith plates, SEM photograph.

B Coccolith plate with calcite overgrowth, note palygorskite fibres in the micrite.

C Microphotograph of coccoliths in foraminifera chamber filled with isotropic silica, crossed polars.

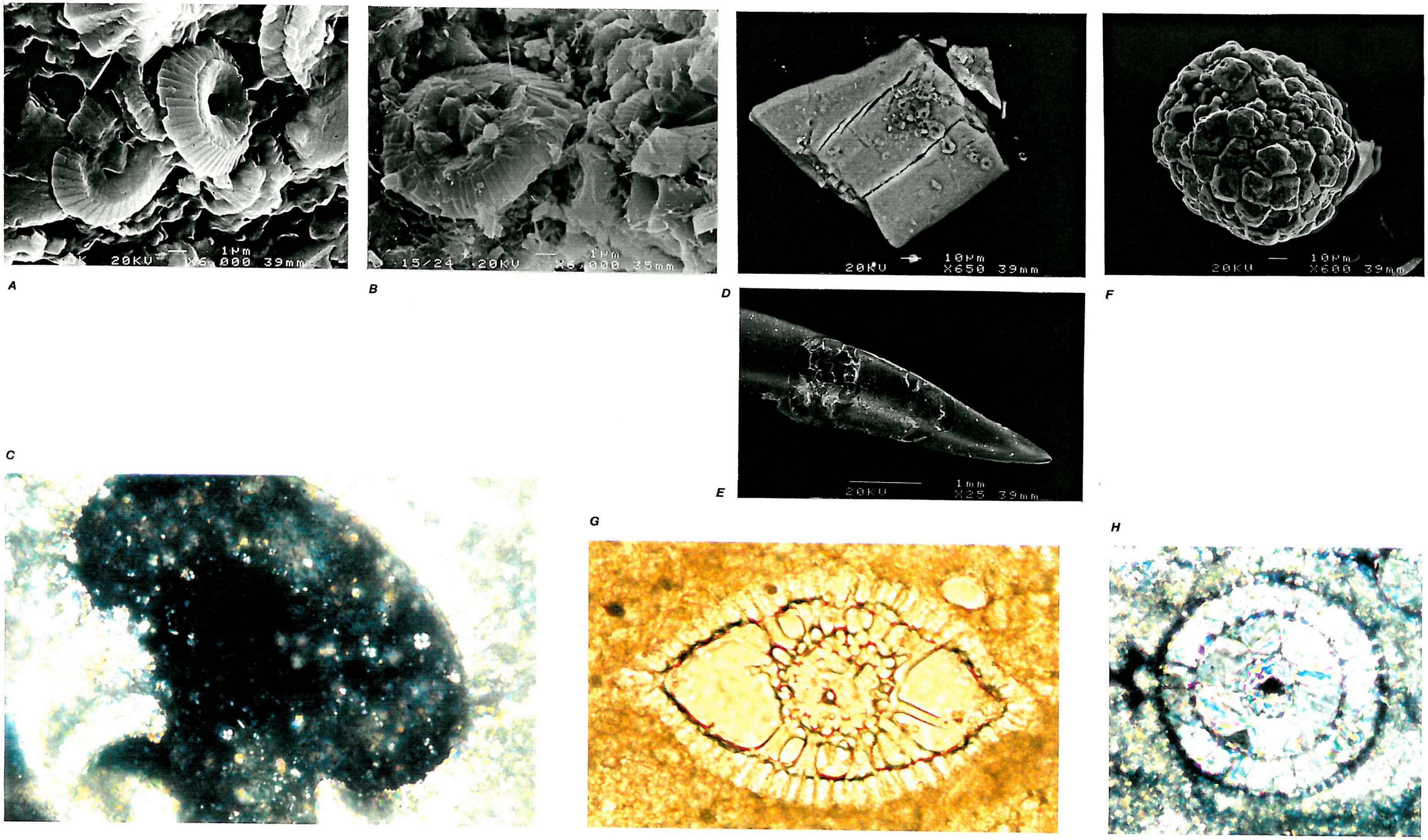
D Bone fragment with attached coccoliths under the SEM.

E Fish tooth.

F Framboidal pyrite.

G Radiolaria (*Spumellaria*) in plain polarised light with clearly visible medullary shell and rods, 200µm.

H As G, different specimen in cross-polarised light, 150µm.


20KV 1µm X6,000 39mm
A
15/24 20KV 1µm X6,000 35mm
B
20KV 10µm X650 39mm
D
20KV 10µm X600 39mm
F
C
1mm
20KV X25 39mm
E
G
H

3.2.4. ALLOCHEMS

The biogenic content found in the Lefkara material consists mainly of planktonic foraminifera and radiolarians including their spines. Molluscs, ostracods, sponge spicules and echinoderm fragments are present but rare, whereas benthic foraminifera (including few larger foraminifera), fragments of fish bones, coccoliths and discoasters are more common. Several bioclasts could not be identified. Lithoclasts are less abundant than the biogenic fraction. They include different types of sediment clasts, which form the majority of the lithoclasts, followed in abundance by volcaniclastic particles and various other minerals as described below.

Planktonic foraminifera:

Planktonic foraminifera are generally the dominant bioclasts found in the thin sections and are therefore used to establish a biostratigraphy (for species see Chapter 2.1.). Their preservation state varies strongly. In packed non-silicified samples the tests are often perfectly preserved but also in sparse micrites rare well preserved planktonic foraminifera are common (e.g. Fig.62 (C)). In many examples the test walls gradually grade into the micritic matrix and all dissolution stages up to very faint ghosts can be seen. The average specimen size varies between the samples. This may be the result of a preferential preservation of different fractions. If a large size range is preserved the test diameters vary between 50μm and 500μm.

Radiolarians:

Radiolarians are present in most thin sections, varying between very few specimens and high abundances, in which case they even dominate the fauna (for species see Chapter 2.1.). Spumellarians are the dominant form, with well preserved nassellarians being less common in thin sections (Fig.54 (B)). This might be related to the shell geometry since spumellarians are typically represented by rather stable, spherical, commonly thick-shelled forms. A comparison with the radiolarian assemblage from the non-carbonate residue >63μm shows about 40% spumellarians if the fauna is well preserved. In contrast, a sample with significant dissolution is almost exclusively composed of moulds of spumellarians.

The originally opaline radiolarian shell material is always dissolved or replaced. In many cases the walls (of the medullary shells too) are perfectly replaced by calcite preserving the rods and all fine details of the wall structure (Fig.53 (G), (H)). The intraparticle void is either filled by large sparry calcite crystals, micrite, or microcrystalline or chalcedonic quartz. Commonly only

Fig.54. Microphotographs of thin sections and rock surfaces under the SEM.

A Basal packed part of a Bouma A-division consisting of sediment clasts (types A and B), glauconite (bottom centre), quartz (light in plain polarised light), benthic foraminifera (bottom right corner), and planktonic foraminifera. Large sediment clast approx. 900μm in length.

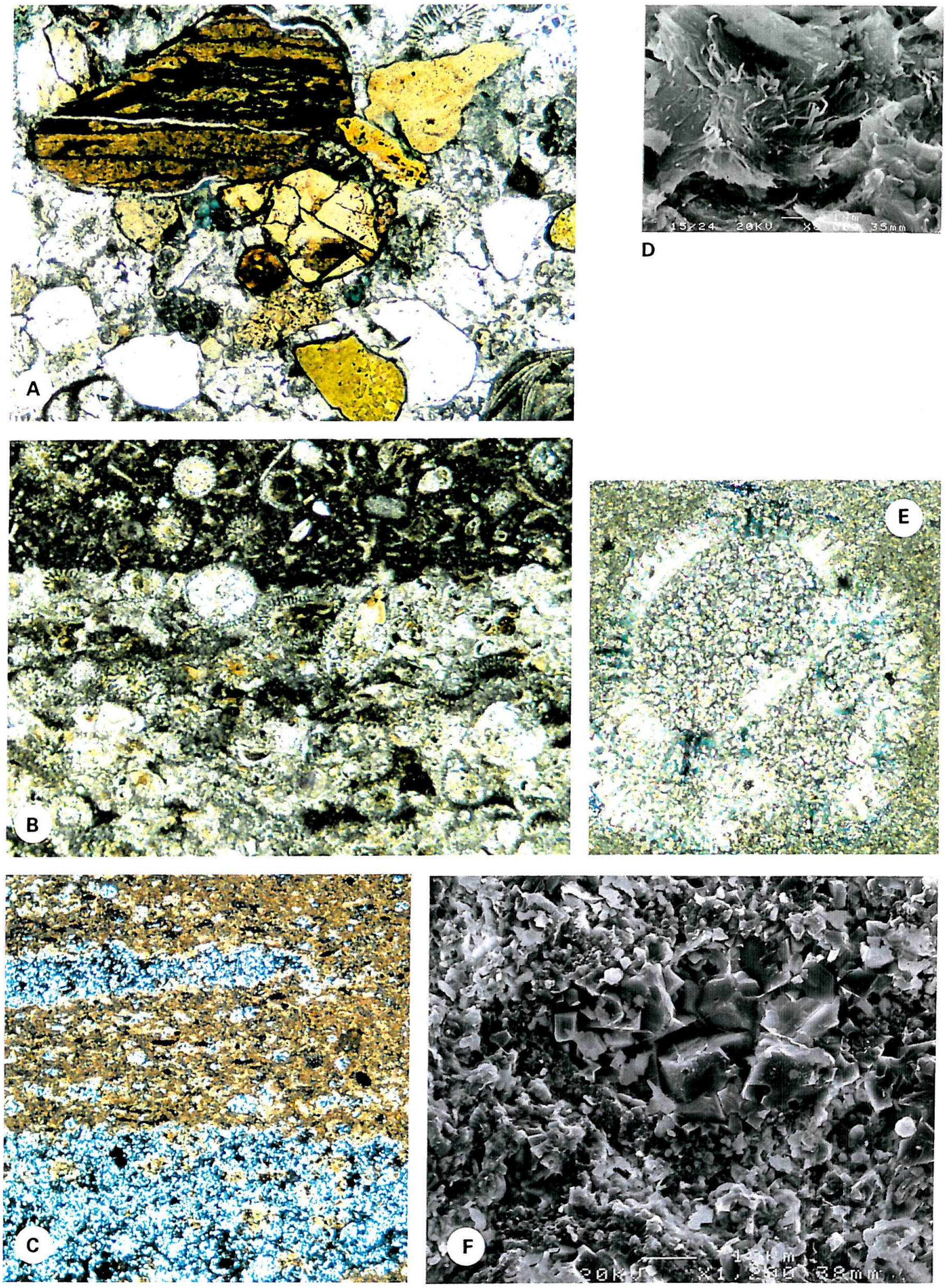
B Transition between packed and sparse lamina of B-division, well preserved nassellarians and radiolarian spines with trilateral symmetry present.

C Chert accumulation enhancing visibility of laminae, bioclasts in the proximity are filled with silica.

D Palygorskite fibres under the SEM.

E Planktonic foraminifera filled with neomorphic spar, 250μm.

F Large rhombohedral calcite crystals in foraminifera chamber, SEM.


A
D
15/24 20KU
35mm
B
E
C
F
20KU X1,200 28mm

casts remain which are composed of different cements or silicified micrite (see section 3.2.5.).

Radiolarian spines are common in thin sections. It appeared to be a problem to distinguish between isolated spines and sponge spicules. Most spines are circular in cross section, 5μm to 25μm in diameter, up to 250μm long, and composed of either quartz or calcite. In many cases they possess a thin central canal (see Fig.62 (A)). Although this is thought to be characteristic for sponge spicules (Horrowitz & Potter, 1971) the size and shape of many of them resemble radiolarian spines. This assumption is confirmed by material studied from the acid insoluble residue which is used for comparison. A canal cannot clearly be detected in radiolarian spines but the most reliable criteria to separate radiolarian spines from sponge spicules seems to be the smaller size of the former. The radiolarian spines are very fine and usually do not exceed a diameter of 25μm. Nevertheless larger specimens might have spines that reach 40μm. Anyway, the quantity of broken and isolated definite radiolarian spines in the residue suggested that most of the small spines in the thin sections are most likely to be of radiolarian origin. Consequently the calcitic ones must have been replaced. Although it is easy to distinguish radiolarian spines and sponge spicules as three-dimensional whole specimens it remains difficult in the section where most of the critical criteria have been lost.

Another kind of spine found in the sections has a trilateral symmetry in cross section (Fig.54 (B)), is usually composed of quartz, and is approximately 25μm in diameter. These are easily identified as radiolarian spines since several species exhibit typical ridges on the spine surface.

Further bioclasts:

Quantitatively few other bioclasts are present in the Lefkara sediments. The most abundant of these are fish bones and sponge spicules. **Fish bones** in thin sections are characterised by a light, often yellowish colour in plain polarised light and by a fine lamellar internal texture. Under crossed polars they show a low birefringence of first order grey. The shapes of larger bones (up to 600μm) are characteristic if a section through a platy scale, a conical or round tooth or a vertebra (Fig.55) is cut. Mostly, only small elongate fragments of bones are preserved, typically ranging between 100μm and 300μm. In the disintegrated sediments fish teeth and brittle, glassy fragments are present which are also identified as bones composed of calcium phosphate under the SEM (Fig.53 (E), (D)).

In some thin sections clearly identified **sponge spicules** occur. They are composed of quartz or calcite, are up to 300μm long with a diameter of approximately 25-100μm, and typically exhibit

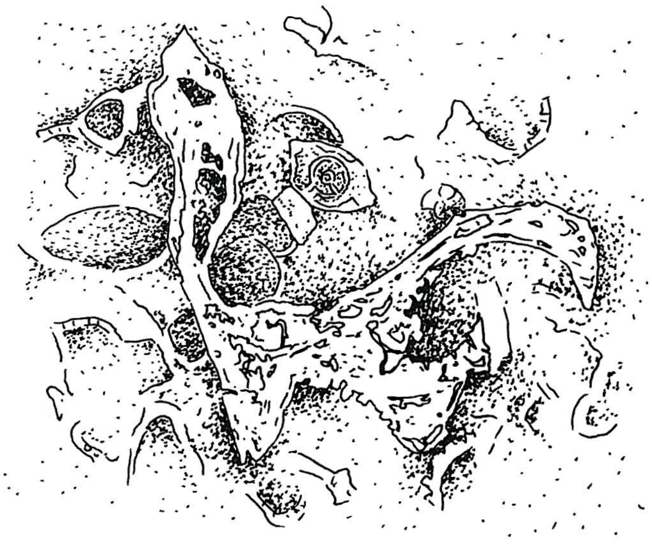


Fig.55. Phosphatic fish vertebra in packed biomicrite, thin section. Length 300μm.

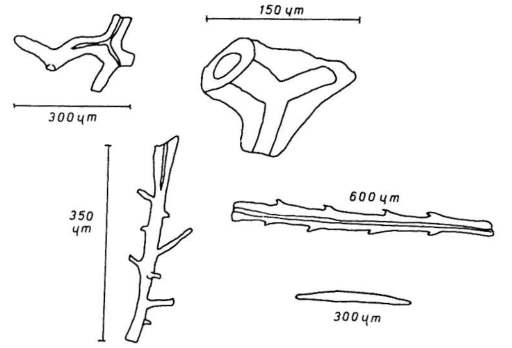


Fig.56. Sponge spicules from the acid-insoluble residue.

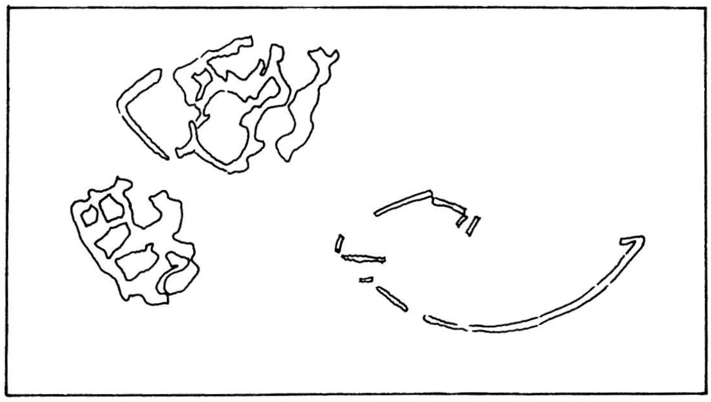


Fig.57. Fragmented ostracod carapace (length 200μm) with characteristic duplicate edge and planktonic foraminifera tests in thin section.

a central canal. A common form is calcitic with fine radial laminae. Only rarely, multirayed sponge spicules or kidney shaped spicules (130µm) are found in thin sections. The difficulty of distinguishing sponge spicules from radiolarian spines has been discussed above. The definite sponge spicules in the carbonate-free residue are multirayed, straight or branched or possess spines at the surface (Fig.56) and 150µm to 600µm long, with a relatively large central canal of approximately 20µm in diameter.

Amongst other rare relics of metazoa are **ostracods**. In few examples whole valves with the typical duplicate margin (Horrowitz & Potter, 1971) (Fig.57) are found. Specimens with complete two valved carapaces are rare. Typically, finely prismatic thin fragments of 250µm to 400µm are the only evidence for the presence of ostracods.

Pelecypod shells are easily identified if the hinge region is preserved. More commonly, however, non-diagnostic shell fragments are found with a size range between 100µm and 1100µm (Fig.58 (F)). These have a layered, prismatic, cross lamellar texture, or the shells are homogeneous or replaced by silica. In these cases no distinction can be made between the different classes of molluscs. Since no indications of any other than pelecypods are found it is assumed that bivalves are the dominant molluscs. In some cases shell fragments are micritised.

Fragments of **larger foraminifera** are present but rare in the thin sections. These belong to the genera *Alveolina, Nummulites, Peneroplidae* (Sartorio & Venturini, 1988) and other unidentified ones, of which only the first mentioned is found as a complete specimen. *Nummulites* fragments seem to be indicated by small prismatic test pieces exhibiting a sharp angle in the outline from the original peripheral margin.

Other **benthic foraminifera** are present in the thin sections but typically only with one specimen per sample. No identifications are made in the sections but a large variety of different test forms are recognised. In several cases the walls are micritised.

Echinoderm fragments are present but rare amongst the metazoa detected. Few plates and echinoderm spines are found. The plates are characterised by a porous consistency, being denser towards the margins and composed of a single calcite crystal (Flügel, 1982). Various plate-shaped large calcite crystals do not exhibit the characteristic porous texture. Consequently, they cannot definitely be identified as of echinoderm origin. The spines found have a maximum length of 600µm with a diameter of 50-200µm and rarely show the characteristic coarsely radial structure.

Fig.58. Microphotographs of thin sections continued.

A SEM photo of a radiolarian shell filled with silicified micrite, wall relics are composed of quartz.

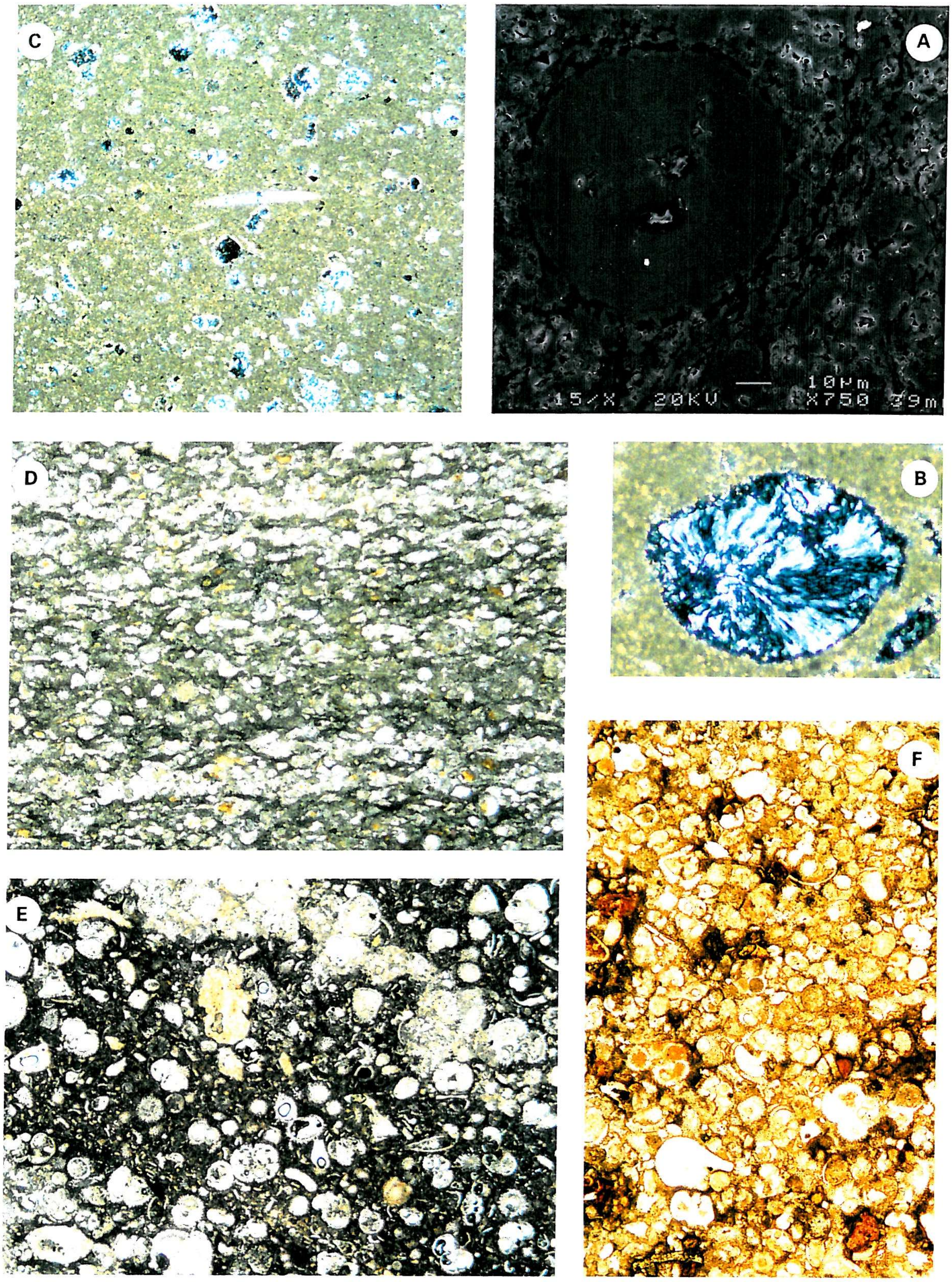
B Radiolarian cavity filled with chalcedonic quartz (200μm), crossed polars.

C Sparse biomicrite under crossed polars, bioclasts filled with microcrystalline quartz or isotropic silica. Sponge spicule in centre is approx. 500μm in length.

D Strongly compacted packed biomicrite from B-division, laminae are produced by variations in bioclast and solution-seam density.

E Cross-laminae of C-division showing a high degree of bioclast fragmentation; intraparticle fillings are mainly isotropic silica.

F Packed biomicrite of A-division in plain polarised light. Allochems consist mainly of planktonic foraminifera, sporadic mollusc fragments and sediment clasts.


C
A
10μm
15/X 20KV X750 39m
D
B
E
F

Nannofossils are common in thin sections. These include isolated coccolith plates and discoasters. Both can be seen easily in crossed polars since coccoliths exhibit a typical cross-like extinction (Fig.53 (C)) and the rarer discoasters are large in size (20-25µm, Fig.59). Nannofossils occur enriched in foraminifera chambers and attached to macrofossil fragments, possibly because they are protected from pressure dissolution here. They are commonly affected by diagenetic overgrowth (Fig.53 (B)), fragmentation or dissolution (Fig.53 (A)).

Endolithic borings in calcitic shells, bones, and micrite particles are visible as a kind of trace fossil. Two different types of borings are found: (1) thin tubes of approximately 1µm in diameter split into filament-like branches of the same size as the stem; (2) slightly thicker tubes of 5-7µm in diameter, with branches having a significantly thinner diameter. These characteristics distinguish them as fungal and algal borings respectively (Bathurst, 1966, 1975). Fungal borings are found in the micritic (later silicified) filling of radiolarians (Fig.60 (A)) whereas algal borings are more frequent in sediment clasts, fish bones (Fig.60 (B)), and also in radiolarian fillings. The micritised shell fragments mentioned above may be the product of endolithic algal activity (Bathurst, 1975) as well.

Fig.59. Discoaster in isotropic silica-filled foraminifera chamber.

Fig.60. Microborings in allochems. **(A)** Fungal borings in filling of a compressed radiolaria (200µm); **(B)** Algal borings in fish bone (200µm).

Lithoclasts:

Sediment clasts form by far the majority of the lithoclasts. Amongst the other rare minerals found (Fig.54 (A)) are quartz and feldspars which seem to be slightly rounded in some samples. Most are of minute size (<100µm); only in few coarse beds do they reach a size of 500µm to a maximum of 800µm. Rounded glauconite grains and rock fragments such as volcanics, showing typical randomly oriented strongly altered feldspar crystals, and possible pumice are present in a few specimens.

The sediment clasts have to be described in more detail since clear differences can be observed between them (Fig.54 (A)). The first group of sediment clasts are clear intraclasts (type S). They consist of more or less the same micritic matrix as the host material and mostly possess a similar faunal content, mainly well preserved planktonic foraminifera. The clasts are 300-1300µm in size and are clearly visible in the matrix since they show a different colour, orientation and, in some cases, a fauna of a different size. These intraclasts are most likely reworked from similarly aged strata from nearby.

A second type or group of sediment clasts show much variability. These clasts vary in size between 50µm and 1100µm and are generally rounded. In plain polarised light the different specimens show colours between yellowish sand colour which then commonly contain small darker inclusions (type A), and a darker, mostly opaque, reddish brown colour, typically with parallel structures and/or a light rim and light veins which resemble a sedimentary relic structure (type B). Round light particles of approximately 50µm in diameter which are found inside many specimens can be positively identified as strongly altered microfossil relics in a few cases.

In crossed polarised light most of the reddish brown clasts of type B do not change their appearance significantly or become slightly darker. The light rim and the fissure fillings of some clasts appears to be quartz. Type A sediment clasts are either isotropic under crossed polars or slightly textured, with some of the inclusions being minute calcite crystals. Under crossed polars a third version of clasts emerges (type C) which resembles type A but becomes greyish white to greenish under crossed polars, with a slightly fibrous appearance and a somewhat undulous extinction.

Comparing the sediment clasts of type A-C it becomes clear that some specimens contain characteristics of at least two of the above described types. These transitions between the observed three types of clasts and the occurrence of nannofossils in some, suggests that all are slight variations of sedimentary origin.

Under the SEM, specimens of the sediment clasts show a matrix with patchwork-like divided or circular areas of lighter and darker colours but no clear difference in composition. No calcite is present in the specimens studied which means that these clasts are either only composed of clay and/or they are silicified to different degrees. X-ray analysis reveals a silica component of 70-80% or higher. Since the SiO_2 percentage in clay minerals does not exceed 60% the excess can be assumed to indicate silicification of the mud.

In summary, the most frequently occurring type of clast is of sedimentary origin which is indicated by the presence of microfossils and nannofossils, possible relics of former sedimentary structures, and the lack of idiomorphic crystals. The beige-sand to brownish colour and the density of the material suggest it to be most likely an argillaceous micrite or a mudstone. The clasts show a variety of appearances. The brown opaque colour in some of the specimens may be an enrichment in iron oxide that occurs in varying amounts in the clasts. The often isotropic behaviour, the quartz rim around some of the clasts, radiolarian casts in few specimens, and SEM studies suggest that the matrix is commonly silicified.

3.2.5. INTRAPARTICLE FILLINGS

The only original pores in the sediment matrix which are still recognisable are bioclast voids. All are infilled with either lime mud (micrite), silicified mud (isotropic silica), spar or quartz which will be discussed now.

Micrite (lime mud):
Many of the foraminifera chambers and the radiolarian shells are filled with lime mud and the material in the former void is identical with the micritic matrix (e.g. Fig.62 (C)). The micrite inside the tests commonly contains nannofossils (compare section 3.2.3.).

Neomorphic spar:
Many of the microfossil voids are filled with very finely crystalline calcite with a grain size of 5-7μm (Fig.54 (E)), visible in transmitted light. This microspar commonly occurs together with micrite in one single foraminifera chamber and is therefore considered to be recrystallised micrite. Common coarser crystal sizes range between 5-15μm to extremes of larger than 65μm (Fig.54 (F)). In these cases microspar and sparry calcite are mixed which also points to a gradual increase in crystal size by neomorphism from an original micrite. In some cases the microspar crystals seem to be diffuse and undefined which is caused by impurities between the single crystals. These crystals seem to have grown from an argillaceous micrite.

Further observations corresponding with the criteria Bathurst (1975) described for the recognition of spar originated by aggrading neomorphism are: (1) an irregularly varying size of the calcite crystals, (2) curved intercrystalline boundaries, (3) the presence of only few enfacial junctions where one angle of a triple junction of calcite crystals is 180°, and (4) relics of micron-sized micrite material.

Neomorphic spar represents the majority of void fillings in most thin sections examined. This indicates that originally most of the tests and shells were filled with calcareous mud rather than being cemented from a void.

Silicified lime mud:
Many of the bioclasts are filled with an isotropic material, that appears light yellowish in plain polarised light (Fig.58 (E), under the SEM: Fig.58 (A)), which commonly contains (still calcitic) coccoliths and discoasters (Figs.53 (C), 59). This either fills the whole pore space or the centre of an otherwise calcite cemented test. In a few cases the filling seems to have a granular texture

in plain polarised light, which appear to be due to inclusions of microspar or altered silicified coccoliths.

Typically, these isotropic void fillings are found in the proximity of silica accumulation patches or voids cemented with microcrystalline quartz (Fig.54 (C)). With increasing distance to the SiO_2 patches pure quartz fillings become rarer and the isotropic fillings become relatively more frequent. Few thin sections are found where diagenetic silica-accumulations actually replace the (argillaceous) micritic matrix without recrystallising to pure quartz. These patches very much resemble the yellowish material inside the particle voids.

The above observations lead to the conclusion that the light yellowish fillings are silicified micrite. Possible large amounts of carbonate are replaced by silica while the clay component remains present to form the isotropic, impure silica rich material. Also SEM studies reveal a composition high in silica with percentages between 75% and 98%. The remaining part is dominated by aluminum and other oxides, indicating the presence of clays.

As described for the sediment clasts (type C), a slightly different type of intraparticle pore filling is a yellowish or greenish, very fine grained material which shows a slightly fibrous texture with grey or greenish birefringence colour under crossed polars. Rare examples are found containing coccoliths and discoasters.

One explanation is that all the bioclasts containing this filling might be reworked from the same source as the sediment clasts exhibiting the same kind of birefringence and extinction pattern. No proof against this theory was found but a strong correlation exists between compaction and this specific type of fibrous filling. Commonly, non-compacted specimens in a thin section are isotropic while lenticular and compacted ones show the fibrous character. It is therefore most likely that it is the result of compactional stress applied on a test which was originally filled with silicified micrite. The compositional analysis under the SEM confirms that no difference in composition exists between the fibrous and the yellowish isotropic fillings.

Other test fillings are present that resemble the type B sediment clasts. These are brown and opaque in plain as well as in polarised light. Again, the cooccurrence of opaque brown fillings and isotropic ones in one specimen suggests a close relationship between these two types.

Calcite cements:

Some of the original intraparticle pore space is cemented by sparry calcite (Fig.53 (H)). The crystals are generally 70-90µm in size and fills either the whole or parts of the bioclasts, or cement crystals show syntaxial growth from foraminifera walls. The identification of cements is based on Bathurst (1975), mainly on the basis of enfacial junctions, straight compromise boundaries, and the homogeneous size of the crystals.

In foraminiferal chambers the cement does not generally fill the whole pore space but commonly only parts are cemented whereas the rest is filled with the smaller and more irregular crystals of neomorphic spar or isotropic silica. No consistent orientation of these half-cemented tests is present but they may be relics of an original geopetal roof sparite which has been rotated either during transport or compaction. The latter possibility would indicate that compaction post-dates cementation.

Radiolarian (spumellarian) shells are most commonly found to be cemented which is thought to be related to the early diagenetic mobilisation of the opaline shell material. Many of the radiolarians are entirely filled with a mosaic of large sparry calcite crystals. Since radiolarians are comparatively small only a few crystals of approximately 50μm fills the whole void.

Quartz fillings:
Most intraparticle voids are filled with quartz when silica accumulations are present in the thin section (Figs.58 (C), 54 (C)). It occurs as microcrystalline to megacrystalline quartz with very varying grain sizes between 2-25μm and up to 70μm. Fibrous chalcedonic quartz (Fig.58 (B)) is less frequent but abundant. It is found mainly inside radiolarian shells and in several cases both quartz varieties are found in one single bioclast.

No statement can be made whether the quartz inside particles is a cement or neomorphic. The microcrystalline quartz crystals inside bioclasts and the ones building up the recrystallised micrite which forms the chert patches seem to be identical. Quartz-replaced foraminifera walls are clearly neomorphic in origin whereas early quartz-filled radiolarians may be cemented.

3.2.6. SEDIMENTARY STRUCTURES

Sedimentary structures seen in thin sections of the Lefkara sediments are parallel and cross lamination, grading, convolute bedding and bioturbation (Figs.54, 58, 61). The characteristics will be discussed in the following section.

Fig.61. Photographs of whole thin sections.

A Packed and sparse strata of C-division with silicified cross laminae. Length of section 4.1cm.

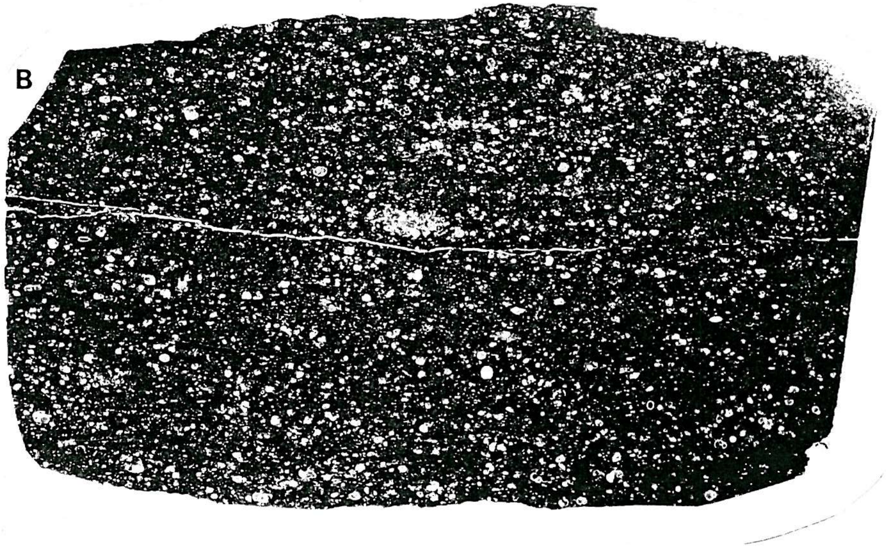
B Pelagic chalk with small compacted burrow in centre. Faint parallel texture is due to compactional seams. Length of section 1.5cm.

C C- and D-divisions of one turbidite with packed and silicified cross laminae. Height of section 3.0cm.

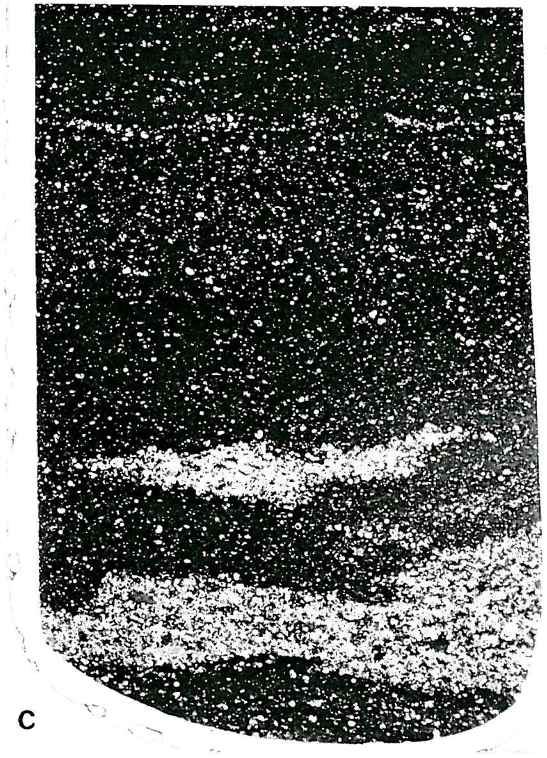
D Detail of C-division affected by microfaulting. Length of section 1.9cm.

A

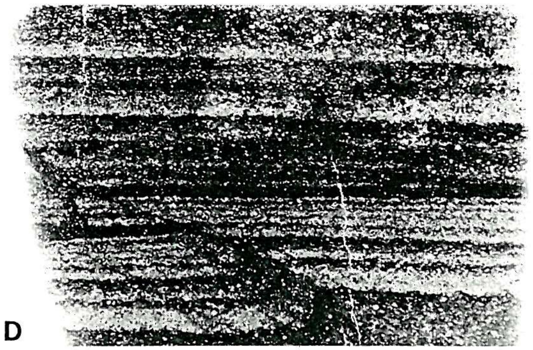
B



C



D



Lamination:

The laminae observed vary in thickness between 200μm and several mm or even cm (Figs.54 (C), 58 (D)). They are mostly formed by a change of bioclast density or size in the micrite (Fig.54 (B)) or by a very thin layer of enriched bioclast fragments (indicating erosion). Chert accumulations in strata enhance or even produce the visibility of a thin bed or lamina (Fig.54 (C)). In other cases the lamination is produced by a repeated change of more or less developed dissolution seams (Fig.58 (D)). Although this is not a primary depositional feature it still most likely reflects a changing susceptibility to compaction due to a change in the original composition (Bathurst, 1991). Cross laminae are characterised by the same features as parallel laminae (Figs.61 (A), (C)), with the addition that cross laminae are commonly enriched in fragments of foraminifera tests (Fig.58 (E)).

Graded beds:

Graded individual beds are observed in few thin sections, with the grading most commonly produced by an upward decrease in size of lithoclasts, together with benthic foraminifera and macrofossil fragments, amongst the dominating planktonic foraminifera.

Only the graded beds contain the rarer type of sediment clast (type S) which is reworked from penecontemporaneous beds of the Lefkara Formation. In well developed examples the majority of the coarsest particles occupies the lowermost part of the bed, usually the first 2-4mm. Sorting is generally poor, with particles of very fine sand-size to very coarse sand-size cooccurring (Fig.54 (A)). Bed thickness varies between 0.5cm and 1.2cm.

The clasts (dominantly sediment clasts) at the bottom of graded beds reach maximum sizes of 1800μm (more typical 500-750μm) and are approximately 400μm on average. Rare minerals and rock fragments with a higher specific weight are relatively smaller. At the top of the graded bed planktonic foraminifera of an average size of 250μm clearly dominate the allochem assemblage. However, not all graded beds show all these characteristics. In several examples only a gradual decrease in size of the foraminifera tests towards the top exists and there are not large amounts of lithoclasts. The foraminifera decrease in the overall size from 300-500μm at the bottom to approximately 250μm near the top.

Convolute bedding:

Larger structures such as convolute bedding are more difficult to identify in a small thin section than in hand specimens. Under the microscope a sudden interruption and distortion of a bed is found (see Fig.68). Otherwise characteristics are identical with cross-laminated beds.

Fig.62. Microphotographs of thin sections continued.

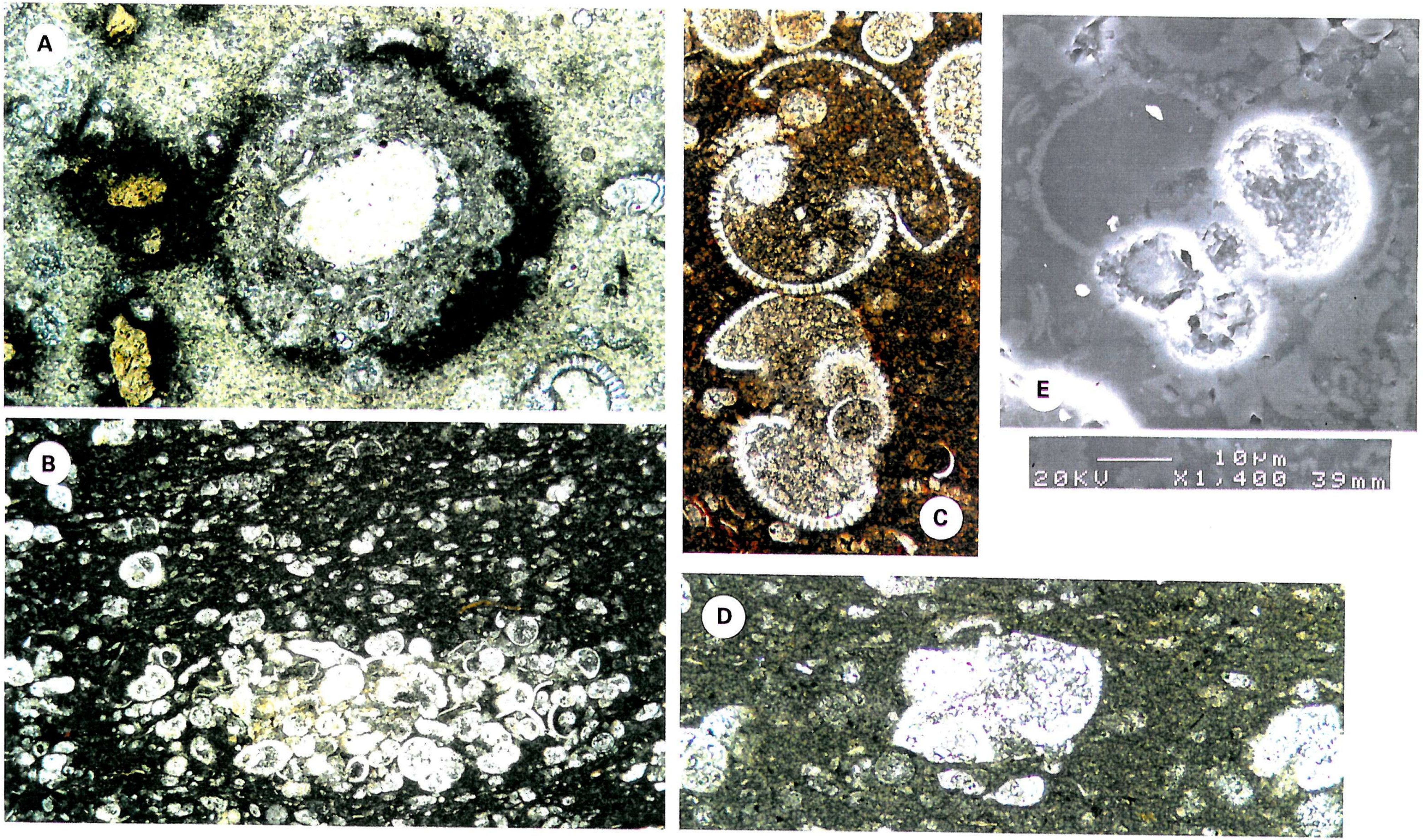
A Circular burrow, 500μm in diameter.

B Compacted burrow highlighted by an enrichment in larger bioclasts, 3mm in length.

C Foraminifera tests showing fragmentation and concave-convex contact due to pressure-solution caused by vertical compactional stress.

D Globigerinid truncated by pressure-solution (250μm).

E Foraminifera under the SEM; youngest chamber is filled with isotropic silica.


A
B
C
D
E
10µm
20KV X1,400 39mm

Microfault:

In one thin section a laminated sequence is disturbed by a microfault (Fig.61 (D)). Some laminae are bent during the movement which indicates faulting before complete lithification. The relative offset is about 3.75mm.

bioturbation:

Bioturbated sediments show an irregular or inhomogeneous distribution of bioclasts in the matrix. This becomes more evident when areas are enriched in significantly smaller or larger foraminifera specimens which fill the former burrow. In some specimens these are concentrated in typical lenticular areas which trace the compacted, originally round, tubes (Scholle, 1971) (Figs.62 (B), 61 (B)). A spreiten burrow is present in one sample (Fig.63) where it is characterised by u-shaped structures of 1.3cm in length parallel to the bedding which become visible due to colour changes.

Small structures of 500-700μm were observed in several thin sections which are assumed to be formed by burrowing organisms as well (Fig.62 (A)). They are more or less lenticularly deformed features, commonly silicified, and enriched in siliceous microfossil relics such as small (radiolarian) spines, radiolarians, and kidney-shaped sponge spicules.

Fig.63. Spreiten burrow in sparse biomicrite, length approx. 1.3cm.

3.2.7. COMPACTION

In thin sections postdepositional compaction of the sediments is detected by a variety of features. These are fracturing of bioclasts, alignment of elongate particles, deformation of bioclasts and intraclasts, concave-convex contact of grains, pressure dissolution seams, and pressure dissolution and truncation of bioclasts. All these features do not always occur together but are all common in the material.

In many thin sections fragments of foraminifera tests are enriched. Although this does not necessarily have to be related to fracturing by compaction, crushed tests can be seen *in situ* in the state of breaking in the micrite (Fig.62 (C)), with the thinner or more brittle component breaking at the contact. This is observed when foraminifera tests are crushed against clasts, or thin fish bones against more stable foraminifera (Fig.64). Fragmentation is a common feature in packed biomicrites and much less in sparse ones. Deformation shows that the pressure worked normal to the bedding plane.

Test fragments, fish bones, lenticular radiolarians, and other elongate particles are parallel aligned in the matrix due to the overburden pressure and rotation in the unlithified matrix (Bathurst, 1975). This resulted in a horizontally oriented compactional fabric parallel to the bedding plane (Fig.58 (D)).

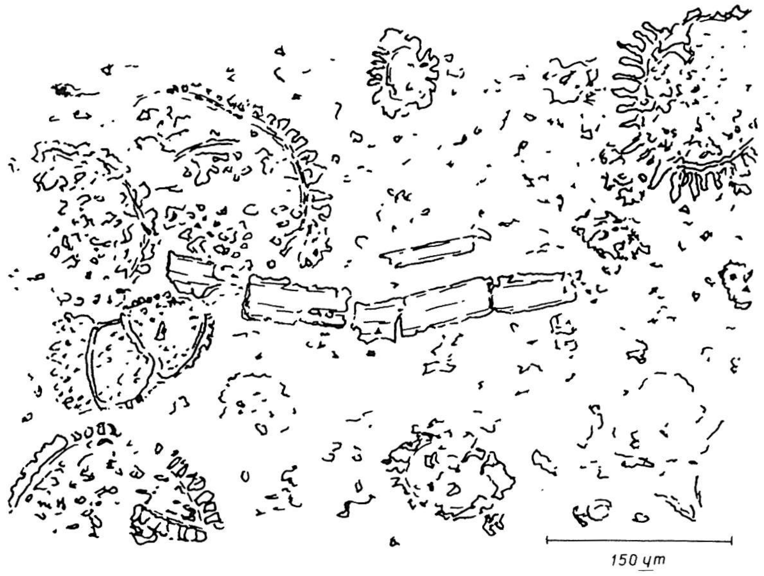


Fig.64. Elongate bone particle fragmented by vertical compaction.

Compression and deformation of the particles during increased pressure led to a lenticular and wavy deformation, commonly without showing any sign of crushing or breaking (Shinn *et al.*, 1976). This is observed for radiolarians that are filled with micrite or silicified micrite and whose walls are thin and replaced by calcite or completely dissolved. Other components showing the same behaviour are the sediment clasts which must have been still somewhat plastic at the time of compaction. They are almost identical with compacted radiolarians where the walls of the latter ones are not preserved. As described in section 3.2.5., compactional stress produced a characteristic fibrous extinction pattern for silicified mud. This is common in both, deformed radiolarians and sediment clasts.

Lenticular burrows (Fig.62 (B)) also reflect compaction since these were originally circular. The degree of compaction and the consequent loss of sediment thickness can be estimated, under the condition that the tube is cut perpendicularly. A typically observed length to width ratio is 2:1 or in some cases even 4:1, as described e.g. by Scholle (1971). This implies a compaction of over 50% to 75% of the original sediment thickness.

Pressure-solution of carbonate, as a result of compaction, results in the dissolution of calcitic bioclasts, leading from truncation of tests (Fig.62 (D)) to a total disappearance of the specimens, or their preservation as faint ghosts (Bathurst, 1975; Schlanger & Douglas, 1974). All gradual transitions are visible, with walls becoming thinner and less defined and finally disappearing entirely into the micrite. Concave-convex contact between two calcitic grains also reflects pressure-solution in the sediments and is most commonly observed between two foraminifera tests but also between lithoclasts and bioclasts (Fig.62 (C)).

Resulting from a similar process, pressure-solution seams (Fig.58 (D)) are relative enrichments of insoluble residue after carbonate dissolution (Bathurst, 1975). They are a common feature in the sediments studied and are characterised by darker, more or less wavy lines or networks of higher clay contents in the micrite. They are generally perpendicular to the compactional pressure and consequently parallel to the bedding plane. Foraminifera tests lying adjacent to a dissolution seam are observed to be truncated and dissolved at the surface of contact.

3.2.8. ABUNDANCE OF ALLOCHTHONOUS MATERIAL IN THIN SECTIONS

An attempt is made to quantify the assumed reworked components observed in the thin sections. Point counts were not made, mainly because the single thin sections are mostly so heterogeneous that counts do not seem to be representative. Therefore semiquantitative estimations of relative abundance categories are made, where 'absent' = 0%, 'rare' = 1-2%, 'present' = 3-5%, 'common' = >5%. Since these are extremely rough estimations only clear trends in the variations should be considered to be significant.

The components identified include lithoclasts, macrofossils, fish remains, and benthic foraminifera. The clasts are mainly represented by sediment clasts and only in rare cases hard rocks or minerals are significant constituents. The macrofossils are a composite group, including unidentified shell fragments, molluscs, ostracods and larger foraminifera. All of them indicate a similar (shallow water) origin. The benthic foraminifera are grouped excluding the larger foraminifera. Typically only one specimen was found in the thin section. This might lead to a quite high probability of errors in the abundance. For comparison, the data listed in Table 8 (thin section descriptions) for the general amount of reworking and the presence of lamination are added. Figure 65 shows the variations in the assumed reworked components in all six sections.

Comparing the trend of the components between the sections (Tab.7), the most significant parallel trend is found in the curves of general reworking (the sum of all assumed allochthonous components) and the clast content. This is expected since clasts are the main reworked component found in the thin sections. It therefore confirms that the reworking is usually defined and determined by the amount of sediment clasts. In many sections (Kalavasos, the Motorway and partly Lefkara and Stavrovouni) the macrofossils also follow the same parallel trend as the reworking. This is not the case in the Kouka and Ayios Nicolaos sections. The comparison of the fluctuations of the clasts and the macrofossil fragments usually does not show any dependency at all with the exception of the Motorway section. An increase in the relative percentage of macrofossils at the top of the succession is observed for the Kouka section.

The fish remains are significantly abundant in the Ayios Nicolaos, Motorway and Stavrovouni sections. In Lefkara and Kalavasos they are more variable but still common while they are even absent in several samples of the Kouka section. In the Lefkara, Motorway, and Stavrovouni sections and in some cases in the Kouka section the bone content varies together with other reworked components, especially with clasts.

ALLOCHTHONOUS CLASTS FROM THIN SECTIONS

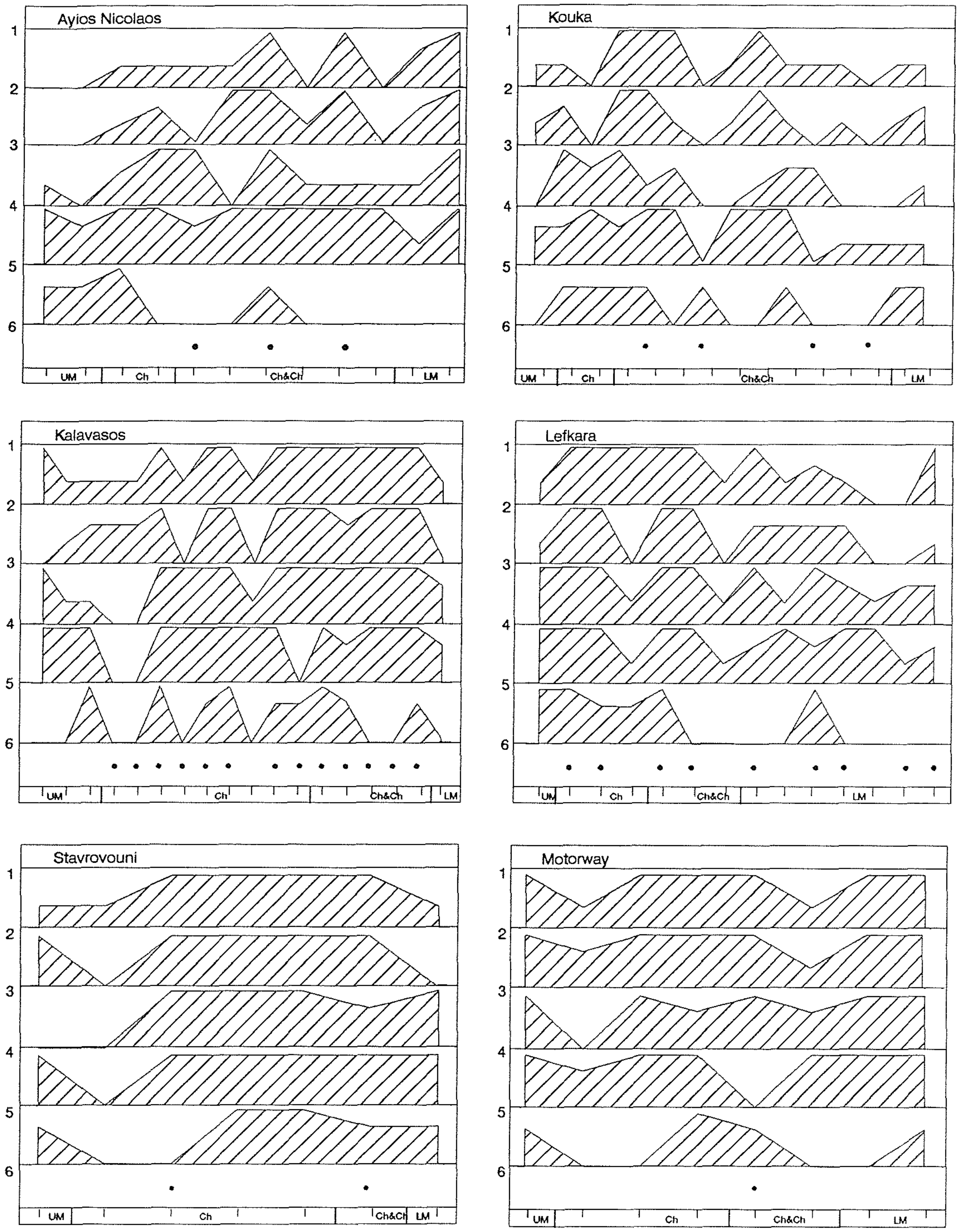


Fig.65. Variations in abundance of different groups of allochems as a measure of reworking. Vertical scale ranges from absent to rare to present to frequent. 1 = general reworking, 2 = lithoclasts, 3 = macrofossils, 4 = fish bones, 5 = benthic foraminifera, 6 = lamination. The origin of the samples from the stratigraphic column is indicated at the x-axis.

Tab.7. Summary of covariations of allochem abundances in thin sections as seen in Fig.65.

section covariations	A.Nicolaos	Kouka	Kalavasos	Lefkara	Stavrovouni	Motorway
general reworking parallel clasts	x	x	x	x	x	x
gen.reworking parallel macrofossils	(no)	no	x	x	x	x
clasts parallel macrofossils	no	no	(no)	(no)	(no)	x
benthic forams frequent near top of formation	x	x	no	x	x	(x)
benthic forams parallel general reworking	no	no	x if > rew.	x if > rew.	(no)	x
fish bones frequent	x	no	(x)	x	x	x
fish bones parallel clasts	no	x	no	x	x	x
lamination combined with abundant allochth.components (excl.benth.forams)	no	no	x	x	x	-
benthic forams not parallel lamination	x	x	x	x	no	-

With the exception of the Motorway section, benthic foraminifera do not covary with any other component. In most sections the relative amount increases towards the top of the succession (Ayios Nicolaos, Kouka, Lefkara and possibly Motorway and Stavrovouni). This is not observed in the Kalavasos section. The only relationship of the benthic foraminifera to the other curves is that benthic foraminifera mainly only occur if significantly large amounts of reworked material are detected without actually reflecting the trend of the curves. This is not verified for the Kouka and less clearly for the Stavrovouni sections. Benthic foraminifera are significantly rare in most of the older part of the Ayios Nicolaos section and possibly of the Lefkara section.

Lamination observed in the thin section is strongly correlated with most of the reworked components in the Lefkara, Kalavasos and Stavrovouni sections but not in the Ayios Nicolaos and Kouka sections. This means that the amount of all components is significantly increased if lamination is present. Benthic foraminifera generally have to be excluded from this relationship.

A further important observation is that the trend of all components (excluding the benthic foraminifera) are strikingly parallel in the Motorway section.

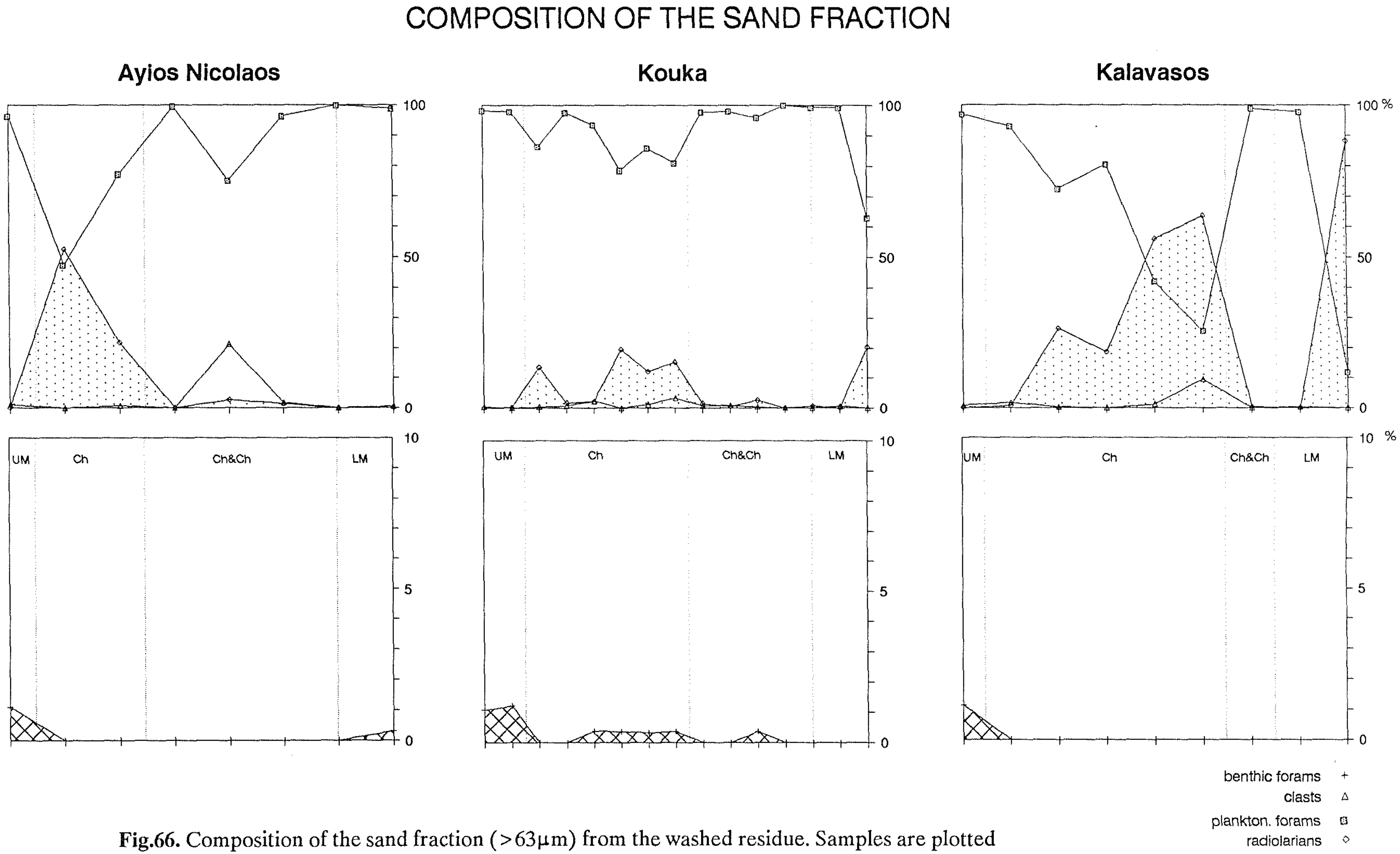
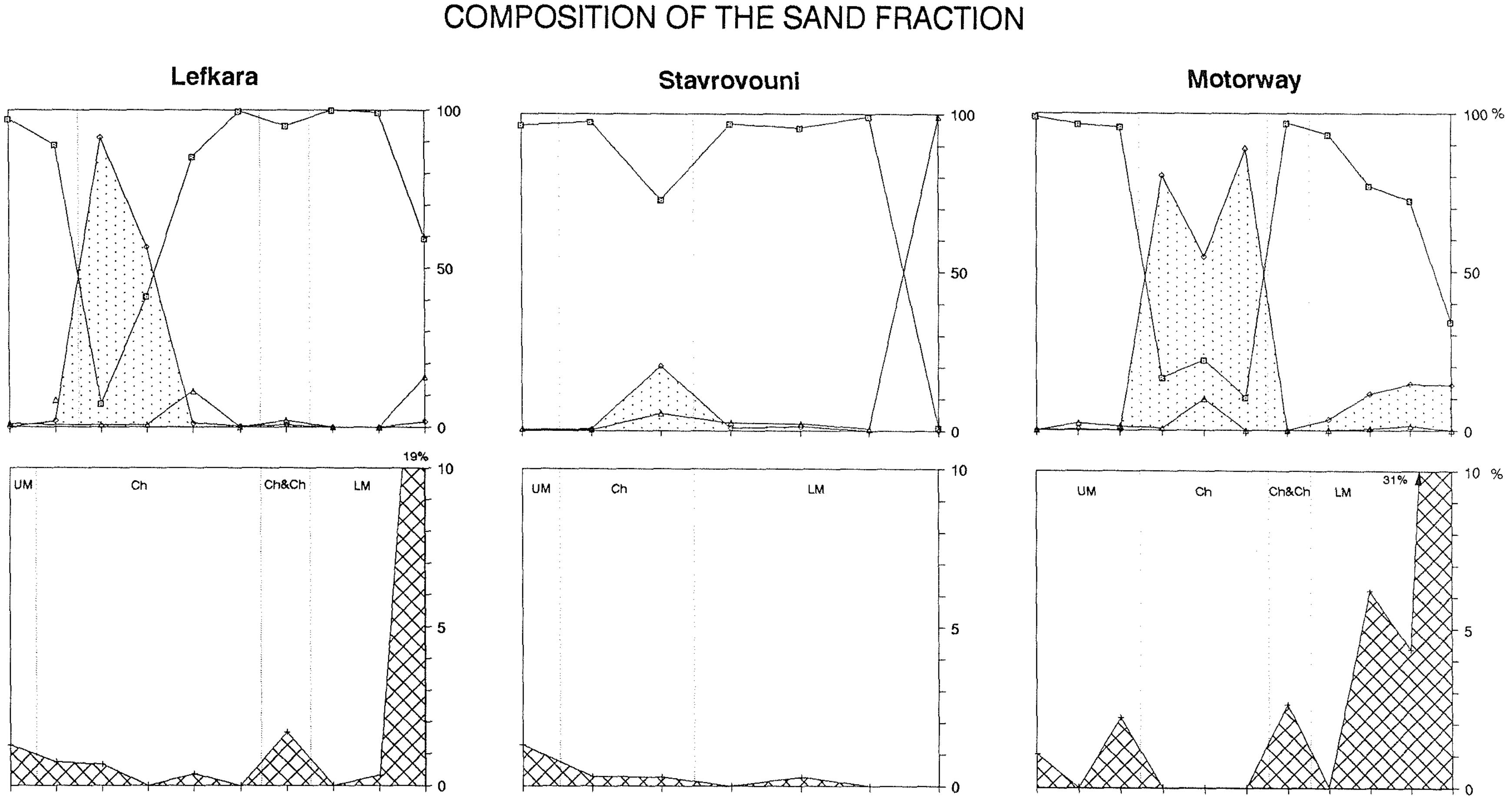


Fig.66. Composition of the sand fraction (>63µm) from the washed residue. Samples are plotted in equal distances to highlight variations in composition between the different lithological units. Abundances of radiolarians and benthic foraminifera are accentuated.



COMPOSITION OF THE SAND FRACTION

Lefkara

Stavrovouni

Motorway

Fig.66 continued.

3.2.9. COMPOSITION OF THE SAND FRACTION

In order to compare changes in the sediment composition of the >63μm fraction, counts were made from the washed residue used for foraminifera identification (see Chapter 2). Samples were selected at approximate regular spacing from the stratigraphic column as well as from important lithological changes. Planktonic and benthic foraminifera, radiolarians and clasts were distinguished and percentages calculated. Because of the processing technique the clasts found are never sediment clasts, dominant in the thin sections, but always igneous rocks or single minerals such as quartz. Radiolarian spines are not included in the counts since their abundance is proportional to the radiolarian occurrence and they therefore do not represent an additional component. All other rather scarce constituents found, such as sponge spicules, fish bones, or pyrite particles, are not considered separately. If possible, 300 specimens are counted per sample to get a statistically reliable result. Only in few samples from the bottom of the succession the material is rare in any of the components so that smaller numbers (below 100 specimens) have to be used. The results of the counts are listed in Appendix C and illustrated in Figure 66.

To avoid any confusion when comparing the results it should be mentioned that all samples examined only represent the lithologies chalk, marly chalk, and marl. Different to the thin sections, cherty material could not be processed in this way. Additionally, samples showing obvious reworking were avoided since originally these samples were prepared for the foraminifera-dating. Therefore, turbiditic sediments from higher flow regimes will not be present in this data set.

Comparing the curves of the counts of the sand fraction, several regularities can be pointed out. **Planktonic foraminifera** dominate the assemblages in the samples from the Lower Marl, the Chalk & Chert unit, and the Upper Marl. Gradually increasing abundances from 34% to 97% are observed in the Motorway section from the bottom of the succession to the Chalk & Chert unit. Except in the Ayios Nicolaos section, planktonic foraminifera are significantly rarer with values between 0% and 63% in the stratigraphically lowest samples of the succession.

In most of the material from the Chalk unit **radiolarians** partly replace the planktonic foraminifera. This even leads to a clear dominance of radiolarians in the Chalk unit with up to 91%. In the Kalavasos section a gradual decrease in radiolarian abundance develops throughout the whole unit. In other units radiolarians are rare or absent. Exceptions are the basal samples of the succession of the Kouka, Kalavasos and Motorway sections which are enriched in radiolarians. In the closely spaced samples from the Lower Marl unit of the Motorway section a gradual decrease towards the Chalk & Chert unit from 14% to 0% becomes apparent. In general, radiolarian abundances are lower in the western Ayios Nicolaos and Kouka sections than in the east.

Benthic foraminifera show low percentages of less than 1% in most sections. The lowest values are found in the Ayios Nicolaos and the Kalavasos sections and slightly more in the Kouka, the Stavrovouni, and the Lefkara sections. Partly higher abundances exist in the Motorway section, especially in the Lower Marl unit, with abundance maxima of 6%. In the bottom sample of the Motorway and Lefkara sections exceptionally high values are found of 31% and 19% respectively. A very vague increase in benthic foraminifera in the Upper Marl might be seen in all sections.

Lithoclasts are present in abundances above 1% only in few samples. These higher values are found mainly at the base of a succession (Lefkara: 16%, Stavrovouni: 99%) or from sporadic samples in the Chalk & Chert or the Chalk units. In most samples lithoclasts are totally absent.

Fish bone fragments are not counted separately. Analysing them separately, they are rare and sporadic in the samples of the Kouka, Ayios Nicolaos, and the Stavrovouni sections. More commonly they are found in the Lower Marl unit of the Kalavasos and the Motorway sections and near the transition between the Chalk and the Upper Marl units in the Lefkara and the Kalavasos sections.

3.2.10. MICROFACIES CLASSIFICATION

In Table 8 the most important components and criteria distinguished in the thin sections are listed. These include sedimentary as well as diagenetic features. Some of these are used to establish microfacies types while others are not considered since too detailed groupings would lead to a confusingly large number of facies types. The purpose of the table is mainly to act as a description of the thin sections. To estimate percentages of bioclasts present in the thin sections the comparison charts published in Flügel (1982) were used. When listing the intraparticle fillings only the main ones are mentioned. Reworked material consists mainly of the common sediment clasts and metazoa fragments as analysed in section 3.2.8..

The main information immediately visible from the tables is that the micrites from the Kouka and Ayios Nicolaos sections and, not as consistently, also from the Motorway section are mainly sparse biomicrites, with a microfossil content mainly between 10% and 20%. Sedimentary

Tab.8. Characteristics of thin sections studied from the Ayios Nicolaos section. For sample position see Figs.24-29; for key see Lefkara section.

sample	lithol. unit	macro-facies	classi-fication	diss. seams	SiO2-accu.	micro-fossils	void filling	rewor-king	sedim. structu	%bio-clasts	micro facies
28/1	UM	marl	sparse	x	no	>forams	micrite recry. <sparry	no	no	5-10%	I2
18/90	Ch	marl	sparse	no	no	forams	<micrite recry.	no	no	20%	I1
28/B	Ch	m.chalk	sparse	<	no	>forams radios	recry. silici. <sparry.	<	bio?	30-40%	I2
28/E	Ch	chalk	sparse	x	no	forams radios	sparry. recry. silici. micrite.	no	bio	10-20	I2
28/C (bad TS)	Ch	m.chalk	sparse	<	no	>forams	?	?	no?	10-15%	I1
18/62	Ch&Ch	chert	sparse+ packed	no	x	forams radios	SiO2 silici.	<	lam.	10-40%	II
18/7	Ch&Ch	chalk chert	sparse	<	x	forams radios	micrite sparry recry. SiO2	<	lam.	20-25%	I2
18/6	Ch&Ch	limestone	sparse	no	no	>forams	sparry recry.	x	<lam.	10-15%	I1
18/5	Ch&Ch	chalk	sparse	no	no	forams	sparry recry.	no	bio	15%	I1
18/8	Ch&Ch	chalk	sparse	no	no	forams	>sparry <recry.	x	<lam. bio	15%	I1
18/4	Ch&Ch	chalk	sparse	no	no	>forams	sparry recry.	no	no	15%	I1
18/2	LM	m.chalk	sparse	no	no	>forams	recry. >sparry	<	no	15%	I1
18/22	LM	m.chalk	packed	>	no	>forams radios	recry. sparry	x	no	80%	I2

Tab.8 continued; Kouka section.

sample	lithol. unit	macro-facies	classi-fication	diss. seams	SiO2 accu.	micro-fossils	void filling	rewor-king	sedim. structur	%bio-clasts	micro facies
15/Q	UM	marl	sparse	x	no	forams	micrite recry.	<	no	max10%	I2
15/R	Ch		sparse	no	no	forams	micrite <sparry recry.	<	no	15%	I1
15/W	Ch	h.chalk	sparse	x	no	>forams	sparry micrite recry.	no	no	15-20%	I2
15/X	Ch	ch.marl	sparse	<	no	radios forams	sparry recry. silici.	x	bio	20%	I2
15/Y	Ch&Ch	chalk chert	sparse	<	x	>forams	SiO2 silici. sparry micrite recry.	>	cross	10-15%	I2
15/Z	Ch&Ch		sparse	<	no	forams radios	sparry recry. <silici.	x	no	15%	I2
15/33	Ch&Ch	h.marl	sparse	x	no	>radios	SiO2 micrite	no	cross	2 1/2% +ghosts	I2
15/26	Ch&Ch		sparse	no	no	>forams	sparry recry.	<	no	10%	I1
15/24	Ch&Ch	m.chalk	sparse	x untyp.	no	>forams	sparry recry.	x	bio	10-20%	I1
15/19	Ch&Ch	limestone	sparse	no	no	>forams	>sparry recry.	<	no	10-15%	I1
15/16	Ch&Ch	limestone	sparse	<	x	forams radios	sparry silici.	<	lam	10-20%	I2
15/15	Ch&Ch	h.marl	sparse	no	no	forams radios	sparry recry.	<	no	20%	I2
15/14	Ch&Ch	h.marl	sparse	x	no	forams radios	SiO2 <silici. micrite	no	bio	20%	I2
15/7	LM	marl	sparse	<	no	forams	>sparry silici.	<	bio	20-25%	I2
15/3	LM	limestone	sparse	x	no	>forams	sparry recry.	<<	no	20-30%	I2

Tab.8 continued; Kalavasos section.

sample	litho unit	macro-facies	classification	diss.se seams	SiO2-acc.	micro-fossils	void filling	reworking	sedim. structur	%bioclasts	micr facie
31/1	UM	ch.marl	sparse	no	no	forams	micrite recry. <sparry	x	no	10%	I1
31/2	UM	marl	sparse	no	no	forams	micrite recry. <sparry	<	no	10%max	I1
31/5 (bad TS)	Ch	chalk	sparse	x	no	forams	>micrite sparry	<	no	10%max	I2
30/4	Ch	chalk	sparse	x	no	forams radios	sparry >micrite	< (no)	<lam bio(?)	10% 30%	I2
30/3	Ch	chalk	sparse	<	no	forams >radios	sparry <micrite recry.	<	<lam	20%	I2
30/J	Ch	calcisiltite	packed	x	no	>forams	>micrite sparry	>	lam	70%	II
30/K	Ch	chalk	sparse	x	no	radios	sparry micrite recry.	<	lam	20–40%	I2
30/H	Ch	hard marl	packed	x	no	forams radios	>micrite sparry SiO2 recry.	x	lam	80%	II
30/G	Ch	chert	packed	x	x	>forams	SiO2 <micrite	x (>)	cross	60%	II
30/E	Ch	limestone	sparse	x (<)	no	>radios	SiO2 <micrite	<?	no	20%	II
30/D1	Ch	silicif. chalk	>packed sparse	<	x	>forams radios	SiO2 micrite <sparry	>	cross	30–35%	II
30/D2	Ch	chalk	packed sparse	x	x	radios forams	SiO2 micrite	x	cross	30–35%	II
30/C	Ch&Ch	chalk	>sparse packed	x	x	forams radios	SiO2 micrite recry <sparry	>	lam.	top:15% 50–60%	II
30/B	Ch&Ch	ch.marl	packed	no	x	>forams	SiO2 micrite	x	lam	60%	II
30/A	Ch&Ch	chalk, chert	>sparse packed	x	x	>forams >radios	SiO2 micrite recry. <sparry	x (>)	convol.	15–60%	II
32/A1	Ch&Ch	chalk	packed	x	no	forams radios	sparry micrite	>	lam. biot.	20–60%	II
32/A2	Ch&Ch	chalk	packed	x	no	radios	sparry	x	lam.	20–30%	II
32/A3	Ch&Ch	chalk	packed	x	no	forams >radios	sparry micrite recry.	x	cross	40%	II
35/3A	LM	ch.marl	sparse	<	no	forams	sparry recry.	<?	no	10%	I1

Tab.8 continued; Lefkara section.

sample	lithol. unit	macro-facies	classi-fication	diss. seams	SiO2 accu.	micro-fosslis	void filling	rewor-king	sedim. structur	%bio-clasts	micro facies
21/79	UM	marl	sparse	no	no (untyp.)	forams	>micrite recry.	<	no	50–60%	I1
21/C	UM	chalk	packed sparse	<	x	>forams radios	>SiO2 <micrite	x	cross	60% 40%	II
21/55	Ch	chalk	both	x	no	>forams radios	recry.	x	cross	<10%– 60%	II
21/58	Ch	chalk	sparse	<	no	forams radios	micrite recry. silici. <sparry	x	no	10%	I2
21/60	Ch&Ch	chert	packed	x	x	forams radios	SiO2 micrite	x	cross	80%	II
21/65 (several	Ch&Ch TS)	chalk h.chalk +/–chert	sparse packed	varyin in TS	x	forams radios	sparry micrite recry. SiO2 silici.	x	lam	<10%– 80%	II + I2
21/7	Ch&Ch	chalk	sparse	<<	no	>forams	sparry micrite	<	no	10–20%	I1
21/5	LM	chalk	sparse packed	<	no	forams	sparry	x	lam	40–60% 10%	II
21/4	LM	chalk	sparse	<<	no	>forams	sparry micrite	<	no	10–15%	I1
21/E	LM	m.chalk	>sparse	x	x	forams radios	SiO2	x	lam	10–20%	I2
21/D	LM	m.chalk	sparse	x	x	>radios forams	>SiO2 micrite	<	lam bio	10–40%	I2
21/C1	LM	ch.marl	sparse	<	x	forams >radios	SiO2 silici.	no	<lam bio	20–25%	I2
21/A (bad TS)	LM	chalk chert	sparse (?)	x	x	>forams	sparite recry.	x	lam	?	I2 ?
21/74	LM	h.marl	sparse	>	x	forams >radios	>SiO2 sparite micrite	no (<<)	lam	10–15%	I2
21/66	LM	h.marl	packed	x	x	forams radios	SiO2 micrite	x	lam	80%	II

ABBRIVIATIONS AND KEY:

m.chalk = marly chalk
ch.marl = chalky marl
h.chalk = hard chalk
recry. = recrystallised micrite
sparry = sparry calcite
silici. = silicified micrite
SiO2–accu. = chert accumulation in micrite
reworking = sum of allochthonous allochems

TS = thin section
x = present
< = rare
> = abundant
UM = Upper Marl unit
Ch = Chalk unit
Ch&Ch = Chalk & Chert unit
LM = Lower Marl unit

Tab.8 continued; Stavrovouni and Motorway sections.

sample	lithol. unit	macrofacies	classification	diss. seams	SiO2 accu.	microfossils	void filling	reworking	sedim. structur	%bioclasts	micro facies
24/5	UM	ch.marl	sparse	x	no	>forams	micrite recry.	<	no	max10%	I1
24/4	Ch	chalk	sparse	no	no	>forams	micrite recry. silici.	<<	no	10%	I2
24/A	Ch	ch.marl	>packed sparse	x	x	forams radios	SiO2 sparry micrite recry.	x	lam bio	40-60%	II
24/F	Ch	silici. chalk	packed	no	x	>forams	SiO2 <micrite	x	lam.	20-60%	II
24/E	Ch		packed	x	no	forams >radios	sparite micrite	x	lam.	40-90%	II
24/B	Ch&Ch	m.chalk	sparse	<	no	forams radios	SiO2 recry. <sparry	x	bio? cross	20-25%	I2
24/1	LM	chalk	sparse	no	no	>forams	micrite recry. <silici.	<	bio	20%	I1

sample	lithol. unit	macrofacies	classification	diss. seams	SiO2 acc.	microfossils	void filling	reworking	sedim. structure	%bioclasts	micro facies
49/101	UM	marl	packed	no	no	>forams	micrite	>	no	30-40%	II
49/7	Ch?	chalk	packed	x	no	forams	micrite silici.	<	no	60%	II
44/2H	Ch	chalk	sparse	<	no	forams radios	micrite <SiO2	x	biot.	10%	I2
44/2F	Ch	chalk	sparse	x	no	forams radios	micrite <SiO2	x	bio	10% (20%+ ghosts)	I2
46/2F	Ch&Ch	silicif. chalk	chert!	no	no	forams radios	SiO2	>	bio	10-15%	
46/2A	Ch&Ch	m.chalk	sparse	no	no	>forams	sparite recry.	<	no	10%	I1
47/2A	LM	marl	sparse	<<	no	>forams	>recry.	x	biot.	15%	I1
48/4	LM	marl	sparse	no	no	forams	>recry	>	spreite?	20%	I1

structures such as lamination are present in several thin sections of these three localities but they are faint or weakly developed. Reworking is detected in many samples. It appears to be rarest in the Ayios Nicolaos and Kouka sections but significantly more common in the Motorway section. In the two first sections, exclusively sediment clasts and few macrofossil relics are found while in the latter one additional quartz, feldspar and other minerals are present. In the three remaining sections, Kalavasos, Lefkara, and Stavrovouni, reworked material is present much more significantly with a higher diversity in the majority of the samples. Sedimentary structures such as lamination are frequent and many samples are classified at least partly as packed biomicrites. Reworking of planktonic foraminifera and radiolarians became apparent when identifying the fauna and establishing the biozones (compare Tab.3). The relative intensity of reworked microfossils does not follow the above grouping of the six sections here. The maximum influence of redeposition is found in the Ayios Nicolaos and Lefkara sections whereas the Kalavasos and Motorway sections show fewest or none. The significance of the allochthonous fraction will be discussed in Chapter 4.3..

All six sections have in common that the occurrence of increased amounts of radiolarians can be related to the presence of silica, either as quartz accumulations in the matrix or inside particles. Exceptions to this exist. Another observation is that micrite inside microfossil voids increased towards the top of the succession in many sections. For the sections Kalavasos and Stavrovouni this is not true. Here micrite fillings are also frequent throughout the whole succession.

Microfacies types:

Considering all characteristics found in the thin sections and listed above, some distinct microfacies types emerge. For others it is difficult to decide which feature to give priority to for distinguishing groups. For example, lamination and silica occurrence are both typically found together in a thin section. For the samples where this is not the case it has to be decided which of the two becomes the facies-determining criterion and this could alter the grouping. Conflicting situations like that make clear that the facies types are not fixed or objective subdivisions but their establishment is already part of the interpretation.

The microfacies types established are listed in Figure 67. Classifying characteristics are the limestone classification, sedimentary structures, and the presence of radiolarians, silica, and solution seams. Any reworked material is not included into the microfacies definition since no consistent relationship to any grouping can be found. The presence and absence of transported material will be discussed later in more detail. The category 'silica' includes all thin sections in which any silica was found, either as accumulations, replacements, cements, or silicified micrite

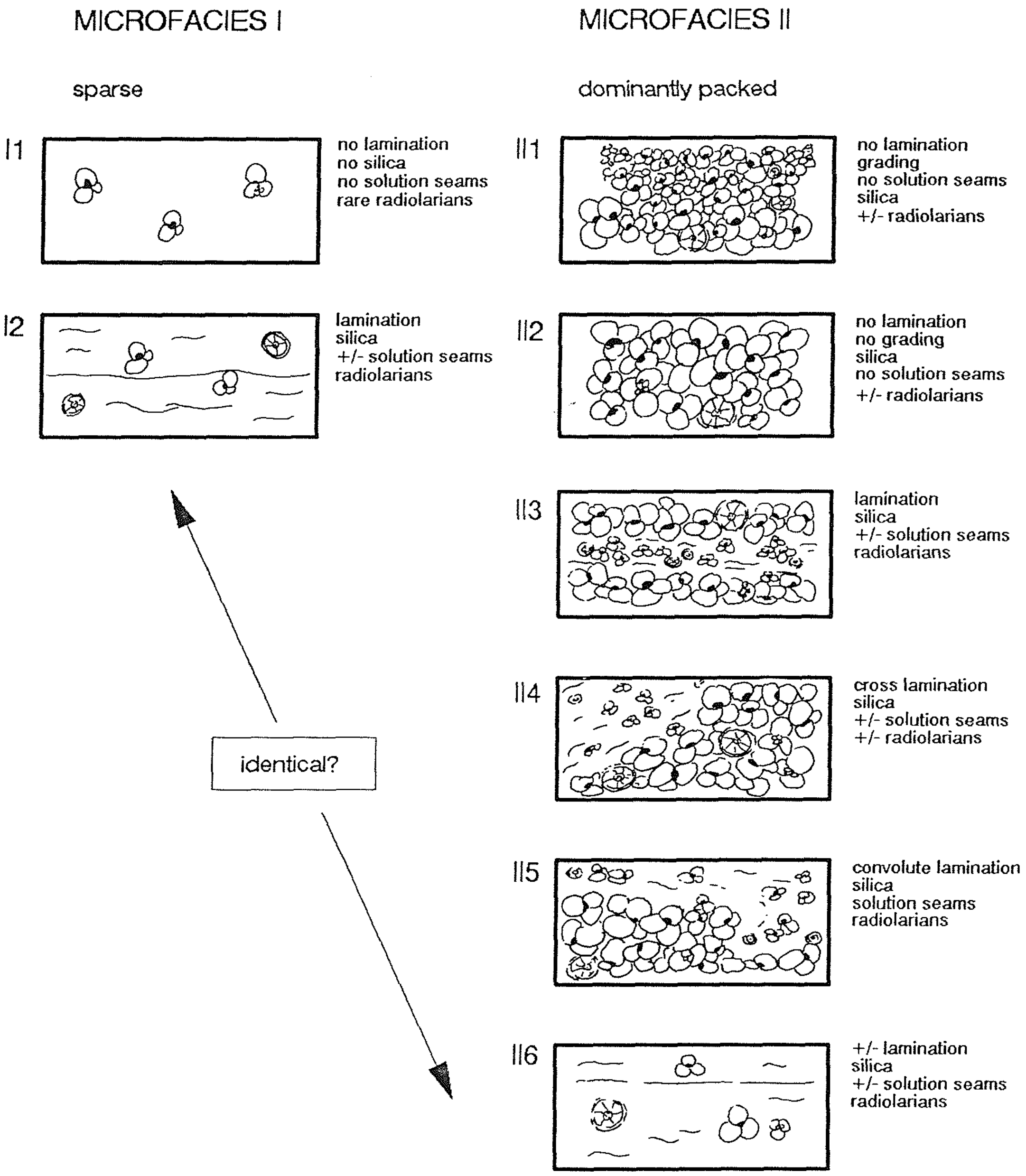


Fig.67. Microfacies types identified. Only the dominant pelagic microfossils are considered amongst the allochems.

inside particle voids. These are combined since they are all thought to be the result of the same process. Lamination is usually a clearly visible feature. Only in two samples (Ayios Nicolaos section) is it faint and questionable and therefore not grouped under 'laminated'. Solution seams are only defined as such for the microfacies if they are clearly developed. The category 'no seams' therefore also includes thin sections where only few or weakly developed seams are recognised. For the radiolarian occurrence no subdivision between frequent and dominant abundance is made. They may be replaced and/or filled by calcite or quartz or only preserved as casts.

The microfacies observed in the Lefkara Formation can be divided into two general microfacies groups, into the sparse microfacies I (considered to be mainly pelagic/hemipelagic in the first instance) and the dominantly packed (turbiditic) microfacies II. These two classes are most evident and therefore established as overall groups although they also include an interpretation of the depositional processes. Both of them can be subdivided into more detailed and descriptive facies types which will be discussed now.

Microfacies group I:
The samples of the first facies group are defined here by being exclusively sparse biomicrites. They can be subdivided into two main facies types, firstly samples that are free of silica and secondly samples that contain silica. In all cases one of the two microfacies types makes up the whole thin section which distinguishes them from the, sometimes similar, turbiditic facies.

In detail, the first microfacies type (I1) is clearly recognised with consistent characteristics: it is free of lamination and any silica and never contains well developed dissolution seams. Additionally, in the majority of samples planktonic foraminifera dominate the fauna and only in few exceptions significant amounts of radiolarians are observed.

The second microfacies type (I2) is mainly characterised by the presence of silica in thin section. Along with this, in many samples lamination is observed and in most samples radiolarians are present in significant amounts. Dissolution seams are present in about 60-70% of the samples studied. The presence of chert accumulation patches is not distinguished as a characteristic for the microfacies but it can be mentioned here that they only occur combined with lamination. Similar, there seems to be a relationship between lamination and radiolarian occurrence since nearly all samples exhibiting lamination also contain radiolarians.

A few sparse samples cannot be grouped into either of these two microfacies types. Four samples do not contain any lamination, silica or radiolarians but exhibited dissolution seams, which are not characteristic of microfacies type I1. Three other samples possess lamination, dissolution seams, and are enriched in radiolarians but do not contain silica. These characteristics are very close to but not diagnostic of the microfacies type I2. These samples might therefore be considered as transitional facies types.

Microfacies group II:

The facies types of the microfacies group II are characterised by sedimentary features. Basically they represent the individual divisions either of a (rarely) complete or incomplete turbidite sequence (Robertson, 1976; Stow *et al.*, 1984) (Fig.68). Thin sections that reveal a clear turbiditic facies are only found from the Kalavasos, Lefkara and Stavrovouni sections and with one exception from the Ayios Nicolaos section. In contrast to the first microfacies group (I), several of the single facies types of the turbiditic facies are commonly found in one thin section. Typically, they have a thickness of a few cm or less. Six different microfacies types are distinguished. Both, sparse and packed biomicrites are present. Most samples contained clasts in varying amounts although these are not considered here.

The first microfacies type of the facies group II (II1) consists of packed and graded beds which consistently do not exhibit any lamination or dissolution seams (and commonly contain large amounts of lithoclasts). Chert-accumulations are common. This facies type is only represented by a small number of examples.

The second microfacies (II2) is characterised by packed strata which show no lamination and no grading. It is therefore similar to the first microfacies type and is most likely closely related to it. The pattern of this facies is relatively homogeneous in the samples, with silica and radiolarians being mostly present, and seams rare.

Representatives of the third microfacies (II3) are packed biomicrites and exhibit parallel lamination. The pattern here is not always consistent but the majority of examples possess some silica and no solution seams. If no silica is present then seams are usually developed. Another distinction can be made, since the examples from most sections contain abundant radiolarians with the exception of the whole Lefkara section. In three cases a coarser lamination is present with packed and sparse strata alternating. These samples are also grouped into this facies.

The fourth microfacies type (II4) is cross-laminated and packed biomicrite and is observed only in the Kalavasos and Lefkara sections. Except for one sample, all those examined contain chert patches. The radiolarian content is very variable. Solution seams are absent in all representatives from the Kalavasos section whereas most of the Lefkara section show seams.

The fifth microfacies type (II5) is based on a feature that was observed in only one thin section and is possibly closely related to microfacies type II4. This comprises contorted or convolute lamination (possibly slump folding) associated with planar lamination, the presence of silica, solution seams, and frequent radiolarians.

The sixth microfacies type (II6) includes all sparse biomicrites occurring in the turbiditic facies group. The majority of these are free of lamination, contain some kind of silica, and are rich in radiolarians. Dissolution seams are apparently randomly present. This last microfacies type is more or less identical to the microfacies of group I, but occurs in close relationship to the turbiditic facies. How far these sparse strata from both of the facies groups are identical is essential for the interpretation of the depositional environment of the pelagic facies group and will be discussed in Chapter 4.3.2.1. 'Microfacies interpretation'.

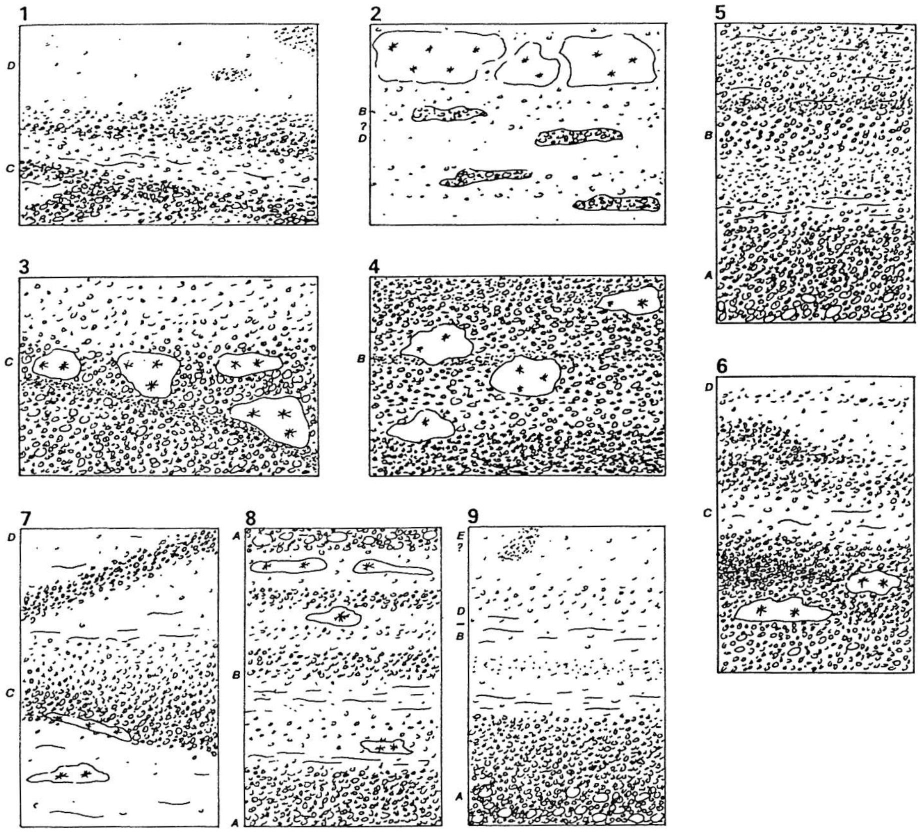


Fig.68. Examples of microstructures from various turbidite divisions (marked to the left of each thin section). Texture symbolises bioclast density, light patches with star ornament = chert accumulations, wavy ornament = solution seams.

3.3. MINERALOGY OF THE LEFKARA SEDIMENTS

3.3.1. WHOLE SEDIMENT MINERALOGY: RESULTS OF X-RAY DIFFRACTION ANALYSIS

The bulk mineralogy of the sediments is examined using x-ray diffraction (for XRD technique see Appendix D.1). The Ayios Nicolaos, Kouka, Kalavasos and the Motorway sections were chosen for comparison, from each of which an average of 11 samples were studied. The samples were selected to cover as even a time spacing throughout the sections as possible and to include all lithological units.

Figure 69 shows three representative plots of the x-ray diffraction counts of the Lefkara sediments. The diagnostic peaks of the minerals identified are labelled. The peak height equals the intensity of a mineral detected and approximately reflects the amount present in the sediment. Most samples analysed show a very similar picture, with the dominant component being calcite. Additionally, quartz and clays are usually present in significant amounts. The clays are studied in detail later in this chapter and therefore no attempt was made to identify or subdivide them in the analysis of the bulk composition. If referred to in this section the non-basal clay peak near 4.45-4.47Å is used to compare the clay abundances in the samples, since the dominant clay minerals (smectite, palygorskite, sepiolite, illite) have secondary peaks at this d-spacing (spacing of the lattice planes of a mineral). In addition to these three main components, opal-CT (disordered cristobalite and tridymite), dolomite, and trace amounts of feldspars are present in some samples. The opal-CT occurrences have been intensively studied by Robertson (1975, 1977).

To compare the relative variations of the main mineral abundances between the samples, the ratios of quartz and clay to calcite are calculated (quartz/calcite, clay/calcite). The absolute intensities reflect abundances only approximately, since machine dependant fluctuations in the peak heights might occur. Calcite is found to be always dominant and is therefore taken as a reference. The results of the bulk mineral analysis are illustrated in Figures 70, 71, 72 (Appendix D.2). They will be discussed separately for quartz and clay, and characteristic trends with respect to the lithological units will be compared between the sections.

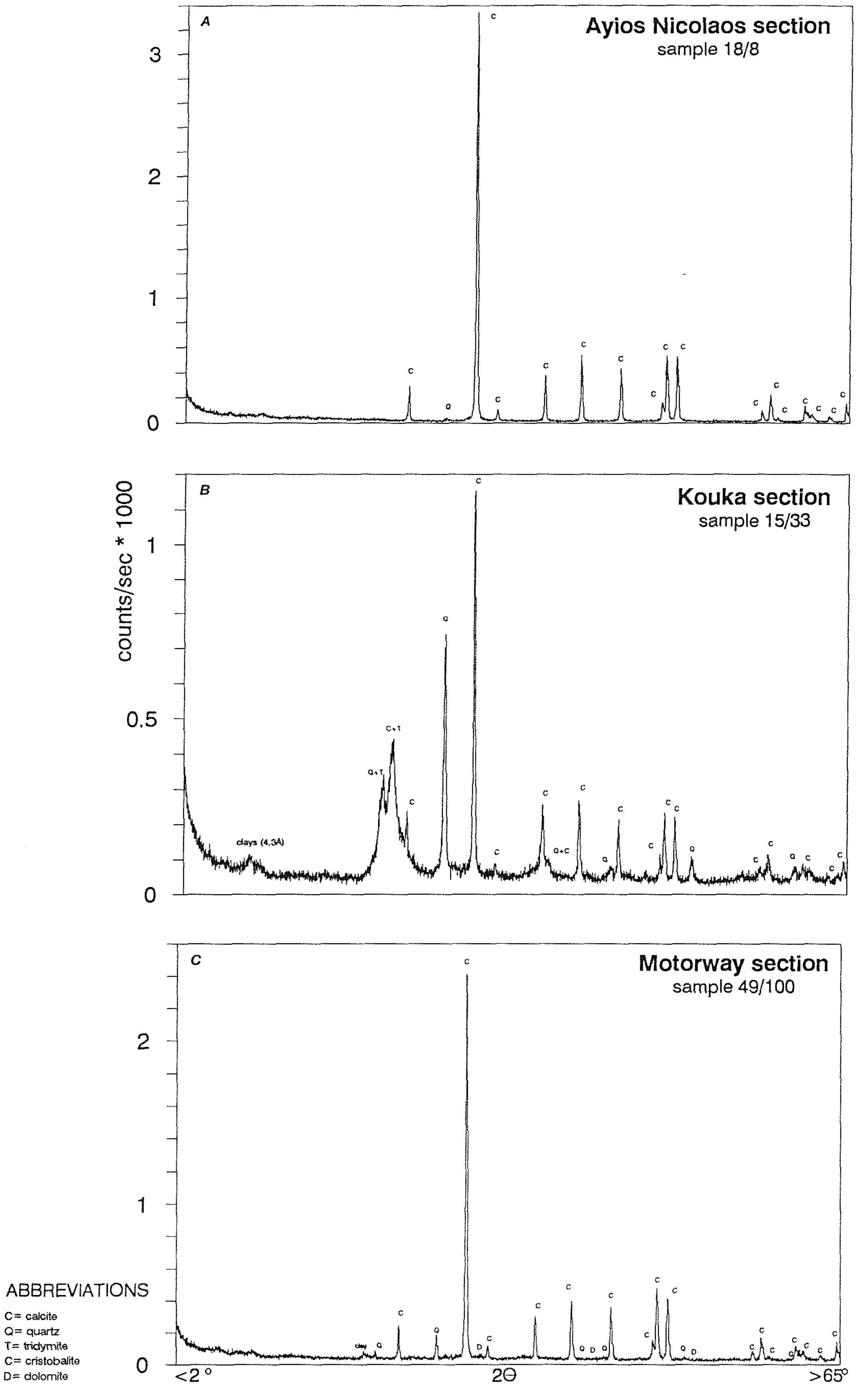


Fig.69. X-ray diffraction plots of the bulk composition of three reference samples. (**A**) Bedded chalk, Chalk & Chert unit; (**B**) Silicified chalk, Chalk & Chert unit; (**C**) Chalk, Upper Marl.

Quartz:

Comparing the relative quartz variations, the four sections studied can be split into two groups, the western sections, Ayios Nicolaos and Kouka, and the eastern ones, Kalavasos and the Motorway. Both groups show an exceptionally high to extremely high quartz content at the bottom and the top of the succession while the rest of the samples are richer in calcite. A quartz minimum after a first rapid decrease is also detected in all sections and is dated consistently to approximately 50Ma. This lies in the basal part of the Chalk & Chert unit in the western sections, Ayios Nicolaos and Kouka (samples 18/8 and 15/19, for sample numbers see Fig.72), and near the base of the Chalk unit in the eastern sections, Kalavasos and the Motorway (samples 30/1 and 43/13).

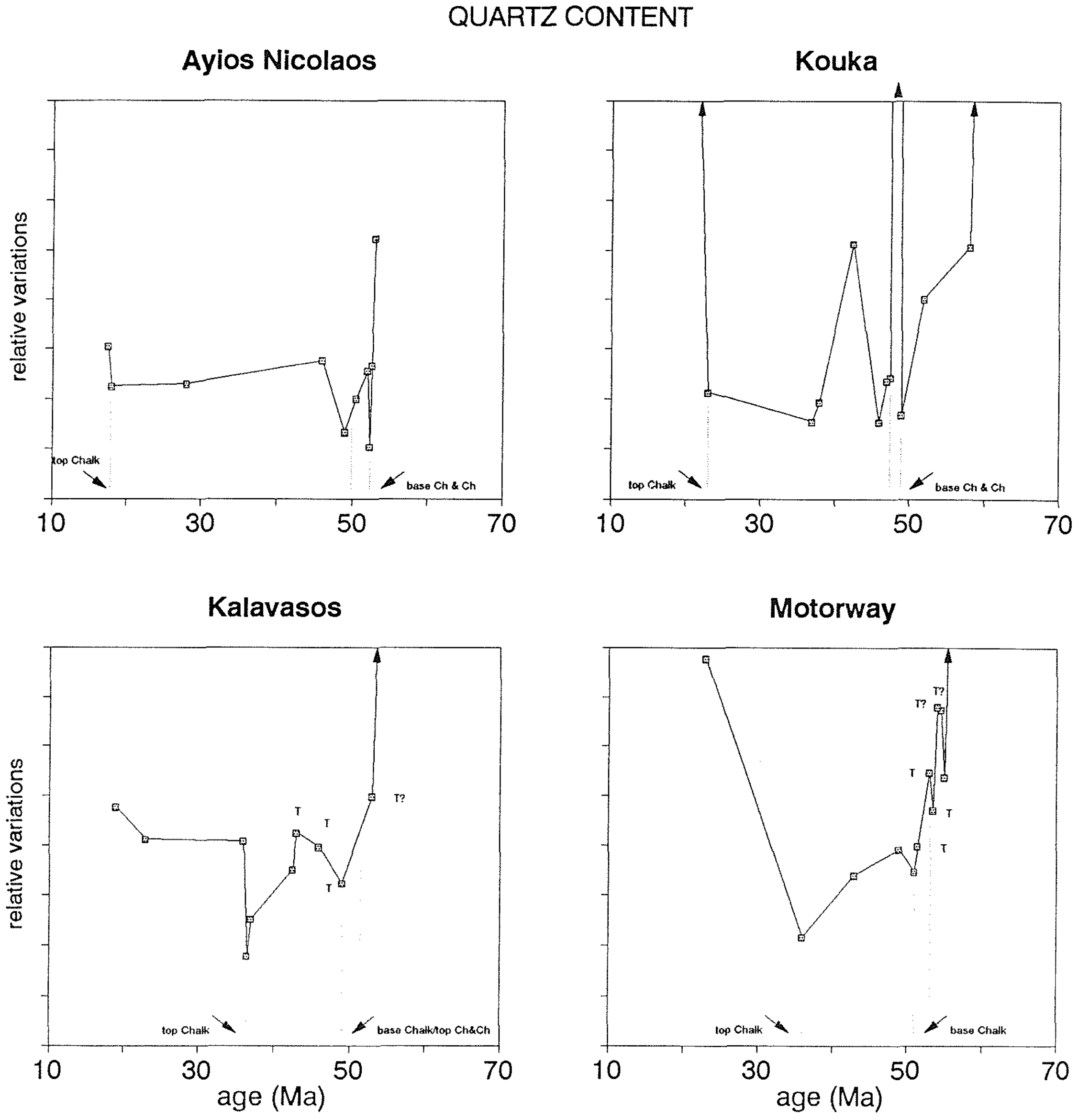


Fig.70. Variations in the amount of quartz in the bulk sediment (XRD results), calculated as the relative deviation from calcite intensities (quartz intensity / calcite intensity * 1000).

Although there is only a low sample density, certain comparable trends are nevertheless believed to be valid. The eastern sections show a parallel trend in quartz abundances in the Chalk unit, with the lowest value of quartz near 37Ma, which coincides with the top of the Chalk unit (samples 31/5 and 49/8). In the western sections, Ayios Nicolaos and Kouka, the trend is more variable in the samples of the Chalk & Chert and Chalk units (50Ma to 20Ma). Nevertheless, an absolute quartz minimum is also resolved in the Kouka section, near 36Ma whereas a gap in samples analysed exists in the Ayios Nicolaos sections at this time. The extremely high quartz value in one sample of the Chalk & Chert unit (sample 15/33) from the Kouka section can be explained by having sampled a silicified chalk layer.

For the most part only chalks or marls were selected for the XRD analysis. Therefore, the common occurrence of chert in the outcrops of the Lower Marl and Chalk & Chert units, is not reflected in the results of the bulk mineral analysis (with the exception of sample 15/33). This explains the fact that no major decrease in the quartz-curve can be seen at the transition from the Chalk & Chert unit to the Chalk unit in the Ayios Nicolaos and Kouka sections (between samples 15/Y and 15/X, and 28/D and 28/C). This also explains the fact that the quartz content in the Chalk unit of the Kalavasos and Motorway sections is in some cases even higher than in the chert-rich lithological units.

The increase in quartz at the top of the succession is associated with the facies change of the Upper Marl and is consequently time transgressive. It is resolved near 20Ma in the western sections and near 36Ma in the eastern sections. A gradually increasing quartz content towards the top of the succession is best resolved in the Kalavasos section.

Although no absolute quartz percentages can be calculated, the average quartz abundance in the western sections is significantly lower than in the eastern ones (excluding sample 15/33).

Clay:

The bulk clay mineral content shows a very similar development for the quartz through time in all sections. This suggests a general cooccurrence and covariation of clays and quartz in the sediments. A minimum in the clay content near 50Ma is present as described for quartz, although the decrease in clay is not as regular as for the quartz. Compared to the quartz curve, the clay minimum occurs slightly earlier in the eastern sections (Kalavasos and Motorway) and consequently approximately coincides with the base of the Chalk & Chert unit similar to the western sections. The exceptionally high quartz content of sample 15/33 in the Kouka section is not reflected in the clay curve, but on the contrary, this sample contains no clay and clearly marks the minimum near 50Ma.

Some differences in the relative dominance of the two components clay and quartz can be observed especially in the eastern sections, Kalavasos and the Motorway, where a relatively higher clay content can be seen in the Chalk unit, compared to the quartz abundance. In absolute terms, there is generally more clay present in the Chalk unit than in the Upper Marl. Comparing the mean relative amounts of the clay minerals studied, a west-east subdivision of the sections is revealed, with a significantly higher average clay content in the eastern Kalavasos and the Motorway sections than in the west.

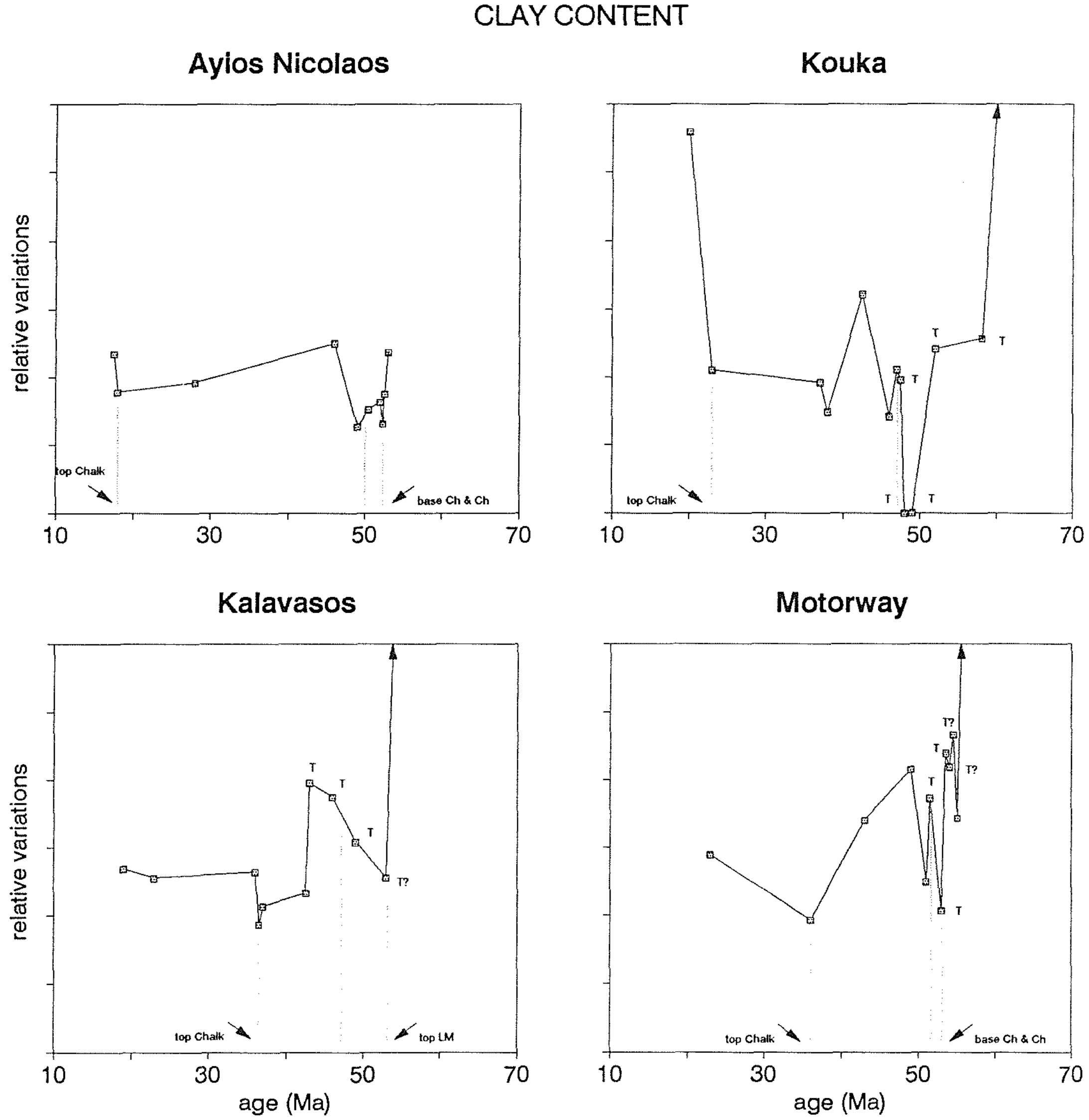


Fig.71. Variations in the amount of clay in the bulk sediment (XRD results), calculated as the relative deviation from calcite intensities (clay intensity / calcite intensity * 1000).

3.3.2. CALCIUM CARBONATE CONTENT OF THE CALCAREOUS ROCKS

To obtain absolute values for the calcium carbonate content in the samples two methods have been applied. (1) The carbon content was measured directly using an elemental analyser, and the results converted into weight percentages of $CaCO_3$. (2) The samples were treated with hydrochloric acid and the weight percentages of dissolved material reflect the total carbonate content. Both methods do not distinguish between calcium carbonate and other carbonates. However, the XRD bulk mineral analysis reveals only sporadic and very small amounts of dolomite as the only additional carbonate in the sediments and therefore the measured carbon and carbonate values are assumed to be mainly calcium carbonate. Again it has to be stressed that only chalks or marls are examined. Cherts, that occur frequently in parts of the succession, are not considered. The intention is to trace the development of the chalky facies only and the chert abundance will be considered elsewhere.

Carbon measurement:

Figure 72 shows the $CaCO_3$-values from the carbon measurements plotted for the Ayios Nicolaos, Kouka, Kalavasos, Lefkara and Stavrovouni sections (Appendix D.3). The relatively low sample density is obvious but this method is mainly used to confirm the reliability of the absolute carbonate values gained by acid treatment. The samples studied show $CaCO_3$-percentages between 57.5% and 97.2% in their extremes, with an average of 83% calcium carbonate. The western sections, Kouka and Ayios Nicolaos, generally show the most consistently high values with maxima of 97% and 90% respectively. In the eastern sections, Kalavasos, Lefkara, and Stavrovouni, abundances are more varied with low values commonly coinciding with samples taken from turbiditic facies. Samples measured from the Upper Marl show comparatively low values in the Kouka and Lefkara sections.

When comparing the carbon measurements with the XRD results (Fig.72) not all peaks, found in the quartz and clay curves, can be traced in the carbonate percentages due to the low sample density. However, the general trend shown for calcite is the close inverse of that shown by non-carbonate components from the XRD analysis.

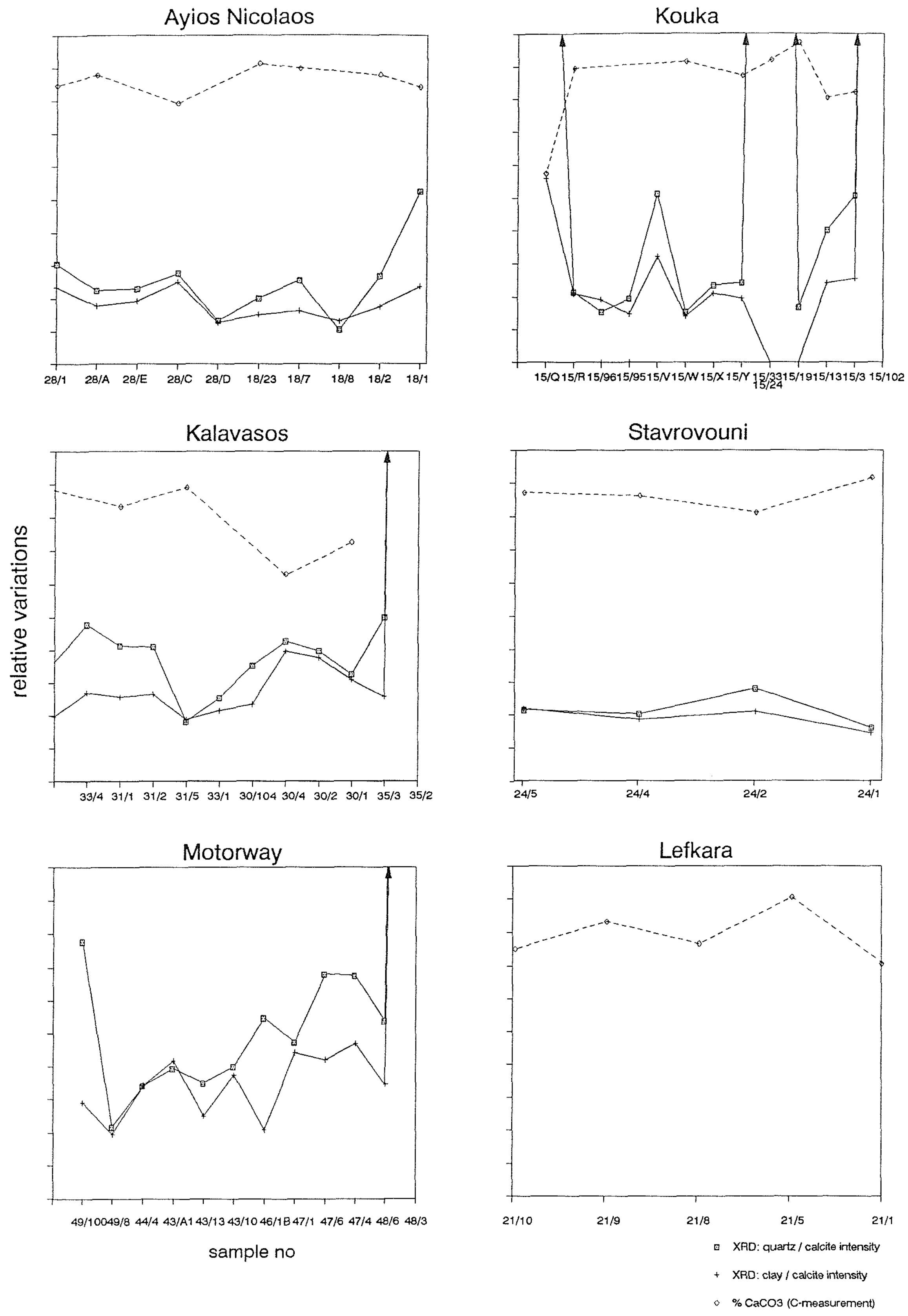


Fig.72. Relative variations in the quartz and clay content in the bulk sediment (XRD results) compared with the opposite trend of the calcium carbonate content (C-measurements).

HCl treatment:

The results of the acid-treatments for three sections (Kouka, Kalavasos, and Motorway sections) are shown in Figure 73 (Appendix D.4). The two methods applied for measuring the carbonate content, should lead to the same absolute results. This is, in fact, confirmed when plotting the resulting percentages in one graph (Fig.74). In most cases the carbonate percentages only differ by as little as 1-2%. Only in two samples is the difference up to 5%, but even this is still low enough not to significantly alter the general trends of both curves. The comparison shows that the relatively simple method of dissolving the carbonate leads to valid results in this study.

Looking at the residue curve (Fig.73, left hand scale) the trend resembles very much the quartz and clay graphs of the XRD bulk analysis, being the sum of both. In all three sections the stratigraphically lowest samples from near the contact with the pillow lava contain a high amount of acid-insoluble material. Consequently the calcium carbonate weight percentages are low between 14% and 9%.

All subsequent younger samples contain a much smaller non-carbonate fraction. A first maximum in carbonate just before 50Ma is found as in the XRD results. Slight differences due to a different sample set confirm the minimum to coincide with the early Chalk & Chert unit in the Kalavasos section.

The further trend of the residue/carbonate curves of all three sections examined is almost identical with the XRD bulk analysis results with the exception of the aberrant sample 15/33 (and 15/V) which is not analysed for the acid soluble residue. The only difference in the curves produced by both techniques is the absence of an extreme increase at the top of the succession as observed for the quartz content using XRD at least in the Kouka and the Motorway sections. This can be explained by the fact that the acid-residue reflects the summary of the components clay and quartz (Motorway section) or by a slightly different sample position (Kouka section).

The mean carbonate values calculated show a west-east shift, with a decreasing tendency from the Kouka section (87%) through the Kalavasos section (83%) to the Motorway section (70%). However, the significance of this result is uncertain since an irregular sample spacing might have led to unreliable results.

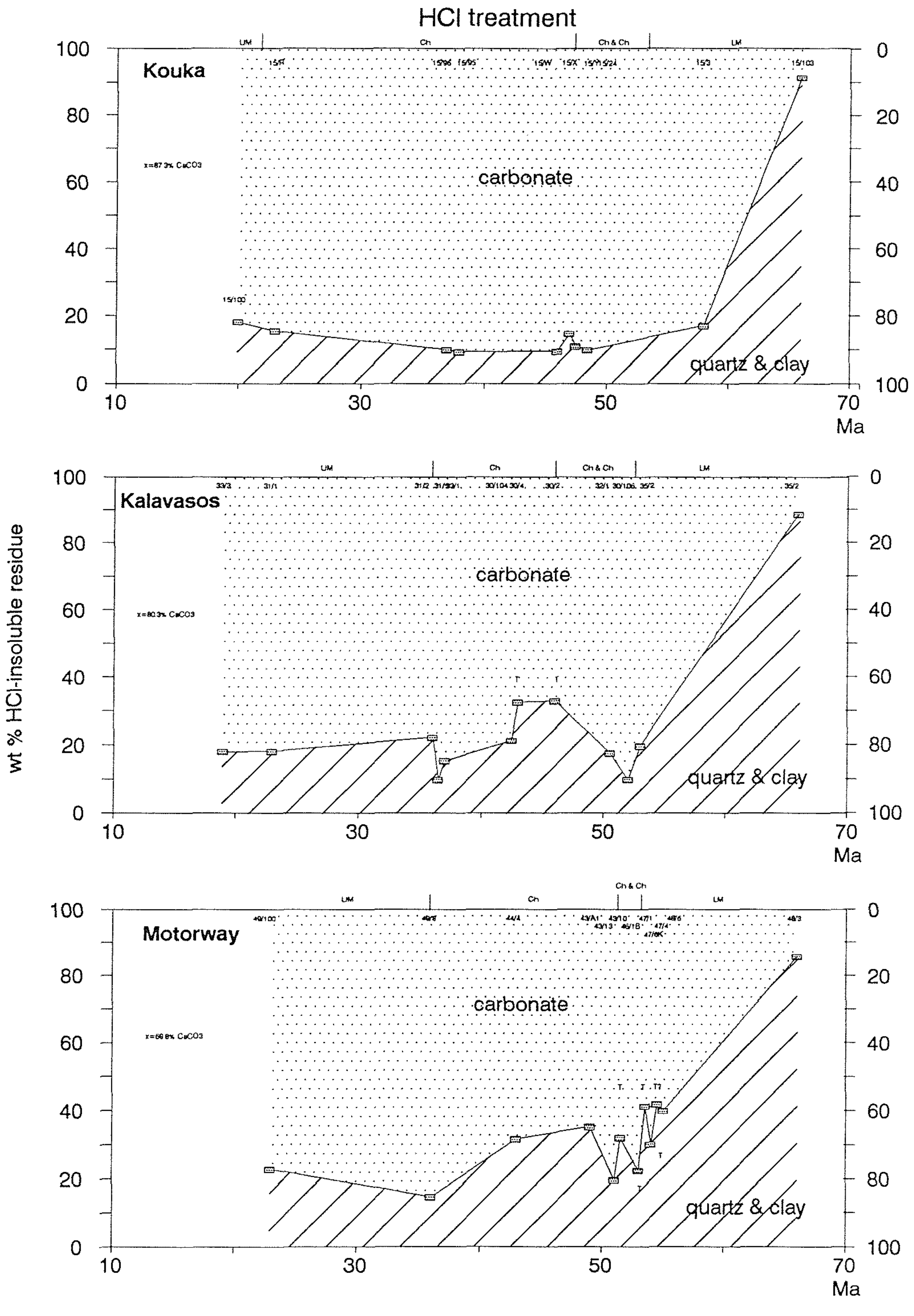


Fig.73. Carbonate content variations determined as the acid-soluble fraction. Samples from turbidite strata are marked 'T', unit boundaries are indicated at the top of each graph.

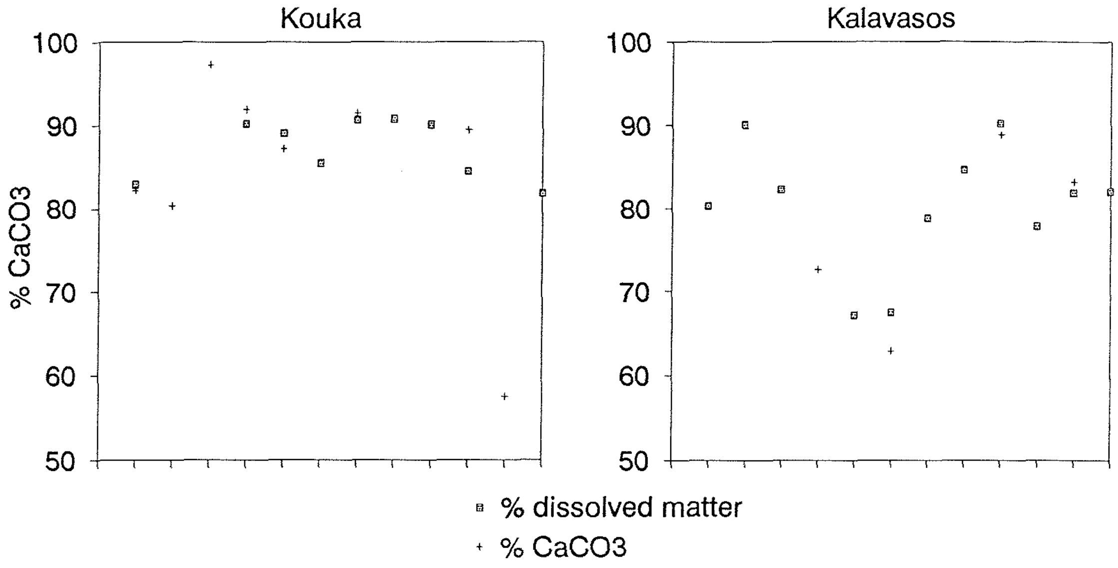


Fig.74. Comparison of results of the two different methods of carbonate determination (carbon measurement and carbonate dissolution). Note the comparatively small deviation between the techniques.

3.3.3. CLAY MINERALOGY OF THE KOUKA, KALAVASOS, AND MOTORWAY SECTIONS

Three sections (Kouka, Kalavasos, Motorway) are examined for the clay mineral content in the sediments, using x-ray diffraction. The clay fraction $<2\mu m$ was isolated and prepared for the XRD analysis, according to standard techniques as described in Appendix E.1. Example plots of the spectra of two samples for the air-dried, glycerol- and glycol-treated and heated specimens are shown in Figure 75.

A: CLAY MINERALS DETECTED

Six clay and associated minerals are positively identified in the samples examined. These are smectite, palygorskite, sepiolite, illite, chlorite, and clinoptilolite/heulandite. Additionally, small amounts of kaolinite and vermiculite may be present. Quartz is found in all samples, sometimes associated with opal-CT. Characteristic peaks of quartz lie near a d-spacing of 3.34Å and 4.24Å, the main reflections of cristobalite near 4.05Å and of tridymite near 4.107Å. The latter ones are

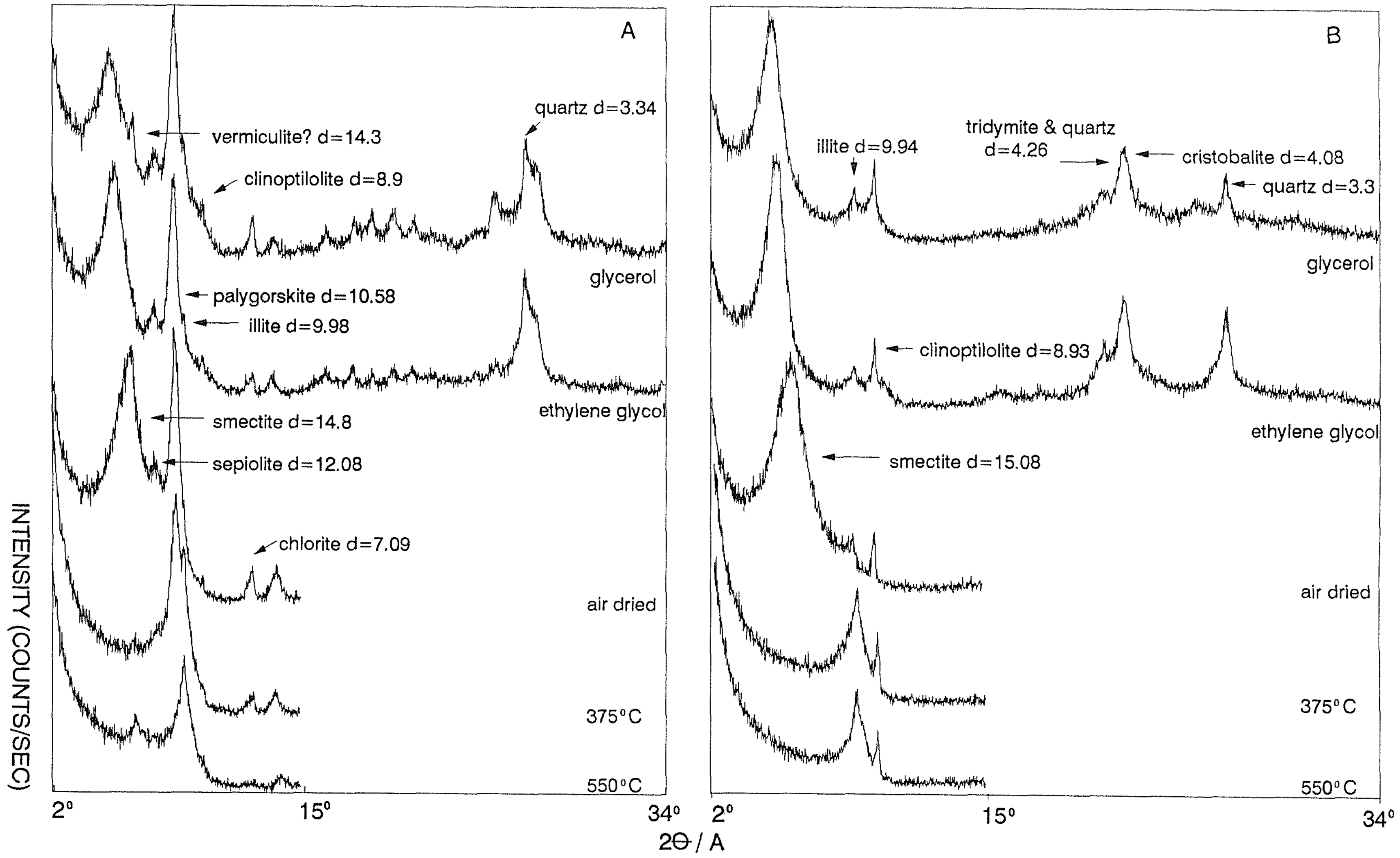


Fig.75. X-ray diffraction plots of two reference samples. **(A)** Lower Marl; **(B)** Lower Marl near the contact to pillow lavas.

Tab.9. Diagnostic characteristics of clay minerals identified (after Brindley & Brown, 1980; Joint Committee on Powder Diffraction Standards, 1974).

mineral	diagnostic d-spacing (Å)	important secondary peaks	ethylene glycol	glycerol	375 °C	550 °C
Mg-smectite	15.5-15.0 (100)	4.49-4.45 (50)	17.0-16.8 8.5 (40)	17.8 8.9 (40)	10.0-9.6	10.0-9.6
sepiolite	12.3-12.0 (100)		no change	no change	12.3-12.0 + 10.4	10.4
palygorskite	10.5-10.3 (100)	6.42-6.36 (10-20) 5.44-5.384 (10-15) 4.49-4.41 (20-60)	no change	no change	10.5-10.3 + 9.2	9.2
illite	10.1-9.9 (100)	5.05-4.95 (40-50) 4.49-4.45 (50-90)	no change	no change	no change	no change
chlorite	7.2-7.05 (60-100)	14.4-14.0 (30-100) 4.7-4.79 (40-90)	no change	no change	7.2-7.1	14.1-13.7 no peak near 7.1
clinoptilolite/ heulandite	9.05-8.97 (100)	7.94-7.89 (20-60)	no change	no change	no change	no change
kaolinite	7.17-7.16 (100)	3.58-3.57 (10-80)	no change	no change	7.17-1.16	collapsed
Mg-vermiculite	14.6-14.0 (100)	4.8 (20) 7.14 (15)	no change-16.35	no change	10.0-9.6	10.0-9.6

only present in a few of samples analysed, mainly from the oldest part of the succession (compare Robertson, 1977). Silica minerals will not be considered here any further since they were discussed in the section whole rock analysis. The clay minerals detected, together with their ideal d-spacing and 2θ angle of the basal or maximal peak and their diagnostic behaviour under special treatment, are listed in Table 9. In Appendix E.2 the positions of the most important peaks of the minerals identified in each sample are listed.

The highest intensities seen in the spectra are usually those of **smectite** (14.3-15.61A), which is present in all samples. Slight variations from the ideal basal d-spacing (see Appendix E.2) might be caused by a peak overlap with chlorite and vermiculite(?).

A small peak near 7.07Å to 7.243Å is assumed to indicate the presence of **chlorite**. The (basal) reflection near 14Å is covered by the basal smectite peak in the air-dried sample, but becomes visible in the glycol- and glycerol-treated specimens. The definite identification of chlorite may be obscured by the possible abundance of vermiculite and/or kaolinite, with kaolinite having a basal reflection at 7.16Å and vermiculite at approximately 14.2Å. Especially if the chlorite peaks are small and the characteristic reflections after heating to 500°C and near the 25°-line are weak or uncertain, the distinction is not reliable. Since the identification of chlorite is definite in all samples showing a higher amount of the mineral it is assumed that all 7.1Å-peaks indicate chlorite although traces of the other clays might increase the apparent chlorite intensity.

Palygorskite (Fig.58 (D)) is identified in strongly varying amounts in the samples. It is characterised by the maximal peak between 10.476Å and 10.61Å. The related mineral **sepiolite** (11.978Å to 12.277Å) usually occurs only in small amounts.

Illite, with a diagnostic peak between 9.913Å and 9.981Å, is present in many samples in moderate amounts. The intensity values have to be considered carefully in the presence of high palygorskite abundance since a peak overlap might influence and increase the illite peak in height. However, no trend of a covariation of palygorskite and illite can be verified.

The zeolite **clinoptilolite/heulandite**, as an accessory mineral, has a sharply defined peaks 8.88Å and 8.989Å. No distinction is made between clinoptilolite and heulandite.

Kaolinite is rarely positively identified. It has a basal reflection at 7.17Å and a characteristic secondary peak near 3.58Å which is left of the 25°-line. In the presence of chlorite only the secondary peak allows a distinction between these minerals. Only in a few samples is a clear reflection of kaolinite near 3.58Å developed, but commonly the peak is diffuse, small or slightly shifted. Only in 2 samples (44/4, 33/4) a positive identification is possible. In the semiquantitative percentages kaolinite is not considered.

One possible but never proved component is **vermiculite** (14.074Å to 14.536Å). It can be distinguished from smectite by treating the sample with glycol since it does not expand, but in the presence of chlorite, with a peak at the same position, no clear distinction can be made. Many samples examined show a peak near 14Å but since also the secondary peaks of vermiculite at 4.8Å and 7.14Å might collide with the reflections of illite and chlorite a proof of vermiculite is never possible.

B: SEMIQUANTITATIVE ANALYSIS

Semiquantitative estimations of mineral abundances are made multiplying the intensities measured with empirical absorption factors characteristic for each mineral (from DSDP, as quoted in Piper, 1978) (Appendix E.3). The weighted clay mineral percentages for the three sections are shown in Figure 76 plotted against time (Appendices E.4 and E.5).

Comparing the curves of all sections, smectite is the dominant clay mineral in most samples. Abundances are generally higher in the (western) Kouka section (around 70%) than in the eastern sections (below 60% in the Kalavasos section). An inverse trend is observed for palygorskite occurrence. The latter mineral is present most commonly in the older part of the succession (up to approximately 50Ma) while smectite dominates in the younger part. A further small increase in palygorskite is resolved near 37Ma. In the basal sample of all sections smectite dominates the assemblage. Sepiolite covaries with palygorskite but is only present in small amounts (<3%).

Chlorite shows generally low values in the Kouka section, high ones in Kalavasos, and fluctuates in the Motorway section. It rarely exceeds 10%. An exceptionally high value of 25% which is observed in the youngest sample of the Kalavasos section includes a significant amount of unspecified kaolinite. Possible additional very small kaolinite occurrences are scattered in all sections.

Illite shows strong variations in abundance but it is present in most samples in relative high amounts up to 20%. In the time interval between approximately 50Ma and 45Ma illite becomes absent, as observed in all three sections. The gap in presence of illite appears to extend longer in the Kouka section until approximately 37Ma.

Clinoptilolite occurs in relatively high abundances (up to 10%) in most samples near the contact with the pillow lava. Otherwise percentages are low with values below 7%. In the Kouka section it has the lowest general abundance and is absent in the upper part of the succession after 49Ma. In the Kalavasos section clinoptilolite is abundant in most samples, while it varies strongly in the Motorway section. An absence during varying time spans exists in all three sections and might be related to the absence of illite.

The comparison of the clay mineral variations between the sections shows that the sediments from the Kouka section contain the smallest diversity of clay minerals and are in biggest contrast to the Kalavasos section. The Motorway section has intermediate trends.

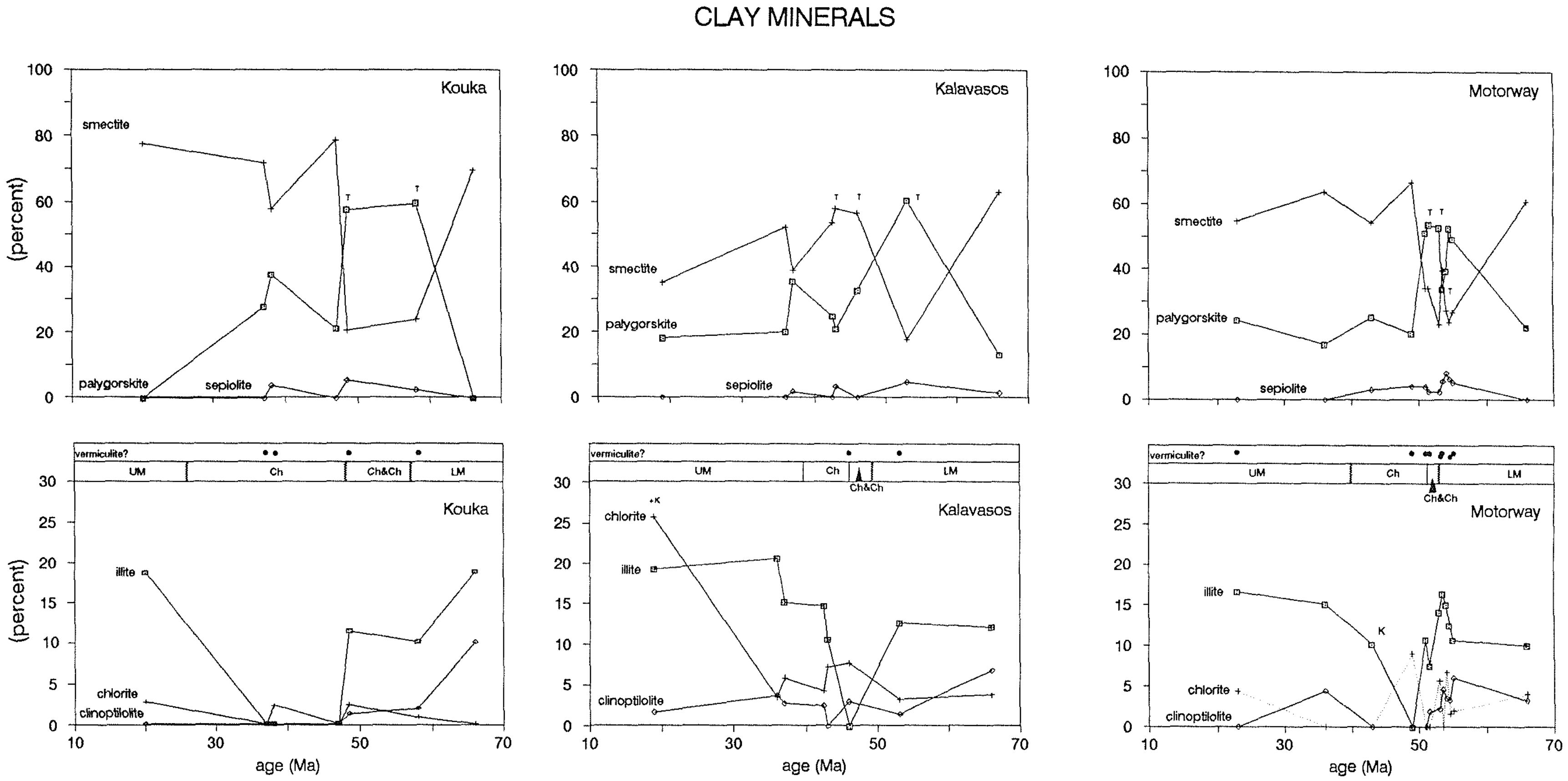


Fig.76. Variation in clay mineral abundances with time. Boundaries of the lithological units and questionable vermiculite occurrences are added. Samples from turbidites are marked 'T', samples containing kaolinite 'K'.

Smectite and palygorskite alternate in dominance throughout the succession whereas illite might be considered as a relatively stable background clay. The clay mineral proportions at the base of the succession are relatively consistent for all three sections with smectite being the dominant clay mineral and illite and clinoptilolite being present in significant amounts. Furthermore, the comparison shows that the absence of illite (and possibly also of clinoptilolite) can be observed in all sections but may be transgressive in time.

CHAPTER 4

INTERPRETATION AND DISCUSSION OF SEDIMENT ANALYSIS

4.1. BULK MINERALOGY AND CLAY MINERALOGY AND VARIATIONS IN TIME

4.1.1. CLAY, QUARTZ, AND CARBONATE CONTENT IN THE LITHOLOGICAL UNITS

The interpretation of the bulk mineralogy will consider the variations in the content of quartz, the sum of clay minerals, and carbonate, as outlined in Chapter 3.3.. Quartz and clays have a generally similar trend although differences in relative quantity indicate some degree of independent development. As seen above, the acid residue reflects the combined trend of both, quartz and clay, whereas the directly measured carbonate (carbon) content varies consistently in opposition. Relating the sediment composition to the macrofacies types established does not seem to be a useful approach and it appears to be much more informative to consider variations in time. However, the facies end members marl and chalk (cherts are not analysed) show differences in mineralogy, as marls have a clearly higher clay content (80% carbonate in average) whereas the chalks are purer carbonates (mostly above 90% carbonate). Marly chalk and chalky marl have strongly variable percentages and cannot be subdivided on the basis of the bulk mineral analysis since definitions used in the field are too flexible.

In the following, interpretation of stratigraphic variations in composition are based on the Figures 70 to 73. Starting with the **stratigraphically lowest samples**, taken at close proximity to the igneous basement in all sections, they contain exceptionally high amounts of both, clay and quartz, and a low carbonate content with values as low as 10%. Since some of these strata are found to contain mm-sized lava fragments in the field (Motorway section) it seems likely that most of the clay was derived from submarine weathering. Nevertheless, the high quartz content might have been derived from (acid) Kannaviou volcanism rather than from altered oceanic crust, which is of basic composition. Another possible source for the high quartz content is biogenic silica which might be relatively enriched by carbonate dissolution. Several of the samples taken from near the contact to the lava basement contain large numbers of radiolarians in the acid insoluble residue, lending support to this assumption (e.g. Ayios Nicolaos, Motorway, Kouka sections; Appendix C).

The younger sediments from the **Lower Marl** samples do not exhibit such high quartz and clay values as the basal samples and a gradual decrease throughout the unit is clearest in the quartz content and the acid insoluble residue. This trend may be related (1) to a decrease in carbonate dissolution in the environment of deposition due to a deepening of the calcite compensation depth (CCD) or uplift of the area, or (2) to a slow increase in the intensity of calciclastic turbidites which would dilute the carbonate-poor background sediments. Indications for both causes are found in the facies analysis, with decreasing carbonate dissolution being found in the microfacies of Lower Marl samples (in the Motorway section, see Chapter 4.3.1.1.) and in the initial gradual increase of turbidites (reflected in chert strata) seen in the logs. Therefore it is indicated that both mechanisms worked at the same time. The increase in carbonate continues consistently in all sections up to approximately 50Ma which is near the base of the Chalk & Chert unit, and therefore approximately coincides with the boundary between two lithological units (between 49-53Ma, due to a low sample resolution). This point possibly marks the end of any in situ carbonate dissolution and is approximately contemporaneous with the first definitely identified turbidites (compare Tab.10).

The residue content in the samples of the **Chalk & Chert and Chalk units** is rather variable but seems to decrease after approximately 42-48Ma towards an absolute minimum at the top of the Chalk unit which is time transgressive. The variable residue or carbonate content respectively in the older part must be caused by the fact that samples are partly taken from turbiditic and partly from interturbiditic strata and from different lithologies. The later comparatively steady decrease in non-carbonate material seems to reflect the decrease in allochthonous material and increase in purely pelagic deposition. Even though no clear turbidites are found in the upper part of the Chalk unit some influence of fine-grained suspension flow deposits might still persist, since a general fading of the sedimentary structures towards the top of the Chalk unit was observed in the outcrops (Chapter 4.3.2.2.). Much of the non-carbonate fraction in the Chalk & Chert and Chalk units therefore seems to originate from transported terrigenous material rather than from pelagic *in situ* deposition.

Although the quartz and the clay curves generally follow the same trend, the clay values are relatively higher than the quartz values in the turbiditic (older) part of the Chalk unit and relatively lower clay abundances are commonly found at times of maximal turbiditic input in the Chalk & Chert unit. This pattern may be caused by a relative enrichment of the fine, allochthonous clay fraction in the turbiditic deposits from less dense currents whereas deposits of high energy contain large amounts of the coarser biogenic quartz fraction. Both are mainly transported which is confirmed by lower clay and quartz, and higher carbonate values in the western less turbidite-influenced sections, Ayios Nicolaos and Kouka, than the turbidite-dominated more 'proximal' sections, Kalavasos and the Motorway, which contain more non-carbonate material.

All samples studied from the **Upper Marl** unit are characterised by an increased residue and reduced carbonate content with particularly high quartz values in the Kouka and Motorway sections. In contrast to the sediments of the other lithological units, no radiolarians are present in the Upper Marl. The quartz therefore must be of detrital origin as indicated by thin sections from the Motorway section which contain quartz clasts. The bulk mineralogy seems to reflect a change in deposition in the Upper Marl sediments. As observed for the Motorway section, the Upper Marl has been influenced by bottom currents (for full discussion see Chapter 5.2.). These may have been responsible for a new input of high amounts of quartz and possibly clay. Nevertheless, the carbonate values never drop much below 80% with abundant pelagic microfossils in the samples studied, which indicates a deep water setting (Flügel, 1982). The lower clay content in the Upper Marl of the eastern sections might indicate a different pattern of currents here than in the western sections.

Although no analysis of the major elements of the sediments has been done, the colour of the marls reflects compositional changes. The grey colours of the marls common in all lithological units seem to depend on the amount of clay present. The characteristic pinkish brownish colour in the Lower Marl unit may be due to iron oxide coatings on sediment particles due to a slower sedimentation rate and widespread oxidation, coupled with possible influence of volcanism (Kennett, 1982). In contrast, the reddish brownish staining of some Upper Marl sediments seems to be caused by redeposited fine-grained lateritic material. The iron compounds can only be present in traces in the sediments since they are not detected in the XRD bulk analysis.

In summary, the bulk mineral analysis reveals carbonate dissolution at the base of the succession, followed by a gradual increase in carbonate preservation during the Lower Marl unit, and a carbonate maximum around 50Ma near the base of the Chalk & Chert unit, coinciding with the first occurrence of clear, comparatively coarse-grained turbidites. Carbonate and residue values fluctuate in the turbidite succession but an increase in carbonate towards the top of the Chalk unit indicates an increase in pelagic deposition. High quartz and clay values in the Upper Marl sediments may be related to transport by bottom currents still under deep water conditions.

4.1.2. INTERPRETATION AND DISCUSSION OF THE CLAY MINERALS PRESENT

Clay minerals detected in sedimentary rocks may be of detrital, authigenic, or diagenetic origin. Most recent deep-sea clays are detritus from the continents and are distributed in geographical (climatic) zonations and thus provide evidence for provenance and continental climate (Biscaye, 1965). In detail, the marine clay mineral assemblages contain information about the conditions of continental neoformation e.g. in soils or from weathering, and about the transport mechanisms such as wind, rivers, gravity and bottom currents. The aim and structure of this chapter is (1) to find evidence for the potential source of the single clay minerals detected in the sediments of the Lefkara Formation, (2) to compile and discuss these results and reconstruct the sedimentological processes working during the time of deposition, and (3) to discuss any possible climatic information gained from the clay minerals. The interpretation is based on Figure 76. Abundance variations are additionally illustrated in Figure 77.

Illite:

Illite is the most abundant clay mineral in modern oceans and, where low values occur, these are usually interpreted as the result of dilution (Biscaye, 1965). Although illite may have an authigenic or diagenetic origin it generally reflects reworking from soils in temperate to cold climates or areas with reduced chemical weathering (Chamley, 1989).

As seen above, illite occurs in the sediments of the Lefkara Formation in most samples in moderate amounts. It most likely represents the background clay, diluted by the varying amounts of the dominant clay minerals, montmorillonite and palygorskite. Although illite is known to increase with progressive diagenesis, no consistent increase in abundance can be seen towards the older part of the succession, i.e. deeper burial, in any of the three sections. The absence of any diagenetic changes in the clay mineral assemblage is consistent with studies on the effect of overburden. The diagenetic alteration of smectite to illite only starts at burial depths greater than 2700m (Aoyagi & Kazoma, 1980). The sediment thickness at the base of the Lefkara Formation should not exceed 2000m, adding the maximal thicknesses for the Lefkara and overlying formations (Cleintuar *et al.*, 1977). A detrital origin is therefore suggested for the illite abundances. The transport mechanism will be discussed in comparison to the other clay minerals.

Chlorite:

Chlorite is a common 'high latitude clay' or better a product of mechanical weathering in cold and/or dry climates (Chamley, 1989). The sources are either chlorite-containing rocks such as metamorphics, shales or plutonics, in the absence of significant chemical weathering (Eslinger & Peaver, 1988).

The highly variable but rather low abundances of chlorite in the Cypriot sediments is interpreted as the result of transport, either by wind or by downslope currents, from the continent. The fact that the western section Kouka contains significantly smaller amounts of chlorite than the eastern sections which contain more turbiditic material favours the explanation of dominant current transport. The source area must have been characterised by freshly weathered rock surfaces under arid climatic conditions.

Kaolinite:

Kaolinite mainly forms under warm and humid conditions and is common in lateritic soils (Chamley, 1989). It is referred to as the 'low latitude clay' and occurs in recent marine sediments most frequently in tropical areas where it has a clearly detrital origin (Biscaye, 1965). The kaolinite content in the deep sea sediments decreases with the distance from the continent due to a relatively large particle size (Gibbs, 1977).

The scarcity or absence of kaolinite in the sediments of the Lefkara Formation is most easily explained by a long distance of transport from the continental source, with distal turbidites and pelagites indicating on open ocean setting. Additionally, the climatic conditions for the formation of the more abundant chlorite are not those that favour kaolinite production in soils (Chamley, 1989), which might explain the absence or scarcity of kaolinite.

Smectite:

Smectite in recent marine sediments does not show a clear latitudinal zonation since it not only reflects climatic conditions in the source area but is also formed in situ in marine sediments. If formed in soils, it reflects warm, temperate climate with alternating wet/dry periods and forms in close relationship to palygorskite as its alteration product (Chamley, 1989). As an alteration product from volcanics, smectite might form on land or *in situ* in marine sediments. The source material can be basalt, volcanic ash dispersed in the marine sediment, or as a minor source hydrothermal springs (Eslinger & Peaver, 1988). It is difficult to distinguish detrital and authigenic smectite in sediments but most early Cenozoic occurrences are considered to be detrital by Chamley (1989).

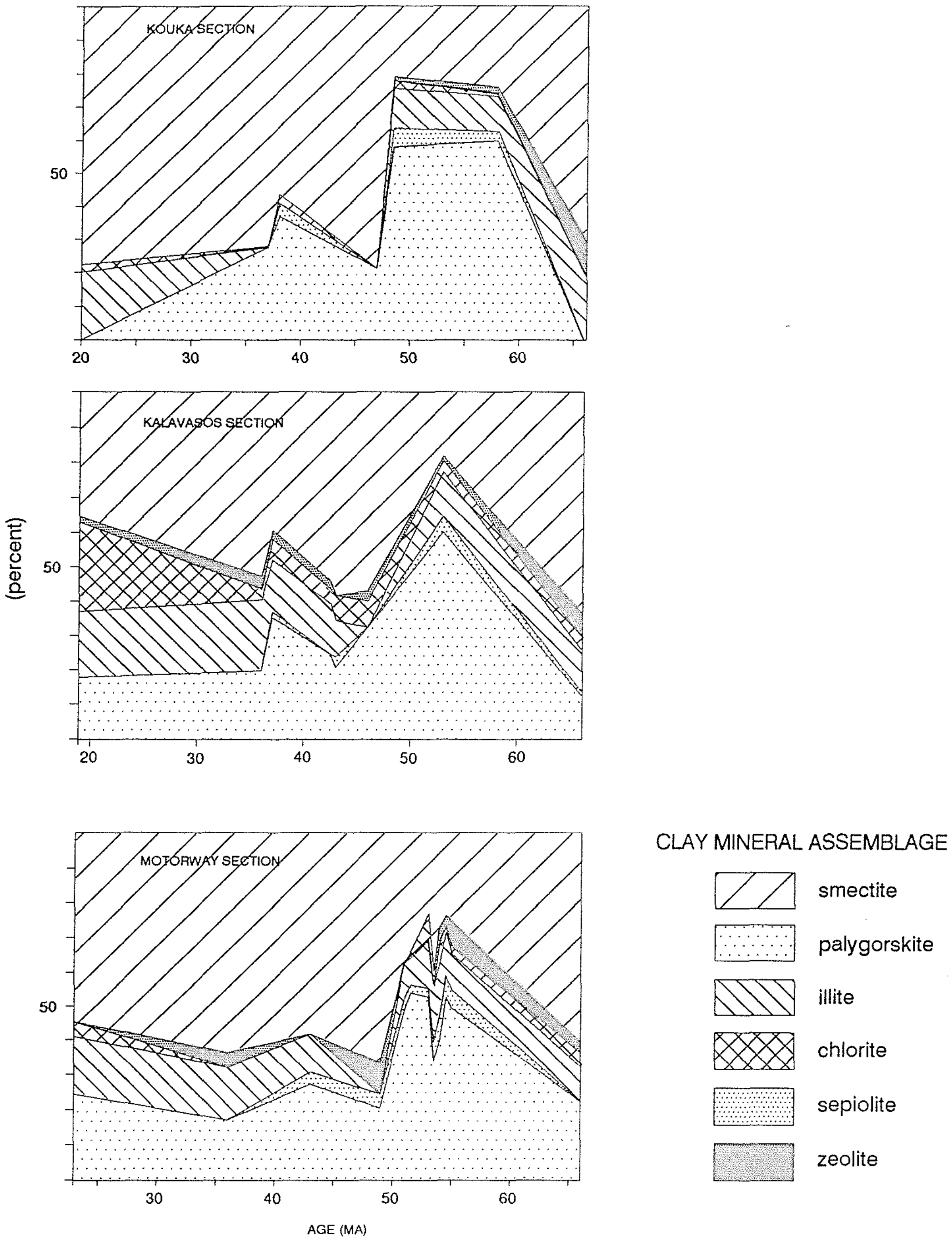


Fig.77. Clay mineral assemblages of the three sections, using the data from Fig.76. Abundance variations of the individual minerals and the alternating dominance of smectite and palygorskite become clearly visible.

Smectite is the dominant clay mineral in most samples studied, which is comparable with the recent Eastern Mediterranean deposits (Venkatarathnam & Ryan, 1971). In the material analysed it varies in clear opposition to palygorskite. This either indicates an occasional dilution of the background clay smectite by the influx of palygorskite, or it indicates the same detrital source of both clays but reflects different climatic signals (see discussion of palygorskite). In the first case smectite can be assumed to be authigenically formed by submarine alteration of basalt or ash. Weathering of basalt or the influence of hydrothermalism can be only assumed to have formed smectite in the lowest samples taken directly from the contact to the igneous rocks since any such influence on the clay mineral composition only extends a few cm into the overlying sediment (Boström *et al.*, 1972). For the stratigraphically higher samples ash may be the source material for smectite since indications for volcanic activity were rarely still found as high as in the Chalk & Chert unit (Robertson, 1976) and volcanic debris was found in the turbiditic strata. Nevertheless, in the turbidite- and ash-free samples higher up in the succession the high abundances of smectite cannot be explained by *in situ* alteration processes. Therefore, in the lower part of the succession up to the end of the turbidites parts of the smectite might have resulted from neomorphism but the high abundances indicate a mainly detrital origin for the whole succession.

A mainly detrital origin of smectite is additionally indicated by the consistent antithetic variations compared to palygorskite since both form in similar terrestrial or perimarine environments. The fact that the increase in smectite after the dominance of palygorskite is rather time than facies dependent, since it is not related to a turbiditic or pelagic facies, indicates a climatic control and consequently detrital origin of both minerals.

Palygorskite, Sepiolite:

The two fibrous clays palygorskite and sepiolite are structurally and genetically closely related. Since sepiolite is only present in small amounts in the material studied and usually follows the same trend as palygorskite, in the following, mainly palygorskite will be referred to. The origin of both minerals may be (1) authigenic from hydrothermal solutions, (2) diagenetic in relationship to alteration of volcanic rocks (Wise & Weaver, 1974) and silica diagenesis (Kastner *et al.*, 1977), (3) authigenic in perimarine evaporitic and lacustrine environments (Weaver & Beck, 1977, Galan & Castillo, 1984), (4) as an alteration product from different clay minerals in lacustrine and evaporitic environments during wet seasons (Galan & Castillo, 1984; Weaver, 1989), or (5) in soils in arid climates (Mackenzie *et al.*, 1984). Thus, in marine sediments fibrous clays may be either authigenic or detrital. A hydrothermal origin is generally considered to be a local phenomenon while most of the palygorskite found in marine sediments is detrital in origin (Chamley, 1989) and is common in marine sediments seaward of continental deposits (Weaver, 1989). For the Mediterranean area transport mechanisms are reported to be wind and turbidites with local redistribution by bottom currents (Callen, 1984).

In the samples studied, all fibrous clays can be assumed to be detrital. A hydrothermal influence or basalt weathering might be still expected in the oldest sediments of the formation but these consistently show low values or an absence which excludes an authigenic origin for the whole succession. Small amounts of palygorskite may be the result of maturation of opal-CT to quartz (Kastner *et al.*, 1977).

As discussed for smectite, the opposite trend of smectite and palygorskite indicates the same detrital origin of these clay minerals, including a climatic signal in the area of formation. Although most samples rich in palygorskite are turbidites, this is not always the case in the Kalavasos section where it is present in some post-turbiditic sediments. A second palygorskite increase higher in the succession near 37Ma also indicates a dominance of time control on the distribution rather than a sole dependency on the turbidite facies since these samples originate from different lithologies (from the Chalk unit in the Kouka section, from the Upper Marl in the Kalavasos section). Nevertheless, the dominant mechanism of transport is gravity flow.

Clinoptilolite/heulandite:

Zeolites, as accessory minerals of clays, are related to the alteration of volcanics and commonly occur in association with authigenic smectite. Although phillipsite is usually considered to be associated with volcanic weathering, Stonecipher (1976) showed that clinoptilolite substitutes phillipsite in sediments of a greater age, a higher sedimentation rate, and a higher carbonate and silica content. Next to the *in situ* origin of clinoptilolite/heulandite in deep sea sediments, Biscaye (1965) found a distribution pattern for zeolites in the Atlantic which indicates a continental source of higher latitudes.

No clear clues about the authigenic or detrital origin of clinoptilolite can be found in the Lefkara sediments. The fact that the percentage is high in the stratigraphically lowest samples of two sections where the highest content of volcanic debris is expected favours the interpretation of neoformation. This is supported by the gradual decrease in abundance in the older part of the succession in the Motorway and Kouka sections although this is not observed in the Kalavasos section. Nevertheless, it can also reflect a decrease in clinoptilolite in a potential continental source area rather than a decrease in *in situ* formation. A covariation of zeolites and smectite in the turbidite influenced part of the Kouka and Kalavasos sections points to a volcanic origin of both minerals, which is believed to have taken place in the source area, regardless of a marine or continental alteration. Clinoptilolite is not clearly more abundant in turbidite influenced samples, containing volcanics, but occurs in all lithologies which simply indicates a detrital origin.

Summarising the origin of the clay minerals present, illite, chlorite, palygorskite and at least partly smectite are found to be detritus from continental erosion. Zeolite is most likely also transported, possibly from areas of terrestrial weathering of volcanic rocks, as might be true also for parts of the smectite content. It cannot be excluded that parts of smectite and possibly zeolite formed authigenically from alteration of volcanic material in the lower part of the succession.

When interpreting the clay mineral assemblages it has to be considered that an increased distance of transport changes the original component ratios. As shown by Gibbs (1977), during marine transport from the river mouth towards outer shelf deposits size sorting leads to an increase in montmorillonite and a decrease in kaolinite and illite. Other studies confirmed the enrichment of smectite and palygorskite in basinal settings, while chlorite, illite and kaolinite decrease in abundance (Adette & Rumley, 1984, as cited in Chamley, 1989). The smallest clay mineral diversity in the western section (Kouka) with high smectite percentages should therefore reflect the farthest transport compared to the two eastern sections.

Only few consistent covariations of the various clay minerals are found in the curves over time. Although illite and chlorite both result from physical weathering they are not found to follow the same trend. This seems to be due to the fact that illite forms under a wider range of conditions and is the more abundant and stable background sediment whereas chlorite is restricted to purely physical weathering. Similar conditions of weathering as for chlorite might have led to the possible scattered occurrences of vermiculite(?). Clinoptilolite has a roughly similar trend to illite, which indicates a common source. In the Eastern Mediterranean basin, modern chlorite and illite occurrences are generally attributed to a detrital input from Europe (Venkatarathnam & Ryan, 1971). A detailed study of the recent Cilicia Basin to the north of Cyprus shows clear transport-patterns of weathered material from the Taurids (Shaw, 1978). The common (ultrabasic and metamorphic) ophiolites, in particular, are thought to be the source of chlorite and possible of clinoptilolite as well. Since the ophiolites had been partly emplaced and exposed by the time of the deposition of the Lefkara Formation (Dercourt *et al.*, 1986) (see Chapter 5), they might have contributed in the same way to the ancient marine deposits of the Lefkara Formation (Fig.78).

Despite the possibility that smectite may be partly neoformed in the sediment, the dominant signal seems to reflect transport from the continent together with palygorskite. In the Eastern Mediterranean, smectite dominates the recent clay assemblage which is mainly transported from the Nile cone (Maldonado & Stanley, 1981) but also from the Taurids (Shaw, 1978). This might have been similar for the smectite distribution in the Lefkara Formation. Palygorskite is an abundant authigenic component in Mediterranean soils which is transported into the marine environments adjacent to the continent. Transport occurs by wind or rivers mainly from Arabia and North Africa (Weaver, 1989; Chamley, 1989). Callen (1984) lists a larger area of palygorskite

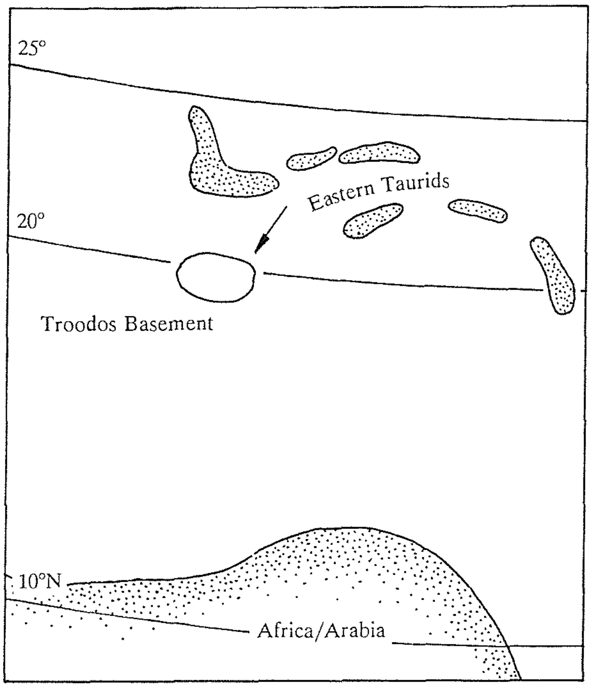


Fig.78. Land areas exposed at the time of the K/T boundary and early Palaeogene (after Dercourt *et al.*, 1986). The arrow indicates the direction of transport of detrital clay minerals.

distribution with maxima between 30-40°N and S for land deposits and for marine sediments generally around the whole Tethyan margin in the Palaeogene of the Mediterranean. This shows that a source of transport by turbidites from the north or north east (Robertson, 1976) can have led to a palygorskite enrichment in the Lefkara sediments.

Continent derived, fibrous clays are believed to be good palaeoclimatic indicators for Mediterranean to semi-arid conditions with contrasting seasons. Comparing the times of major palygorskite occurrences in the Mediterranean (Callen, 1984) with the maximal abundances in the samples studied, a clear parallelity becomes obvious. Times of high average palygorskite values in DSDP samples are the Early and Late Eocene and Late Oligocene (Fig.79). Similarly, the highest abundances in the Lefkara Formation are concentrated in all three sections between 58Ma and 49Ma, depending on the sample density, *i.e.* between Early and early Middle Eocene.

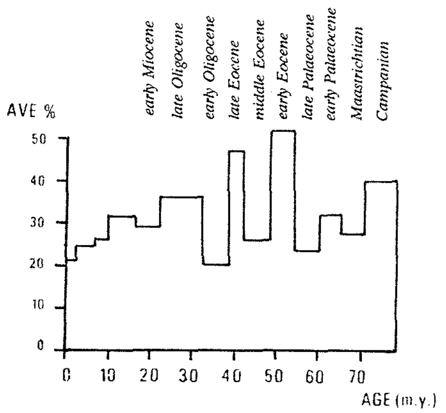

AVERAGE PALYGORSKITE/SEPIOLITE %

Fig.79. Age distribution of palygorskite and sepiolite from DSDP during the last 80Ma (after Callen, 1984).

Although palygorskite is reported to be rather rare in the Middle Eocene, the transported origin of the clays in the chalks, including possible fluvial, costal and later turbiditic stages, can explain the slightly younger occurrences. Such phenomena produced by reworking of older strata commonly delay climatic signals (Singer, 1984). The second smaller peak in palygorskite near 38Ma and 37Ma from the Late Eocene, resolved in the Kouka and Kalavasos sections, perfectly matches the Late Eocene, slightly lower, palygorskite peak from the DSDP sites. A Late Oligocene palygorskite increase is not resolved in the sediments of the Lefkara Formation since this time is characterised by hiatuses and no samples have been analysed from this time. This comparison shows that the Cypriot material matches the Mediterranean palygorskite occurrences well and consequently also reflects palaeoclimatic conditions with a slight overprint by the effects of transport. This also shows that the decrease in palygorskite near 50Ma, which coincides with the end of turbiditic input in most sections, is in fact related to a change in climate and does not reflect a change in the source area of transport.

Comparing the development of the whole clay mineral assemblage of the three sections in time shows a (weakly resolved) break near 48Ma which is close to the first post-turbiditic sample inferred from the absence of sedimentary structures found in outcrops. Most minerals except smectite are absent or show a drastic decrease during the whole Chalk unit in the Kouka section

(Fig.76,77). Only some of them reappear in the uppermost sample of the Upper Marl. A less consistent but similar development is observed for the two eastern sections. Minima or absences of illite, clinoptilolite, and palygorskite here do not all coincide in one single sample but they are concentrated around the oldest samples of the Chalk unit or near the top of the turbidites. Higher up, in the Chalk and Upper Marl units, the clay mineral composition changes, having lower palygorskite values and being dominated by smectite. This break which roughly coincides with the end of the turbiditic input is shown to be climate-dependent for the fibrous clays. Whether therefore climate is reflected also in the variations in the other components or whether a change in transport mechanism occurs additionally (e.g. the end of turbidites) is not clear. The source of transported material does not seem to alter since the clay mineral assemblage generally does not change. Most likely, a constant background supply by wind delivered the main clay proportion after the turbidite input had ended and, as will be seen later, before contourites became significant near the top of the Chalk unit. The gradual increase in the illite abundance after the 48Ma-break possibly reflects the gradual increase of terrestrial material redistributed by bottom currents.

Another break in composition is present in the Upper Marl samples of the Kouka and Kalavasos sections. In the first one, a sudden increase in illite and an absence in palygorskite is found. In the latter one, at least for the uppermost sample, chlorite reaches a particularly high value (including some kaolinite) which results in the relative decrease in smectite. This development seems to indicate some new influence in clay input.

The palaeoclimatic information gained from the clay minerals of the sediments indicates a rather dry climate with contrasting seasons, and significant physical and reduced chemical weathering. It is possibly that illite, chlorite, zeolite, and partly smectite are weathered and transported from freshly exposed rocks of Late Cretaceous obducted Taurid ophiolites (Dercourt *et al.*, 1986; Dilek & Moores, 1990) while the fibrous clays and smectite are transported from evaporitic perimarine environments or originate from soil erosion (Fig.78). This would either suggest two different continental sources for the clays or one inland and one perimarine.

4.2. DIAGENESIS

4.2.1. INTRODUCTION

Post depositional alterations had a significant influence on the micro- and macrofacies of the sediments studied. A detailed discussion of the chert formation was done by Robertson (1975, 1977). Here, (1) the origin of micrite, the occurrence of solution seams, and the dependency of the preservation of silica on the rate of deposition will be discussed (section 4.2.2.: 'The influence of diagenesis on the microfacies'); (2) the post depositional alteration of the microfossil assemblage will be studied (section 4.2.3: 'Influence of diagenesis on the planktonic microfossil assemblage'); and (3) the sequence and order of diagenetic processes will be outlined (section 4.2.4: 'Diagenetic history').

4.2.2. THE INFLUENCE OF DIAGENESIS ON THE MICROFACIES

Origin of sparse and packed biomicrites:

The first question to be considered is whether the sparse samples are of depositional or of diagenetic origin, that means whether they have been originally packed and whether they developed the sparse facies by micritisation processes. The grain-size variations seen in the turbiditic intervals A-C (microfacies II) are clearly depending on the decreasing speed and power of the current from which the sediment is released. In the lowest Bouma division A only the largest particles or the ones with the highest specific weight are deposited (Fig.54 (A)), that means that clay-sized grains are originally not present in this layer. In the divisions B and C, which are deposited from a slower current, layers alternate between being packed, less packed, or sparse, with the latter ones being primarily enriched in clayey or muddy material (Bouma, 1962, Fig.58 (D)). Solution seams and other indicators for diagenetic carbonate solution are present mainly in the laminae containing less bioclasts and more clay or micrite. Since pressure-solution may have decreased the number of bioclasts later during diagenesis the sparse micrites of the turbiditic facies types have to be considered as an original feature but may be enhanced by the effect of pressure-solution.

The assumption that the packed microfacies types II1 and II2 kept their packed nature, rather than being micritised during diagenesis, because they were early cemented and therefore more resistant to pressure-solution does not appear correct. The bioclasts in these layers do not contain large amounts of early cement but are rather filled with lime mud or late diagenetic neomorphic spar. Consequently they were not more protected against diagenetic dissolution than the ones in less packed or sparse strata. This also indicates that packed strata are poor in micrite due to their primary coarser composition.

In contrast to the turbidite-influenced facies types, only little allochthonous fine-grained material might be expected to be delivered into the sediments of the pelagic microfacies I1 which was (most likely) not influenced by currents. The clay content in these samples is generally low (see Chapter 3.3) which is consistent with the absence in terrigenous input by low density turbidity currents. The large amount of fine-grained material in these sediments partly has to be explained by the primary deposition of coccoliths and other fine-grained material suspended in the water column. Later micritisation processes have been (1) the breakdown of larger particles due to diagenetic processes (Bathurst, 1975) (2) slow sedimentation and a subsequent high synsedimentary carbonate dissolution combined with test fracturing at the sediment-water interface (Berger, 1970), and (3) biological processes such as bioturbation or boring activity (Bathurst, 1975). *In situ* dissolution on the sea floor cannot have been very strong since increased amounts of benthic foraminifera as a typical indicator of this process are not observed in microfacies I1.

Some thin sections studied may indicate a dominating role of pressure-solution for developing a sparse microfacies. Few cases are found where faint ghosts are frequent ('packed') in the micrite but only few well preserved bioclasts are left in the otherwise sparse matrix. It is possible that in other cases similar ghosts are pressure-dissolved to a larger extent without leaving any trace at all but just producing a sparse micritic matrix. In few other laminated sparse samples silica accumulations are found to have preserved packed layers and lenses (Fig.68 (2)). This may suggest that the whole sediment was originally rich in sand-sized particles, most of which were completely dissolved during diagenesis with the exception of the areas where early diagenetic silica protected them against pressure-solution. On the other hand it can be argued on a sedimentary base that only small layers or lenses of high bioclast density were deposited in an otherwise mud-rich sediment. These areas of higher porosity may have later been preferentially filled and replaced with silica. However, these last two features are only found in layers of slow deposition from distal turbidity currents where an accumulation of slightly coarser material should not be expected.

Similar diagenetic alterations from a packed towards a sparse microfacies were studied by

Schlanger & Douglas (1974). They showed a decrease in bioclasts with increasing burial depth for the ooze to limestone transition, which resulted in an almost complete dissolution of planktonic foraminifera.

The evidence seems to point to an original (slight) difference in grain size for packed and sparse samples at the time of burial. In addition to this, the now sparse microfacies must have undergone significant diagenetic micritisation processes of pressure-solution during compaction. This was most likely triggered by a primary higher micrite or clay content since oozes which originate from more rapidly deposited turbidites escaped this extensive solution.

Dissolution seams:

The amount of primarily deposited clay in the carbonate influenced the degree of pressure-solution in the sediment, at least in cases where solution seams are developed. Although it is commonly thought that pressure-solution leads to clay enriched seams rather than that the seams develop because of higher clay contents in the sediment (Bathurst, 1991) this does not seem to be true for the carbonates of the Lefkara Formation. Here the dilution by clay during deposition must have partly prevented later cementation which enhanced compaction. In some samples the lamination in packed strata is mainly produced by varying abundances of solution seams present in layers (Fig.58 (D)). This could be (1) produced by a primary change in the amount of clay and a related seam development in clay-rich strata or (2) by stratified cementation of the bioclasts in seam-free layers (Bathurst, 1987). No evidence can be found for a difference in early lithification between these strata which would explain the varying susceptibility for the formation of dissolution seams. Therefore, a difference in the amount of deposited clay is postulated as a cause for the varying seam distribution.

Sparse samples from the microfacies type I1 which are believed to have been deposited most slowly with the least terrigenous influence are typically lacking in solution seams. Therefore the original absence of clay would explain why seams did not develop in I1 although compaction has worked here as much as in the seam-bearing samples.

Rate of burial:

Evidence for the proposed low depositional rate of the sediments of microfacies I1 is provided by the variation in silica content in the micrites. A rapid burial would incorporate opaline organisms before they are dissolved into the water column (Decker, 1991; Riech & von Rad, 1979). Consistently, high concentrations in silica are found in turbidites, especially in the rapidly deposited divisions A to C. Even the deposits from the more distal turbidity currents, although they do not show characteristic turbidite sequences, obviously accumulated rapidly enough to retain silica in the deposits of the Chalk & Chert unit. During slow sedimentation the freshly deposited material was exposed to the sea water for a longer time which resulted in complete dissolution of the siliceous organisms by the undersaturated sea water. Consequently, deposits of the pelagic microfacies type I1 are free of silica.

Considering the above processes, radiolarians, as the main source of silica in the Lefkara Formation, naturally occur under similar conditions as the silica. As an apparent contradiction, the most rapidly deposited turbidite divisions A contain only few or no radiolarians. The reason for this observation may lie in the low specific weight and the small size of the radiolarians which would not be deposited in the comparatively coarse-grained sediment deposited from a high density current. The fact that in many samples the A-division is rich in silica may be explained either by post-depositional migration of silica into the highly porous layer or by the original presence of relatively few but sufficient radiolarians deposited with the calcareous bioclasts followed by *in situ* silicification. In all higher divisions of the turbidite sequence radiolarians are generally present or even dominant (Figs.54 (B), 58 (D)). Because of the high sedimentation rate the opaline microfossils are prevented from being dissolved at the sediment-water interface and incorporated into the sediment. In the microfacies I1 radiolarians are rare or absent because they have been exposed to the undersaturated water for a long time and have dissolved.

Possibly a later diagenetic process led to a relative enrichment of radiolarians in the sediments, mainly in the samples under turbiditic influence. Radiolarians are commonly cemented during early diagenesis (see section 4.2.4.) either with sparry calcite or with quartz. This made them resistant to pressure-solution during compaction. In contrast, the planktonic foraminifera are mainly mud-filled and therefore more susceptible to dissolution. This led to a post-depositional change in faunal composition from foraminifera-dominated to radiolarian-dominated. This may better explain the extreme high percentages of radiolarians found in many of the turbiditic samples rather than an extremely high original radiolarian abundance, which is more difficult to account for. A similar diagenetic concentration of radiolarians was described by Baltuck (1983).

Summarising the effect of diagenesis on the microfacies, the micritic and clay-rich material in the sediments is of primary or synsedimentary origin but pressure-solution clearly increased the relative amount of fine-grained material. Pressure-solution may have even changed the original faunal composition in samples where radiolarians are dominant. Silica and radiolarians present in the sediments of the turbiditic deposits indicate a comparatively high sedimentation rate. The lack in these and the clay-poor nature of the pelagic microfacies I1 indicate a slower rate of deposition. Dissolution seams develop only in strata of a high primary clay abundance.

4.2.3. INFLUENCE OF DIAGENESIS ON THE PLANKTONIC MICROFOSSIL ASSEMBLAGE

The study of the sand fraction of the sediments allows conclusions about the abundances of the individual bioclasts, reworked components, and differences in composition of the lithological units of the Lefkara Formation. In this section mainly planktonic foraminifera and radiolarian occurrences will be considered.

While foraminifera form the majority of the planktonic microfossils in most samples, radiolarians are common or even dominant only in samples of the Chalk unit and are rare in all other lithological units (Fig.66). The reason for their absence in the Lower Marl and Chalk & Chert units must lie mainly in diagenetic processes. In the chert-bearing units most of the opaline radiolarians have been dissolved during diagenesis and reprecipitated as silica to form chert. Although the material studied was not taken from chert-bearing strata but from the interbedded chalks and marls, radiolarians are almost absent. This may be explained by a vertical (and partly horizontal) migration of the silica into areas of chert accumulation, the chert beds. In contrast, in the Chalk unit where no or few cherts developed, radiolarians are present since no early diagenetic dissolution had taken place. Further evidence for this theory is found in the Kouka section. Here radiolarians are generally increased in the samples from the Chalk unit except in two samples that are taken from the short interval of intercalated chert strata at the top of the unit. This cooccurrence of chert with the absence of radiolarians in a unit generally rich in radiolarians strongly suggests a diagenetic and not a primary reason for their absence.

Nevertheless, thin sections studied show that radiolarians are in fact present in samples of the Chalk & Chert and Lower Marl units. This is not surprising since radiolarians are considered to be the source of the chert. The different results obtained from the thin section analysis and the sand fraction counts must be explained by the different sizes of radiolarian specimens considered. The radiolarians found in the thin sections are dominantly spumellarians of silt size (50-60μm). Clearly, these would not be present in the >63um fraction. In contrast, the radiolarians of the sand-sized residue contain large amounts of nassellarians which are less dissolution-resistant and therefore not present in the chert-bearing material. It can therefore be concluded that the sediments of the Lower Marl and Chalk & Chert unit are not barren in radiolarians but rich in small specimens while the larger but more fragile ones have been dissolved. In the chert-free Chalk unit even the (larger) nassellarians are well preserved and may reflect the original sediment composition less influenced by diagenetic opal mobilisation. For the chert-free Upper Marl unit sedimentological or environmental reasons for the absence of radiolarians, which is also reflected in the thin sections, have to be considered.

The western sections, Ayios Nicolaos and Kouka, are rather sparse in their radiolarian content in the Chalk unit, with the exception of one sample in the Ayios Nicolaos section. If it is true that a higher radiolarian content is related to a more rapid sedimentation it is consistent that the sections exhibiting mainly the (at least partly) pelagic/hemipelagic microfacies I are depleted in these microfossils. Additionally, if radiolarians are related to turbiditic transport, fewer might have been carried into more distal environments in the west.

4.2.4. DIAGENETIC HISTORY

Early diagenesis:

The first diagenetic process that took place and can be traced in the sediments is the mobilisation of opal. The source for the silica that forms the chert accumulations most likely comes mainly from dissolved siliceous microfossils (Robertson, 1977) since direct indications of their alteration can be found. Other sources may be the release of silica from clays and volcanic glass during diagenesis. Although volcanic fragments and ash layers in the Lefkara sediments are mentioned in several publications (see Chapter 1.5) in this study no autochthonous volcanic material was found in any of the sections and is therefore considered to be at least an insignificant source for chert. The clay minerals montmorillonite, palygorskite, sepiolite, and also clinoptilolite, all found in the sediments, may be products of the alteration of volcanic glass with a subsequent liberation of silica (Kastner, *et al.*, 1977; Williams *et al.*, 1985). Nevertheless, this is considered to be rather an insignificant source for silica (Wise & Weaver, 1974; Robertson, 1975). However, the clay mineral analysis shows the source of these clay minerals to be dominantly terrigenous and transported and in the majority of cases not authigenic (see Chapter 4.1.2.). It can therefore be concluded that most of the silica in the Lefkara sediments must have a biogenic origin.

Radiolarians, their spines, and sponge spicules are the only siliceous microfossils found in the sediment and these must have provided most of the silica. Additionally, diatoms and silicoflagellates may have delivered some opal for the chert formation but none of these are preserved. Diatoms are less likely to occur in large numbers in open marine tropical waters (Kennett, 1982) and start to increase in the geological record in quantitative significance only during the Palaeogene (Harper & Knoll, 1975). Since they are more susceptible to dissolution than radiolarians (Kastner *et al.*, 1977; Hein & Obradovic, 1989) they were possibly not incorporated into the sediment in the first place.

The biogenic silica was mobilised at an early stage of diagenesis. Possibly depending on the rate of dissolution of the radiolarians, the silica may have migrated without preserving any relics of the wall structure and only leaving a spherical cavity which was later infilled. If the rate of dissolution was slower the opal may have been replaced by calcite so that the wall structure of the radiolarian specimens were preserved perfectly (Fig.53). The released silica was reprecipitated close to the source area (Robertson, 1975). Commonly it was trapped in highly porous layers as in the packed bioclastic sand layers of turbidite deposits (Figs.54 (D), 61 (C)).

Still before compaction many of the spumellarians became cemented by calcite and therefore resisted any later compactional deformation (Fig.80). The carbonate for the cement may have originated from metastable aragonite of pteropods or high magnesium shell debris (Bathurst, 1991). Since this is generally rare in the sediment the early diagenetically altered radiolarians are preferentially cemented in this process but only very few foraminiferal chambers.

Most silica is found to be reprecipitated before any compaction has taken place. Bioclasts, now filled with quartz, have all preserved their original shape without being compressed although many of the surrounding uncemented tests and shells are deformed or crushed during late compaction. Similarly, areas of accumulated chert, in which bioclasts and parts of the micrite are infilled or replaced respectively by quartz, were protected and do not show any signs of compaction. They retained their original shape, do not show any fracturing or pressure-solution and no dissolution seams occur (Fig.80). The micrite around the diagenetic chert is highly compacted which shows that the competent quartz must have existed before compaction took place.

In contrast, the bioclasts infilled with silicified mud do show strong indications of compaction and deformation (Fig.58 (B)). Either these microfossils were deformed while they were being filled with micrite and silicified later in a second stage after compaction, or the isotropic silica was more flexible because of a less developed crystallinity and could be deformed

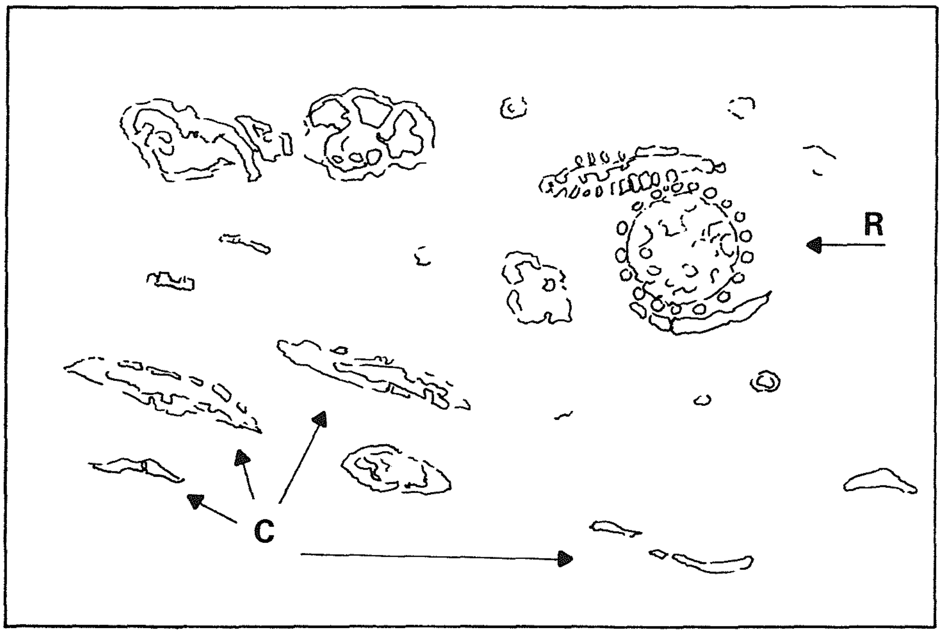


Fig.80. Compacted biomicrite (thin section). "C" = compressed radiolarian shells filled with isotropic silica; "R" = undeformed cemented spumellaria.

after penetrating the microfossil. This would imply a silicification of the micrite during the same process as the quartz cementation and not after compaction. The latter case proves to be true since all deformed specimens show the slightly fibrous character of isotropic silica under crossed polars which is thought to be related to compactional stress (see Chapter 3.2.5.). The bioclasts therefore have been silicified prior to compaction. All silicified mud fillings that are undeformed are clearly isotropic and black rather than fibrous in crossed polarised light.

Compaction stage:

The diagenetic process after opal mobilisation/reprecipitation has been mechanical compaction which led to a reduction of the pore space in the sediment and possibly increasingly to the infilling of pores with mud. Furthermore, burrows, sediment clasts and mud-filled radiolarian shells were deformed (Fig.62 (B)) and tests partly crushed (Fig.62 (C)). Such plastic or brittle grain deformation is characteristic for rapid deposition of fine-grained carbonate influenced by later faulting (Scholle & Halley, 1985). The deformation of the originally circular burrows shows a loss in vertical volume between 50% and 75%. This is exactly the order of magnitude of compactional loss (2/3) which was found in experiments (Shinn *et al.*, 1976) and which was calculated for the diagenetic development of ooze to limestone (Moore, 1969).

Chemical compaction, *i.e.* pressure-solution, as a late diagenetic process resulted in solution-seam development and the dissolution of calcareous tests (Bathurst, 1975). During the compactional process increasingly more calcium carbonate dissolved which led to relative clay-enriched seams (Fig.58 (D)), concave-convex contacts between calcareous bioclasts (Fig.62 (C)) and truncation of tests. The carbonate-rich fluids circulated in the still existing pore space and initiated the neomorphic spar development in the tests. Consistently, bioclasts are commonly recrystallised in areas of an originally high pore space as in the packed layers. These pores were most likely initially partly filled with mud but not cemented at an early stage due to a low diagenetic potential of the original sediment being composed mainly of low magnesium calcite and lacking significant amounts of metastable aragonite or high magnesium calcite (Schlanger & Douglas, 1974; Bathurst, 1991). The amount of neomorphic spar decreases towards the top of the formation as indicated by an increase in mud-filled tests. This may be related to the relatively shallow burial depth near the top of the succession. Similarly, syntaxial overgrowths of calcite and a related thickening of the foraminifera walls is mainly observed in the sediments of the older part of the formation while this neomorphic process is not observed in younger strata.

An increase in compaction is indicated by small nannofossil specimens disintegrating into micron-sized crystals while larger coccoliths and discoasters increase in size through overgrowths and recrystallisation (Schlanger & Douglas, 1974) (Figs.59, 53 (B)). Schlanger & Douglas further observed an increasing pressure-solution of planktonic foraminifera with increasing compaction, leading to the almost entire disappearance of planktonic foraminifera near the limestone stage. The parallelity of these observations with the material of the pelagic microfacies I1 of the Lefkara Formation suggests a similar development here.

Burial depth:

Opal-CT and quartz are the two different varieties of crystalline silica found in the sediments. Since the diagenetic maturation from biogenic silica (opal-A) to quartz is dependent on time and temperature, *i.e.* burial depth, the silica in the sediments can give information on the diagenetic history of the sediment. Siever (1983) modelled the temperature-time path of sediment deposited under different depositional conditions. Using this analogue, the presence of both opal-CT and quartz in the older strata of the Lefkara sediments indicates a burial depth of less than 1800m, assuming a relatively low geothermal gradient of 20°C/km. This geothermal gradient seems reasonable considering the distance of the area from any (active) mid ocean ridge and the absence of any volcanism. Measurements of the (maximal) thickness of the overlying sediments lead to a similar value of approximately 2000m overload (Cleintuar *et al.*, 1977).

Since the fields of stability for opal-CT and quartz are additionally dependent on the composition of the host sediments, e.g. on the influence of clay minerals and the alkalinity in carbonate rocks (Kastner, *et al.*, 1977; Robertson, 1977) this assumed burial depth can only be a rough approximation. Robertson (1975, 1977) explained the cooccurrence of opal-CT and quartz in contemporaneous strata of the Lefkara Formation by the retarding influence of clay minerals on the silica maturation, since lussatite (opal-CT) was found in granular, clay enriched cherts while quartz was present in the vitreous, calcite-rich basal turbiditic layers.

Summary of the diagenetic history as seen in thin sections:

1. Deposition as foraminifera-nanoplankton ooze; the radiolarians dissolved at the water-sediment interface or became incorporated into the sediment, depending on the rate of deposition.
2. De-watering processes; bioclasts became partly infilled with mud.
3. Opal mobilisation and reprecipitation as opal-CT:
(a) Radiolarian shells dissolved and the cavities infilled or cemented with silica or calcite, forming casts (although a later pressure-solution of calcite-replaced shell walls is also possible).
(b) Radiolarian shells were replaced by calcite and infilled or cemented with silica or calcite.
(c) Silica reprecipitated as cement in foraminifera chambers and replaced the walls and/or the micritic matrix.
4. Increased compaction led to:
(a) Grain orientation.
(b) Increased filling of voids with lime mud.
(c) Fragmentation and deformation of bioclasts.
(d) Development of solution seams and pressure-solution of calcitic allochems including small nannofossils and the gradual decrease in planktonic foraminifera.
(e) Neomorphic spar developed parallel to the pressure-solution of calcite in pores and as overgrowths on microfossils and large nannofossils.
(f) Maturation of opal-CT to quartz at about 1.8km(?) burial depth.

4.3. THE DEPOSITIONAL ENVIRONMENT OF THE LEFKARA FORMATION

4.3.1. DEPTH OF DEPOSITION AND PALAEO-SALINITY

4.3.1.1. DEPTH OF DEPOSITION

Evidence for the depositional depth of the sediments of the Lefkara Formation is gained from microfossils, microfacies characteristics, and the mineralogy. First of all it is apparent that almost the whole succession is carbonate-rich which indicates a depositional environment above the CCD. Signs of carbonate dissolution such as shale layers between rapidly deposited turbiditic strata (Hesse, 1975) or a change in the faunal composition by a relative increase in the solution-resistant forms, benthic foraminifera and radiolarians, are not observed (except in the stratigraphically lowest samples). The carbonate content is even generally higher in the sediments of the western (turbidite-poor) sections where an increased carbonate dissolution should be expected since they underlay slower deposition. Consequently, they were situated well above the CCD. The dominance of radiolarians during some time intervals could be shown to be caused partly by relative enrichment during diagenesis and partly by transport, but not by *in situ* dissolution processes. In fact, most Tethyan radiolarites were formed above the CCD (Greensmith, 1989).

Low percentages of benthic foraminifera of the whole fauna >63µm indicate that carbonate dissolution is insignificant. In Pleistocene unconsolidated foraminifera-nannofossil oozes from the equatorial Atlantic percentages of benthic foraminifera of larger 1% of the fraction >63µm were common and the values even increased to 8% in exceptional cases (Kähler, 1990). These samples were taken from a water depth of approximately 2400m, which is clearly above the CCD. Only a minority of the samples analysed from the Lefkara Formation show values above 1% benthic foraminifera (Fig.66) so there is little doubt that deposition was in the normal range of deep sea sediments from above the CCD. Only marls at the bottom of the successions of the Lefkara and the Motorway sections show increased numbers of benthic foraminifera as which will be discussed below.

Reconstructions of the Tertiary CCD (Riedel & Funnell, 1964; Berger & van Rad, 1972; Berger, 1973, Ramsay, 1977) revealed a depth of the CCD comparable to the recent position back into Oligocene time for the lower mid-latitudes (recent CCD: 4200-4500m for the Pacific,

>5000m for the Atlantic; Kennett, 1982). During the Eocene the CCD was 500m to 1000m shallower in all oceans. Deposits between the lysocline and the CCD are characterised by rhythmically occurring silica-rich ooze (Berger, 1970) and may, in extreme cases, lie up to 1000m above the CCD (Berger, 1973, 1974). Since in the Lefkara Formation silica-rich strata are mainly related to turbiditic input and not a product of carbonate dissolution and the pelagic strata are chert-free and since no decrease in carbonate can be seen in the pelagic facies, deposition obviously took place above the calcite lysocline. Assuming a CCD depth of around 3500m for the Eocene and a shallow lysocline due to a high productivity (indicated by abundant radiolarians) for the Chalk & Chert and Chalk units a maximum depth of deposition may be estimated around 2500m to 3000 m. No relics of pteropods or other aragonitic fossils are found in the sediments. This may indicate that the depositional depth lay beneath the aragonite compensation depth (ACD) which can be 1000m or more above the calcite lysocline (Kennett, 1982).

The stratigraphically lowest samples of several sections taken directly from the contact to the pillow lava do not exhibit the same lithology as the material described above. The different composition becomes most obvious in the study of the sand fraction (Fig.66). The bottom strata are commonly depleted in calcareous bioclasts with only few specimens present (see Appendix C) and also in carbonate (Fig.73). Additionally, the relative amount of benthic foraminifera (Motorway and Lefkara sections) and radiolarians (Motorway, Lefkara and Kalavasos sections) is commonly increased, which indicates carbonate dissolution. High amounts of quartz in the bulk composition (Fig.70) mainly reflect increased presence of biogenic silica. Robertson (1975) interpreted the succession of discontinuously occurring radiolarites below the Lefkara Formation (Perapedhi Formation) and the overlying chert-free part of the Lower Marl unit as being deposited below and close to the CCD respectively. The transition between the basal dissolution-influenced samples of the Lower Marl and the stratigraphically higher samples is rapid, with the latter one not being corroded, which indicates a rapid decrease in dissolution, possibly due to a drop of the CCD. Nevertheless, the exceptionally continuous outcrop of the Lower Marl succession in the Motorway section shows a gradual decrease in the amount of benthic foraminifera and radiolarians (Fig.66) which may reflect a gradual decrease of slight carbonate dissolution during the deposition of the whole Lower Marl unit. Phosphatic bone fragments found in increased abundance in the Lower Marl sediments of the Kalavasos and Motorway sections may also be the result of carbonate dissolution. Whether the diachronously dated base of the formation (Late Palaeocene for the Kouka, Ayios Nicolaos, Lefkara sections, upper Early Eocene for the Kalavasos, Stavrovouni, Motorway sections) reflects different positions of different localities in respect to the CCD (e.g the later end of carbonate dissolution in the eastern sections due to a topographically lower position) would need to be examined by further studies.

The microfacies types observed in the Lefkara Formation also indicate that the whole succession is deposited in an environment below the typical slope facies (Wilson, 1975, Flügel, 1982). A shallow water origin can be excluded since characteristic autochthonous organisms, such as benthic algae as well as wave ripples, are absent, indicating an accumulation area below 250m water depth. The microfacies types of the Lefkara sediments are closely related to the descriptions Flügel lists for a deep marine setting: the dominance of micrite, common planktonic microfossils, rare sparite cements, common intraclasts, the absence of extraclasts and a low quartz content. With respect to bathymetry, the sediments are most characteristic of a basin margin setting (Flügel, 1982; Tyrell, 1969). The depth of deposition of the Lefkara Formation therefore has to be placed somewhere near the lower bathyal zone which is around 2000-3000m water-depth.

The depth of deposition is further reflected in the planktonic/benthonic foraminiferal ratio (P/B ratio; Fig.81). As shown by Gibson (1989; Murray, 1976) the percentage of the planktonic foraminifera in the sediments from above the CCD increases clearly as a function of water depth. P/B ratios calculated from the sand fraction counts of the disintegrated sediments all have values clearly above 90% planktonic foraminifera with the exception of two samples from the base of the formation. Foraminifera faunas dominated by planktonic forms with 90% and above were found by Gibson only in environments deeper than 2000m, while at shallower depths

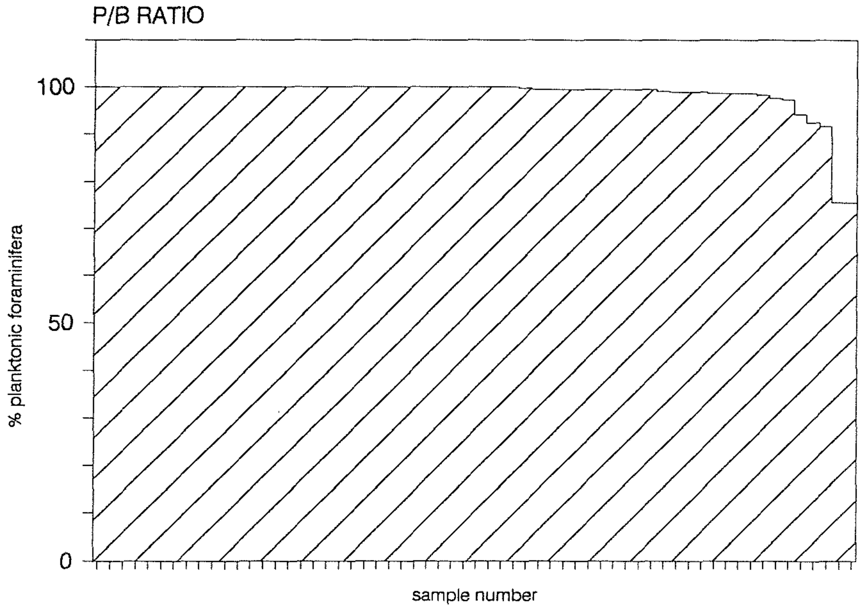


Fig.81. Planktonic/benthonic foraminiferal ratio calculated from counts of the sand fraction (after the formula P / P + B * 100).

significantly more samples contained lower percentages. Although diagenetic processes may have altered the relative amount of planktonic foraminifera in the chalks it would have only caused a decrease, altering the results towards an interpretation of shallower conditions. Therefore the P/B ratio indicates a bathyal depositional environment for the Lefkara Formation. Nevertheless, the counts of the sand fraction (Fig.66) and most of the thin sections of the Upper Marl samples show a slight increase in the percentage of benthic foraminifera compared to the whole assemblage which is either related to a slight shallowing of the sea (Zomenis, 1968) or to current processes.

In summary, the sediments of the Lefkara Formation were mostly deposited above the CCD. The depth of deposition is estimated to have been between 2000m and 3000m, with no indications for a much shallower deposition even for the Upper Marl samples. Only samples from the base of the formation shows signs of carbonate dissolution which is possibly related to a raised CCD near the Cretaceous/Tertiary boundary (Worsley, 1971).

4.3.1.2. SOURCE OF ALLOCHTHONOUS MATERIAL

Since the facies analysis confirms the deep water origin of the Lefkara sediments most of the bioclasts of a benthic habitat can be assumed to be transported. The study of the allochems in thin sections (Fig.65, Tab.7) shows the allochthonous origin of the benthic organisms and clasts but does not consider the significance of the single organism or component groups and the source of transport. Therefore, the habitats of the fossils found and the source of the clasts will be considered now to get information about the origin of the allochthonous material.

Many of the organism groups observed in the thin sections occur in a wide range of water depths and are therefore unsuitable to provide any information about the source of the reworked material. Members of the benthos such as pelecypods, ostracods, echinoderms, and siliceous sponges all live in depths from shallow water up to 2000m (Flügel, 1982) and therefore can have been transported from different parts of the slope or shelf or, in some cases, might even be autochthonous. The occurrence of calcareous sponge spicules is more significant. Although some of the calcitic spicules may have been diagenetic products and originally opaline, other spicules definitely originate from calcisponges. In recent sediments these are restricted to a habitat above 100m. Larger foraminifera also indicate a shallow water source. The observation of *Alveolina* species and fragments of *Nummulites* indicates reworking from an inner platform or platform edge respectively in Early to Middle Eocene time (Sartorio & Venturini, 1988). Micritised mollusc shells and algal borings also indicate a shallow water source of the reworked particles from the photic zone, that means shallower than 200m. A clear shallow water origin from shelf or even beach deposits could also be assured for the few glauconite and rounded quartz grains found in the turbiditic deposits. All this evidence leads to the assumption that the allochthonous fraction must have been at least partly reworked from a shelf environment.

The origin of the sediment clasts is clear for the intraclasts of type S, composed of micrite identical to the sediments of the Lefkara Formation. These are only found in turbidites. The carbonate-free sediment clasts (types A-C) are not easy to interpret since these are not characteristic for the deposits of the Lefkara Formation. This type of clast occurs enriched in the turbiditic strata but is also present in the pelagic facies. However, it is found to be related to transport (Chapter 3.2.8.) and the main characteristics suggest them to be intraclasts: (1) they have been most likely originally micrites and are secondarily silicified, (2) contain pelagic coccoliths and radiolarians, and (3) they are of a similar composition as the silicified mud fillings in some autochthonous pelagic bioclasts. These are therefore most likely reworked from silicified strata of the Lefkara Formation. The fact that they must already have been silicified at the time of transport explains their more common occurrence than the intraclast type S.

The source of other rare lithoclasts such as volcanic rock fragments and various minerals cannot be specified. Since the rounded quartz grains and glauconite have a clear shallow water origin this might be true for the rest of the lithoclasts as well because they are found in the same assemblage. Quartz and alkali feldspar are not characteristic of the ultramafic Troodos ophiolite which makes an origin from submarine erosion from already uplifted parts of the basement unlikely. Since they only occur in significant amounts in turbidites they are considered to be transported by far travelled turbidity currents and originate from the Taurids (see Chapter 5).

The material deposited as turbidites under relatively high flow conditions (A- to C-divisions) can be considered to be totally allochthonous. Even here, the reworked shallow water components are generally low in percentage and the strata are mainly composed of pelagic microfossils. The turbidites therefore either completely originate from the lower slope which was only slightly influenced by a shallow marine facies (Wilson, 1975) or pelagic material was additionally picked up by the turbidity current by erosion of deep marine deposits (Stow *et al.*, 1984). The common mixture of planktonic foraminifera and radiolarian species from several biozones in one sample proves the reworked origin of parts of the pelagic sediments (Chapter 2, Tab.3). In any case, the material is influenced by various shallow marine deposits and is therefore most likely not reworked from isolated submarine highs but rather indicates a near-continent source area of the calciturbidites of the Lefkara Formation.

4.3.1.3. PALAEO-SALINITY OF THE SEA WATER

During deposition of the whole Lefkara Formation the salinity of the sea water must have been normal. Planktonic foraminifera occur commonly in the fauna throughout all the succession which indicates that the salinity cannot have exceeded 36‰ (Bé, 1977). Preceding the Late Miocene salinity crisis, it may be assumed that the environmental conditions during deposition of the Upper Marl (Oligocene to Early Miocene) might have been slightly hypersaline. Echinoderms and calcisponges are organism groups which are sensitive to salinity changes and do not occur in water with a salinity above 40‰ (Flügel, 1982). Relics of these groups were found occasionally in the deposits of the Upper Marl but these might have been reworked from older strata. The stenohaline radiolarians, which only live in normal saline water between 30‰ and 40‰ (Flügel, 1982), are completely absent in sediments of the Upper Marl. Although this may be related to an increase in salinity by the time of deposition of the Upper Marl, it seems more likely to have a sedimentological cause (see Chapter 5.2). Reefs overlying the Lefkara Formation also indicate a normal salinity at the time of deposition of the Upper Marl (Follows & Robertson, 1990).

4.3.2. FACIES INTERPRETATION

4.3.2.1. MICROFACIES INTERPRETATION

A: TURBIDITIC MICROFACIES (MICROFACIES GROUP II)

Having established and at the same time partly interpreted the microfacies groups, the individual facies types, characteristics, and associations will be looked at now in detail. Comparison with the macrofacies and discussion of the depositional setting on a larger scale follows in subsequent sections of this chapter and in Chapter 5. Some examples of thin sections are shown in Figure 68. The relationship of the microfacies facies types of microfacies group II (Fig.67) with the turbidite divisions at this stage follows the original descriptions of Bouma (1962) (Fig.82) since most characteristics can, in fact, be observed in the sequence although all deposits result from a low flow regime.

Facies type II1, internally graded, poorly sorted beds of sand-sized particles, together with several examples of facies type II2, thin structureless layers, are here interpreted as division A

(T_a) of the Bouma sequence. Penecontemporaneous micritic intraclasts (type S), obviously reworked from the Lefkara Formation by the turbidity current, are found only in this facies, indicating the comparatively high erosional power of the currents. Similarly, large bio- and lithoclasts are enriched at the base of the strata of microfacies II1.

The fossil assemblages of the layers of turbidite division A are most likely exclusively allochthonous, consisting of transported and rapidly deposited material. Nevertheless, the fact that the turbidity current must have picked up intraclasts by eroding material from the basin implies that parts of the reworked pelagic microfossils are penecontemporaneous to the age of deposition. Sediments from division A will definitely not reflect the sediment composition of the area of the final deposition.

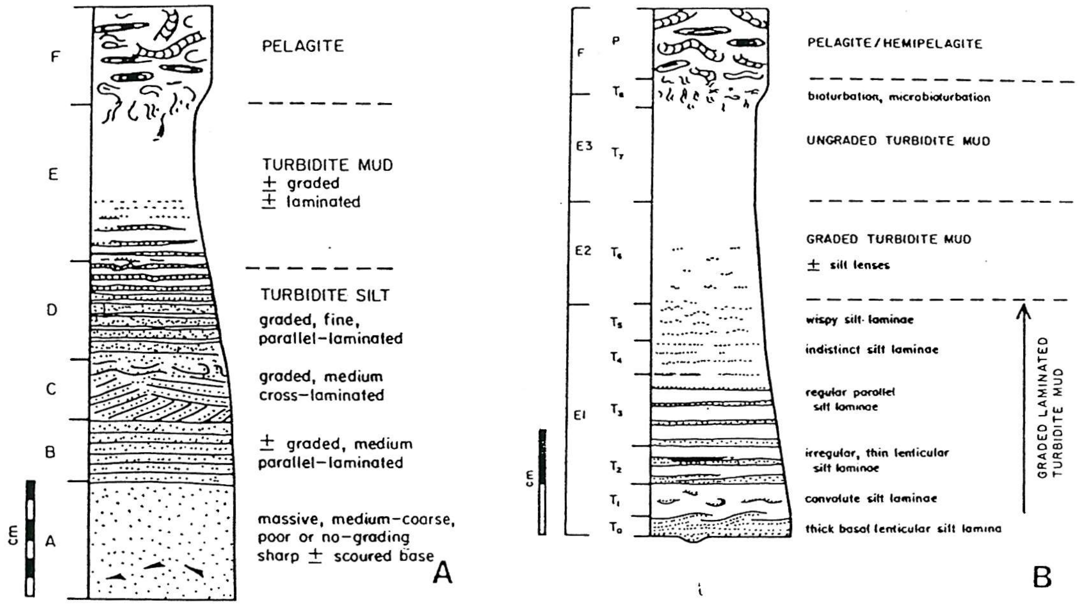


Fig.82. Models of silt and fine-grained turbidites (after Stow, 1985). **(A)** Classical Bouma sequence, applicable for silt turbidites; **(B)** Mud turbidite with Stow divisions (T_0 to T_8).

Parallel-laminated sediments, represented by microfacies II3 in the material from the Lefkara Formation, occur in several thin sections overlying division A in gradual transition and are therefore interpreted as equivalent to the B-division of Bouma (1962). These layers are characterised by distinct parallel laminae as described in Chapter 3.2.6. and show an alteration in the degree of packing and in grain size. Reworked material is abundantly present.

Microfacies II4, cross-laminated strata above the B-division, is interpreted as turbidite division C which is formed by current ripples. The cross lamination is either characterised by a number of parallel foresets or one inclined erosional horizon (Scholle, 1971). Comparatively large reworked particles are abundant which, together with fragmented tests as indications of erosion, seem to be in contrast to the fact that division C is deposited in a lower flow regime than B. Nevertheless, it reflects the comparatively high energy of the turbidity current during the formation of facies II4.

Facies II5, only represented by one thin section (Fig.68), shows convolute lamination and is therefore part of interval C. It is the result of a displacement of the still mobile sediment directly after deposition (Bouma, 1962).

The contact between the turbidite divisions C and D (the upper interval of parallel lamination) is commonly present in thin sections. Division D is either characterised by microfacies type II3, similar to the lower division of parallel lamination, with more or less packed strata. More commonly, the micrite is of microfacies type II6 which is sparse and shows less defined laminae. The mud-rich composition reflects a low energy current which carried only a small amount of reworked material. In this interval burrows are observed. Although the material above the C-division is predominantly micrite the structural sequence established for fine-grained turbidites (Stow & Shanmugam, 1980; Piper, 1978; Fig.82) cannot be recognised consistently. As discussed later, this indicates a depositional setting typical of calcarenitic turbidites exhibiting Bouma sequences (Stow, 1984).

Division E might be present in the thin sections of the turbiditic microfacies group but is never identified for certain, either due to depositional or post-depositional reasons. The problem of distinguishing between E-divisions and interturbidites is common in calciturbidites (Eberli, 1987). In the few cases where this division may be classified (possibly Fig.61 (B)), the strata exclusively belong to facies type II6 of sparse biomicrites and are not laminated. Bioturbation is present in several cases which indicates a slow sediment accumulation, allowing post-depositional burrowing.

In summary, most microfacies types of the turbiditic facies group (II) can be related to a specific division of the turbidite sequence. Only if depositional conditions of two intervals are similar or result in similar features the same microfacies may be found in two different divisions of the turbidite sequence. Consistent with the fact that one complete sequence is the deposit of a gradually waning current, a general fining upwards can be observed in many of the single intervals but also throughout the whole sequence.

In at least a few of the examples studied the transition and association of the microfacies types expected according to the order of the Bouma sequence is observed. In most cases only parts of one turbidite are present in the slide.

B: SPARSE MICROFACIES (MICROFACIES TYPES I AND II6)

Comparison of microfacies types I2 and II6:

As mentioned when establishing the microfacies types, the microfacies II6, representing all sparse strata in turbidites, and the microfacies I2 closely resemble one other. They have most characteristics in common except the fact that II6 only occurs in close association with other turbiditic facies types which are not found in the microfacies I. Considering where the sparse turbiditic facies occurs in the Bouma sequence, it becomes apparent that, with few exceptions, all examples are recognised as deposits from a D- or possibly E-interval, that means they are deposited under extremely low flow conditions. This implies a clear relationship between relatively slow deposition and micrite-rich sediments. It also contributes to the assumption that the whole sparse microfacies group I may have been deposited under slow sedimentation rates.

Most examples from the sparse turbiditic microfacies II6 show the same characteristics as microfacies type I2. They contain silica, radiolarians, and laminae in the majority of cases, and show a varying presence of dissolution seams. This similarity between the two facies points to the interpretation that the 'pelagic' facies type I2 may also have been deposited from a turbidity current under low flow regime or at least was deposited under similar conditions. The fact that I2 is more varied in sedimentary characteristics than the other microfacies types, *i.e.* the characteristics are not consistent for all samples, suggests that this facies type may be a mixture of different original depositional types. I2 may include various turbidite divisions that are not developed typically because of a more distal setting, diagenetic alteration, or the fine-grained character of the sediment. It may also in part include pelagic sediments which are mixed by bioturbation with the uppermost fine-grained turbidite division.

Occurrence of the sparse microfacies in the succession and its relationship to turbidite deposits:

As stated, facies type I2 resembles II6 and therefore might be deposited under a similar low flow regime of a turbidity current even if no other evidence for a gravity flow exists in the macrofacies. This assumption makes it important to find out where and when sediments of the microfacies I2 occur in the sections. To examine this only the sparse samples from the microfacies group I (I1 and I2), taken from outcrops where no apparent turbidites are seen, are compared with the macrofacies.

In the outcrops near Kouka no clear turbiditic macrofacies is present and all thin sections analysed are sparse biomicrites. The majority of the samples of the microfacies type I2 are from the Chalk & Chert unit. Only one sample comes from the upper part of the Lower Marl and one from the lower part of the Chalk unit. The fact that some samples show cross and parallel lamination and mainly occur in the Chalk & Chert and in the nearest samples from the adjacent units reveals a close similarity to the turbiditic microfacies II6 in the eastern sections. It implies the same origin for microfacies types I2 and II6 as a distal turbidite. Since no massive or graded packed beds are found at all in the Kouka section it may be suggested that the samples of microfacies I2 represent base cut-cut sequences of a turbidite where only C- to E-divisions were deposited which is typical for a distal position. Related to Stow's models (Stow & Shanmugam, 1980; Fig.82) it is comparable to a mud turbidite with rare cross lamination (T_2) (see section 4.3.2.3.).

Other thin sections from the Chalk & Chert unit of the Kouka section are of microfacies type I1 which are believed to be deposited as an autochthonous pelagic sediment. The samples analysed from the lower part of the Lower Marls, the upper part of the Chalk unit, and the Upper Marl are of facies type I1 or of the slightly exceptional variety (Chapter 3.2.10).

The Ayios Nicolaos section shows a few rare turbidite beds near the top of the Chalk & Chert unit in the field. Nevertheless, fewer thin sections than in the Kouka section are found to be of the microfacies type I2. These are from the top of the Chalk & Chert unit and the lower part of the Chalk unit and show bioturbation or parallel lamination. Most samples analysed from the Chalk & Chert unit and also the ones from the Lower Marl, the upper part of the Chalk, and the Upper Marl are of microfacies type I1. In spite of the (rare) turbiditic strata, the overall picture in the Ayios Nicolaos section seems to indicate a rather slow pelagic deposition which even dominated the chalks in the Chalk & Chert unit.

In the Motorway section indications of turbiditic deposits in the macrofacies are present but rather weak. The samples analysed for the microfacies from the Lower Marl and the lower part of the Chalk & Chert are of the I1 microfacies type and therefore indicate at least relatively long periods of pelagic sedimentation. The two thin sections analysed from the Chalk unit both are of the facies type I2 which therefore may have been deposited under a slight turbiditic influence although only few sedimentary structures and bioturbation were seen in the field.

One of the localities with the best developed turbidites in the Chalk & Chert unit and in the lower part of the Chalk unit is the Kalavasos section. Samples of the pelagic microfacies type I1 occur in the upper part of the Chalk unit, the Upper Marl, and the Lower Marl. Interesting is that three samples from the transitional facies of type I2 (not containing any silica) are from the upper part of the Chalk unit and therefore lie between the samples of the turbiditic microfacies group and the pelagic facies I1. A similar pattern as for the Kalavasos section is found for the Stavrovouni section.

In the third turbidite-rich section, the Lefkara section, the sparse biomicrites are mainly defined as microfacies I2. Since the microfacies I2 is dominating amongst the samples of the Lower Marl and Chalk units, with most of them showing distinct laminae, it may suggest a longer ranging turbiditic influence in this area.

In summary, in the apparently nearly turbidite-free sections, Kouka and Ayios Nicolaos, many samples are found to be of the microfacies type I2. These occur mainly in the Chalk & Chert and the lower part of the Chalk unit which are the lithological units characterised by turbidites in the eastern sections, Kalavasos, Lefkara, and Stavrovouni. Since microfacies I2 is most likely equivalent to the turbiditic facies type II6 this observation confirms the assumption that the sediments of I2 are deposited from distal turbidites. In the higher part of the Chalk unit of the Motorway section also a slight turbiditic or further current influence may be interpreted. Similarly, in the Lefkara section the observation of the microfacies I2 in the Lower Marl and Chalk units suggests an extended turbiditic influence compared to the other sections.

Deposits of microfacies type I1 are found commonly alternating with type I2 in the Kouka and Ayios Nicolaos sections, in the Chalk & Chert and Chalk units. This indicates the existence of longer times of slow pelagic sedimentation than in the turbidite-rich sections, assuming that the sample spacing is representative. In most sections the samples from the lower part of the Lower Marl and the Upper Marl show the microfacies I1 (or slightly transitional types) and are therefore most likely free of turbidites. Only the Motorway section shows a different microfacies in the Upper Marl.

Microfacies I1 is considered to be the product of purely pelagic deposition above the lysocline on the basis of the abundance of silica and radiolarians, a low clay content, the absence of sedimentary structures, and the stratigraphic relationship to the turbidites. A high proportion of the microfacies type I1, overlying turbidites as F-divisions, must be obscured by post depositional burrowing and mixing and so mimicking microfacies II6 or I2. Microfacies studies of comparable pelagic carbonates and lime muds (Eberli, 1987; Whitham, 1993) do not show the same characteristics but are abundant in radiolarians and therefore do not support the microfacies interpretation of this study. Nevertheless, a different depositional environment such as greater water depth or higher productivity may be responsible for the apparent differences.

The presence of some allochthonous material, as recognised by few intraclasts and even less macrofossil fragments, in the pelagic microfacies I1 indicates either an extremely slow deposition from suspension (e.g. from nepheolid layers) or a slight redistribution of turbiditic material by bottom currents (Stow, 1994). These can only have been low energy processes since no sedimentary structures were formed.

4.3.2.2. VERTICAL VARIATIONS OF THE TURBIDITIC FACIES

The turbidite sequences observed in the outcrops of the Kalavasos, Lefkara, and Stavrovouni sections show significant variations in the vertical distribution of structures. These will be analysed in the following section and a comparison between the localities will be made. Evidence from the field data is supplemented with information gained from rock specimen and thin section studies. Figure 83 illustrates the alteration of beds containing the coarser A-, B-, and/or C-divisions and chalk beds of the higher turbidite divisions or interturbidites, to distinguish roughly between high and low energy depositional environments. Pelagic strata cannot be distinguished reliably.

Kalavasos section:

In both outcrops of the Kalavasos section showing turbiditic structures, a vertical development of facies variations can be observed. In the Chalk & Chert outcrop the beds are comparatively thin with a rapid variation in material. This is caused by a high frequency of turbidite beds many of which start with A- and B-divisions, including C- and higher fine-grained divisions (Fig.83). A-, B- and C-strata are typically thin with the sum of these varying between 3cm and 27cm while the fine-grained divisions are up to 40cm thick. Bouma division E is never positively identified and complete A/D sequences are generally rare. Nevertheless, the structures indicate that parts of these deposits are classical turbidites (e.g. Figs.49 (D), 84 (B)). Although the material is not siliciclastic, the hydrodynamic behaviour of silt to sand-sized calcareous material is comparable and results in similar structures (Stow *et al.*, 1984; Eberli, 1991).

On the other hand, sequences which start with division C are more common in the Kalavasos section. These may be classified as mud turbidites (Stow & Shanmugam, 1980, Fig.82) although the standard sequence is not found to be complete. Parts if not the majority of the seemingly structureless beds which overlie the C-divisions are most likely deposits of the higher turbidite divisions T_1 to T_7. Rare silty horizons, laminae and silt lenses in the chalks indicate a turbiditic origin. The uppermost part of the unsilicified chalks is bioturbated in some cases which is consistent with pelagic deposition (F-division, T_8) at least between some of the turbidite sequences.

The lower part of the overlying outcrop of the Chalk unit (Fig.83) is dominated by chalky beds which are cross-laminated at the base and otherwise parallel-laminated, graded, and with rare clear bioturbation. These beds vary in thickness between a few and 40cm. Only relatively few A- and B-horizons are detected which are rarely silicified. Interbedded structureless chalks and marls are rare and thin. These sediments indicate a rapid succession of turbidite sequences starting with C-divisions while no thick interturbidite layer could develop before the next sequence was deposited.

The middle part of the outcrop of the Chalk unit shows a decrease in frequency in the beds starting with cross-lamination. Thicker chalk beds are interbedded which are laminated and partly bioturbated. These strata are interpreted as representing a slow accumulation of turbidites which led to thick pelagic interbeds and more thorough bioturbation.

Near the top of the outcrop all beds are formed by one whole turbiditic sequence (C/F-sequences) with a cross-laminated base (equivalent to T_0), positive grading and calcarenitic lenses near the top (as in T_6). Beds are thicker between 25cm and 80cm. These strata are possibly deposited from more regularly occurring but scarce gravity flows of low energy. The top but also the laminated part of each bed are strongly bioturbated (Fig.38 (A)) which indicates a longer time of pelagic sedimentation (F-division) and development of an endobenthic fauna.

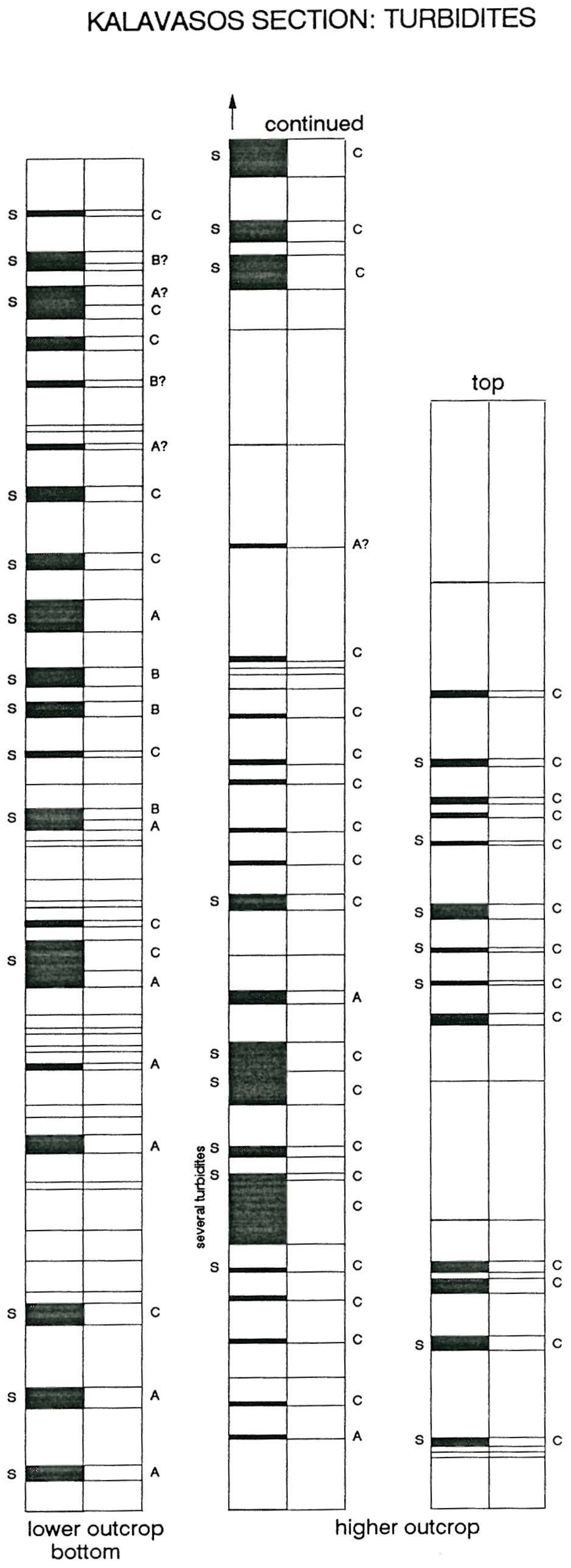


Fig.83. Logs of turbidite sequences in various outcrops of the Kalavasos and Lefkara sections (scale 1:100). Beds containing silica (S) and/or deposits of turbidite divisions A to C (shown at the right) are marked black.

LEFKARA SECTION: TURBIDITES

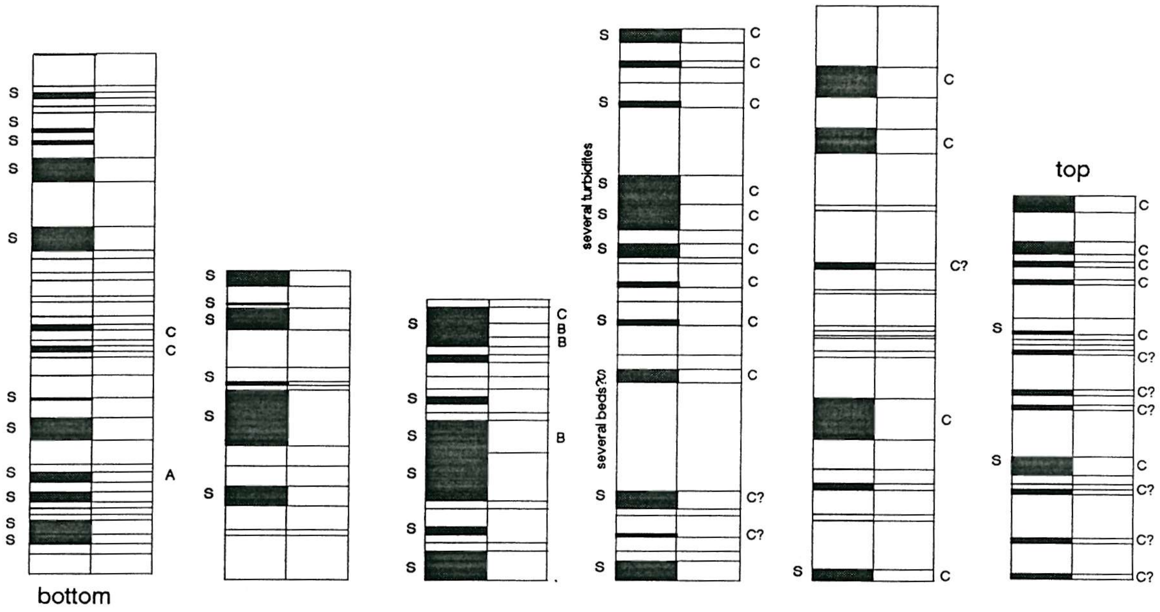


Fig.83 continued.

The uppermost accessible 120cm of chalks at the outcrop are parallel-laminated and bioturbated with no visible bedding (Fig.50 (E)). Ripples are absent but lamination and silt and sand lenses are present as is characteristic for low density turbidite deposits and indicate D/F sequences.

The vertical succession of the sum of all turbidite deposits in the outcrops of the Kalavasos section clearly reflects a decrease in frequency, velocity and density of the gravity flows with time. The younger outcrops above the described turbidite deposits do not show any sedimentary structures and the thin sections indicate a purely pelagic facies.

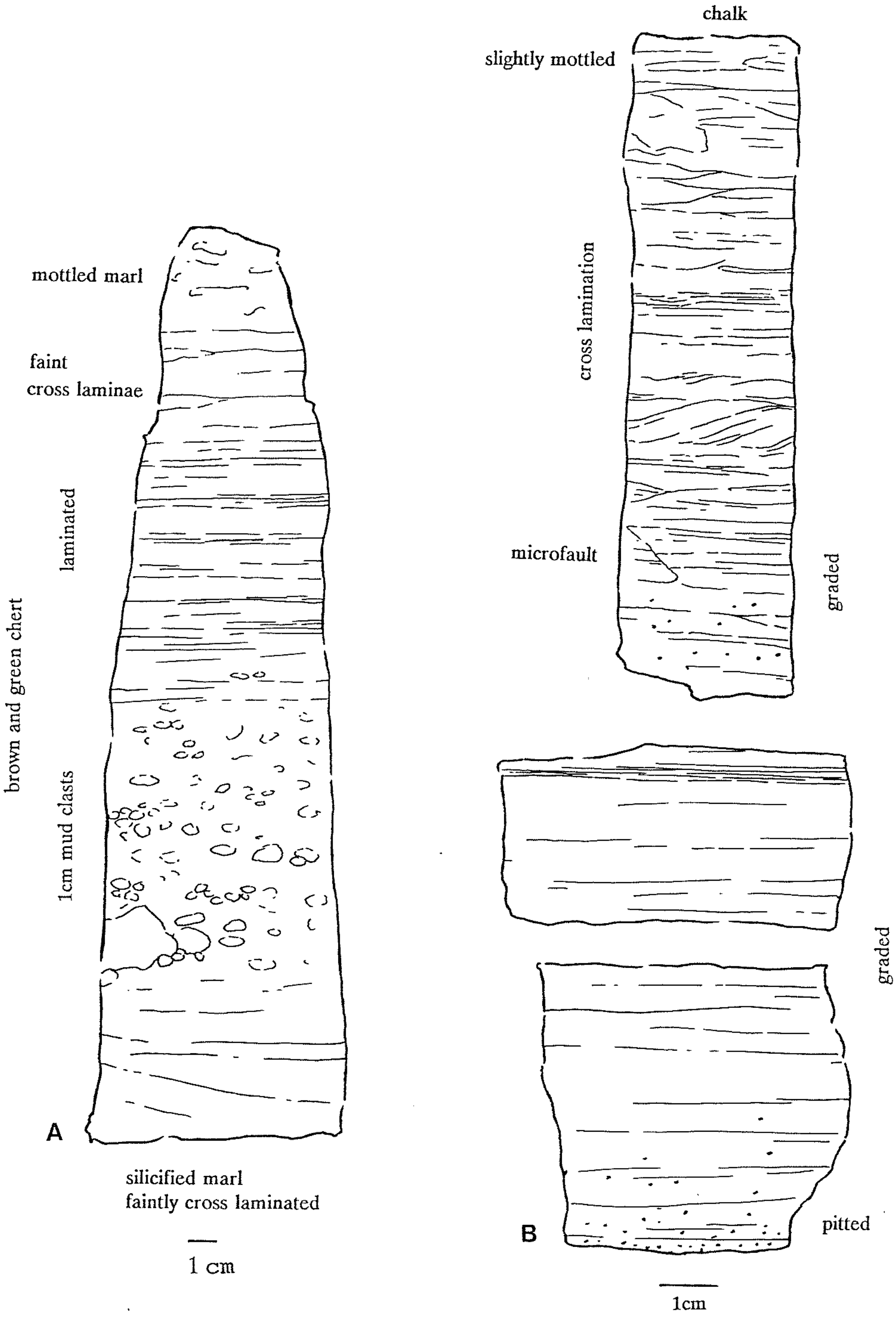


Fig.84. Examples of two complete turbidites. (A) Lefkara section; (B) Kalavasos section.

Lefkara section:

In the Lefkara section a gradual change of the turbidite deposits from the bottom to the top of the succession can be seen similar to that observed in the Kalavasos section (Fig.83). In the lowest turbiditic deposits from the top of the Lower Marl unit the presence of thick A/F sequences indicates deposition from a comparatively high energy current (Fig.50 (F)). These turbidite sequences could rarely be recognised in the field since the cherts are mainly structureless and highly concentrated in silica. Hand specimens reveal cm-sized clasts in some basal turbidite beds (A-divisions; Fig.84). The interbedded chalks contain lamination overlain by bioturbated sediments, indicating comparatively long periods of interturbiditic pelagic sedimentation. The strata of the overlying outcrop from the bottom of the Chalk & Chert unit do not contain any clear turbidite structures except faint laminae but are highly chertified.

Stratigraphically above, the Chalk & Chert unit seems to be rather uncharacteristic for turbidite sequences with coarse laminated and burrowed calcarenitic beds of cm to dm in thickness (Figs.85, 49 (C), 50 (A)). Most beds are silicified and identified as B- and D-divisions, with cross lamination being weakly developed. Although bioturbation is not a common feature in the lower turbidite divisions, Seilacher (1962) described similar burrows in sandy turbiditic layers (Fig.40 (A)). The intercalated pure chalks are not laminated but strongly bioturbated (Fig.49 (C)). The microfacies of these chalks is either classified as I1 or I2 which indicates a partly fine-grained turbiditic and partly interturbiditic origin.

Higher in the succession, the deposits of the Chalk & Chert unit are rich in characteristic turbiditic structures with cross lamination, convolute lamination, rare grading, a high chert content, and a high turbidite frequency. Intercalated chalks show only few laminae and bioturbation. Both, the structured and pure chalk beds, are 1-20cm thick but unstructured strata dominated in frequency. Most turbidites are base-cut sequences starting with C-divisions. Convolute bedding points to disturbances of the unconsolidated sediments. D-divisions are recognised and the scarcity of bioturbation might suggest thin interturbiditic beds.

The strata of the Chalk unit contain little silica with thick chalk strata (30-40cm) which are rare in obvious sedimentary structures except a few laminae, and thin structured or calcarenitic beds (4-20cm). This reflects a decrease in turbidites. Bioturbation is rarely observed and chalks analysed for the microfacies are of microfacies I2 and therefore at least partly of turbiditic origin. The presence of one exceptionally thick ripple structure of 18cm shows that turbidites from denser currents occur sporadically.

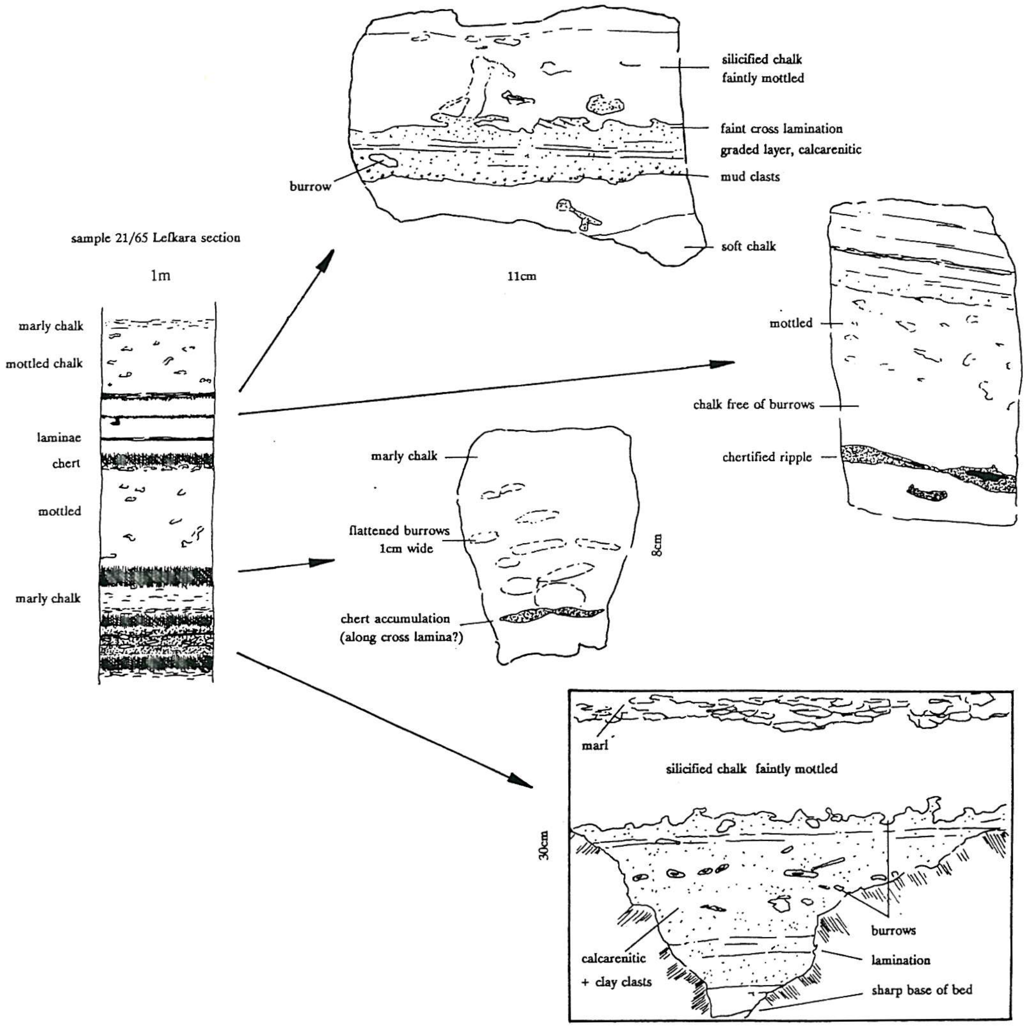


Fig.85. Reference log from the turbidite sequence of the Chalk & Chert unit, Lefkara section (compare Fig.49 C). **(A)** Bouma B- and C-divisions overlain by mottled pelagic chalk; **(B)** C-division overlain by increasingly mottled chalk, at top B-division of following base-cut turbidite; **(C)** Cross laminae of C-division (?) overlain by burrowed pelagic chalk; **(D)** Burrowed B-division and mottled pelagic chalk.

The top of the turbiditic succession is mainly composed of thick chalks (20-30cm) containing rare laminae and more common deep burrows which are interbedded with thin, cross and parallel laminated layers (1-4cm, max.15cm). This succession is assumed to be deposited mainly as pelagic sediments interbedded with thin fine-grained turbidites. Although not all calcarenitic beds show clear cross lamination thin sections show that most of them are C-divisions which grade into fine-grained turbiditic and interturbiditic strata. The faint structures of the Stow divisions are not observed.

Near the highest strata of turbidites in the Lefkara section, not included in the logs, several 10cm thick silicified beds are exposed which start with cross-laminated C-divisions and are assumed to be the product of bottom currents.

Stavrovouni section:

The turbiditic succession of the Stavrovouni section is most likely incomplete and is therefore not discussed here in detail. Nevertheless, the sediments studied show distinct turbiditic structures starting with A- and B- or more commonly C-divisions. The rapid succession of individual turbidite beds in the outcrop and the prominent coarse-grained sedimentary structures suggest a relatively high energy depositional environment comparable to the older sediments of the Kalavasos section.

In summary, the two main localities containing turbidites, the Kalavasos and Lefkara sections, show a parallel vertical development of the turbidite deposits. Both sections start with deposits of the highest energy environment with strata containing A- and/or B-divisions or pure cherts as an assumed equivalent. Bioturbation is commonly present and indicates long pelagic intervals. The deposits higher in the succession originate from high frequency turbidite events, most starting with C-divisions. Bioturbation is rare or absent. In both sections the younger chalk beds above become thicker, with the structured calcarenitic strata being significantly thinner and bioturbation being well developed in the Kalavasos section which reflects a decrease in turbidite frequency. The highest turbidites exposed, all show thin C-divisions, thick chalks, and distinct burrows. The uppermost turbiditic sediments found in the Kalavasos section do not contain any cross lamination but parallel-laminated and bioturbated chalks indicate deposits starting with D-divisions.

The general trend observed is a fining and thinning upwards of the turbiditic strata. The decrease in frequency and thickness of the calcarenitic turbidite divisions (A,B or C) throughout the successions and the general increase in bioturbated chalks indicate a gradual decrease in energy and/or density of the turbidity currents.

Dating of the turbidites:

Although the precise dating of the turbidite sequence is difficult due to incomplete successions and the absence of clear sedimentary structures in the macrofacies it is essential to know its start and end for interpretation of the sedimentary environment. The base of the sequence is not clear since only a gradual increase in the frequency of chert-rich beds can be observed. Although no sedimentary structures were found, they are most likely formed due to a periodically quicker burial from turbidity currents. This would imply start of turbiditic input with the earliest dated sample of biozone P6 (Kouka section) at the boundary between Late Palaeocene and Early Eocene. On the other hand, the first definite turbidite deposits showing turbiditic structures or at least regularly occurring bedded cherts are dated to biozone P9 (53Ma, top of the Early Eocene) in most sections (Tab.10).

Tab.10. Ages of turbidites as dated in this work.

TIMES OF TURBIDITE DEPOSITION

section time (Ma)	Ayios Nicolaos	Kouka	Kalavasos	Lefkara	Stavrovouni	Motorway	average age
top of succession	not exposed	not clearly recognised	43	41	? (tectonically truncated)	50?	approx 42
base of succession	not exposed	52-57	53	53	53	53-54	53
biozone: top	?	?	P13	P14?	?	P10?	
biozone: bottom	?	P6-P10	P9	P8/9	P8/9	P8	
duration:	---	?	10Ma	8Ma	?	4Ma?	

The top of the turbiditic deposits is equally difficult to recognise. The sedimentary structures slowly fade but in some sections contourites seem to take over and are difficult to distinguish. According to the microfacies, the uppermost samples taken from the Chalk unit are of the microfacies I1 which is thought not to be turbiditic in origin. The youngest definite turbiditic sediments are dated at approximately 42Ma (P14) from the top of the Middle Eocene in the eastern sections. Although for the western 'distal' sections no dates could be obtained, since no sedimentary structures were found above the Chalk & Chert unit, a similar age for termination as for the eastern ones might be assumed. The inclusion of most of the structureless chalks into the turbidite influenced succession would be consistent with the assumption that at least the bedded chalks of the Kouka section above the chert-bearing unit reflect turbiditic deposition. Similarly, the comparatively high sedimentation rate of the almost structureless Chalk unit of the Stavrovouni section (Chapter 2.3.4.) suggests a partly turbiditic origin. Therefore, an overall top of the turbidites at the end of the Middle Eocene is assumed.

4.3.2.3. CHARACTERISTICS OF CALCAREOUS TURBIDITES AND CONDITIONS OF DEPOSITION

The results of the facies studies show that the turbidites are characterised by most of the structures typical for siliciclastic Bouma sequences. These include definite A/D sequences while E-divisions are not positively identified. Although calcareous turbidites follow generally the same depositional processes as siliciclastic ones (Eberli, 1987) some features are characteristic for calciturbidites. These are the development of silicified layers, the uncommon presence of water escape structures and bottom marks, a poor sorting in medium to coarse grained deposits, and the common absence of E-divisions of the Bouma sequence (Eberli, 1987, 1991). Inverse grading is not observed in this study which might indicate low density flows since inverse grading is the result of restricted particle settling in a high density flow deposits. The low density calciturbidite may be either deposited as an end member from a long travelled (siliciclastic) turbidity current or as a turbidite resulting from slumping of unconsolidated pelagic sediment (Eberli, 1991).

Although several calcarenitic turbidites of the Lefkara Formation are found starting with A- and/or B-divisions most of the turbiditic deposits, particularly higher in the stratigraphic column, start with cross laminated C-divisions of varying thickness (see also Robertson, 1976). These base-cut sequences are typical for biogenic calcilutite turbidites as described by Stow (1984), with a basal calcarenitic parallel- and/or cross-laminated layer and overlain by fine-grained material. The characteristic structural sequence of fine-grained turbidites as described by Stow & Shanmugam (1980) is not found to be complete since biogenic turbidites generally do not develop clearly defined structures due to the lack of electrostatic adhesion between calcareous particles (Stow, 1985, Eberli, 1991). However, cross and parallel laminae and silt lenses or silt pseudonodules may be classified as T_0 to T_7 divisions but the fine-grained sequence is incomplete and grading not visible.

The size-grading and development of structures in the higher turbiditic divisions may have been superimposed by admixture of the fine-grained turbidite material with autochthonous nanoplankton-foraminifera ooze with a large component of sand-sized particles during settling, as described by different authors (e.g. Stow *et al.*, 1984; Stow, 1994). Additionally, resuspension and later settling as pelagic sediments of the finest top layers of the turbidites may have obscured the uppermost structures and even inhibited the development of a Bouma E-division (Eberli, 1991). Also bottom currents commonly erode turbidite deposits and obscure the characteristic sequence (Stanley, 1993). Diagenesis may also have altered the grain size distribution in the turbidites. Small specimens of planktonic foraminifera with thin test walls may have been selectively dissolved during pressure dissolution (Chapter 4.2.) which may have obscured any originally existing gradation in the (mud supported) chalks.

A compositional grading is commonly observed in the turbidites. Typically, lithoclasts, large intraclasts, and benthic foraminifera with thick calcareous tests are enriched in the lowest layer of a high energy bed (A- to C-divisions). Radiolarians which are generally smaller in size and with an openly constructed thin shell of a lower density (Decker, 1991; Vecsei *et al.*, 1989) are generally rare in massive and packed basal A-divisions but common in the higher deposits of a lower flow regime. Since planktonic foraminifera are dominant in the packed layers the cherty turbiditic facies of the Lefkara Formation cannot be identified as clear radiolarian turbidites (Decker, 1991). Nevertheless, a high percentage of radiolarians is present in the reworked sediments but not in the pelagic strata. Although dissolution at the sediment surface can partly explain the absence of radiolarians in the pelagites the contrast in the composition in the redeposited sediments points to additional original differences in the radiolarian content.

The turbidites may have been either enriched in radiolarians due to an increase in productivity induced by upwelling in the source area (Vecsei *et al.*, 1989; see section 4.3.2.6.) or by a general reworking of radiolarian richer sediments during travel. In the second case older material may have been reworked that was deposited under the influence of carbonate dissolution at times when the CCD was shallower or the source area was positioned deeper. Maastrichtian, Palaeocene, and Early Eocene sediments in the north eastern part of the Kyrenia Range contain radiolarites and carbonate-poor deposits (Robertson & Woodcock, 1986) which may have been reworked and redeposited in the turbidites of the Lefkara Formation. The reworking of these oldest silica-rich strata could explain the chert-richer base of the turbidite succession while the higher deposits contain material of reworked calcareous ooze rather than extremely radiolarian-rich strata and consequently no chert developed. In fact, the change in the silica content in the vertical succession of the turbidites must be a function of (1) the combined effect of the decrease in density of turbidity currents, which would be reflected in a lower amount of transported silica, and a lower rate of deposition, (2) the uplift of the area and a consequent shallower depositional depth and a lower *in situ* dissolution with time, and (3) a changing composition in the source sediments either due to productivity or the sediments reworked.

4.3.2.4. THE TURBIDITES OF THE LEFKARA FORMATION IN THE CONTEXT OF EXISTING FACIES MODELS

The distinct decrease in turbidite structures in the Kalavasos and Lefkara sections with time and the local contemporaneous differences in facies if compared with the Kouka and Ayios Nicolaos sections indicate both, a vertical and lateral shift in the depositional environment. In this section the turbidites of the Lefkara Formation will be compared with existing facies models to understand these facies variations.

The comparison of the turbiditic facies of the sediments studied with the classical criteria for proximality of a turbiditic deposit to its source (Walker, 1967; Flügel, 1982) reveals a distal setting for the whole Lefkara Formation.

The turbidite facies of the Lefkara Formation therefore either indicates deposition in a 'distal' environment of a siliciclastic turbidite, such as the tail, overspills at levees, or interchannels (Piper, 1978) or as a slope apron deposit which is more characteristic for calcareous turbidites (Mullins & Cook, 1986). As discussed in Chapter 5, the turbidites of the Lefkara Formation are the distal part of turbidite deposits of the Kyrenia Range. The more proximal deposits to the north are characterised by breccia at the base, are dominated by intrabasinal calciclastic and siliciclastic turbidites, with an increase in turbidite input with increasing amounts of exotic material from Late Palaeocene to early Middle Eocene (Robertson & Woodcock, 1986). Although the geometry of the turbiditic facies associations is not fully mapped, deposition as a submarine fan does not seem to be indicated and no deposits are found in the Lefkara Formation pointing to a channelised flow. Nevertheless, lower fan deposits are also free of channels so that a distal setting in a deep sea fan (e.g. in a distal outer fan lobe; Nelson & Nilsen, 1984) cannot be excluded. However, no channel deposits are reported from the Kyrenia range either and there the deposits are also calciclastic (Ayios Nicolaos Formation). Therefore, the setting seems to be best explained as a slope apron (Einsele, 1991), with the Lefkara Formation being part of the outer facies belt (Mullins & Cook, 1986). A slightly sloping environment is indicated by few synsedimentary displacements seen in the deposits studied (convolute bedding, microfaults; Whitham, 1993).

The facies associations in the three examples of calciturbidites (Kalavasos, Lefkara, Stavrovouni) are comparable with the basin plain association described by Mullins & Cook (1986) for slope aprons. Characteristics are a calcarenitic to calcilutitic lithology, with base-cut Bouma sequences cooccurring with fine-grained pelagic and hemipelagic sediments, and episodes of calcarenites with classical Bouma sequences. Although a prograding turbidite system is described for the Kyrenia Range this can only be observed in the onset and lowest part of the turbidite succession of the Lefkara Formation (reflected in the gradual increase in chert beds). After a maximal turbidite development near the top of the Lower Marl unit a fining and thinning upward succession is present. This must be explained by a reduction in sediment supply, partly due to the gradual development of a counter slope related to the uplift of the Troodos Terrane (see Chapter 5). The depositional environment therefore resembles the setting in an asymmetric basin as described in the model developed by Eberli (1987), although only the distal parts are studied in this work. In this model, a thin-bedded turbidite association with dominating Bouma B- and C-divisions (equivalent to the coarsest turbidites of the Lefkara Formation) grade vertically into a basin plain association with thin, fine-grained, incomplete Bouma sequences and an increase in pelagic deposition (equivalent to the chert-free, faintly structured higher part of the Cypriot turbidites).

The turbidites from the western sections of the Lefkara Formation, Kouka and Ayios Nicolaos, show rare cross and parallel lamination but otherwise hardly any sedimentary structures in the contemporaneous strata of the higher density deposits of the eastern sections. These are characteristic for a more 'distal' basin plain facies (according to Eberli's model not necessarily at a much greater distance from the source) with few C- and D-divisions present but generally being composed of fine-grained sediments from higher apparently unstructured turbidite layers and interturbidites.

The Motorway section shows turbidites intermediate between the western lower energy and the eastern higher energy settings, and intensive bioturbation indicates lower turbidite frequencies and longer periods of pelagic deposition. Although positioned close to the Kalavasos and Lefkara sections, the Motorway section must have been slightly isolated from the main current deposition and possibly positioned at the margin of the slope apron or topographically elevated. The earlier start of the Chalk & Chert unit (Fig.21) in this section may indicate an earlier onset of turbidites and, combined with that, an earlier end of slight carbonate dissolution which is responsible for the Lower Marl facies.

When comparing the bed thicknesses of the strata from the western sections with the more proximal ones in the east, no differences are found in the Lower Marl unit (Fig.46). In the outcrops of the Chalk & Chert unit a slight increasing tendency from west (9-12cm) to east (14-17cm) is observed. In the turbiditic strata of the Chalk unit the pattern is not consistent and the end of turbiditic deposits cannot be determined with certainty in several sections. Nevertheless, in the Kouka section chalks overlying the Chalk & Chert unit are thinner (10-13cm) than in the eastern sections (10-29cm).

Since the bed thicknesses compared are mean values and include the thickness of interturbidites as well the comparison of any lateral shift of the turbidite deposits will not lead to very accurate results. Nevertheless they vaguely indicate a lateral increase in bed thickness from west to east which might reflect the higher sedimentation rates and thicker deposits of the turbidites in the east.

Also the sedimentation rates calculated from unit thicknesses taken from the literature, show an increase for the combined Chalk & Chert and Chalk units from west to east (Chapter 2.3.4.). For the areas south of the Troodos Complex (analogue to the western sections) 10m/Ma are calculated and 29m/Ma for the east (around Lefkara and Kalavasos), reflecting higher turbidite sedimentation in the east. Together with this, an increased terrigenous influence may be reflected in a higher chlorite content in the sediments in the eastern section (Kalavasos section) than in the west (Kouka section). Chlorite abundances fluctuate in the Motorway section which may indicate less stable turbidite deposition.

Eustatic sea-level variation and turbidites:

The termination of the turbidites of the Lefkara Formation can be related to the tectonic evolution of the Kyrenia Range as the source area for the redeposited material (Chapter 5.1). Although eustatic sea-level variations may have also had influence on the turbidite intensity, no dominant dependency is reflected in the Lefkara Formation. The sea-level was relatively high during the entire time of turbidite deposition (Haq *et al.*, 1987). This provided the base for high stand shedding of calciclastic turbidites due to increased carbonate production on a northern carbonate platform (Eberli, 1991; Stow *et al.*, 1984). The early termination of the turbidites in the Lefkara Formation with the end of Middle Eocene indicates a tectonic control and no global sea-level control since a major fall only occurred in Late Oligocene (Haq *et al.*, 1987). A smaller sea-level drop at the end of the Middle Eocene may, on the other hand, have added to the termination of turbidite supply. Further sea-level changes reflected in the global eustatic record, e.g. the fall in late Lower Eocene time, did not seem to have any influence on the turbidite deposition.

4.3.2.5. BIOTURBATION

Bioturbation is found in varying intensity in different strata and times. Ichnotaxa identified in the micro- and macrofacies are *Chondrites* and *Zoophycos* which are in some cases considered characteristic of a deep marine environment (Ekdale & Bromley, 1984). *Thalassinoides* tubes (Fig.50 (C)) are also rarely observed and occur in slightly increased amounts at the top of the Chalk unit and in the Upper Marl, possibly indicating a slight shallowing in the depositional environment.

Although expected, burrows are not always observed in the turbidite-free pelagic chalks, either because they are destroyed by thorough bioturbation or due to the homogeneous nature of the sediment. The chalks overlying the turbiditic strata are commonly bioturbated (F-division). In several strata burrows are found which partly extend into the laminated calcarenitic B- and C-divisions (e.g. Fig.85). However, they show an increase in intensity towards the top of the interturbiditic chalks (Seilacher, 1962; Robertson, 1976; Stow, 1884). Since burrows can reach depths up to 50cm and more into the substrate (Ausich & Bottjer, 1982) comparatively thin turbidite beds may therefore be completely disturbed if there was time enough for the development of a benthic fauna. In low frequency turbiditic deposits bioturbation therefore is not necessarily restricted to F-divisions.

4.3.2.6. CHERT FACIES

In the Lefkara, Kalavasos, and Stavrovouni sections a turbiditic origin for the cherts in the Chalk & Chert unit and parts of the Lower Marl unit is identified on the basis of macro- and microstructures as discussed above. Other chert occurrences in the formation are less easy to interpret and productivity cycles cannot be ruled out in the first place. For the structureless cherts in the Chalk & Chert unit of the western section a turbiditic origin is indicated by the equal age with the siliceous turbidites in the east, the evidence from the microfacies (Chapter 4.3.2.1. B), as well as rare structured strata.

Also the generally structureless cherts in the lower part of the Lower Marl unit are most likely formed by turbidites. This is supported by the observation of rare laminated chert strata and few but well developed A/D turbidite sequences in flint-like cherts in the Lefkara section. The scarcity of sedimentary structures in most of the cherts here is due to a diagenetic overprint of highly concentrated silica, which partly forms as large, vitreous chert nodules. Thin sections of vitreous cherts show the complete disappearance of the shapes of foraminifera and radiolarians in the quartz matrix. This process would have also destroyed any sedimentary structures caused by variations in bioclast density and other changes in composition (Baltuck, 1983). The strata of the Lower Marl unit containing less silica are silicified marl beds with few pure chert accumulations and with common turbiditic structures. Therefore, the high amount of silica in the Lower Marl unit must be responsible for the apparent absence of turbiditic structures. Since high amounts of silica in the sediments are related to a high sedimentation rate this even implies a higher turbidite influence in the lower strata of the Lower Marl where no structures are found.

The absence of lamination also in the marl strata between these structureless pure cherts of the Lower Marl unit may indicate a large proportion of interturbiditic sediments with long periods of pelagic deposition. This is consistent with the fact that the marls or chalky strata and even the cherts are commonly mottled. The occurrence of thick marl strata intercalated with thin chert layers in the Lower Marl unit (Fig.46) also indicates a lower turbidite frequency while the carbonate-rich and silicified beds in the Chalk & Chert unit are of approximately equal thickness.

The presence of chert due to a significantly higher *in situ* productivity (Ramsay, 1971), compared to chert-free intervals, seems unlikely. The quantitative analysis of the sand fraction of samples from the chert-free Chalk unit reveals high abundances of well preserved nassellarians and spumellarians in all sections. Thus, the productivity does not seem to have been reduced significantly in times of the absence of chert but chert did not form due to other factors.

Nevertheless, the chert-bearing deposits of the Lefkara Formation seem to be related to the broad equatorial belt of siliceous deposits from the Eocene. By analogy with recent time, this reflects the palaeo-equatorial divergence zone (Pisciotto, 1981) which was found to have been established already in the Lower Tertiary (Riedel & Funnell, 1964). Many of these early Middle Eocene cherts (seismic reflector A) are also found to be turbiditic in origin (e.g. Berggren, 1971; Kelts & Arthur, 1981; Pisciotto, 1981; Isaacs, 1983). Palaeomagnetic data show a position of Cyprus at approximately 19°N palaeo-latitude, with a significant northward movement only starting in Oligocene time (Abrahamsen & Schönharting, 1987). If compared to the recent position of the equatorial upwelling zone between 20°S and 20°N (Leggett, 1985), this implies a high surface productivity for the Cyprus area at that time, with a high rate of *in situ* deposition of calcareous and siliceous microfossils as well as in the source area of the turbidites. In the Atlantic and Indian Oceans, Eocene radiolarian turbidites were even found as far as 35°N (Kelts & Arthur, 1981). Transport and erosion took place in the north, most likely mainly from the area of the Kyrenia terrane. The end of the chert preservation in the turbiditic succession cannot be explained by the migration of the Cyprus area out of the high productivity belt since the cherts terminated at the end of Middle Eocene, prior to the northward shift. Possible reasons for the decrease in the silica content in the succession are discussed in detail in Chapter 4.3.2.3..

Coastal upwelling in the source area of the turbidites causing high productivity and a subsequent bloom of radiolarians is less likely to have been a significant factor. The general surface currents flowed from east to west in the Palaeogene (Leggett, 1985) and therefore would not have led to any upwelling due to Ekman transport on a northern coast (e.g. Bearman, 1989; Smith, 1983), unless the current pattern was more complex.

4.3.2.7. PELAGIC CHALKS

Unstructured chalks and marls grouped in microfacies I1 are considered to have been deposited under quiet pelagic conditions. They dominate or even exclusively form the lower part of the Lower Marl and the upper part of the Chalk unit whereas they are intercalated with turbidites in the other parts of the succession. Only the Upper Marl seems to be dominated by bottom currents (Chapter 5). For the most part, pelagic deposits are developed as thick bedded to massive chalks as in the Ayios Nicolaos and Stavrovouni sections above the Chalk & Chert unit. Massive chalks are also observed in the Kalavasos section above the fine-grained uppermost turbidites and reflect the background deposition higher up in the stratigraphic column.

Bioturbation in chalks is mainly observed in pelagic strata overlying turbidites since here faint changes in material enhance the visibility. In homogenous chalks mottling is rarely observed in the macrofacies.

As mentioned above, the typical pelagic micofacies I1 may be mixed with the fine-grained sediments of turbidites by bioturbation and thus, although pelagic, appear to be I2. Also bottom currents influencing pelagic chalks may have redistributed siliceous radiolarians which would have resulted in microfacies I2. This is possibly the case in the Chalk unit of the Motorway section if no unrecognised fine-grained turbidites are present. The presence of few allochthonous clasts (sediment clasts and macrofossil fragments) in all pelagic deposits may indicate a slight continuous redeposition by bottom currents.

Most chalk successions, even the massive strata, show faint material changes or thin marl layers between beds. If they are not recognised as contourites as near the top of the Chalk unit, these may reflect cyclic variations in the depositional environment, possibly even Milankovitch cycles (Einsele & Ricken, 1991). No systematic study of this has been carried out but productivity cycles appear likely. The marl strata in the Chalk & Chert unit are rather a product of diagenesis since pressure dissolution is enhanced at the contact with the hard cherts.

A high productivity at least in the chalks of the Middle and Upper Eocene is reflected in high abundances of radiolarians (and some phosphate debris) in the Chalk unit which possibly developed under equatorial upwelling (see section 4.3.2.6.). Sedimentation rates between 5m/Ma and 17m/Ma are calculated for the whole unit. Considering that this even partly includes turbidite deposits, the values are lower than modern sedimentation rates in upwelling areas of 100-600m/Ma (Witham, 1993), even if a compaction of 50-75% is assumed. Nevertheless, rates are higher than during purely pelagic sedimentation which lie between 1 and 7.5m/Ma (Piper & Stow, 1991). Sedimentation rates of the Chalk unit therefore reflect an increased productivity, possibly at the margin of the equatorial upwelling zone.

4.3.2.8. MOTORWAY SECTION: TURBIDITES AND CONTOURITES

With regard to the turbiditic facies the Motorway section stands somewhat between the western distal and eastern more proximal (or, better, less distal) sections and exhibits some exceptional characteristics. The slow increase in chert occurrences in the Lower Marl unit and the vitreous highly concentrated cherts near the Lower Marl - Chalk & Chert transition, indicating maximal turbidite deposition, are comparable to the eastern sections. However, sedimentary structures are rare in most of the Chalk & Chert unit and only one thin section (with an exceptional microfacies) from the lower Chalk & Chert unit shows the presence of transported material. In the highest outcrop of the Chalk & Chert and lower part of the Chalk units clear sedimentary structures such as slight grading, parallel and cross lamination, and silicified strata are present and interpreted as fine-grained base-cut turbidites. Although turbidite structures are rather scarce in the Motorway section they are much clearer than in the western sections Ayios Nicolaos and Kouka.

Most of the Chalk unit in the Motorway section is composed of massive chalks containing only few faint sedimentary structures. These structures are characterised by rare but distinct burrowed horizons, several 1/2mm thick laminae, and finer hardly visible laminae in between (Fig.38 (D)). Ripple structures are absent and the microfacies is of type I2. The distinct bioturbated layers, individual rather isolated laminae, the lack of repetitive structural sequences, and the weakly developed bedding are not characteristic of the fine-grained turbidites observed in the other sections. These features are perhaps better interpreted as due to the influence of bottom currents on fine-grained sediments. Their characteristics are equivalent to those of muddy contourites (Stow & Lovell, 1979; Faugeres & Stow, 1993). Nevertheless, the gradual fading of turbidite structures above the Chalk & Chert deposits and the onset of indications for bottom currents seems to indicate an interplay between these two processes at least near the transition, with the uppermost turbidites most likely being reworked by bottom currents (Stanley, 1993). The time spans of intense burrowing reflect periods of sediment starvation due to erosion of the contourites (Piper, 1978).

The facies found in the highest sediments of the Motorway section is considered to be the equivalent to the Upper Marl unit (which is not found in the locality) although it shows an entirely different facies (Fig.86). Here the bedded chalks at the top of the Chalk unit are calcarenitic due to a higher amount of sand-sized planktonic foraminifera. Higher up, thick marl strata are intercalated and many of the chalk beds are entirely parallel-laminated, cross-laminated and strongly burrowed. No grading or repetitive structural sequences are observed. These strata show many characteristics of sandy contourites (Stow & Lovell, 1979; Faugeres & Stow, 1993) reflecting a higher current velocity compared to the structures found in the underlying chalks. The observed coarser lithology of several strata between the marls and a foraminifera-increased microfacies (Tab.8) without lamination but increased fragmentation of the bioclasts indicate the episodic removal of finer material by winnowing currents and variations in the strength of the current (Duan *et al.*, 1993). The dominant facies resembles the calcilutite contourite facies described by Duan *et al.* (1993) concerning structures and micritic matrix which points to a moderate strength of the current even in the best developed contourites of the Motorway section.

Intensive bioturbation is observed in most strata of all lithological units in the Motorway section. This indicates long times of pelagic intervals also during times of turbidite sedimentation. In contrast, the western even more distal turbidites do not show the same intense bioturbation. This may indicate a shallower depth of deposition for the Motorway section. The better developed contourites in the Motorway section indicate a different current pattern than in the other sections. The consistent covariation of all reworked components found in the thin sections (Fig.65) and the increased percentages of benthic foraminifera in the sand fraction (Fig.66) indicate either a shallower depth of deposition or an enrichment in allochthonous shallow water bioclasts by a possibly more regular and stronger mechanism of reworking than observed elsewhere.

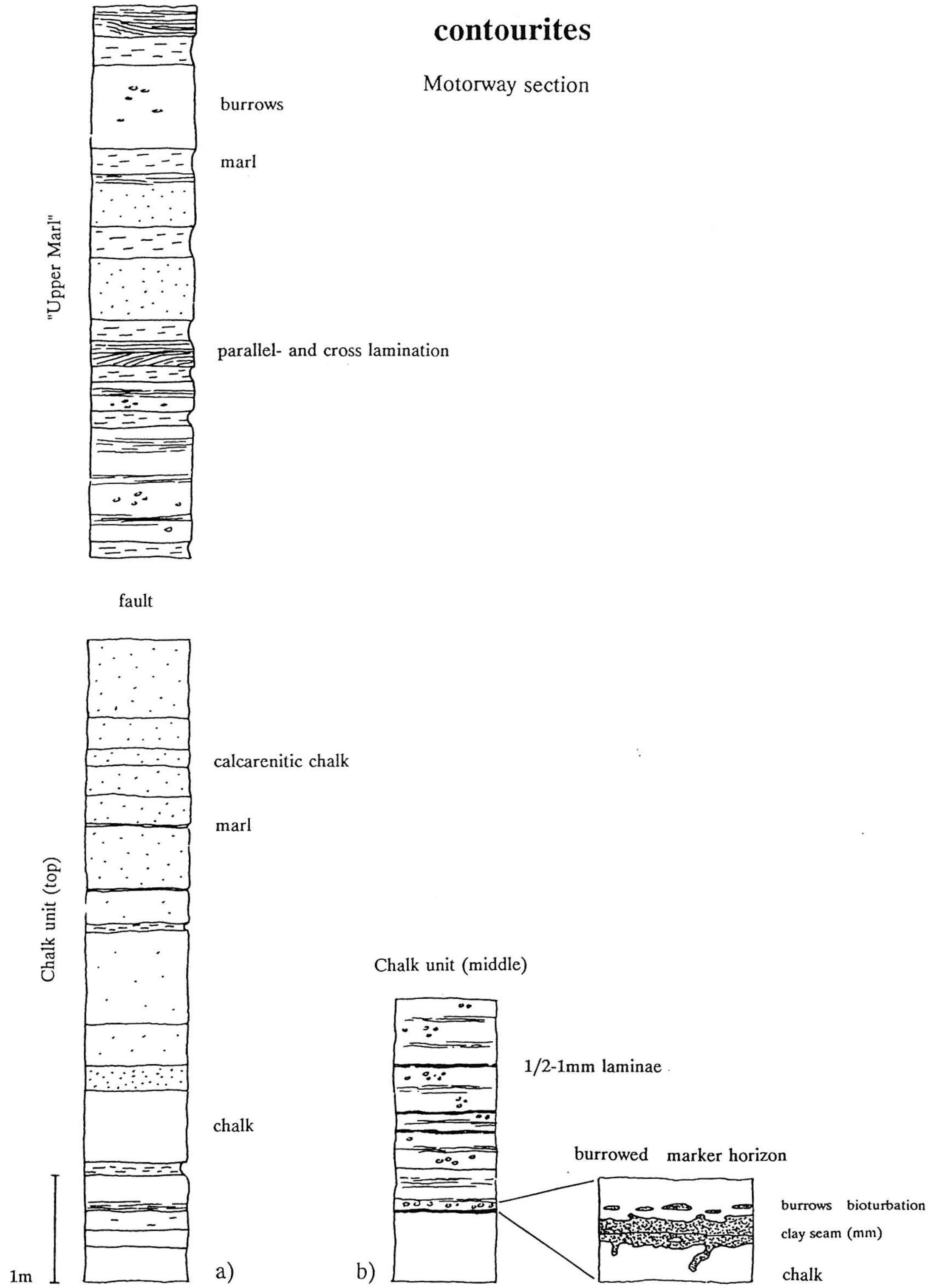


Fig.86. Logs of contourite sequences of the Motorway section. **(a)** outcrop containing the Chalk /Upper Marl unit transition; **(b)** reference log of the central Chalk unit.

CHAPTER 5

TECTONIC AND SUPRA-REGIONAL CONTROL ON THE DEPOSITION OF THE LEFKARA FORMATION

5.1. DEPOSITION IN THE FRAMEWORK OF THE TECTONIC HISTORY OF CYPRUS

Tectonic or tectonic-related processes influencing the Troodos terrane during or close to the deposition of the Lefkara Formation are (1) the deposition of the volcaniclastic Kannaviou Formation; (2) the rotation of the Troodos microplate; (3) the underthrusting of continental crust from the south under Cyprus; and (4) the parallel tectonic evolution of the Kyrenia Range. In this section, the consequences of the new dating of the Lefkara Formation and the dependency of the sedimentation on these tectonic influences will be discussed.

Kannaviou volcanism:

The volcanogenic Kannaviou Formation underlying the Lefkara Formation was deposited between the Campanian and Maastrichtian (Robertson & Hudson, 1974). Acid volcanism seems to have extended somewhat longer, although only one case of fresh quartz shards in an interturbiditic sample is reported from in the Chalk & Chert unit which was then dated as Palaeocene (Robertson, 1976). Also Bagnall (1960) described tuffs and lapilli interbedded into the sediments of the Chalk & Chert unit but in this earlier paper the basal turbiditic beds were thought to be of volcanic origin. Applying the datings of the Lefkara Formation obtained from this study to the end of the Kannaviou volcanism during the deposition of the chert-bearing chalks indicates that the volcanism may have still persisted into early Middle Eocene time. Nevertheless, no volcanic deposits were detected in the scope of the present work at all and volcanic eruptions must have been rather scarce after Maastrichtian time.

Palaeorotation of the Troodos plate:

Although the timing of the rotation of the Troodos plate is not consistent in the literature, by Maastrichtian time, the onset of the Lefkara Formation, the microcontinent was rotated 60° anti-clockwise, according to Robertson (1990; Fig.87). This means that the remaining 20-30° rotation took place during deposition of the lower part of the Lefkara Formation. The palaeomagnetic data show that the rotation was completed before the start of the massive chalks of the Lefkara Formation which Robertson dated as Early Eocene (pre 55Ma). Although no clear lithologies of the strata analysed for the palaeomagnetism are given, this most likely means that the whole turbiditic succession including the chert-free upper part was deposited during the last phase of rotation. If that was the case the new datings would imply that the palaeo-rotation took place up to the end of Middle Eocene (43Ma), which is approximately the top age of the turbidites. This implies termination of rotation more than 10Ma later than previously thought, with a consequently longer duration of rotation.

Comparing other publications, discrepancies in previous datings lead to different timings of the rotation. These range from the completion of the initial 60° rotation in Maastrichtian time (Robertson, 1990), before the end of Palaeocene (Clube *et al.*, 1985) and some time during Middle Eocene (50Ma, Abrahamsen & Schönharting, 1987). The final 20-30° rotation is dated by the same authors to the top of Palaeocene, during Early Eocene, and during the last 50Ma. Since the lithologies of the strata analysed are not provided in the publications (except Robertson, 1990, as discussed) it is not possible to comment on these differences.

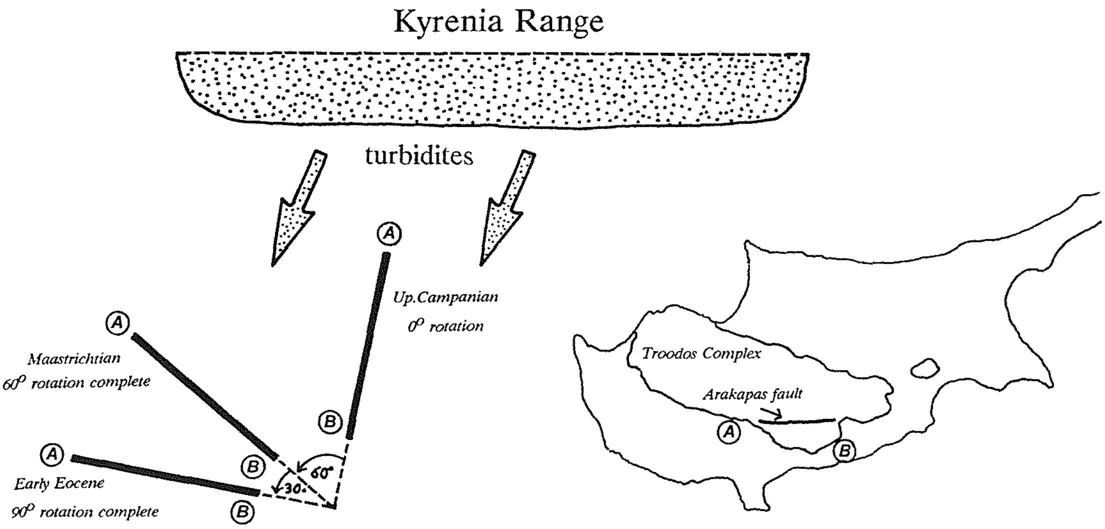


Fig.87. Relative position of the section localities during phases of microplate rotation in relation to the direction of turbidite shedding; Arakapas fault is used as a reference. 'A' = Kouka section ('western sections'); 'B' = Kalavasos section ('eastern sections').

The rotation of the Troodos plate does not appear to have had a major influence on the sedimentation of the Lefkara Formation. In Figure 87 the positions for the sections relative to the turbidite source area in the different times are shown (development adopted from Robertson, 1990). In Maastrichtian time the two localities Ayios Nicolaos and Kalavasos must have lain almost next to each other in respect to the transport direction. The change in angle rotated the western sections into a farther distance. This would mean that at least the earliest turbidites should have a similar facies in the western and eastern sections if the rotation of the relative position had any significance, which is not the case. The change in position was therefore of less importance than other topographic and tectonic factors which will be discussed below.

Northward subduction of continental crust under Cyprus:

Subduction to the south of recent Cyprus leads to underthrusting of continental crust under the island (Poole & Robertson, 1991). The onset is dated to the beginning of the Early Miocene (22Ma, with a slightly different time scale used; Robertson 1990). This dating is based on the sedimentological evidence of the start of the Pakhna Formation (Robertson *et al.*, 1991), with the uplift of Cyprus resulting in tectonically controlled basins in which the Pakhna sediments are deposited. As an additional mechanism, the uplift of the Troodos area was partly caused by serpentine diapirism which was active throughout the lower Tertiary (Robertson, 1977).

According to the new datings of the Lefkara Formation, the Upper Marl unit extends into the Early Miocene and terminates within the Burdigalian. The consequently later start of the Pakhna Formation would postdate the onset of the underthrusting. On the other hand, the strong local variations of the start of the Upper Marl unit between Early Oligocene and Burdigalian, as revealed in this study, may suggest an earlier tectonically controlled deposition of the top-sediments of the Lefkara Formation, similar to the Pakhna Formation, with some areas still being under quiet pelagic conditions while others are earlier uplifted and have a marly facies. If the deposition of the Upper Marl sediments can be proved to be tectonically controlled, the start of the subduction can be dated to the beginning of the Oligocene.

Evidence for this is found in the hiatuses or time gaps observed between Oligocene and Early Miocene or possibly even earlier within the Late Eocene. These may be related to times of increased uplift or the start of uplift and consequent enhanced erosion. Consistent with the hiatuses found, Robertson (1977) observed numerous washouts and local unconformities in the Upper Marl in the sediments in the south and east of the island. Similar to the hiatuses, an extremely low sedimentation rate is calculated for in the Upper Marl at least in the Kalavasos section, indicating erosion. Comparing the three eastern sections Kalavasos, Stavrovouni, and the Motorway sections, a time transgressive start of the Upper Marl unit can be observed (Fig.21). If the facies is really related to the uplift this indicates that the underthrusting was earliest in the southernmost section (Kalavasos) and latest in the northernmost (Motorway). Since the onset of the collision is dated by lithologic evidence (Robertson, *et al.*, 1991) it is proposed that it coincides with the start of the Upper Marl deposition in Oligocene time.

Further tectonic events recorded in the sediments:

A further tectonic movement of a partial uplift of the Mamonia terrane in the south and southwest of Cyprus is reconstructed by Robertson (1990) for the Maastrichtian to Early Eocene time (Middle Eocene according to the new stratigraphy). Although the Mamonia complex lies west of the westernmost areas logged for the present study, an extended influence of this uplift may explain the more 'distal' turbidite facies of the Ayios Nicolaos and Kouka sections. The deposition of the fining upward turbidite sequence can be otherwise explained by the tectonic development of the Kyrenia Range (see following section). As seen above, the palaeogeographic position related to rotation of the Troodos terrane does not explain the lower input of turbidites in the western areas (Fig.87).

A possible additional influence on the turbidite facies may have been the uplift of the northern part of the Troodos terrane between Maastrichtian and Middle Eocene (Robertson & Woodcock, 1986; Robertson, 1977). The increasing uplift may have enhanced the decrease in turbidite intensity towards the end of the sequence by cutting off the source of transport from a northern slope. Together with the uplift in the Mamonia areas, this explains the more distal facies of the turbidites in the western sections since the barrier formed more extensively in the northwest and less in the northeast. This uplift of the northern margin of the Troodos terrane thus may have led to the formation of a narrow (asymmetric) basin as suggested in Chapter 4.3.2.4.).

The turbidites of the Lefkara Formation and the tectonic evolution of the Kyrenia Range:

The depositional environment of the Lefkara Formation was largely controlled by the tectonic evolution of the area. Based on bioclasts found and current directions, Robertson & Woodcock (1986; Baroz, 1980; Robertson, 1976) assumed the source area for the turbidites to be the Kyrenia Range in the north. The turbiditic input, therefore, must be closely related to the tectonic history of the Kyrenia terrane. Comparing the sedimentary successions (all following data are based on Robertson & Woodcock, 1986), both terranes, Troodos and Kyrenia, show parallel development from Maastrichtian to Middle Eocene time, being composed of pelagic carbonates. The corresponding formations to the Lefkara Formation of the Troodos terrane are the Lapithos Group (Maastrichtian to Eocene) and parts of the overlying Kythrea Group (Oligocene to Miocene) in the Kyrenia Range.

From Maastrichtian to early Middle Eocene (Fig.88) the area of the Kyrenia Range, juxtaposed to the Troodos terrane, underwent subsidence. The deposits of the purely Maastrichtian Melounda Formation are thin-bedded pinkish chalks (planktonic foraminifera-radiolarian micrites), similar to the lowest deposits of the Lower Marl unit of the Lefkara Formation, but they were already influenced by turbidites and contain terrigenous debris, chert layers, and clasts. The shallow water debris indicates a closer position of the Kyrenia terrane to the northern source area of the turbidites whereas the Maastrichtian counterpart in the Troodos terrane lay topographically deeper, close to the CCD, and is turbidite-free. The gradual subsidence of the Kyrenia terrane is locally reflected in Palaeocene cherty and carbonate-poor deposits from close to the CCD.

The Ayios Nicolaos Formation of the Lapithos Group is dominated by turbidites from Late Palaeocene to early Middle Eocene with an increasing tendency from Palaeocene to Early Eocene. This shows a strong parallel development to the turbidites of the Lefkara Formation which show lower sedimentation rates in the Lower Marl unit (Late Palaeocene to Early Eocene) than in the Chalk & Chert unit (late Early Eocene to early Middle Eocene) and a gradual increase in intensity in the early turbidites. The subsidence of the Kyrenia range together with an obduction event in the north (Alanya ophiolite) must have been responsible for the increase in turbiditic input. The turbiditic material of the Ayios Nicolaos Formation is thought to have been shed mainly from within the area of the Kyrenia Range and is partly composed of exotic clasts possibly from the northwest. The allochthonous fraction is composed of dolomite, chert, lava clasts, radiolarians, larger foraminifera, algae, and pelecypods amongst others, indicating a similar composition but a more shallow water influence than for the Lefkara turbidites and therefore a shorter distance to the source area.

Starting later in early Middle Eocene and during the whole Late Eocene the Kyrenia Range was strongly faulted due to the overthrusting over the Troodos terrane (Kalograia-Ardana Formation). The gradual uplift of the area led to coarsening upwards turbidites at the base of the syntectonic sedimentary succession, with the material being derived from the north. Later, debris flows, conglomerates, and breccias were deposited and finally parts of the area emerged.

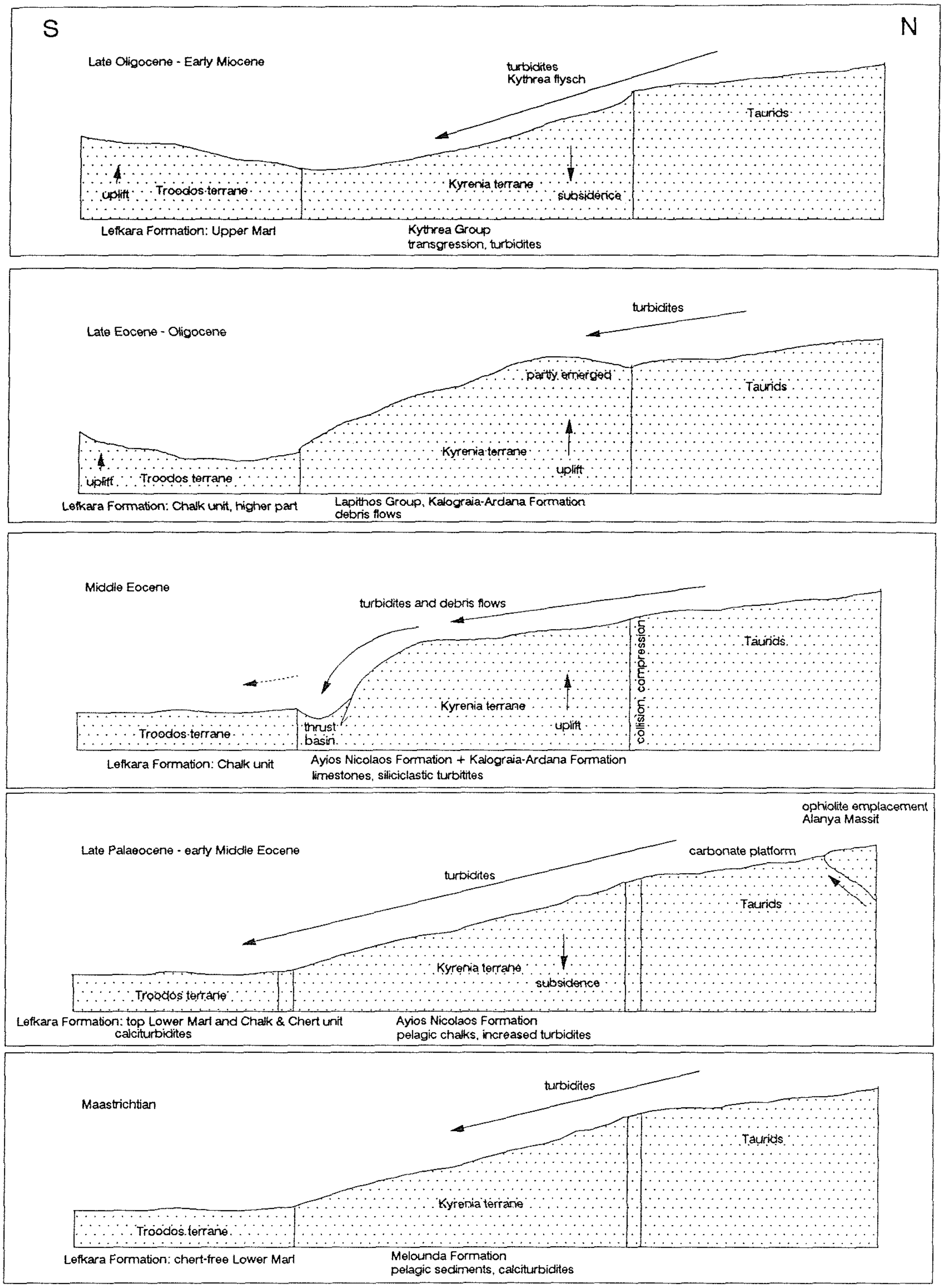


Fig.88. Palaeotopography, tectonic evolution and sedimentation in the Kyrenia and Troodos terranes between Maastrichtian and Early Miocene. Data for reconstruction mainly from Robertson & Woodcock, 1986.

Since Middle Eocene time turbidites and olistostromes were deposited into a basin developed in front of the thrust. In comparison, the Lefkara Formation shows a decrease in turbidite intensity during the Middle Eocene, with the more rapidly deposited cherty sediments extending only into the early Middle Eocene, and the whole turbiditic facies complete at the end of the Middle Eocene. Although the sedimentological development seems to be in opposition to the Lapithos turbidites, the fining and thinning upwards tendency can be explained by the cut-off of the Kyrenia Range turbidites. Most of the turbiditic material forming the allochthonous deposits of the Kyrenia Range has been trapped in a basin developed south of the thrust zone between the terranes and which finally terminated the Lefkara turbidites in the Middle Eocene.

After early Oligocene time the Kyrenia Range collapsed and submerged rapidly and a large fan system, shed from the northern Taurids, formed in the early Kythrea Formation. The Lefkara Formation does not seem to be directly influenced by these turbidites since the Troodos area started to uplift during this time. Nevertheless, an increased clay content in the Upper Marl facies may reflect these northern turbidites. The uplift of the Troodos terrane may have led to the development of contour currents eroding the elevating contours of southern Cyprus, as discussed above.

5.2. CONTOURITES AS INDICATORS FOR LOCAL AND GLOBAL ENVIRONMENTAL CHANGES

Evidence for contourites is found in the youngest part of the Lefkara Formation and described in different sections in this work. The information found so far are summarised in the following.

(1) Contourites are identified on the basis of sedimentary structures which are most obvious in the Motorway section (Chapter 4.3.2.8.). The chert strata and structures found in the Kouka and most likely Lefkara sections near the top of the Chalk unit are most likely formed by contour currents due to winnowing of radiolarians (Decker, 1991; Sarnthein & Faugeres, 1993). Also the regularly intercalated marl beds at the top of the Chalk unit in the Ayios Nicolaos section may be a winnowing product by bottom currents. Similarly, clay seams in the matrix of flaggy chalks, found only near the top of the Chalk unit, may reflect bottom currents at an early stage. Although clear identifications of contourites are only found from Oligocene time onward, faint lamination and burrowed horizons in Middle Eocene strata may be partly the result of contour currents at this time.

(2) The contourite facies can be related to hiatuses which are detected mainly in Oligocene but also in Late Eocene and Early Miocene successions (see Chapter 2.3.4.). Low sedimentation rates are found in the Motorway section starting with contourite deposits, and hiatuses are detected in the contouritic chert facies of the Kouka and Lefkara sections and the stratigraphic highest marl-chalk intercalations in the Ayios Nicolaos section.

(3) Contour current-formed hiatuses and contourites are possibly dependent on tectonic developments, such as the subduction from the south and the consequent uplift of the Troodos terrane (section 5.1.), with a gradual increase in structures visible in the Motorway section. The developing submarine high must have led to contourite accumulation (Faugeres *et al.*, 1993). The Tethyan seaway was still open in Oligocene and Early Miocene time (Dercourt *et al.*, 1986) which allowed an unrestricted westward surface current flow. Although the Levant was shallowing at that time, eastward and possibly also westward flowing undercurrents are assumed which may have formed the contourites.

(4) The Upper Marl facies as a whole is possibly formed under the influence of bottom currents and seems to reflect the uplift of the area (section 5.1.). Low sedimentation rates in the Upper Marl (Kalavasos section) are consistent with current erosion. A shallow water interpretation for the lithology is not supported by the microfacies and the bioclast assemblages. The relatively high clay content is rather the result of current winnowing and an enrichment of redeposited material from the Kythrea flysch.

(5) The mineralogy (Chapter 4.1.), analysed for the calcium carbonate, insoluble residue, and clay mineral content, also reveals a change in the Upper Marl samples. The clay mineral

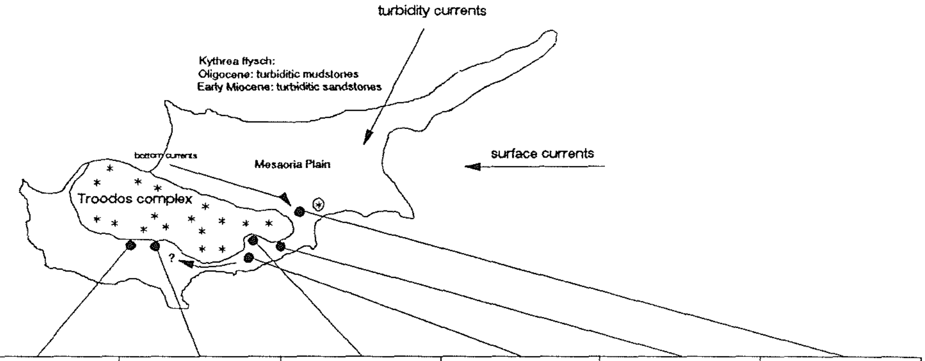
assemblage of the Kouka and Kalavasos sections shows a sudden increase in illite and chlorite/kaolinite respectively which indicates a possible change in transport mechanism which might be increased contour currents. The detected increase in quartz in the Upper Marl unit in the absence of radiolarians strongly indicates a new source of terrigenous input.

Some additions have to be made concerning the dating and sedimentological evidence combined with the contourites. Together with the increased occurrence of hiatuses, increased reworking of planktonic foraminifera and more significantly of radiolarians are found in the samples from Oligocene time onwards (Fig.89, Tab.3). This is most obvious in the Ayios Nicolaos section, slightly less in the Kouka section, and in the whole time span starting with the Middle Eocene in the Lefkara section. In these localities contour currents must have redeposited sediments, eroded from older strata, while in the Kalavasos, Motorway, and Stavrovouni sections, which are lacking in significant bioclast reworking, either exclusively contemporaneous material was redeposited or only erosion but no redeposition took place. Displacement and accumulation of radiolarians by contour currents has been described from different ages, e.g. in Eocene contourite deposits in the Atlantic (Sarnthein & Faugeres, 1993), or in the Jurassic Ruhpolding Formation (Vecsei *et al.*, 1989).

Another difference between these two groups of sections lies in the diachrony of the start of the Upper Marl unit (Fig.89). The topmost Chalk unit is enriched in reworked planktonic bioclasts whereas the contemporaneous Upper Marls (and all sediments of the whole unit) are barren in these. This time-transgressive change in facies seems to reflect palaeocurrent patterns. Mud turbidites in the Mesaoria Plain started to be deposited in the Oligocene (Kythrea flysch, Robertson & Woodcock, 1986). The bottom currents, traced by hiatuses of the same age, must have either eroded fine-grained turbidite material or transported turbiditic nepheolid layers southward (Faugeres & Stow, 1993). This led to the formation of the Upper Marl facies in the eastern sections Kalavasos and Stavrovouni where the currents might have been strongest. At the same time a bottom current influence and erosion was prominent in the Motorway section as reflected in the sedimentary structures and also present in the Ayios Nicolaos, Kouka and Lefkara sections, but in the latter ones no marls were deposited. The redeposition of older bioclasts but no clays in the latter three localities may be explained by the strong adhesive character of clay aggregates and coccolith mud and a relatively easier transport of the larger but non-adhesive calcareous and siliceous components (Decker, 1991; Kelts & Arthur, 1981).

In Early Miocene time, turbidite activity had increased in the Mesaoria plain and turbiditic sandstones were deposited. Consequently, also in distal areas the amount of clay-rich fine-grained turbiditic material must have increased and was distributed farther by the bottom currents. This

CONTOURITES



section	Ayios Nicolaos	Kouka	Lefkara	Kalavasos	Stavrovouni	Motorway
macrofacies of contourite deposits	chalk, marl	chalk, marl, chert	chalk, marl (chert?)	transitional zone: chalk --> marl	increase of marl content in chalks	structured chalks, marls
basal age of contourites	boundary N6/7	P17 - N4/6	boundary N6/7	P18/19	P18/19	P18/19
Oligocene facies	Chalk unit	Chalk unit	Chalk unit	Upper Marl	Upper Marl	'Upper Marl'
reworked radiolarians in contourites	yes	yes	yes	no	no	no
earlier structures observed	no	no	yes	no	no?	yes
				→ diachronous start of Upper Marl unit		

Fig.89. Some of the characteristics of contourites compared for all sections.

led to the deposition of the marl facies of the Upper Marl unit also in the areas of the Lefkara Formation where bottom currents were less strong, at the southern margin of the Troodos Complex (Ayios Nicolaos and Kouka sections). Additionally, bottom current velocity and subsequent transport potential might have been enhanced by the progressive uplift of the Troodos terrane.

The high erosional power of the contour currents during the time of Upper Marl deposition is reflected in the complete absence of radiolarians in this facies. Their removal by winnowing currents or a change in bottom water chemistry due to bottom currents seems to be a more plausible explanation than a restricted oceanic environment or a higher salinity (see Chapter 4.3.1.3.; Robertson, 1977). Similarly, the increase in benthic foraminifera, seen in the composition of the sand fraction (Fig.66), can be rather explained as a winnowed residue than a shallowing of the sea (compare Chapter 4.3.1.1.). The higher amounts of transported allochems seen in the thin sections of the Upper Marl in the Kalavasos and Motorway sections but not in the western sections, again, indicates a higher current activity in the east.

Although the Lefkara, Kalavasos, and Stavrovouni sections lie closely together, the first one differs from the latter ones by a later start of the Upper Marl unit, and a more extensive reworking of the planktonic bioclasts. Palaeocurrent measurements made by Robertson (1976) (Fig.90) revealed highly erratic values towards the top of the succession only in this section. He suggested that sedimentary structures of the turbidite succession might partly be produced by bottom currents. This is also indicated by the fact that the palaeocurrent directions have a significant component perpendicular to the palaeoslope (Stow & Lovell, 1979; Stanley, 1993). In the Lefkara section, therefore, a simultaneous influence of turbidites and contourites at least in the higher part of the succession can be inferred.

Also the macrofacies points to an overprint of contourites on the turbidite facies. Comparatively coarse but thin Bouma B- and weak or absent C-divisions are observed underlying unstructured lutite (Figs.49 (C), 85 (A) ,(D)). Here, contourites possible eroded and truncated turbidites (Stanley, 1993). Increased bioturbation as well as reduced amounts of radiolarians in the microfacies of the Lefkara section (Chapter 3.2.10.) contribute to this interpretation.

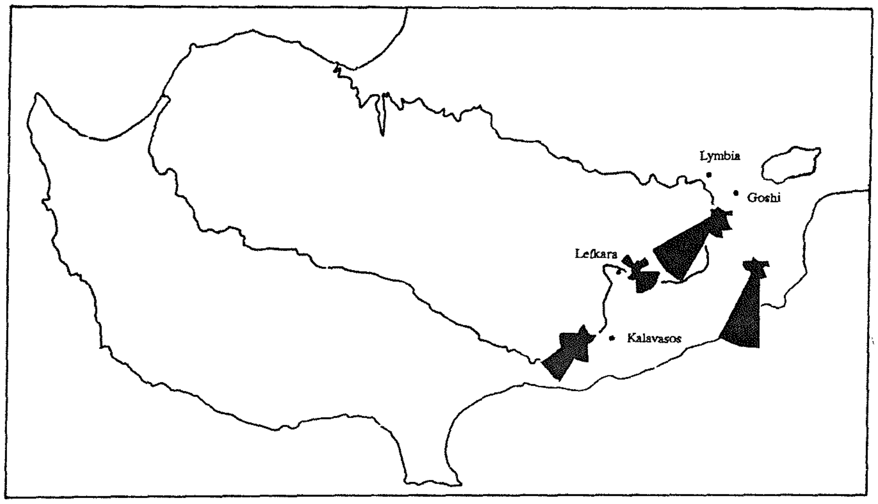


Fig.90. Palaeocurrent directions measured in the calciturbidites (from Robertson, 1976).

Nevertheless, the later start of the Upper Marl (assuming a contourite origin) seems to indicate less strong currents in this section. The explanation for this may lie in the geographic position of the locality in a topographic indentation of the already uplifting ophiolitic basement. This locality was therefore sheltered from the main currents passing the eastern margin of the massif. Contourite velocities must have been higher and unrestricted at the outer margin of the massif near the localities Kalavasos and Stavrovouni (Figs.89, 5) which both show an early start of the Upper Marl.

In a global view, the time between Late Eocene and Oligocene is characterised by a low sea-level due to the start of glaciation (Haq *et al.*, 1987) and common hiatuses, caused by the subsequent onset of bottom current erosion, with maxima in the Early Miocene, Oligocene, and Late Eocene (Miller *et al.*, 1987; Vail *et al.*, 1980; Ramsay, 1977). The hiatuses found in this study are dated to the same times and therefore seem to indicate a sedimentological response in the Lefkara Formation to a change in climate. Consequently, hiatuses in Cyprus are at least not exclusively caused by local uplift, as proposed above, and as shown by Robertson *et al.* (1991) for the overlying Pakhna Formation. The most widespread hiatuses or reduction in deposition in the Lefkara Formation all fall into times of worldwide regional gaps in deposition between Late Eocene and Early Miocene time which strongly suggests at least some global cause. If the whole Upper Marl facies is in fact related to bottom current processes and the bottom currents, on the other hand, are the result of enhanced cold deep-water production in the Antarctic the decrease in carbonate in this unit may be the result of dissolution (Sarnthein & Faugeres, 1993) in addition to the sedimentary causes discussed previously.

The uncertainty of the sample dating of the Cypriot material might obscure the exact timing of some of the erosional phases. Times of widespread hiatuses earlier in the stratigraphic record are not reflected in the Lefkara material since here turbidites were superimposed on normal marine depositional processes. Nevertheless, reduced sedimentation found in the Palaeocene and Early Eocene of the Lower Marl unit (Chapter 2.3.4.) may also be related to erosion due to global sea level changes during these time spans (Haq *et al.*, 1987). In fact, the global control on hiatus development seems to be more convincing than a tectonic related explanation in the Lefkara Formation. Nevertheless, evidence for uplift-related contourites are: (1) Submarine contours are the basic condition for contour currents so that some uplift of the Troodos terrane must have taken place. The gradual increase in current structures in the Motorway section may reflect the progressing uplift. (2) The eastern sections, Kalavasos, Stavrovouni, and the Motorway, show a diachronous onset of the contourite-formed Upper Marl unit which reflects the progressive underthrusting starting in the southeast.

CHAPTER 6

CONCLUSIONS AND SUMMARY

Planktonic microfauna and stratigraphy:

Ninety five planktonic foraminifera species and fifty nine radiolarian species, mainly from the nassellarian suborder Cyrtida, were identified in the sediments of the Lefkara Formation. Planktonic foraminifera are present in all the samples studied but bad preservation and alteration of the fauna led to uncertainties in identification and dating. Radiolarians are commonly well preserved but absent or reworked in many samples.

Although broadly similar to earlier work, the high resolution dating obtained in this study shows several significant differences from previous publications. For the Lefkara Formation as a whole, a planktonic foraminifera biozone dating between P5 (Late Palaeocene) and the boundary N6/7 (Early Miocene) is obtained. Reworked species from the biozone-range P3-P4 (Middle Palaeocene) were found in the material studied and indicate the presence of older deposits of a similar kind in the area. The radiolarian fauna was dated from *B. clinata* (Early Eocene) to *T. bromia* zone (Late Eocene to Early Oligocene) and was used to confirm and refine the foraminifera dating.

In more detail, a marked diachrony of individual lithological units is observed. The start of deposition of the Lower Marl unit is dated as P5 (Late Palaeocene) in the western sections and as P8 (Early Eocene) in the east, whereas the end is apparently more synchronous in biozones P9 to P10 (Early Eocene to Middle Eocene). The Chalk & Chert unit is dated as starting in the P9/P10 biozones and ending in P11/P12 (Middle Eocene). The base of the Chalk unit then appears more or less synchronous, being dated as P11 or more likely P12, whereas the upper termination is diachronous between biozones P17 (Late Eocene) and N6/7 (Early Miocene). Consequently, the start of the Upper Marl is also time transgressive between P18/19 (Early Oligocene) and N6/7. The top of the formation is dated consistently near the N6/7 boundary (Early Miocene). The new dating of the lithological units group the sections into two categories, with the Ayios Nicolaos, Kouka, and Lefkara sections having an older age at the base, a late end of the Chalk unit, and a consequent short duration of the Upper Marl, while the Kalavasos, Stavrovouni, and Motorway sections have a younger age at the base and an earlier start of the Upper Marl unit.

The comparison with most of the previous dating of the Lefkara Formation led to generally similar results compared to the present work but had a lower resolution and did not consider any systematic diachronism. The use of biostratigraphic subdivisions of the formation instead of mappable lithostratigraphic units led to confusion in comparing dated lithologies. Maastrichtian samples from the base of the formation, as found by most authors, were not present in the material studied here.

Sedimentation rates calculated using unit thicknesses from the literature and the dating from the present work led to 1-20m/Ma for the Lower Marl, 50m/Ma for the Chalk & Chert unit, 7-17m/Ma for the Chalk unit (10-29m/Ma for the sum of the Chalk & Chert and Chalk units), and 3-40(?)m/Ma for the Upper Marl. This roughly reflects an initial increase and later decrease in the sedimentation rate, depending on the turbiditic input and current erosion near the top. Sedimentation rates calculated from the few and short outcrops logged for this study led to much lower rates which can only be explained by strong regional differences in sediment thickness: 0.4-2m/Ma for the Lower Marl (with the higher values reflecting turbidites in the eastern sections), 2-5m/Ma for the Chalk & Chert unit, 0.2-5.5m/Ma for the Chalk unit (with the high values reflecting undisturbed deposition and the low ones current erosion near the top of the unit), and 1m/Ma for the Upper Marl. Reduced sedimentation or hiatuses were common at the top of the Chalk unit, after Middle Eocene between 34 and 23Ma. These are interpreted as the result of erosion by contour currents.

The new dating places the end of volcanic activity in the region, *i.e.* the last evidence for Kannaviou volcanism, later than previously thought at early Middle Eocene. Similarly, according to the new stratigraphy, the rotation of the Troodos terrane would have been completed as late as the end of Middle Eocene (43Ma) instead of Palaeocene or early Eocene, if the correlation of the lithologies given in the literature are correct. The northward subduction beneath Cyprus is generally taken as the start of tectonically controlled deposition of the Pakhna Formation at the beginning of the Miocene. However, the new dating shows a longer duration of the Lefkara Formation and hence later start of the Pakhna Formation in the Burdigalian (N6/7). Since the Upper Marl unit is interpreted in this study to have been tectonic-related as well, an earlier start of the subduction within the Oligocene seems more likely.

General depositional setting:

The Lefkara Formation is a succession of deep-sea sediments which were deposited as the first calcareous material after sea-floor spreading ended. The Formation has been subdivided into the purely lithological units Lower Marl, Chalk & Chert, Chalk, and Upper Marl which reflect the change in composition from marl-dominated, to chalk-dominated and chert-rich, to chalk-dominated, and back to marl.

The microfacies, faunal assemblage, and carbonate content indicate that almost the whole succession was deposited between 2000 to 3000m water depth, above the CCD and most likely below the ACD, in a basin margin environment under normal marine conditions. Only the Upper Marl sediments show any slight indication of shallowing.

The lowermost strata close to the contact with the underlying formation were deposited close to the CCD, showing signs of carbonate dissolution, and were possibly slightly influenced by submarine weathering of ash and/or volcanics. A diachronous base of the formation was resolved between the western sections (including the Lefkara section) starting with biozone P5 and P6, and the eastern sections, starting with biozone P8 and P9. This was possibly related to localised tectonic uplift and a consequent elevation of the area above the CCD, in addition to the result of deposition in hollows of the lava surface (Robertson & Hudson, 1974).

Micro- and macrofacies data and the sediment composition indicate that much of the succession was deposited by pelagic processes as ooze, with dominant planktonic microfossils and a small allochthonous component. These rocks form calcilutites or sparse biomicrites respectively. Clay minerals identified are dominated by smectite (average 70%), palygorskite (up to 50%), and illite (0-20%). They appear to be mainly detrital in origin and were transported by water currents and wind.

Turbidity currents were the main mechanism of transport for the allochthonous material up to approximately 48Ma (as resolved for the clay minerals). Turbidites are prominent in parts of the Lower Marl, the Chalk & Chert, and lower Chalk units in the sections at the eastern margin of the Troodos Massif. The chert strata and a common microfacies of packed biomicrites reflect rapid burial. Structureless cherts are also interpreted as of turbiditic origin and reflect a high productivity related to the equatorial upwelling belt. Further rare chert occurrences near the top of the Chalk unit can be related to contourites. The vertical succession of facies developed through the formation indicates mainly pelagic conditions at the onset, a gradual increase and following decrease of turbidites, followed once more by mainly pelagic deposition, and then a gradual increase in contour current activity.

The clay mineral assemblage reflects the conditions in the source area, indicating (1) physical weathering from freshly exposed rocks under arid to semiarid conditions, and (2) erosion from soils or perimarine environments. Warm time periods with strong seasonality are reflected in a high palygorskite content in Early Eocene and, less clearly, in Late Eocene time.

The turbidite sequence:

Turbidites are well developed to the east of the Troodos Massif and are dated between 53Ma (biozone P9) and 42Ma (biozone P14), *i.e.* during Early and Middle Eocene or slightly earlier. The micro- and macrofacies reveal deposition as calciclastic and biogenic calciturbidites, dominantly of calcilutite grade, from low density currents. These are interbedded with pelagic deposits and affected by subsequent diagenetic modification. Except for clear E-divisions, all Bouma divisions were recognised, with CD- and D-sequences dominating over AD-and BD-sequences. The vertical development shows an initial gradual increase in turbidite input (seen in the chert and clay content), with the climax near the top of the Lower Marl and the base of the Chalk & Chert units (extensive chert developments, highest carbonate content near 50Ma, AD-sequences, high sedimentation rate), possibly slightly less common but clearly visible turbiditic structures in the whole Chalk & Chert unit, and a gradual thinning and fining upwards (absence in chert, base-cut sequences, waning in structures, decrease in exotic allochems, decrease in clay and quartz content, break in clay minerals at the top of the sequence) and a dominance of pelagic deposition in the lower part of the Chalk unit. The bulk mineralogy, microfacies, and sedimentation rate suggest that some of the structureless higher chalks of the Chalk unit might still be slightly influenced by turbidites. The turbidites most likely formed in a basin plain environment of a carbonate slope apron, possibly in an asymmetric basin.

The allochthonous material of the turbidites consists mainly of pelagic planktonic bioclasts which, together with the intraclasts, were eroded by the turbidity current as it crossed the slope. Shallow water bioclasts and lithoclasts originate from a northern carbonate shelf and are mainly present in coarser grained turbiditic strata.

The termination of the turbidites coincides with a small drop in sea-level at the end of the Middle Eocene but is mainly and clearly related to tectonics. Proximal turbidites in the area of the Kyrenia terrane and the distal turbidites of the Troodos terrane show a parallel evolution, with the source area being the Kyrenia Range itself and the Taurids in the north. The initial gradual increase in turbidite intensity can be related to the subsidence of the Kyrenia terrane during Maastrichtian to early Middle Eocene time, while its following uplift and faulting during the Middle and Late Eocene gradually cut off the source for the Lefkara Formation and finally terminated the turbidite deposition. The collapse of the Kyrenia Range in Oligocene and Early Miocene time and the subsequent deposition of turbidites is not directly reflected in the Lefkara Formation since the Troodos terrane was itself uplifting. However, distal turbidites were most likely redistributed by bottom currents and thus contributed to the clay content in the Upper Marl unit. The simplified palaeotopography at the time of the Lefkara Formation, the position of the tectonic terranes and the sedimentary processes during the main phases of turbidite and contourite deposition are reconstructed in the block diagram in Figure 91.

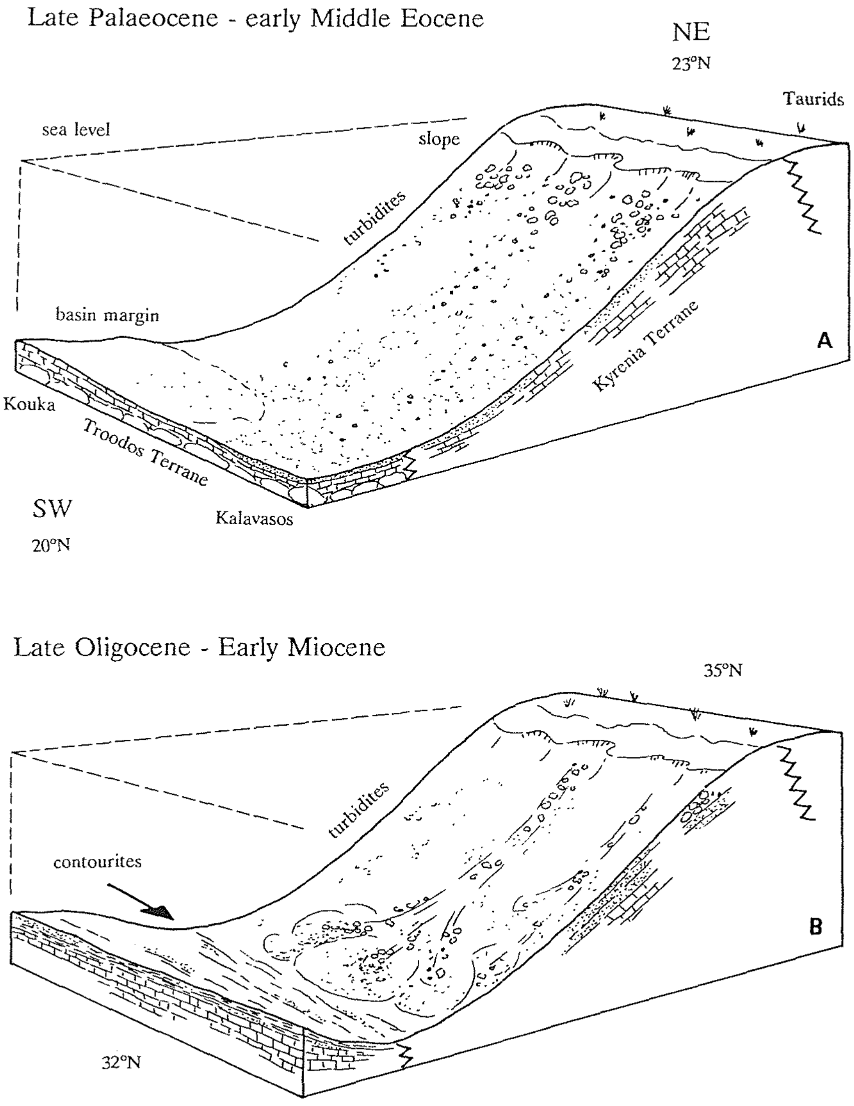


Fig.91. Block diagrams of the palaeogeography, palaeotopography and turbidite and contourite deposition in the Kyrenia and Troodos terranes (compare also Fig 86). **(A)** Proximal turbidite deposition on the Kyrenia terrane, distal turbidites on the Troodos terrane with lesser influence in the topographically elevated west; **(B)** Flysch deposition on the Kyrenia terrane, marls and contourites on the uplifting Troodos terrane.

Lateral facies variations of the turbidites:

Contemporaneous lateral facies variations were found mainly between the turbidite-dominated sections in the east and the sections in the west at the southern margin of the Troodos Massif. Indications for turbidite deposits also in the west are: (1) the chert facies of a similar age as the turbidites in the east, indicating rapid deposition, (2) faint turbiditic structures (CD- and D-sequences mainly seen in the microfacies), (3) the equivalence of the sparse microfacies I2 with the turbiditic microfacies II6, and (4) the presence of scarce allochems of reworked origin. Further differences between the western and eastern sections, indicating weaker turbidity currents and more pelagic sedimentation in the west, are: slightly thinner turbidite beds, higher abundances of the pelagic microfacies I1, less terrigenous non-calcareous and relatively more autochthonous carbonate material, and a less diverse clay mineral assemblage.

The more distal basin plain facies of the western turbidites can be explained by (1) an extended influence of the uplift of the southwestern Mamonia Complex between the Maastrichtian and Early Eocene creating a counterslope, (2) the uplift of the northwestern margin of the Troodos Massif between the Maastrichtian and Middle Eocene (Robertson, 1977) and a consequent reduction or cut-off in turbidite input, and (3) a general local uplift of southern Cyprus leading to a shallower depositional environment.

The facies of the Motorway section stands intermediate between the western and eastern sections, showing moderate development of turbiditic structures, significant amounts of pelagic deposition in the turbidite sequence (bioturbation, microfacies I1), increased benthic foraminifera (most likely indicating increased bottom currents), and a more fluctuating clay mineral assemblage. This might reflect a setting at the apron edge on a slight topographic high.

Contourites:

Contourites were recognised on the basis of sedimentary structures and differences in the microfacies and composition in the highest Chalk and Upper Marl units in several localities but most clearly in the Motorway section. Extensive hiatuses between the Late Eocene and the Early Miocene with a climax in the Oligocene indicate bottom current erosion. This could be correlated to a global cooling in climate with subsequent bottom current formation, but local tectonics might also have had some influence. The whole Upper Marl unit has most likely been influenced by bottom current winnowing. The facies development and timing of the Upper Marl was dependent on (1) tectonic uplift starting in the southeast, (2) an increase in input of clay-rich material from the northern flysch deposits as a result of tectonic evolution of the Kyrenia Range,

(3) the distribution, winnowing, and erosion of sediments by bottom currents which were stronger at the eastern margin of the Troodos Massif (earlier onset of marls, higher detrital quartz content, very regular pattern of reworking in the Motorway section) than in the south or the isolated and protected locality Lefkara (later onset of the unit, higher proportions of redeposited rather than eroded material at the base of contourites), and (4) carbonate dissolution due to cold bottom currents.

Diagenesis:

Strong diagenetic processes led to alteration of the original facies and partly obscured as well as enhanced sedimentary structures. These changes include silicification, compaction, pressure dissolution of calcareous bioclasts, a change in the composition of the allochems, and clay seam development. Due to a low diagenetic potential of the sediment composition, few pores were cemented but compaction up to 2/3 of the thickness or more was common in the non-silicified strata during late diagenesis. The micritic matrix is mainly a product of diagenesis and the sediment was originally deposited as nannofossil-radiolarian-foraminifera ooze. Micritisation was enhanced by primary differences in the clay content transported by currents (leading to clay seam development) and by slow burial. The varying rate of deposition led to the formation of the different microfacies groups of sparse and packed biomicrites.

Chert formation and the preservation of radiolarians can be related to a rapid burial of the siliceous material, whereas chert- and radiolarian-free (sparse) sediments of microfacies I1 are pelagic deposits originally lacking in significant allochthonous input. The stage of silica maturation indicates a probable burial depth of less than 2km.

Future work:

Many of the problems studied in this work have the potential for further more detailed and extended investigation. Amongst these, the most interesting would be as follows:
(1) Selection of further sections for establishing a detailed stratigraphy all over the island. This could reveal a more complete picture of the diachrony of the lithological units and may confirm or specify the sedimentological and tectonic causes interpreted in this study. In addition, a systematic mapping of the thicknesses of the units would show the local variations in sedimentation rates. To complete the study of the Lefkara Formation, some sections of the condensed deposits north of the Troodos Complex and on top of the Mamonia Complex should be analysed for the same sedimentological and stratigraphic questions as have been addressed in this study, in order to date the onset of the earliest uplift and to reveal its influence on

sedimentation.

(2) Mapping the turbidites of the Troodos and Kyrenia terranes, including borehole samples from the Mesaoria Plain and the potential source area of some of the turbiditic material in the Taurids. A more complete picture of the lateral facies variations should give evidence of the geometry of the slope apron - basin plain system, the mode of transport, the exact provenance and the relationship between proximal and distal deposits.

(3) A more detailed study of the contourites in terms of their facies, distribution over the island, development in time, and the possible continuation in the Pakhna Formation. Especially in the Lefkara section, the interplay of turbidites and bottom currents exhibits a field for future work. Palaeocurrent measurements of contourites could test the direction of bottom current flows proposed in this work.

(4) Confirmation of the validity of the facies criteria for the pelagic origin of microfacies (I1) found in this study by comparison with other deep sea deposits. This should allow the establishment of a model for pelagites under various environmental conditions.

(5) Analysis of the microfaunal assemblages for their oceanographic and climatic information. In addition to information on sea surface waters, which can be gained from planktonic foraminifera, benthic foraminifera assemblages may contribute especially to the study of bottom water circulation (Murray, 1987). Although selective dissolution may have altered the assemblages significantly, not all strata are adversely affected and the original composition is preserved at least in the packed biomicrites. On the other hand, the influence of pressure dissolution or the crushing behaviour on selective species may be worked out as a measure for the influence of diagenesis.

REFERENCES

Abrahamsen, N., & Schönharting, G. (1987): Palaeomagnetic timing of the rotation and translation of Cyprus.- Earth and Planetary Science Letters, 81, 409-418.

Allen, C.G. (1966): Summary of microfaunas, Cyprus.- Annual Report, Geological Survey Department, Nicosia, 8-10.

Aoyagi, K. & Kazama, T. (1980): Transformational changes of clay minerals, zeolites and silica minerals during diagenesis.- Sedimentology, 27, 179-188.

Ausich, & Bottjer, (1982): Tiering in suspension-feeding communities on soft substrata throughout the Phanerozoic.- Science, 216, 173-174.

Bagnall, P.S. (1960): The geology and mineral resources of the Pano Lefkara-Larnaca area.- Geological Survey Department Cyprus, Memoir 5, 116pp.

Baltuck, M. (1983): Some sedimentary and diagenetic signatures in the formation of bedded radiolarite.- in: Iijima, A., Hein, J.R. & Siever, R., Developments in Sedimentology, 36, 299-315.

Baroz, F. (1980): Volcanism and continent-island arc collision in the Pentadactylos Range, Cyprus.- in: Panayiotou, A., Ophiolites: Proceedings of the International Ophiolite Symposium, Cyprus 1979, Cyprus Geological Survey Department, 73-85.

Bathurst, R.G.C. (1966): Boring algae, micrite envelopes and lithification of molluscan biosparites.- Geological Journal, 5, 15-32.

Bathurst, R.G.C. (1975): Carbonate Sediments and Their Diagenesis.- Developments in Sedimentology, 12, 658pp.

Bathurst, R.G.C. (1987): Diagenetically enhanced bedding in argillaceous platform limestones: stratified cementation and selective compaction.- Sedimentology, 34, 749-778.

Bathurst, R.G.C. (1991): Pressure-dissolution and limestone bedding: the influence of stratified cementation.- in: Einsele, G., Ricken, W. & Seilacher, A., Cycles and Events in Stratigraphy, Springer Verlag, 450-463.

Bé, A.W.H. (1977): An ecological, zoogeographical and taxonomic review of recent planktonic foraminifera.- in: Ramsay A.T.S., Oceanic Micropalaeontology, Vol.1, Academic Press, 1-100.

Bear, L.M. (1960): The geology and mineral resources of the Akaki-Lythrodondha area.- Geological Survey Department Cyprus, Memoir 3.

Bearman, G. (ed.) (1989): Ocean Circulation.- The Open University, Pergamon Press, 238pp.

Berger, W.H. (1970): Planktonic foraminifera: selective solution and lysocline.- Marine Geology, 8, 111-138.

Berger, W.H. (1973): Cenozoic sedimentation in the eastern tropical Pacific.- Geological Society of America Bulletin, 84, 1941-1954.

Berger, W.H. (1974): Deep-sea sedimentation.- in: Butk, C.A. & Drake, C.D., The Geology of Continental Margins, Springer Verlag, 213-241.

Berger, W.H. & van Rad, U. (1972): Cretaceous and Cenozoic sediments from the Atlantic Ocean.- in: Hayes, D.E., Pimm, A.C. *et al.*, DSDP Initial Reports 14, 787-954.

Berggren, W.A. (1971): Palaeogene planktonic foraminiferal faunas on Legs I-IV (Atlantic Ocean), Joides Deep Sea Drilling Program - a synthesis.- in: Farinacci, A., Proceedings of the second planktonic conference, Roma 1970, 57-77.

Berggren, W.A. & Van Couvering, J.A. (1974): The late Neogene. Biostratigraphy, geochronology and paleoclimatology of the last 15 million years in marine and continental sequences.- Palaeogeography Palaeoclimatology Palaeoecology, 16 (1-2), 1-215.

Berggren, W.A., Kent, D.V. & Flynn, J.J. (1985): Palaeogene geochronology and chronostratigraphy.- in: Snelling, N.J., The chronology of the geological record, Geological Society, Memoir 10, Blackwell Scientific Publications, 141-186.

Berggren, W.A., Kent, D.V. & Van Couvering, J.A. (1985): The Neogene: Part 2. Neogene geochronology and chronostratigraphy.- in: Snelling, N.J., The chronology of the geological record, Geological Society, Memoir 10, Blackwell Scientific Publications, 211-250.

Biscaye, P.E. (1965): Mineralogy and sedimentation of recent deep-sea clays in the Atlantic Ocean and adjacent seas and oceans.- Geological Society of America Bulletin, 76, 803-832.

Blome, C.D. & Irwin, W.P. (1985): Equivalent radiolarian ages from ophiolite terranes of Cyprus and Oman.- Geology, 13, 401-404.

Blow, W.H. (1969): Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy.- Proceedings First International Conference on Planktonic Microfossils, Geneva, 1967, 1, 199-422.

Blow, W.H. (1979): The Cainozoic Globigerinida, 3 Volumes.- Brill, Leiden, 1413pp.

Blow, W.H. & Banner, F.T. (1962): The Mid-Tertiary (Upper Eocene to Aquitanian) *Globigerinaceae*.- in: Eames, F.E., Banner, F.T., Blow, W.H. & Clarke, W.J., Fundamentals of Mid-Tertiary Stratigraphical Correlation, Cambridge University Press, Cambridge, 61-151.

Bolli, H.M. & Krasheninnikov, U.A. (1977): Problems in Palaeogene and Neogene correlations based on planktonic foraminifera.- Micropaleontology, 24/4, 436-452.

Bolli, H.M. & Saunders, J.B. (1982): *Globorotalia mayeri* and its relationship to *Globorotalia saikensis* and *Globorotalia continuosa*.- Journal of Foraminiferal Research, 12 (1), 39-50.

Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K. (1985): Plankton Stratigraphy, Vol.1: Planktonic Foraminifera, Calcareous Nannofossils and Calpionellids.- Cambridge University Press, 599pp.

Bolli, H.M. & Saunders, J.B. (1985): Oligocene to Holocene low latitude planktic foraminifera, in: Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K. (1985): Plankton Stratigraphy, Vol.1: Planktonic Foraminifera, Calcareous Nannofossils and Calpionellids.- Cambridge University Press, 155-262.

Boström, K, Joensuu, O., Valdes, S. & Riera, M. (1972): Geochemical history of South Atlantic Ocean sediments since Late Cretaceous.- Marine Geology, 12, 85-121.

Bouma, A.H. (1962): Sedimentology of Some Flysch Deposits.- Elsevier, 168pp.

Brindley, G.W. & Brown, G. (eds.) (1980): Crystal Structures of Clay Minerals and Their X-ray Identification.- Mineralogical Society, London, 495pp.

Callen, R.A. (1984): Clays of the palygorskite-sepiolite group: depositional environment, age and distribution.- in: Singer, A. & Galan, E., Palygorskite-sepiolite, Occurrences, Genesis and Uses, Developments in Sedimentology, 37, Elsevier, 1-37.

Chamley, H. (1989): Clay Sedimentology.- Springer Verlag, 623pp.

Cleintuar, M.R., Knox, G.J. & Ealey, P.J. (1977): The geology of Cyprus and its place in the East-Mediterranean framework.- Geologie en Mijnbouw, 56/1, 66-82.

Clube, T.M.M & Robertson, A.H.F. (1986): The palaeorotation of the Troodos microplate, Cyprus, in the late Mesozoic - early Cenozoic plate tectonic framework of the Eastern Mediterranean.- Surveys in Geophysics, 8, 375-437.

Clube, T.M.M., Creer, K.M. & Robertson, A.H.F. (1985): Palaeorotation of the Troodos microplate, Cyprus.- Nature, 3/7, 522-525.

Cockbain, A.E. (1961): Foraminiferal faunas from the Lapithos Group.- Geological Magazine, 48/3, 177-194.

Decker, K. (1991): Rhythmic bedding in siliceous sediments - an overview.- in: Einsele, G., Ricken, W. & Seilacher, A., Cycles and Events in Stratigraphy, Springer Verlag, 464-479.

Dercourt, J., Zonenshain, L.P., Ricou, L.-E., Kazmin, V.G., Le Pichon, X., Knipper, A.L., Grandjacquet, C., Sbortshikov, I.M., Geyssant, J., Lepurier, C., Pechersky, D.H., Boulin, J., Sibuet, J.-C., Savostin, L.A., Sorokhtin, O., Westphal, M., Bazhenov, M.L., Lauer, J.P. & Biju-Duval, B. (1986): Geological evolution of the Tethys Belt from the Atlantic to the Pamirs since Lias.- Tectonophysics, 123, 241-315.

Dilek, Y. & Moores, E.M. (1990): Regional tectonics of the eastern Mediterranean ophiolites.- in: Malpas, J., Moores, E.M., Panayiotou, A. & Xenophontos, C., Ophiolites Oceanic Crust Analogues, Proceedings of the Symposium "Troodos 87", Geological Survey Department, Nicosia, Cyprus, 295-309.

Duan, T., Gao, Z., Zeng, Y. & Stow, D.A.V. (1993): A fossil carbonate contourite drift on the Lower Ordovician palaeocontinental margin of the middle Yangtze Terrane, Jiuxi, Northern Huan, Southern China.- Sedimentary Geology, 82, 271.284.

Dunham, R. (1962): Classification of carbonate rocks according to depositional texture.- American Association of Petrologists and Geologists, Memoir 1, 108-121.

Eaton, S. & Robertson, A.H.F. (1993): The Miocene Pakhna Formation, southern Cyprus, and its relationship to the Neogene tectonic evolution of the Eastern Mediterranean.- Sedimentary Geology, 86, 273-296.

Eberli, G.P. (1991): Calcareous turbidites and their relationship to sea-level fluctuations and tectonism.- in: Einsele, G., Ricken, W. & Seilacher, A., Cycles and Events in Stratigraphy, 340-359.

Eberli, G.P. (1987): Carbonate turbidite sequences deposited in rift-basins of the Jurassic Tethys Ocean (Eastern Alps, Switzerland).- Sedimentology, 34, 363-388.

Einsele, G. (1991): Submarine mass flow deposits and turbidites.- in: Einsele, G., Ricken, W. & Seilacher, A., Cycles and Events in Stratigraphy, Springer Verlag, 313-339.

Einsele, G. & Ricken, W. (1991): Limestone-marl alteration - an overview.- in: Einsele, G. et al., Cycles and events in stratigraphy, Springer Verlag, 23-47.

Ekdale, A.A. & Bromley, R.G. (1984): Comparative ichnology of shelf-sea and deep-sea chalk.- Journal of Paleontology, 58/2, 322-332.

Ellis, B.F., Messina, A.R., Charmatz, R. & Ronai, L.E. (1969): Catalogue of Index Smaller Foraminifera, Vol.2: Tertiary Planktonic Foraminifera.- Special Publication of the American Museum of Natural History, New York.

Eslinger, E. & Peaver, D. (1988): Clay minerals for petroleum geologists and engineers.- Society of Economic Paleontologists and Mineralogists, short course notes 22.

Faugeres, J.-C. & Stow, D.A.V. (1993): Bottom-current-controlled sedimentation: a synthesis of the contourite problem.- Sedimentary Geology, 82, 287-297.

Faugeres, J.C., Mezerais, M.L. & Stow, D.A.V. (1993): Contourite drift types and their distribution in the North and South Atlantic Ocean basins.- Sedimentary Geology, 82, 189-203.

Flügel, E. (1982): Microfacies Analysis of Limestones.- Springer Verlag Berlin, 633pp.

Folk, R.L. (1962): Spectral subdivisions of limestone types.- in: Ham, W.E., Classification of Carbonate Rocks, AAPG Memoir 1, 62-84.

Follows, E.J. & Robertson, A.H.F. (1990): Sedimentology and structural setting of Miocene reefal limestones in Cyprus.- in: Malpas, J., Moores, E.M., Panayiotou, A. & Xenophontos, C., Ophiolites Oceanic Crust Analogues, Proceedings of the Symposium "Troodos 87", Geological Survey Department, Nicosia, Cyprus, 207-215.

Foreman, H.P. (1973): Radiolaria of Leg 10 with systematics and ranges for the families *Amphipyndacidae*, *Artostrobiidae*, and *Theoperidae*.- in DSDP Initial Reports, 10, 407-474.

Galan, E. & Castillo, A. (1984): Sepiolite-Palygorskite in Spanish Tertiary basins: genetical patterns in continental environments.- in: Singer, A. & Galan, E., Palygorskite-Sepiolite, Occurrences, Genesis and Uses, Developments in Sedimentology, 37, 87-124.

Garrison, & Fischer, (1969): Deep-water limestones and radiolarites of the Alpine Jurassic.- in: Friedman, G.M., Depositional Environments in Carbonate Rocks, Society of Economic Paleontologists and Mineralogists, Special Publications, 14, 20-55.

Gass, I.G. (1960): The geology and mineral resources of the Dhali area.- Geological Survey Department, Cyprus, Memoir 4, 116pp.

Gass, I.G. (1968): Is the Troodos Massif of Cyprus a fragment of Mesozoic ocean floor?- Nature, 220, 3-42.

Gibbs, R.G. (1977): Clay-mineral segregation in the marine environment.- Journal of Sedimentary Petrology, 47, 237-243.

Gibson, T.G. (1989): Planktonic benthonic foraminifera ratios: modern patterns and Tertiary applicability.- Marine Micropaleontology, 15, 29-52.

Greensmith, J.T. (1989): Petrology of the Sedimentary Rocks.- Unwin Hyman, 241pp.

Haq, B.U., Hardenbol, J., & Vail, P.R. (1987): Chronology of fluctuating sea levels since the Triassic.- Science, 235, 1156-1167.

Harper, H.E. & Knoll, A.H. (1975): Silica, diatoms, and Cenozoic radiolarians evolution.- Geology, 3/4, 175-177.

Hein, J.R. & Obradovic, J. (1989): Siliceous deposits of the Tethys and Pacific regions.- in: Hein, J.R. & Obradovic, J. (eds.), Siliceous deposits of the Tethys and Pacific regions, Springer Verlag, 1-17.

Henson, F.R.S., Browne, R.W., McGinty, J. (1949): A synopsis of the stratigraphy and geological history of Cyprus.- The Quarterly Journal of the Geological Society of London, 105, 1-41.

Hesse, R. (1975): Turbiditic and non-turbiditic mudstone of Cretaceous flysch sections of the Eastern Alps and other basins.- Sedimentology, 22, 387-416.

Horowitz, A.S. & Potter, P.E. (1971): Introductory Petrography of Fossils.- Springer Verlag, 302pp.

Iaccarino, S. (1985): Mediterranean Miocene and Pliocene planktic foraminifera.- in: Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K. (1985): Plankton Stratigraphy, Vol.1: Planktonic Foraminifera, Calcareous Nannofossils and Calpionellids.- Cambridge University Press, 283-314.

Iaccarino, S. & Salvatorini, G. (1982): A framework of planktonic foraminiferal biostratigraphy for Early Miocene to Late Pliocene Mediterranean area.- Paleontol. Stratigr. Evol., 2, 115-125.

Isaacs, C.M., Pisciotto, K.A. & Garrison, R.E. (1983): Facies and diagenesis of the Miocene Monterey Formation, California: a summary.- in: Iijima, A., Hein, J.R. & Siever, R., Developments in Sedimentology, 36, 247-282.

Joint Committee on Powder Diffraction Standards (1974): Selected powder diffraction data for minerals. Databook.

Kähler, G. (1990): Oberflächentemperaturen im äquatorialen Atlantik während der letzten 330000 Jahre (Meteor Kern 16772).- Unpublished Diplom thesis, Christian-Albrechts-Universität Kiel, Germany.

Kastner, M., Keene, J.B. & Gieskes, J.M. (1977): Diagenesis of siliceous oozes - I. chemical controls on the rate of opal-A to opal-CT transformation - an experimental study.- Geochimica et Cosmochimica Acta, 41, 1041-1059.

Kelts, K. & Arthur, M.A. (1981): Turbidites after ten years of Deep-Sea Drilling - wring out the mop?.- in: Warme, J.E., Douglas, R.G. & Winterer, E.L., SEPM, 32, 91-127.

Kennett, J. (1982): Marine Geology.- Prentice-Hall, 813pp.

Kennett, J.P. & Srinivasan, M.S. (1983): Neogene Planktonic Foraminifera. A phylogenetic Atlas.- Hutchinson Ross, Publ.Co., Stroudsburg, Pennsylvania, 265pp.

Kluyver, H.M. (1969): Report on a regional geological mapping in Paphos District.- Bulletin Geological Survey Department Cyprus, 4, 21-36.

Leggett, J.K. (1985): Deep-sea pelagic sediments and palaeo-oceanography: a review of recent process.- in: Brenchley, P.J. & Williams, B.P.J., Sedimentology Recent Developments And Applied Aspects, Geological Society of London, Special Publications 18, 95-121.

Mackenzie, R.C., Wilson, M.J. & Mashhady, A.S. (1984): Origin of palygorskite in some soils of the Arabian Peninsula.- in. Singer, A. & Galan, E., Palygorskite-Sepiolite, Occurrences, Genesis and Uses, Elsevier, 177-186.

Maldonado, A. & Stanley, D.J. (1981): Clay mineral distribution patterns as influenced by depositional processes in the Southeastern Levantine Sea.- Sedimentology, 28, 21-32.

Mantis, M. (1970): Upper Cretaceous-Tertiary foraminiferal zones in Cyprus.- Scientific Research Centre of Cyprus, Epithyris 3, 227-241.

McGowran, B. (1968): Reclassification of early Tertiary Globorotalia.- Micropaleontology, 14/2, 179-198.

Miller, K.G., Fairbanks, R.G. & Mountain, G.S. (1987): Tertiary oxygen isotope synthesis, sea level history and continental margin erosion.- Paleoceanography, 2/1, 1-19.

Moore, D.G. (1969): Reflection profiling studies of the California continental borderland.- Geological Society of America, Special Publications 107.

Moores, E.M. & Vine, F.J. (1971): The Troodos Massif, Cyprus and other ophiolites as oceanic crust: evolution and implications.- Philosophical Transactions of the Royal Society of London, A.268, 443-466.

Moores, E.M., Robinson, P.T., Malpas, J. & Xenophontos, C. (1984): A model for the origin of the Troodos Massif, Cyprus and other mideast ophiolites.- Geology, 12, 500-503.

Mullins, H.T. & Cook, H.E. (1986): Carbonate apron models: alternatives to the submarine fan model for paleoenvironmental analysis and hydrocarbon exploration.- Sedimentary Geology, 48, 37-79.

Murray, J.W. (1976): A method of determining proximality of marginal seas to an ocean.- Marine Geology, 22, 103-119.

Murray, J.W. (1987): Benthic foraminifers and Neogene bottom-water masses at Deep Sea Drilling Project Leg 94 North Atlantic sites.- in: Orlofsky, S., DSDP Initial Reprts 94/2, 965-979.

Nelson, C.H. & Nilsen, T.H. (1984): Modern and ancient deep-sea fan sedimentation.- SEPM Short Course 14.

Nigrini, C. (1977): Tropical Cenozoic *Artostrobiidae* (Radiolaria).- Micropaleontology, 23/3, 241-269.

Panayiotou, A. (1987): An overview of the geology of Cyprus.- in: Xenophontos, C. & Malpas, J.G., Field Excursion Guide Book, International Ophiolite Symposium, Nicosia, Cyprus, 4-10 October, 1987, Geological Survey Department, Cyprus, 7-22.

Pantazis, Th.M. (1967): The geology and mineral resources of the Pharmakas-Kalavassos area.- Geological Survey Department Cyprus, Memoir 8, 190pp.

Petrushevskaya, M.G. & Kozolova, G.E. (1972): Radiolaria: Leg 14, Deep Sea Drilling Project.- in: Pimm, A.C., DSDP Initial Reports 14, 495-648.

Piper, D.J.W. (1978): Manual of sedimentological techniques.- unpublished manual.

Piper, D.J.W. (1978): Turbidite muds and silts on deep sea fans and abyssal plains.- in: Stanley, D.J. & Kelling, G., Sedimentation in Submarine Canyons, Fans, and Trenches, Dowden, Hutchinson & Ross, 163-176.

Piper, D.J.W. & Stow, D.A.V. (1991): Fine-grained turbidites.- in: Einsele, G., Ricken, W. & Seilacher, A., Cycles and Events in Stratigraphy, Springer Verlag, 360-376.

Pisciotto, K.A. (1981): Distribution, thermal histories, isotopic compositions, and reflection characteristics of siliceous rocks recovered by the Deep Sea Drilling Project.- in: Warme, J.E., Douglas, R.G., & Winterer, E.L., The Deep Sea Drilling Project: a decade of progress, SEPM, Special Publication 32, 129-147.

Poole, A.J. & Robertson, A.H.F. (1991): Quaternary uplift and sea-level change at an active plate boundary, Cyprus.- Journal of the Geological Society London, 148, 909-921.

Postuma, J.A. (1971): Manual of Planktonic Foraminifera.- Elsevier Publishing Company, Amsterdam, 420pp.

Premoli Silva, I. & Bolli, H.M. (1973): Late Cretaceous to Eocene planktonic foraminifera and stratigraphy of Leg 15 sites in the Caribbean Sea.- in: Edgar, N.T., Kaneps, A.G. & Herring, J.R., DSDP Initial Reports, 15, 499-547.

Ramsay, A.T.S. (1971): Occurrence of biogenic siliceous sediments in the Atlantic Ocean.- Nature, 233, 115-117.

Ramsay, A.T.S. (1977): Sedimentological clues to palaeo-oceanography.- in: Bé, A.W.H., Oceanic Micropaleontology, 1371-1453.

Riech, V. & von Rad, U. (1979): Silica diagenesis in the Atlantic Ocean: diagenetic potential and transformations.- in: Talwain, M., Hay, W.W. & Ryan, W.B.F., Deep Drilling Results in the Atlantic Ocean: Continental Margins and Paleoenvironment, 315-340.

Riedel, W.R. & Funnell, B.M. (1964): Tertiary sediment cores and microfossils from the Pacific Ocean floor.- Quarterly Journal of the Geological Society of London, 120, 305-368.

Riedel, W.R. & Sanfilippo, A. (1970): Radiolaria, Leg 4, Deep Sea Drilling Project.- in: Bader, R.G., Gerard, R.D. *et al.*, DSDP Initial Reports 4, 503-575.

Riedel, W.R. & Sanfilippo, A. (1978): Stratigraphy and evolution of tropical Cenozoic radiolarians.- Micropaleontology, 23/1, 61-96.

Robertson, A.H.F. (1975): Studies of the Pre-Miocene Sedimentary Cover of the Troodos Massif, Cyprus.- PhD-thesis, University of Leicester.

Robertson, A.H.F. (1976): Pelagic chalks and calciturbidites from the Lower Tertiary of the Troodos Massif, Cyprus.- Journal of Sedimentary Petrology, 46/4, 1007-1016.

Robertson, A.H.F. (1977): Tertiary uplift history of the Troodos Massif, Cyprus.- Geological Society of America, Bulletin, 88, 1763-1772.

Robertson, A.H.F. (1977): The origin and diagenesis of chert from Cyprus.- Sedimentology, 24/1, 11-30.

Robertson, A.H.F. (1978): The sedimentary evolution of the Troodos Ocean: an excursion guide to the sedimentary geology of southern Cyprus.- Sedimentology in Israel, Cyprus and Turkey, Guide book, part III:Turkey and Cyprus, International Association of Sedimentologists, Tenth International Congress on Sedimentologists, 21-75.

Robertson, A.H.F. (1990): Tectonic evolution of Cyprus.- in: Malpas, J., Moores, E.M., Panayiotou, A. & Xenophontos, C., Ophiolites Oceanic Crust Analogues, Proceedings of the Symposium 'Troodos 87', Geological Survey Department, Nicosia, Cyprus, 235-250.

Robertson, A.H.F. & Hudson, I.D. (1973): Cyprus umbers: chemical precipitates on a Tethyan ocean ridge.- Earth Planetary Science Letters, 18, 93-101.

Robertson, A.H.F. & Hudson, J.D. (1974): Pelagic sediments in the Cretaceous and Tertiary history of the Troodos Massif, Cyprus.- International Association of Sedimentologists, Special Publications 1, 403-436.

Robertson, A.H.F. & Woodcock, N.H. (1986): The role of the Kyrenia Range lineament, Cyprus, in the geological evolution of the eastern Mediterranean area.- Philosophical Transactions of the Royal Society of London, A 317, 141-177.

Robertson, A.H.F., Eaton, S., Follows, E.J., McCallum, J.E. (1991): The role of local tectonics versus global sea-level changes in the Neogene evolution of the Cyprus active margin.- International Association of Sedimentologists, Special Publications, 12, 331-369.

Sanfilippo, A. & Riedel, W.R. (1973): Cenozoic radiolaria (exclusive of Theoperids, Artostrobiids and Amphipyndacids) from the Gulf of Mexico, DSDP leg 10.- in: DSDP Initial Reports 10, 475-611.

Sanfilippo, A. & Riedel, W.R. (1982): Revision of the radiolarian genera *Theocotyle*, *Theocotylissa* and *Thyrsocyrtis*.- Micropaleontology, 28/2, 170-188.

Sanfilippo, A., Westberg-Smith, M.J. & Riedel, W.R. (1985): Cenozoic radiolarians.- in: Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K. (1985): Plankton Stratigraphy, Vol.1: Planktonic Foraminifera, Calcareous Nannofossils and Calpionellids.- Cambridge University Press, 631-712.

Sarnthein, M. & Faugeres, J.C. (1993): Radiolarian contourites record Eocene AABW circulation in the equatorial East Atlantic.- Sedimentary Geology, 82, 145-155.

Sartorio, D. & Venturini, S. (1988): Southern Tethys Biofacies.- Agip, 235pp.

Schlanger, S.O. & Douglas, R.G. (1974): The pelagic ooze-chalk-limestone transition and its implications for marine stratigraphy.- in: Hsü, K.J. & Jenkyns, H.C., Pelagic Sediments: On Land and Under the Sea, 117-148.

Scholle, P.A. (1971): Diagenesis of deep-water carbonate turbidites, Upper Cretaceous Monte Anatola Flysch, Northern Apennines, Italy.- Journal of Sedimentary Petrology, 41/1, 233-250.

Scholle, P.A. & Halley, R.B. (1985): Burial diagenesis: out of sight, out of mind!- in: Schneidermann, N. & Harris, P.M., Carbonate Cements, SEPM, Special Publication 36, 309-334.

Seilacher, A. (1962): Palaeontological studies on turbidite sedimentation and erosion.- Journal of Geology, 70, 227-234.

Shaw, H.F. (1978): The clay mineralogy of the recent surface sediments from the Cilicia Basin, Northeastern Mediterranean.- Marine Geology, 26, M51-M58.

Shinn, E.A., Halley, R.B., Hudson, J.H. & Lidz, B.H. (1976): Limestone compaction: An enigma.- Geology, 5, 21-24.

Siever, R. (1983): Evolution of chert at active and passive continental margins.- in: Iijima, A., Hein, J.R. & Siever, R., Developments in Sedimentology 36, 7-24.

Singer, A. (1984): The paleoclimatic interpretation of clay minerals in sediments - a review.- Earth-Science Reviews, 21, 251-293.

Smith, R.L. (1983): Circulation patterns in upwelling regimes.- in: Suess, E. & Thiede, J., Coastal Upwelling, Its Sediment Record. Part A: Responses of the Sedimentary Regime to Present Coastal Upwelling, Plenum Press, 13-35.

Stainforth, R.M., Lamb, J.L., Luterbacher, H., Beard, J.H. & Jeffords, R.M. (1975): Cenozoic planktonic foraminiferal zone and characteristics of index forms, appendix.- The University of Kansas Paleontological Contributions, Article 62, 1-425.

Stanley, D.J. (1993): Model for turbidite to contourite continuum and multiple process transport in deep marine settings: examples in the rock record.- Sedimentary Geology, 82, 241-255.

Stonecipher, S.A. (1976): Origin, distribution, and diagenesis of phillipsite and clinoptilolite in deep-sea sediments.- Chemical Geology, 17, 307-318.

Stow, D.A.V. (1984): Turbidite facies, associations and sequences in the south eastern Angola Basin.- in: Hay, W.W., Sibuet, J.-C. *et al.*, DSDP Initial Reports, 75, 785-795.

Stow, D.A.V. (1985): Fine-grained sediments in deep-water: an overview of processes and facies models.- Geo-Marine Letters, 5, 17-23.

Stow, D.A.V. (1994): Deep sea processes of sediment transport and deposition.- in: Pye, K., Sediment Transport and Depositional Processes, 257-291.

Stow, D.A.V. & Lovell, J.P.B. (1979): Contourites: their recognition in modern and ancient sediments.- Earth-Science Reviews, 14, 251-291.

Stow, D.A.V. & Shanmugam, G. (1980): Sequence of structures in fine-grained turbidites in comparison of recent deep-sea and ancient flysch sediments.- Sedimentary Geology, 25, 23-42.

Stow, D.A.V., Wezel, F.C., Savelli, D., Rainey, S.V.R. & Angell, G. (1984): Depositional models for calcilutites: Scaglia Rossa limestones, Umbro-Marchean Appennines.- in: Stow, D.A.V. & Piper, D.J.W., Fine-grained sediments: deep-water processes and facies, Geological Society, Special Publications 15, 223-241.

Toumarkine, M. & Luterbacher, H. (1985): Paleocene and Eocene planktic foraminifera.- in: Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K., Plankton Stratigraphy, Vol.1, Cambridge University Press, 87-154.

Tyrell, W.W.Jr. (1969): Criteria useful in interpreting environments of unlike but time-equivalent carbonate units (Tansill-Capitan-Lamar), Capitan Reef Complex, West Texas and New Mexico.- in: Friedman, G.M., Depositional Environments in Carbonate Rocks, SEPM, Special Publications 14, 80-97.

Vail, P.R., Mitchum, R.M., Shipley, T.H., & Buffler, R.T. (1980): Unconformities of the North Atlantic.- Philosophical Transactions of the Royal Society of London, A294, 137-155.

Vecsei, A., Frisch. W., Pirzer, M. & Wetzel, A. (1989): Origin and tectonic significance of radiolarian chert in the Austro-Alpine rifted continental margin.- in: Herin, J.P. & Obradovic, J., Siliceous deposits of the Tethys and Pacific regions, Springer Verlag, 65-80.

Venkatarathnam, W. & Ryan, B.F. (1971): Dispersal patterns of clay minerals in the sediments of the Eastern Mediterranean Sea.- Marine Geology, 11, 261-282.

Vita-Finzi, C. (1990): ^{14}C dating of late Quaternary uplift in western Cyprus.- Tectonophysics, 172/1-2, 135-140.

Walker, R.G. (1967): Turbidite sedimentary structures and their relationship to proximal and distal depositional environments.- Journal of Sedimentary Petrology, 37/1, 25-43.

Weaver, C.E. (1989): Clays, Muds and Shales.- Developments in Sedimentology, 44, Elsevier

Weaver, C.E. & Beck, K.C., (1977): Miocene of the S.E. United States: a model for chemical sedimentation in a peri-marine environment.- Sedimentary Geology, 17, 234p.

Whitham, A.G. (1993): Facies and depositional processes in an Upper Jurassic to Lower Cretaceous pelagic sedimentary sequence, Antarctica.- Sedimentology, 40, 331-349.

Williams, L.A., Parks, G. & Crerar, D.A. (1985): Silica diagenesis, I. solubility controls.- Journal of Sedimentary Petrology, 55/3, 0301-0311.

Wilson, J.L. (1975): Carbonate Facies in Geological History.- Springer Verlag, 471pp.

Wilson, R.A.M. (1959): The geology of the Xeros-Troodos area.- Geological Survey Department Cyprus, Memoir 1. 184pp.

Wise, S.W. & Weaver, F.M. (1974): Chertification of oceanic sediments.- in: Hsü, K.J. & Jenkyns, H.C., Pelagic Sediments: On Land and Under the Sea, Blackwell, 301-326.

Worsley, T.R. (1971): Terminal Cretaceous events.- Nature, 230, 318-320.

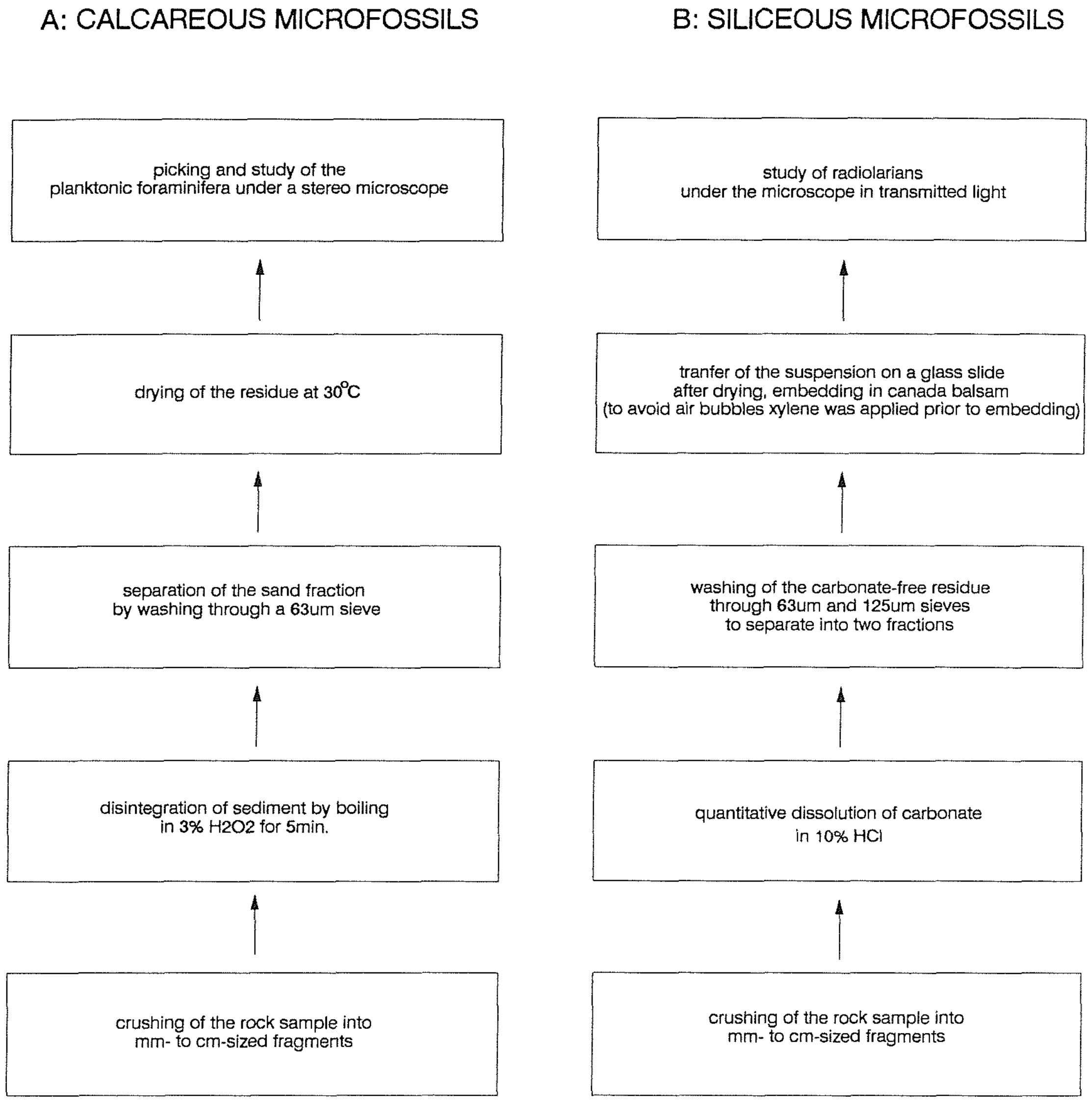
Wright, V.P. (1992): A revised classification of limestones.- Sedimentary Geology, 76, 177-185.

Xenophontos, C., Zomenis, S., Afrodhisis, S. (1987): The Circum-Troodos sediments.- in: Xenophontos, C. & Malpas, J.G., Field Excursion Guide Book, Symposium Troodos 87, Ophiolites and Oceanic Lithosphere, Nicosia, Cyprus 4-10 October, 1987, Geological Survey Department Nicosia, 114-129.

Zomenis, (1968): Stratigraphy and hydrogeology of the Neogene rocks in the northern foothills of the Troodos Massif, Annual Report of the Geological Survey Department Cyprus, Nicosia, 22-90.

APPENDIX

APPENDIX A.1. Sample preparation techniques for microfossil studies.



A: CALCAREOUS MICROFOSSILS

picking and study of the planktonic foraminifera under a stereo microscope

drying of the residue at 30°C

separation of the sand fraction by washing through a 63um sieve

disintegration of sediment by boiling in 3% H2O2 for 5min.

crushing of the rock sample into mm- to cm-sized fragments

B: SILICEOUS MICROFOSSILS

study of radiolarians under the microscope in transmitted light

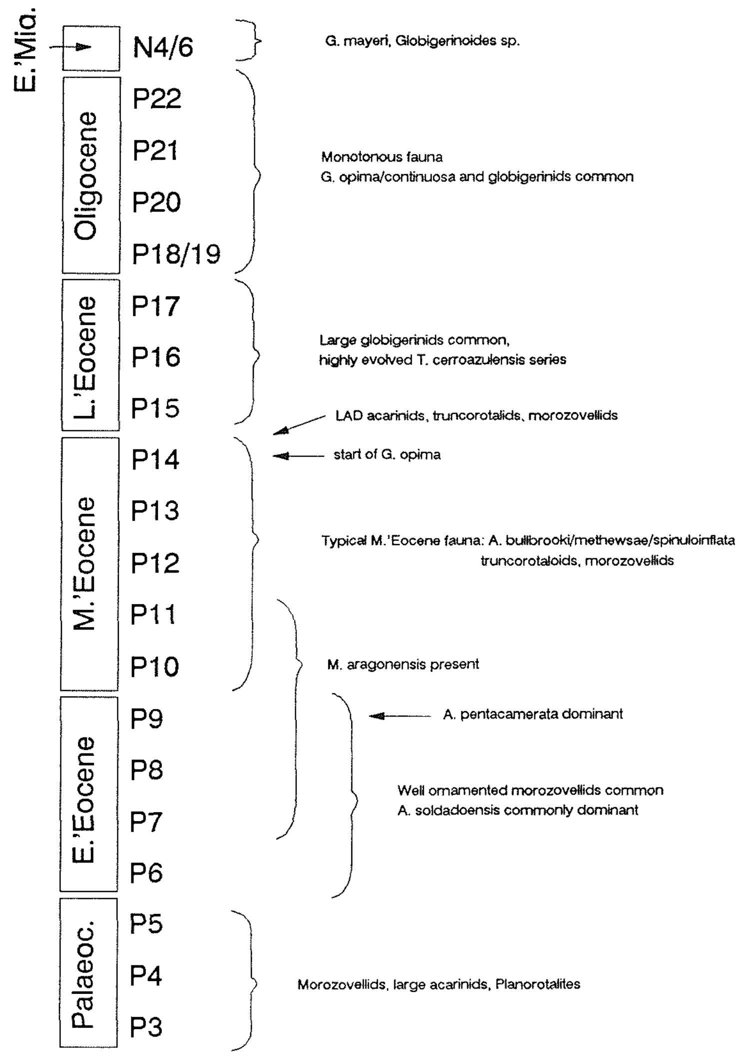
tranfer of the suspension on a glass slide after drying, embedding in canada balsam (to avoid air bubbles xylene was applied prior to embedding)

washing of the carbonate-free residue through 63um and 125um sieves to separate into two fractions

quantitative dissolution of carbonate in 10% HCl

crushing of the rock sample into mm- to cm-sized fragments

APPENDIX A.2. Characteristics of foraminifera asemblages in different time periods (key for Appendix A.3); mainly after Toumarkine & Luterbacher, 1985; see also Chapter 2.2. this work.



APPENDIX A.3.

List of planktonic foraminifera and radiolarians in the samples examined. '?': questionable identification due to bad preservation; 'TS': taxa found in thin sections; 'conf. TS': identification of uncertain specimens from the washed residue is confirmed by thin section studies; 'rew.': cooccurrence of species from different biozones reveals reworking.

Following the species list, the resulting biozone of the definitely identified species is given ('zone according to definite species'). Under 'remarks to the fauna', the assemblage is discussed to confirm and/or to restrict the biozone or zone range. Finally, the most likely biozone (range) is proposed under 'suggested biozone'.

The planktonic foraminifera and radiolarian faunas are discussed and dated independently. Any discrepancies are examined in Chapter 3. Similarly, an unlogical succession of suggested biozones is not considered here but eliminated in Table 3.

Ayios Nicolaos section:

sample 18/22:

FORAMINIFERA:
A. soldadoensis
G. triloculinoides?
M. acuta
M. angulata
M. conicotruncata
P. pusilla pusilla
Pseudohastigerina sp.

Zone according to definite species: range P5-6 and rew. P3-4.
Remarks on the fauna: G. triloculinoides?, *M. angulata* and *M. conicotruncata* must be reworked from P3-4 horizons, while *P. pusilla pusilla* might be confused with *M. convexa* (range P3-7) and would consequently not be reworked.

sample 18/1:

FORAMINIFERA:
A. mckannai
A. soldadoensis?
M. acuta
M. praecursoria?

Zone according to definite species: range P3-5
Remarks on the fauna: *Pseudohastigerina* and thick keeled morozovellids are absent, many large acarininids and only *A. soldadoensis*? are present, indicating the end of Late Palaeocene.
Suggested biozone: P5 and rew. P3.

RADIOLARIA:
B. clinata?
D. urceolus?
P. striata striata
P. papalis

S. babylonis
S. elizabethae?

Zone according to species: *P. striata* zone.
Remarks on the fauna: very few specimens are identifiable.

sample 18/2:

FORAMINIFERA:
A. mckannai?
A. nitida?
A. pentacamerata?
A. soldadoensis?
M. angulata
P. pusilla pusilla?

Zone according to definite species: range P3-4.
Remarks on the fauna: only definite identifications are of Palaeocene age but some evidence exists for Early Eocene.
Suggested biozone: range P8 and rew. P4?.

sample 18/3:

FORAMINIFERA:
A. bullbrooki
A. matthewsae
A. pentacamerata
A. soldadoensis
M. formosa?
M. quetra
T. collactea?

Zone according to definite species: zone P9.
Remarks on the fauna: *A. soldadoensis* and *A. pentacamerata* are common.

RADIOLARIA:
D. amphora
D. urceolus
S. acephala?
S. elizabethae

Zone according to definite species: range *P. striata* - *T. triacantha* zone.
Remarks on the fauna: only few specimens are present in the sample.

sample 18/4 TS:

FORAMINIFERA:
A. pentacamerata
A. primitiva?
A. soldadoensis
Pseudohastigerina?
T. collactea?

Zone according to species: range P8-9.

sample 18/8:

FORAMINIFERA:
- *A. nitida?*
- *A. pentacamerata*
- *A. soldadoensis*
- *G. velascoensis*
- *M. aequa*
- *M. angulata*
- *P. wilcoxensis*

Zone according to definite species: range P8-9 and rew. P4.
Remarks on the fauna: *A. bullbrooki* and truncorotaliids are absent, indicating a zone of possibly older P9; *A. soldadoensis* is common.
Suggested zone: P8.

RADIOLARIA:
- *D. urceolus*
- *L. archaea*
- *P. striata striata*
- *R. ornatum*
- *S. babylonis*
- *S. elizabethae*
- *S. acephala*
- *S. lineata*

Zone according to definite species: range *P. striata* - *D. mongolfieri* zone.
Remarks on the fauna: the radiolarians are moderately common in the sample but *D. mongolfieri* is absent.
Suggested zone: *P. striata striata* zone.

sample 18/5:

FORAMINIFERA:
- *A. broedermanni?*
- *A. bullbrooki*
- *A. pentacamerata*
- *A. soldadoensis?* (conf.TS)
- *G. linaperta*
- *M. aragonensis* (TS)
- *M. spinulosa?*
- *P. pseudoscitula* (TS)
- *P. wilcoxensis* (TS)
- *T. rohri*

Zone according to definite species: P9.
Remarks on the fauna: *A. pentacamerata is* dominating; the *A. bullbrooki* group is weakly developed.

sample 18/6:

RADIOLARIA:

D. urceolus?
L. archaea?
S. babylonis
S. elizabethae?

Remarks on the fauna: very few and badly preserved specimens are present.
Suggested biozone: range B. *clinata* - *D. mongolfieri* zone?.

sample 18/7:

FORAMINIFERA:

A. bullbrooki
A. pentacamerata? (conf.TS)
A. spinuloinflata?
G. officinalis?
Globigerinatheka?
M. spinulosa?
P. pseudoscitula (TS)
P. micra
T. collactea? (conf.TS)
T. topilensis

Zone according to definite species: range P9-12.
Remarks on the fauna: large globigerinids are absent, indicating the early part of Eocene; *A. pentacamerata* is not dominant and *A. soldadoensis* is absent, indicating an age younger P9.
Suggested biozone: range P10-12.

RADIOLARIA:

L. archaea
S. babylonis?
S. acephala
S. elizabethae

Zone according to definite species: range *P. striata* - *D. mongolfieri* zone.
Remarks on the fauna: only few specimens are present in the sample, no zonal markers are present; the absence of *D. amphora*, *D. mongolfieri* and *T. rhizodon* may suggest the *P. striata* zone.

sample 28/D:

FORAMINIFERA:

A. bullbrooki
A. broedermanni
A. pentacamerata
G. hagni
G. praebulloides?
P. pseudoscitula?
P. micra
T. collactea
T. rohri

Zone according to species: range P9-12.
Remarks on the fauna: *A. pentacamerata is* weakly developed, indicating an age younger P9; *A. soldadoensis* is absent, indicating a time later P9; large globigerinids are present.
Suggested biozone: P11-12.

sample 18/59:

FORAMINIFERA:

A. pentacamerata?
G. yeguaensis?
Globigerinatheka sp.?
G. cerroazulensis cerroazulensis
P. pseudoscitula?
T. collactea?
T. libyaensis?

Zone according to most likely species: range P12-14.
Remarks on the fauna: the fauna is badly preserved; identification of *A. pentacamerata* is most likely correct but *G. yeguaensis* is questionable.
Suggested biozone: P12.

RADIOLARIA:

A. clava
C. ampulla
C. hispida
D. ampulla
D. mongolfieri
D. urceolus
L. vespertilio
P. striata
P. diamesa
P. dorus?
R. ornatum
S. acephala
S. elizabethae
T. anaclasta
T. anapographa
T. ficus
T. triacantha

Zone according to definite species: *T. triacantha* zone.

sample 28/C:

A. broedermanni
A. bullbrooki
A. matthewsae
A. pentacamerata?
A. primitiva
G. cryptomphala?
G. linaperta?
G. praebulloides (TS)
Globigerinatheka?
P. pseudoscitula?
P. micra

T. rohri?
T. collactea?

Zone according to definite species: range P9-12.
Remarks on the fauna: *A. soldadoensis* is absent, indicating an age P9; *A. pentacamerata* and *Globigerinatheka sp.* are not common, indicating a zone younger P9 or P11 respectively; the *A. bullbrooki* group is well developed
Suggested biozone: P11-12.

sample 28/E:

FORAMINIFERA:
A. bullbrooki?
C. dissimilis
G. ciperoensis ciperoensis
G. euapertura
Globigerinoides sp.
G. mayeri
G. opima nana-continuosa transition

Zone according to definite species: N3 and rew. Middle Eocene?.
Remarks on the fauna: *A. bullbrooki* must be reworked.

RADIOLARIA:
C. hispida
D. amphora
D. mongolfieri
D. urceolus
E. fistuligerum
E. lagena
L. biaurita
P. striata
P. ampla
R. ornatum
S. babylonis
S. acephala
S. elizabethae
T. hirsuta
T. rhizodon
T. triacantha

Zone according to definite species: *P. ampla* zone and rew..
Remarks on the fauna: *T. hirsuta* and *D. urceolus* indicate reworking.

sample 18/58:

RADIOLARIA:
A. clava
C. hispida
D. amphora
D. mongolfieri
D. urceolus
E. fistuligerum
L. biaurita

P. striata striata
P. papalis
S. babylonis
S. triconiscus
S. acephala
S. lineata
T. hirsuta
T. rhizodon

Zone according to definite species: *P. mitra* zone and rew..
Remarks on the fauna: zonal marker is absent; the zone is established by the overlap of *P. striata/L. biaurita* and *S. triconiscus*; *A. clava*, *D. urceolus* and *T. hirsuta* must be reworked.

sample 28/B TS:
G. euapertura
G. venezuelana?
G. dehiscens
G. mayeri
G. scitula praescitula

Zone according to species: N7.

sample 28/A:

FORAMINIFERA:
A. pentacamerata
C. dissimilis?
G. kugleri?
G. mayeri?
G. opima opima-nana transition
M. subbotinae
T. libyaensis?

Zone according to most likely species: N3-4 and rew. Early and Middle Eocene.
Remarks on the fauna: *G. kugleri* is not definite but likely; *A. pentacamerata*, *M. subbotinae* and *T. libyaensis*? must be reworked.

RADIOLARIA:
C. hispida
D. amphora
D. mongolfieri
D. urceolus?
P. fistuligerum
P. striata?
P. mitra?
P. papalis
R. ornatum
S. babylonis
S. triconiscus
S. acephala
T. rhizodon
T. triacantha

Zone according to definite species: *P. mitra* zone.

Remarks on the fauna: *S. elizabethae* is absent, indicating a zone younger *P. ampla* zone; the marker species is present with one damaged specimen; the zone is established for certain by the overlap of *R. ornatum* and *S. triconiscus*.

sample 18/57:

RADIOLARIA:
C. hispida
D. mongolfieri
P. fistuligerum
S. striata
P. papalis
S. babylonis
S. triconiscus
S. acephala
S. nodosaria
T. hirsuta

Zone according to definite species: *P. mitra* zone.
Remarks on the fauna: zonal marker is absent, the zone is established by the overlap of *P. striata striata* and *S. triconiscus*; *T. hirsuta* indicates reworking.

sample 18/61:

RADIOLARIA:
D. amphora
D. mongolfieri
E. fistuligerum
L. aristotelis
L. amphitrite
P. striata striata
S. babylonis
S. acephala
T. bromia
T. tetracantha

Zone according to definite species: *T. bromia* zone and rew..
Remarks on the fauna: the assemblage is typical of the *T. bromia* zone, *P. striata striata* must be reworked.

sample 28/1:
C. dissimilis
G. angioporides?
G. ciperoensis angustiumbilicata
G. euapertura?
G. praebulloides occlusa
G. venezuelana
Globigerinoides sp.
G. continuosa
G. increbescens?
G. mayeri?
G. scitula praescitula?
G. suteri

Zone according to definite species: N6 and rew. P15-19?.
Remarks on the fauna: if the identification of *G. increbescens*? and *G. angioporides*? must be reworked.

Kouka section:

sample 15/3:
- *A. nitida?*
- *A. soldadoensis*
- *G. velascoensis?*
- *M. acuta* (TS)
- *M. aequa?* (conf.TS)
- *M. edgari?*
- *M. formosa formosa*
- *M. formosa gracilis*
- *P. chapmani* (TS)
- *P. wilcoxensis*

Zone according to species: P6.
Remarks on the fauna: *A. pentacamerata* is absent, indicating a zone older than P8; *Pseudohastigerina* sp. and well ornamented morozovellids and large acarininids are present, indicating the Early Eocene; *A. soldadoensis* is common, indicating zone P6.

sample 15/52:

FORAMINIFERA:
- *A. pentacamerata?*
- *A. primitiva?*
- *A. soldadoensis*
- *G. velascoensis?*
- *M. f. gracilis*
- *M. lensiformis?*
- *P. chapmani?*
- *P. pseudoscitula*
- *P. wilcoxensis*

Zone according to definite species: P7 and rew. P3-6?.
Remarks on the fauna: large acarinids especially *A. soldadoensis* are dominant and only few questionable *A. pentacamerata* are present, indicating an age of Early Eocene younger P9; reworking of P3-6 is suggested by the presence of *G. velascoensis*? and *P. chapmani*?.

RADIOLARIA:
- *B. tetradica*
- *P. exquisa?*
- *S. babylonis*
- *S. elizabethae*

Zone according to definite species: *B. clinata* zone.
Remarks on the fauna: the zonal marker is absent, only few specimens are found in the sample.

sample 15/7 TS:

FORAMINIFERA:

A. matthewsae?
A. pentacamerata
A. soldadoensis
G. linaperta?
M. formosa formosa
P. wilcoxensis

Zone according to definite species: P8.
Remarks on the fauna: *A. matthewsae* might be wrongly identified as *A. soldadoensis* in the cross section.

sample 15/13:

A. pentacamerata?
A. primitiva
A. spinuloinflata?
Globigerinatheka sp.
P. micra?
T. collactea?
T. topilensis

Zone according to definite species: range P9-13.
Remarks on the fauna: the fauna is badly preserved; *A. soldadoensis* is absent, *A. pentacamerata* is not dominant, *Truncorotaloides sp. and Globigerinatheka sp.* are present, indicating a zone later P9; large globigerinids are absent, indicating an age not younger than early Middle Eocene.
Suggested biozone: P10.

sample 15/15 TS:

FORAMINIFERA:

A. crassata
A. matthewsae
A. pentacamerata
A. soldadoensis?
A. spinuloinflata
M. spinulosa
P. collactea
P. pseudoscitula
P. micra

Zone according to definite species: range P9-12.
Remarks on the fauna: the *A. bullbrooki* group and other typical Middle Eocene taxa present, *A. soldadoensis* is uncertain, indicating Middle Eocene.
Suggested biozone: P10-12.

sample 15/19:

FORAMINIFERA:

A. bullbrooki?
A. crassata?
A. pentacamerata?

G. eocaena?
M. aragonensis
M. spinulosa?
T. collactea?

Zone according to species: range P9-11.
Remarks on the fauna: the specimens are badly preserved but it seems to be a typical Middle Eocene fauna; *A. soldadoensis* is absent, indicating an age of younger than P9.
Suggested biozone: P10-11.

sample 15/Y:

FORAMINIFERA:
A. broedermanni
A. bullbrooki
A. crassata
A. matthewsae
A. pentacamerata
A. spinuloinflata
G. carcoselleensis?
Globigerinatheka sp.?
P. micra
T. libyaensis
T. topilensis

Zone according to definite species: range P10-12.
Remarks on the fauna: *A. pentacamerata is* well developed but not dominant, indicating a zone later P9 and not near the end of the range; a well developed *A. bullbrooki* group and a typical Middle Eocene fauna is present; *G. carcoselleensis* is uncertain but might indicate an age younger P10.
Suggested biozone: P11.

RADIOLARIA:
D. urceolus
L. biaurita
P. striata
S. babylonis
S. acephala
S. elizabethae
T. anapographa
T. rhizodon

Zone according to definite species: range *P. striata* - *T. triacantha* zone.
Remarks on the fauna: only few specimens are present in the sample; *D. amphora* and *D. mongolfieri are* absent, indicating the *P. striata* or *T. cryptocephala* zone?.

sample 15/W:
A. bullbrooki
A. crassata?
A. pentacamerata
G. eocaena?
G. officinalis?
G. linaperta?
G. senni? (TS)

Globigerinatheka? (TS)
M. spinulosa?
P. australiformis?
P. pseudoscitula (TS)
P. pseudoscitula-palmerae transition (TS)
P. micra
P. wilcoxensis (TS)
Turborotalia sp.?
T. topilensis (TS)

Zone according to definite species: range P9-12.
Remarks on the fauna: *A. pentacamerata* is rare; the *A. bullbrooki* group is well developed; large globigerinids are present but not identifiable.
Suggested biozone: P12.

sample 15/V:

FORAMINIFERA:
A. matthewsae
A. pentacamerata?
A. spinuloinflata
G. pseudovenezuelana?
G. senni
G. praebulloides?
Globigerinatheka sp.
M. spinulosa?
T. topilensis?
T. c. cerroazulensis?
T. wilsoni?

Zone according to definite species: range P9-14.
Remarks on the fauna: all specimens are badly preserved and partly truncated; *A. pentacamerata* is uncertain; *G. pseudovenezuelana* and *T. c. cerroazulensis* are most likely correctly identified.
Suggested biozone: P13-14.

RADIOLARIA:
C. hispida
D. amphora
D. mongolfieri
L. aristotelis?
Lithochytris sp.O
P. striata?
P. chalara
P. papalis
S. pachystylus
T. triacantha?

Zone according to definite species: *P. chalara* zone.

sample 15/95:

FORAMINIFERA:
C. dissimilis
G. eocaena

G. pseudovenezuelana?
G. juvenilis?
G. collactea?
G. c. cerroazulensis
G. frontosa?
G. kugleri?
G. opima nana
G. pomeroli
M. acuta?
P. micra?

Zone according to definite species: range P14-17 and rew. Early to Middle Eocene?.
Remarks on the fauna: *G. frontosa*? and *M. acuta*? might be reworked; *G. kugleri* must be wrongly identified; the *A. bullbrooki* group is absent, indicating an age younger P14.
Suggested biozone: range P15-17 and rew.?.

sample 15/96:

FORAMINIFERA:
C. dissimilis ?
G. praebulloides?
G. kugleri?
G. mayeri?
G. opima nana?
G. scitula praescitula?

Remarks on the fauna: no definite identifications are possible; the fauna is not typical for Middle and Late Eocene and might be therefore younger.

RADIOLARIA:
C. turris
D. mongolfieri
L. capito?
S. acephala
T. bromia
T. rhizodon
T. tetracantha

Zone according to definite species: *T. bromia* zone.
Remarks on the fauna: the zonal markers *C. azyx* and *L. aristotelis/angusta* are absent.

sample 15/R:

FORAMINIFERA:
C. dissimilis
G. euapertura
G. praebulloides occlusa
G. venezuelana
G. dehiscens?
G. ruber
G. kugleri?
G. mayeri
G. obesa?
G. opima nana-continuosa transition?
G. suteri?

Zone according to definite species: range N5 - N6.
Remarks on the fauna: large globigerinids are common; *T. cerroazulensis cerroazulensis* is absent, indicating an age of younger Late Eocene; only one definite specimen of *G. ruber* found.

RADIOLARIA:
D. amphora
S. babylonis
S. acephala

Zone according to definite species: *P. striata* - *T. bromia* zone.
Remarks on the fauna: very few and dissolved specimens are present in the sample.

sample 15/98:

RADIOLARIA:
D. mongolfieri
S. babylonis

Zone according to definite species: range *D. mongolfieri* - *T. bromia* zone.
Remarks on the fauna: only very few specimens are present in the sample.

sample 15/Q:

FORAMINIFERA:
C. dissimilis?
G. bollii lentiana?
G. praebulloides sp.
G. cf. tripartita
G. trilobus immaturus?
G. dehiscens?
G. kugleri?
G. mayeri
G. obesa
G. opima nana-continuosa transition
G. suteri

Zone according to definite species: range N5-6.
Remarks on the fauna: *G. opima nana-continuosa* transition is dominant; *G. tripartita* and *G. kugleri* must have been wrongly identified or reworked.

sample 15/100:

FORAMINIFERA:
C. dissimilis
G. falconensis
G. p. praebulloides
G. immaturus?
G, mayeri?
G. opima nana/continuosa transition or G. continuosa
G. s. praescitula
G. zealandica?

Zone according to definite species: N6and7.

Kalavasos section:

sample 35/1:

FORAMINIFERA:

- *A. matthewsae?*
- *A. pentacamerata*
- *A. soldadoensis*
- *G. linaperta?*
- *T. collactea?*

Zone according to definite species: range P8-9.
Remarks on the fauna: *A. pentacamerata* is common and morozovellids were not certainly identified, indicating that the age is not of the central Early Eocene; there are only a few questionable members of the *A. bullbrooki* group and truncorotaliids which is not typical of a Middle Eocene assemblage.
Suggested biozone: P9.

sample 35/3:

FORAMINIFERA:

- *A. broedermanni*
- *A. bullbrooki*
- *A. pentacamerata*
- *A. soldadoensis?*
- *G. c. frontosa?*
- *M. aragonensis?*
- *T. collactea*
- *T. topilensis*

Zone according to definite species:range P9-12.
Remarks on the fauna: *A. pentacamerata* is common, the *A. bullbrooki* group is rare, uncertain *A. soldadoensis*? identifications probably indicate the end of its range, in zone P9.
Suggested biozone: P9.

sample 30/106:

FORAMINIFERA:

- *A. bullbrooki*
- *A. pentacamerata*
- *A. soldadoensis*
- *P. pseudoscitula*
- *T. collactea?*
- *T. libyaensis*

Zone according to definite species: P9and10.
Remarks on the fauna: *A. pentacamerata* is common and clearly more common than in sample 35/3.
Suggested biozone: boundary P9/10.

RADIOLARIA:

- *S. babylonis?*

S. elizabethae

Zone according to species: range *B. clinata* - *P. ampla* zone.
Remarks on the fauna: very few specimens are present in the sample.

sample 30/1:

FORAMINIFERA:
A. bullbrooki
A. matthewsae
A. pentacamerata
G. hagni?
G. praebulloides?
Globigerinatheka sp.
M. spinulosa coronata
T. topilensis?
T. c. frontosa

Zone according to definite species: range P9-12.
Remarks on the fauna: *A. soldadoensis* and large well ornamented morozovellids are absent, indicating a zone of younger P9; *A. pentacamerata* and the *A. bullbrooki* group are well developed.
Suggested biozone: P10-11.

sample 30/C TS:

FORAMINIFERA:
A. bullbrooki
A. spinuloinflata?
T. rohri
T. cerroazulensis cerroazulensis

Zone according to definite species: range P12-14.

sample 30/2:

RADIOLARIA:
D. amphora
D. mongolfieri
E. lagena
P. ampla
S. babylonis
S. elizabethae
T. rhizodon

Zone according to definite species: *P. ampla* zone.

sample 30/3:

FORAMINIFERA:
A. broedermanni
A. bullbrooki

A. matthewsae
A. pentacamerata
G. eocaena?
G. praebulloides occlusa?
Globigerinatheka sp.
T. collactea?
T. rohri
T. topilensis

Zone according to definite species: range P9-12.
Remarks on the fauna: *A. bullbrooki* and *A. pentacamerata* and *Globigerinatheka sp.*are dominant.
Suggested biozone: P11-12.

sample 30/4:

FORAMINIFERA:
A. bullbrooki
A. crassata?
A. matthewsae
A. primitiva
G. angioporides?
G. linaperta?
G. praebulloides occlusa
G. pseudovenezuelana?
M. spinulosa
P. pseudoscitula
P. micra
T, collactea
T. c. cerroazulensis

Zone according to definite species: P13.
Remarks on the fauna: *A. pentacamerata* is absent, indicating a zone of younger P12; *T. opima nana* is absent, indicating a zone of older P14.

RADIOLARIA:
C. hispida
D. amphora
D. mongolfieri
D. urceolus
E. fistuligerum
L. biaurita
P. striata striata
P. ampla
R. ornatum
R. pipa
S. babylonis
T. rhizodon
T. triacantha

Zone according to definite species: *P. ampla* and *P. mitra* zone.
Remarks on the fauna: *E. lagena* and *P. mitra* are absent.
Suggested biozone: *P. ampla* zone.

sample 30/104:

FORAMINIFERA:
- *G. cryptomphala*
- *G. hagni*
- *G. pseudovenezuelana*
- *G. rubriformis*
- *G. yeguaensis*
- *Globigerinatheka sp.*
- *G. c. cerroazulensis*
- *G. cocoaensis*
- *G. opima nana?*
- *G. pomeroli*
- *G. possagnoensis*
- *P. pseudoscitula*
- *T. libyaensis?*
- *T. cf. collactea*

Zone according to definite species: P14.
Remarks on the fauna: large globigerinids are common, indicating late Middle Eocene or Late Eocene; highly evolved members of the *G. cerroazulensis* lineage are present, only a few and questionable acarinids and truncorotaliids are present, indicating latest Middle Eocene or Late Eocene; few questionable *G. opima nana* are present.

RADIOLARIA:
- *C. hispida*
- *D. amphora*
- *D. mongolfieri*
- *D. urceolus*
- *E. fistuligerum*
- *P. chalara*
- *P. papalis*
- *S. acephala*
- *S. lineata*
- *T. rhizodon*
- *T. triacantha?*

Zone according to definite species: *P. chalara* zone.
Remarks on the fauna: *P. striata* is absent, indicating a zone younger *P. mitra* zone.

sample 33/1:

FORAMINIFERA:
- *G. praeturrilina?*
- *G. pseudovenezuelana?*
- *G. juvenilis?*
- *G. c. cerroazulensis*
- *G. opima nana*
- *G. naguewichiensis?*
- *G. suteri*
- *P. pseudoscitula?*

Zone according to definite species: range P14-17.
Remarks on the fauna: acarinids and truncorotaliids are absent, indicating an age younger Middle Eocene; the *G. cerroazulensis* lineage is dominant, indicating Late Eocene.

Suggested biozone: range P16-17.

RADIOLARIA:

C. turris
C. azyx
D. amphora
D. mongolfieri
D. pirium
E. montiparum
P. papalis
S. babylonis
S. ovata

Zone according to definite species: *T. bromia* zone.
Remarks on the fauna: the zonal marker is absent.

sample 31/5:

FORAMINIFERA:

C. dissimilis
G. outachitaensis gnaucki
G. p. praebulloides
G. pseudovenezuelana?
G. yeguaensis?
G. opima nana
P. naguewichiensis
T. cerroazulensis cerroazulensis

Zone according to definite species: range P16-17.
Remarks on the fauna: acarinids and truncorotaliids and *Globigerinatheka sp.* are absent, indicating age of younger Middle Eocene; *G. yeguaensis*? is common; only few *T. cerroazulensis cerroazulensis* are present, possibly indicating the end of the range; *G. mayeri* is absent, suggesting a zone of older N3.
Suggested biozone: P17.

sample 31/2:

FORAMINIFERA:

C. dissimilis
G. euapertura
G. pseudovenezuelana
G. yeguaensis
G. altispira globularis?
G. opima nana
P. naguewichiensis

Zone according to definite species: range P17-18/19.
Remarks on the fauna: *G. mayeri*, *G. opima opima*, *G. scitula praescitula* are absent, indicating an age older Middle Oligocene; the T. cerroazulensis lineage is absent, indicating an age younger Late Eocene; large globigerinids, especially *G. yeguaensis*, are common, indicating an Oligocene age.
Suggested biozone: P18/19.

sample 31/1:

FORAMINIFERA:
- *C. dissimilis*
- *G. ciperoensis angustiumbilicata?*
- *G. euapertura*
- *G. praebulloides occlusa?*
- *G. praebulloides praebulloides*
- *G. venezuelana*
- *G. yeguaensis?*
- *Globigerinoides sp.?*
- *G. altispira globularis?*
- *G. mayeri*
- *G. opima nana/continuosa transition*

Zone according to definite species: N3-6.
Remarks on the fauna: large globigerinids are dominant, mixing of small specimens of *G. yeguaensis* and *Globigerinoides sp.* is possible; *G. ciperoensis angustiumbilicata* is only present as one specimen.

sample 33/4:

FORAMINIFERA:
- *C. dissimilis*
- *G. juvenilis?*
- *G. praebulloides*
- *G. venezuelana?*
- *Globigerinoides?*
- *G. mayeri*
- *G. opima nana/continuosa transition*
- *G. suteri*

Zone according to definite species: range N3-6.

Lefkara section:

sample 21/Z:

no dating is possible, only a few small unidentifiable planktonic foraminifera are present.

sample 21/66:

FORAMINIFERA:
- *A. soldadoensis*
- *G. triloculinoides?*
- *G. velascoensis*
- *M. acuta?*
- *M. aequa*
- *M. convexa*
- *M. formosa formosa*
- *M. formosa gracilis*
- *M. subbotinae*
- *P. chapmani*

Zone according to definite species: P6.
Remarks on the fauna: lightly built morozovellids are common; identification of *G. triloculinoides* must be wrong.

sample 21/68:

RADIOLARIA:
D. fragoides?
D. urceolus
S. acephala

Zone according to definite species: range *P. striata* - *T. triacantha* zone.
Remarks on the fauna: very few specimens are present in the sample.

sample 21/1:

FORAMINIFERA:
A. nitida?
A. pentacamerata?
A. soldadoensis
G. inaequispira?
G. velascoensis?
M. acuta
M. convexa?
M. pseudotopilensis
P. chapmani

Zone according to definite species: P6.
Remarks on the fauna: all specimens are badly preserved, Planorotalites sp. and Acarinina sp. specimens are common; A. pentacamerata? and *G. inaequispira?* point slightly towards P8.
Suggested biozone: P8? and rew..

RADIOLARIA:
B. clinata?
C. ampulla
S. elizabethae

Zone according to species: *B. clinata and P. striata* zone.
Remarks on the fauna: only a few specimens are present in the sample.

sample 21/74:

FORAMINIFERA:
A. pentacamerata
A. soldadoensis?
G. eocaena
M. spinuloinflata
Truncorotaloides sp.?

Zone according to definite species: range P9-12.
Remarks on the fauna: if *A. soldadoensis* is correct the zone must be P9.
Suggested biozone: P9?.

sample 21/2:

FORAMINIFERA:
A. broedermanni?
A. pentacamerata
A. primitiva?
A. soldadoensis? (conf.TS)
A. spinuloinflata? (conf.TS)
M. aragonensis
Pseudohastigerina sp.?
Truncorotaloides sp.?

Zone according to definite species: P9.
Remarks on the fauna: *A. pentacamerata* is dominant, indicating P9; the *A. bullbrooki* group and *Truncorotaloides sp.* are weakly developed.

RADIOLARIA:
D. amphora

Zone according to definite species: range *P. striata - T. bromia* zone.
Remarks on the fauna: very few specimens are present.

sample 21/3:

FORAMINIFERA:
A. broedermanni
A. matthewsae
A. pentacamerata
Globigerinatheka sp.?
P. micra
T. collactea
T. rohri
T. cerroazulensis sp.?
T. wilsoni?

Zone according to definite species: range P 9-12.
Remarks on the fauna: *A. soldadoensis* is absent, indicating a zone of later P9; the *A. bullbrooki* group is weakly developed; *A. pentacamerata and Globigerinatheka* sp.(?) are common; *T. cerroazulensis sp.* from the older part of the lineage is present.
Suggested biozone: P10.

RADIOLARIA:
B. clinata
D. fragoides
S. elizabethae
T. hirsuta

Zone according to definite species: range *B. clinata - P. striata* zone.
Remarks on the fauna: very few specimens are present in the sample and therefore absences are not reliable.

sample 21/4:

FORAMINIFERA:
A. matthewsae
A. pentacamerata?
Globigerinatheka sp.?
M. aragonensis
M. spinulosa
P. micra
T. collactea

Zone according to definite species: range P9-11.
Remarks on the fauna: *A. pentacamerata* is well developed but not dominant, *A. soldadoensis* is absent, indicating an age of younger P9.
Suggested biozone: P10-11.

sample 21/7:

FORAMINIFERA:
A. broedermanni?
A. bullbrooki
A. matthewsae
A. pentacamerata
A. spinuloinflata
Globigerinatheka sp.?
P. micra
T. collactea?
T. topilensis
T. cerroazulensis sp.?

Zone according to definite species: range P9-12.
Remarks on the fauna: *Globigerinatheka sp.*(?) and the *A. bullbrooki* group are well developed; *A. soldadoensis* is absent, indicating an age of younger P9.
Suggested biozone: P10-12.

RADIOLARIA:
B. clinata
C. castum
D. urceolus
L. archaea
P. striata exquisa
P. striata striata
P. diamesa
S. babylonis
S. elizabethae
T. nigrinae?
T. alpha?
T. hirsuta

Zone according to definite species: *B. clinata and P. striata* zone.
Remarks on the fauna: a cooccurrence of *P. striata striata* and *P. striata exquisa* exists.

sample 21/8:

RADIOLARIA:
D. amphora
D. urceolus
L. archaea
L. biaurita
P. striata exquisa
P. striata striata
P. aphorma
P. papalis
S. babylonis
S. acephala
S. elizabethae
T. anapographa?
T. hirsuta

Zone according to definite species: *B. clinata and P. striata* zone.
Remarks on the fauna: cooccurrence of *P. striata striata* and *P. striata exquisa*.
Suggested biozone: *P. striata* zone.

sample 21/9:

FORAMINIFERA:
A. broedermanni?
A. matthewsae
A. pentacamerata
C. dissimilis
M. aragonensis
M spinulosa?
Truncorotaloides sp.?

Zone according to definite species: P11 and P12.
Remarks on the fauna: cooccurrence of *C. dissimilis* and *M. aragonensis* indicates mixing of zones.
Suggested biozone: boundary P11/12.

sample 21/91:

FORAMINIFERA:
A. bullbrooki?
A. pentacamerata
Globigerinatheka?
T. collactea?

Zone according to definite species: range P9-12.
Remarks on the fauna: all specimens are badly preserved.

RADIOLARIA:
A. clava
C. hispida
D. fragoides
D. amphora
D. mongolfieri

- *D. urceolus*
- *E. lagena*
- *E. fistuligerum*
- *L. biaurita*
- *P. striata striata*
- *P. papalis*
- *S. babylonis*
- *S. acephala*
- *S. elizabethae*
- *P. aphorma*
- *P. fasciola*
- *P. sinuosa*
- *T. rhizodon*
- *T. triacantha*

Zone according to definite species: *T. triacantha* (and *P. ampla*) zone.
Remarks on the fauna: the fauna indicates *T. triacantha* zone, an exception is *P. fasciola*; the zonal marker *T. triacantha* is present.

sample 21/57:

FORAMINIFERA:
- *G. c. cerroazulensis?*
- *G. opima nana?*
- *P. pseudoscitula?*

Zone according to species: P14?.
Remarks on the fauna: no definitely identifiable foraminifera are present, the sample contains only few specimens.

RADIOLARIA:
- *C. hispida*
- *D. amphora*
- *D. mongolfieri*
- *D. urceolus*
- *E. lagena*
- *E. fistuligerum*
- *L. biaurita*
- *P. striata striata*
- *P. diamesa*
- *P. papalis*
- *R. ornatum*
- *S. babylonis*
- *S. acephala*
- *S. elizabethae*
- *S. lineata*
- *T. rhizodon*

Zone according to definite species: *T. triacantha* zone.
Remarks on the fauna: the zonal marker is absent.

sample 21/50:

FORAMINIFERA:
- *C. dissimilis*
- *G. ampliapertura*
- *G. ciperoensis angustiumbilicata*
- *G. eocaena?*
- *G. euapertura?*
- *G. tapuriensis?*
- *G. venezuelana*
- *G. yeguaensis*
- *G. opima opima?*
- *G. opima nana/continuosa transition or G. opima nana?*

Zone according to definite species: N1 and N2 and rew. P18?.
Remarks on the fauna: many large globigerinids are present, indicating an age of Late Eocene or younger; members of the *G. cerroazulensis* lineage and *P. micra* are absent, indicating an age of younger Late Eocene; species identified as *G. opima opima*? have dimensions between 0.36mm and 0.47mm, these belong to the transition *G. opima nana/ opima opima* which is also restricted to N2 (Bolli & Saunders, 1985)); only questionable species indicate an Oligocene age: *G. tapuriensis*? and *G. eocaena*?.
Suggested biozone: boundary N1/2 and rew..

sample 21/10:

FORAMINIFERA:
- *G. c. ciperoensis*
- *G. gortanii?*
- *Globigerinoides sp.*
- *G. cf. altispira globosa*
- *G. dehiscens?*
- *G. continuosa*
- *G. mayeri?*
- *G. opima opima*
- *G. scitula praescitula?*
- *G. zealandica?*

Zone according to species: range N6-7 and rew. N2.
Remarks on the fauna: *O. universa* is absent, indicating an age older N9; *C. dissimilis* is absent, indicating an age of younger N6; one group of species indicates a range from N6 to N7, a second one N2.
Suggested biozone: N7 and rew..

RADIOLARIA:
- *D. amphora*
- *L. biaurita*
- *S. elizabethae*

Zone according to definite species: range *P. striata - P. ampla* zone.

sample 21/77:

FORAMINIFERA:
- *C. dissimilis*

G. euapertura
Globigerinoides sp.?
G. continuosa
G. mayeri
G. cf. hexagonus

Zone according to definite species: N3-6.
Remarks on the fauna: *G. hexagonus* is not certain but most likely, indicating N7.
Suggested biozone: boundary N6/7.

Stavrovouni section:

sample 24/50:

FORAMINIFERA:
A. matthewsae?
A. pentacamerata
A. soldadoensis
G linaperta?
M aragonensis
M quetra?
T. collactea?
T. rohri?
T. topilensis?

Zone according to species: range P8-9.
Remarks on the fauna: only a few morozovellids are present, indicating an age of younger central Early Eocene; large acarinids are common, indicating Early Eocene; *A. soldadoensis is rare* and *A. pentacamerata* is dominant, indicating zone P9.
Suggested biozone: P9.

sample 24/1:

FORAMINIFERA:
A. mckannai? (TS?)
A. pentacamerata
A. primitiva?
A. soldadoensis
G. triloculinoides?
G. velascoensis
M. acuta?
M. aequa?
M. angulata
M. conicotruncata
P. chapmani (TS)
P. pusilla pusilla?
P. wilcoxensis (TS)
T. collactea
T. rohri

Zone according to definite species: P9 and rew. P3-4.
Remarks on the fauna: many ornamented undetermined morozovellids and large acarinids are present: the fauna is dominated by Palaeocene taxa; clear evidence for P9 is one specimen of *T.*

rohri and the dominantly badly preserved *A. pentacamerata* and *T. collactea*.
Suggested biozone: P9 and rew..

RADIOLARIA:
C. hispida
D. urceolus
L. biaurita
P. striata exquisa
P. papalis
S. babylonis
S. elizabethae
T. acroria
T. hirsuta

Zone according to definite species: *B. clinata* zone.
Remarks on the fauna: the zonal marker is absent.

sample 24/62:

FORAMINIFERA:
A. bullbrooki
A. pentacamerata?
M. aragonensis?
M. spinulosa?
Truncorotaloides sp.?
T. topilensis?

Zone according to definite species: range N9-14.
Remarks on the fauna: the sample contains very few planktonic foraminifera specimens all in a bad state of preservation.
Suggested biozone: P9-11.

RADIOLARIA:
D. amphora
D. mongolfieri?
D. urceolus
L. archaea
L. biaurita
P. striata striata
P. diamesa?
P. papalis
S. babylonis
S. acephala
S. elizabethae
T. anapographa?
T. tensa

Zone according to definite species: range *P. striata* - *D. mongolfieri* zone.
Remarks on the fauna: Only a few specimens are present in the sample, therefore the absence or presence of species is unreliable.

sample 24/2:

FORAMINIFERA:
A. broedermanni
A. bullbrooki
A. pentacamerata
A. spinuloinflata
G. hagni?
'H.' cf. cf. bolivariana
M. formosa formosa?
P. pseudoscitula
P. micra
T. rohri
T. topilensis?
T. wilsoni

Zone according to species: range P9-12.
Remarks on the fauna: *Globigerinatheka sp.* is absent and a few members of the *A. bullbrooki* group are present, indicating early Middle Eocene; *A. pentacamerata* is common but not dominant, *A. soldadoensis* is absent, indicating an age of younger P9; *'H.' cf. bolivariana* is uncertain; *M. formosa formosa* is possibly reworked.
Suggested biozone: P10 and rew..

RADIOLARIA:
C. ampulla
D. amphora
D. mongolfieri
D. urceolus
E. lagena?
L. archaea
L. biaurita
P. striata striata
P. aphorma
P. hirsuta
P. papalis
P. sinuosa
R. ornatum
S. babylonis
S. acephala
S. elizabethae
S. lineata
T. anaclasta
T. cryptocephala
T. ficus
T. rhizodon
T. tensa?

Zone according to definite species: *D. mongolfieri* zone.

sample 24/F TS:

FORAMINIFERA:
A. broedermanni
A. bullbrooki
Globigerinatheka sp.

M. aragonensis
T. cerroazulensis sp.

Zone according to species: range P9-11.

sample 24/4:

FORAMINIFERA:
A. broedermanni?
A. bullbrooki
A. crassata
A. matthewsae
A. pentacamerata?
A. spinuloinflata
G. eocaena
G. pseudovenezuelana
G. yeguaensis
Globigerinatheka sp.?
M. spinulosa
P. micra
T. rohri
T. c. cerroazulensis
T. c. pomeroli?
T. wilsoni?

Zone according to definite species: P13-14 and rew. P9-12?.
Remarks on the fauna: a typical Middle Eocene fauna is present; large globigerinida are common; *G. opima nana* is absent, indicating a zone earlier P14; *A. broedermanni*?, *A. pentacamerata?* and *T. wilsoni*? might indicate reworking of zones P9-12.
Suggested biozone: P13 and rew..

RADIOLARIA:
C. hispida
D. amphora
D. mongolfieri
D. urceolus?
E. fistuligerum
P. striata striata
P. helenae?
P. mitra
P. papalis
S. babylonis
S. triconiscus
S. acephala
S. pachystylus
T. ficus
T. lochites
T. rhizodon
T. triacantha

Zone according to definite species: *P. mitra* zone.
Remarks on the fauna: *S. elizabethae* is absent, indicating a zone of younger *P. ampla* zone.

sample 24/55:

RADIOLARIA:
C. hispida
D. amphora
D. mongolfieri
D. cf. pirium
D. urceolus
E. fistuligerum
P. chalara
P. papalis
S. babylonis
S. acephala
S. lineata
S. nodosaria
T. rhizodon

Zone according to definite species: *P. chalara* zone and rew..
Remarks on the fauna: *D. urceolus* and *P. aphorma* must be reworked from *P. striata* sediments.

sample 24/56:

FORAMINIFERA:
C. dissimilis
G. opima nana
G. opima nana/continuosa transition?
G. permicra?

Zone according to most likely species: P17-N1.
Remarks on the fauna: the fauna is monotonous which possibly indicates selective dissolution; the T. cerroazulensis lineage is absent, indicating an age younger than Late Eocene.
Suggested biozone: P18/19-N1.

sample 24/57:

FORAMINIFERA:
C. dissimilis?
G. ciperoensis sp.?
G. euapertura?
G. officinalis?
G. yeguaensis?
Globigerinatheka sp.?
G. opima nana?
T. c. pomeroli?

Zone according to most likely species: P17 to N1.
Remarks on the fauna: no definitely identifiable specimens are present but *G. opima nana*-like specimens are common.
Suggested biozone: N1?

RADIOLARIA:
C. turris
D. amphora
D. mongolfieri

L. plegmacantha
L. aristotelis
L. amphitrite
P. striata striata
S. acephala
S. lineata
S. babylonis
T. cryptocephala
T. tuberosa?
T. bromia
T. rhizodon
T. tetracantha
montiparum

Zone according to definite species: *T. bromia* zone and rew..
Remarks on the fauna: *L. plegmacantha*, *P. striata striata* and *T. cryptocephala* must be reworked from *D. mongolfieri* biozone.

sample 24/5:

FORAMINIFERA:
A. spinuloinflata
C. dissimilis
G. euapertura
G. venezuelana
G. yeguaensis?
Globigerinoides sp.?
G. suteri?
P. micra?
T. cerroazulensis cerroazulensis

Zone according to species: uncertain range of N1-6 and rew. P12-14.
Remarks on the fauna: *A. spinulosa*, *P. micra* and *T. cerroazulensis cerroazulensis* indicate a reworked Middle Eocene fauna; *G. yeguaensis* and *Globigerinoides sp.* cannot be distinguished and certified.
Suggested biozone: N1 and rew..

Motorway section:

sample 48/6:

FORAMINIFERA:
A. pentacamerata?
A. soldadoensis?

Remarks on the fauna: very bad fossil preservation; only a few planktonic foraminifera specimens are present; large undetermined acarinids are present.
Suggested biozone: P8-9?.

sample 47/4:

FORAMINIFERA:
A. pentacamerata?

Remarks on the fauna: no identifiable specimens were found; large acarinids and morozovellids are dominant.
Suggested biozone: Early Eocene.

sample 47/5:

FORAMINIFERA:
A. pentacamerata?
A. primitiva?
A. soldadoensis
G. velascoensis?
M. formosa

Zone according to definite species: range P6-8.
Remarks on the fauna: large acarinids and morozovellids are common, the *A. bullbrooki* group is absent, indicating an Early Eocene age; the cooccurrence of *A. soldadoensis* and *A. pentacamerata*? and *M. formosa* might indicate the zone P8; *G. velascoensis*? might indicate reworked material from P6.
Suggested biozone: P8? and reworking.

RADIOLARIA:
B. tetradica?
D. fragoides?

Zone according to species: range *B. bidartensis* - *B. clinata* zone.
Remarks on the fauna: very few specimens are present in the sample, no definite identifications are possible.

sample 47/6K:

RADIOLARIA:
B. tetradica

Zone according to definite species: range unzoned interval - *B. bidartensis* zone.

sample 47/6A:

FORAMINIFERA:
A. pentacamerata?
A. soldadoensis?
G. linaperta?

Remarks on the fauna: no specimen can definitely be identified.
Suggested biozone: range P8-9.

sample 46/1C:

FORAMINIFERA:
- *A. pentacamerata*
- *A. soldadoensis*
- *A. spinuloinflata*
- *G. cryptomphala*
- *G. linaperta?*
- *M. f. formosa*
- *M. spinulosa?*
- *T. wilsoni?*
- *T. collactea*

Zone according to definite species: P8 and 9.
Remarks on the fauna: *A. pentacamerata* is common, indicating zone P9; *A. soldadoensis* is common, indicating Early Eocene.
Suggested biozone: boundary P8/9.

sample 43/A1:

RADIOLARIA:
- *C. hispida*
- *D. amphora*
- *D. mongolfieri*
- *D. urceolus*
- *E. fistuligerum*
- *E. lagena?*
- *L. biaurita*
- *P. striata striata*
- *P. diamesa?*
- *P. papalis*
- *S. babylonis*
- *S. elizabethae*
- *S. lineata*
- *T. rhizodon*
- *T. triacantha*

Zone according to definite species: *T. triacantha* zone.

sample 44/4:

RADIOLARIA:
- *C. hispida*
- *D. amphora*
- *D. mongolfieri*
- *D. urceolus*
- *E. fistuligerum*
- *E. lagena*
- *P. pentas*
- *P. mitra?*
- *S. babylonis*
- *T. rhizodon*
- *T. triacantha?*

Zone according to definite species: *P. mitra* zone.
Remarks on the fauna: one specimen of the marker species is present but damaged.

sample 49/14:

FORAMINIFERA:
- *A. broedermanni*
- *A. bullbrooki*
- *A. matthewsae*
- *A. spinuloinflata*
- *G. linaperta*
- *T. collactea*
- *T. rohri?*

Zone according to definite species: range P9-12.
Remarks on the fauna: the sample shows a typical Middle Eocene fauna; *A. pentacamerata* is absent, possibly indicating an age of later P12; *A. soldadoensis* is absent, indicating a zone of younger P9; no large globigerinids are present.
Suggested biozone: P12.

RADIOLARIA:
- *C. hispida*
- *D. amphora*
- *D. mongolfieri*
- *D. urceolus*
- *E. fistuligerum*
- *E. lagena*
- *L. vespertilio?*
- *L. biaurita*
- *P. papalis*
- *P. sinuosa*
- *R. pipa*
- *S. babylonis*
- *S. elizabethae*
- *S. lineata*
- *T. ficus*
- *T. rhizodon*
- *T. triacantha*

Zone according to definite species: *T. triacantha* zone.

sample 49/5:

FORAMINIFERA:
- *C. dissimilis*
- *G. ampliapertura?*
- *G. eocaena*
- *G. euapertura*
- *G. praebulloides*
- *G. pseudovenezuelana?*
- *G. sellii*
- *G. venezuelana*
- *G. yeguaensis?*
- *G. increbescens*

G. opima nana
G. carcoselleensis?
G. suteri

Zone according to definite species: P18/19 and N1.
Remarks on the fauna: *G. suteri* is common; undetermined specimens similar to *G. mayeri* were found; the Mediterranean zones overlap the low latitude N1 partly, therefore *G. venezuelana* starts in Early Oligocene according to the N/P zonation.

sample 49/16:

FORAMINIFERA:
C. dissimilis
G. ciperoensis ciperoensis
G. euapertura
G. juvenilis?
G. venezuelana
G. suteri
G. increbescens
G. mayeri
G. opima nana

Zone according to definite species: N3 and rew. Late Eocene?.
Remarks on the fauna: *C. dissimilis* is common; *G. opima opima* is absent, indicating an age younger or older than N2; some large globigerinids and few specimens resembling the *G. cerroazulensis* lineage are present, possibly indicating reworked Late Eocene material.
Suggested biozone: N3 and rew.?.

sample 49/100:

FORAMINIFERA:
C. dissimilis
G. ciperoensis ciperoensis
G. euapertura
G. falconensis?
G. praebulloides leroiy
G. praebulloides praebulloides
Globigerinoides sp.
G. dehiscens?
G. mayeri
G. opima nana / continuosa transition
G. suteri

Zone according to species: range N3-6.
Remarks on the fauna: *Globigerinoides sp.* is common, possibly indicating an Early Miocene age.
Suggested biozone: range N4-6.

APPENDIX B. Field relationship of samples studied for sedimentation rates and discussion of dating.

In the **Ayios Nicolaos section**, the comparatively closely spaced samples 18/22 and 18/1 with only few metres estimated between them shows a time jump from biozone P5 to P9 (59-53Ma), indicating slow sedimentation, non-deposition, or erosion near the base of the Lower Marl. Most of the Chalk & Chert unit in this locality was not measured but a regular decrease in age can be assumed throughout the deposition of the unit. A possible but not proved time jump is present between samples 28/C and 28/E. Both were taken from the massive chalks but not from the same outcrop so that a tectonic disruption between them cannot be excluded. But since the samples come from the same facies the dating of the biozones P12 from the Middle Eocene and N3 from the Late Oligocene might indicate a break or decrease in deposition. Evidence for the existence of some deposition during this time span was found in sample 18/57 which contains reworked radiolarians from the (foraminifera) biozone range P15-18/19. A definite time jump from biozone N3 to N6/7 is present between sample 28/E and sample 28/B dated from 2m above. The lower sample is taken from the top of the massive chalk facies and the younger one from the start of the bedded chalks intercalated with 10cm thick marl beds near the top of the unit. No unconformity can be seen between the two sample positions. A sedimentation rate of approximately 0.2m/Ma is calculated (10Ma in 2m) indicating erosion or a very slow rate of deposition. The only Upper Marl sample dated in this section has the same age as the top of the Chalk unit (N6/7).

The lowest outcrop of the **Kouka section** from the highest, chert-bearing part of the Lower Marl unit is only 3m thick but shows a steady decrease in age in a high sample density from foraminifera biozone P6 at the bottom, over P7, and P8, to P10 at the top of the outcrop and unit. This includes sediments with approximate ages between 58 and 51Ma, leading to a sedimentation rate of 0.4m/Ma. Except the basal sample of the Chalk & Chert unit which is dated to biozone P10 all further samples of the unit, most likely up to the top, are of biozone P11. Assuming a start of the unit in the middle of P10 and ranging up to the middle of P11 (51-47Ma) leads to a duration of the Chalk & Chert unit of 4Ma. Although faults were observed in the succession the whole unit is most likely only 20m thick, leading to a sedimentation rate of 5m/Ma which is significantly higher than the one calculated for the Lower Marl.

Due to faulting and folding no good resolution in dating and logging was obtained from the Chalk unit of the Kouka section. Only in the uncharacteristic outcrop near the top of the unit where regularly interbedded silicified strata are present the calculation of the sedimentation rate is possible. The lowest sample is of the biozone range P15-P18 (sample 15/96) which does not indicate any irregularity in time-development during the deposition of the Chalk unit up to this point. A time jump is present between this sample and the one taken from approximately 4m above and dated to N4/6 (sample 15/R). An approximation of the sedimentation rate (assuming a time range between 37Ma and 21Ma in 4m) leads to a low value of 0.3m/Ma. Above, no indications for a low sedimentation can be seen since the lowest sample from the Upper Marl is dated to N4/6 (sample 15/Q) and the highest possible one to the boundary N6/7 (sample 15/100) but no sediment thickness could be measured due to incomplete outcrops and strong weathering.

The sediments of most of the **Lefkara section** are strongly disturbed by tectonics which obscure the relationship of the outcrops to each other and made logging difficult. A slow sedimentation in the lower chert-rare part of the Lower Marl unit might be assumed since the samples dated from two different but most likely closely spaced outcrops show a rapid decrease in age from P6 (sample 21/66) to P9 (sample 21/68). In the higher part of the unit two closely spaced samples are dated to P9 and P10 but no sedimentation rate can be calculated since both samples might lie close to the boundary of the biozone and might therefore be of similar age. .

The bottom of the Chalk & Chert unit (sample 21/7) are dated to P10-12 (assumed P11 here) and the next sample from a separate outcrop high up in the Chalk unit already has an biozone-age of the base of P12. This indicates a rather high sedimentation rate for the Chalk & Chert unit. Although the unit could not be measured in total about 13m were logged, being the minimum of the real thickness. For 13m the sedimentation rate would approximate 4.3m/Ma but a higher rate must be assumed.

Taking the base of the Chalk unit as being at the start of P12 (sample 21/9) (although it might include parts of P11) the next sample dated is from the chert-bearing interval in the highest part of the unit and is dated to biozone P14 (sample 21/57). This suggests a gradual decrease in age during the deposition of the unit. A possible time jump is detected towards the next higher sample near the top of the unit (21/10). Although the succession is strongly folded and the field relationship not clear, the distance between the two samples should be only in the order of magnitude of tens of metres, including the long time span from P14 to the boundary between the biozones N6/7. The Upper Marl sample dated is of the same age as the underlying chalks.

The **Kalavasos section** is free of tectonic disturbance and only logged from the Chalk & Chert unit onwards. A gradual time succession is assumed from the top of the Lower Marl (sample 35/3, P9) to the bottom of the Chalk & Chert unit (sample 30/106, boundary P9/10). The lowest part of the unit could not be measured but the above outcrop logged ranges approximately from the middle of P10 up to the highest sample dated near the top of the Chalk & Chert unit of approximately the top of P11. A duration of 5Ma (51-46Ma) for 10m leads to a approximate sedimentation rate of 2m/Ma.

The bottom part of the Chalk unit of the Kalavasos section, still being composed of turbidite deposits, is dated between P12 (sample 30/2, 46Ma) and P13 (sample 30/4, 42.6Ma) for the sediment succession of 18m, indicating a sedimentation rate of 5m/Ma. Higher up in the Chalk unit only isolated outcrops were found, showing a regular time-succession of the dated samples from P14 (sample 30/104) to P17 (sample 31/5) at the top of the unit and to P18/19 in the transitional zone towards the Upper Marl (sample 31/2). The sedimentation rate of the complete Upper Marl unit is calculated between the transitional zone from the Chalk unit to the top of the Upper Marl unit which is assumed to be the top of biozone N4/6. The time span of 18Ma in 18m of the succession measured leads to a significantly smaller sedimentation rate than for the turbiditic part of the Chalk unit with 1m/Ma.

The **Stavrovouni section** shows a gradual time development from the oldest Lower Marl sample from the chert-bearing part of the unit up to the top sample of the unit, from biozone P8/9 (sample 24/1) over P9 (sample 24/62) to P10 (sample 24/2). The calculated sedimentation rate for 2Ma in 6m turbiditic succession is 3m/Ma.

The lowest sample of the Chalk unit right above the fault that possibly terminated the Chalk & Chert unit is dated to P11 (49Ma). This indicates a high sedimentation rate, considering that most of the underlying unit is missing. The next sample approximately 35m higher up in the continuously measured outcrop is dated to P14 (42.6Ma) which leads to a sedimentation rate of 5.5m/Ma which is higher than the Lower Marl turbidite succession. The bottom sample of the higher outcrop is dated to P14 too (sample 24/55), confirming the assumption that the two outcrops formed a more or less continuous succession. After few metres of chalk facies the overlying sample (24/56) is of P 18/19 which indicates a time jump. Since the whole outcrop is strongly sheared and faulted the time-break might be caused by tectonics although a hiatus or slower sedimentation cannot be excluded. The sample several metres above (24/57) from the flaggy and marl-containing highest part of the Chalk unit is still dated to P18/19 and the Upper Marl sample to biozone N1 (24/5), not showing any reduced sedimentation rate in this time period.

In the **Motorway section** all samples of the Lower Marl unit, starting from the contact to the pillow lava, are most likely from biozone P8. The outcrop is nearly continuously logged over 20m (total thickness estimated to 40m) and assuming a time range between 55 and 53Ma a high sedimentation rate of 10 to 20m/Ma is calculated.

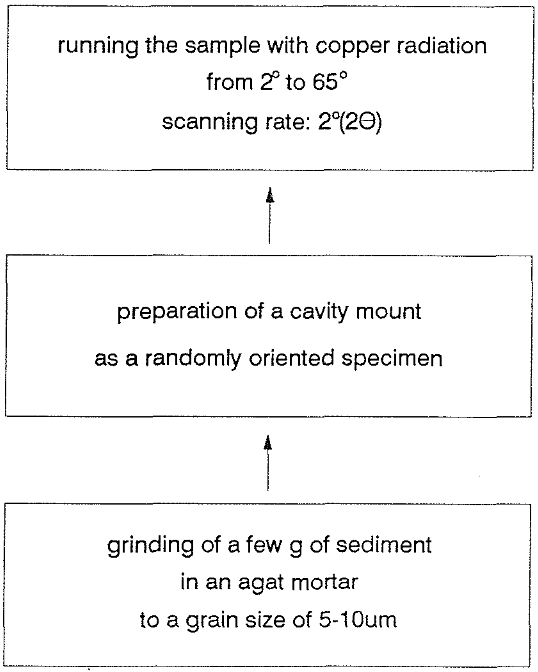
The Chalk & Chert unit is most likely sampled near its base and is dated to the start of P9. A sample taken from an isolated, tectonically disrupted Chalk & Chert outcrop is dated to P10-11 (sample 49/14) but the dating of a sample from the base of the Chalk unit (sample 43/A1) indicates the end of the Chalk & Chert unit during P10. This indicates a comparatively high sedimentation rate but no thicknesses and sedimentation rates for the unit could be obtained here.

The Chalk unit of the Motorway section starts near the top of P10 (sample 43/A1) and is dated to the top of P12 in a separate outcrop. The highest sample dated is from the top of the Chalk unit near the transitional zone to the Upper Marl unit and is of biozone P18/19 (sample 49/5). No relationship between the single outcrops could be found. The next sample (49/16) dated 5m above the highest Chalk sample (49/5: 35Ma) and located in the transitional facies towards the Upper Marl already is dated to the (mid) of N3 (26Ma), resulting in a sedimentation rate of 0.6m/Ma. Silty sandy beds in the transitional zone might be first indicators of erosion, as contourites are confirmed for the overlying Upper Marl unit. The low sedimentation rate might be therefore explained by erosion and non-deposition. Although the Upper Marl succession is divided from the transitional zone by a zone of numerous faults the only Upper Marl sample dated is of biozone N4/6 which might also indicate a slow sediment accumulation for the highest part of the formation.

APPENDIX C. Composition of the sand fraction (radiolarian spines not included into percentages).

sample	plankt. forams	benth. forams	radios	radio spines	clasts	indet.	sum count	% plankt.	% benthic	% radios	% clasts
18/22	320	1	0	0	2	1	324	98.77	0.31	0	0.62
18/3	250	0	0	0	0	0	250	100	0	0	0
18/7	273	0	4	1	5	1	284	96.47	0	1.41	1.77
18/23	142	0	5	0	40	2	189	75.13	0	2.65	21.16
18/59	243	0	0	0	0	1	244	99.59	0	0	0
28/C	248	0	70	1	2	1	322	77.26	0	21.81	0.62
28/E	156	0	173	14	0	0	343	47.42	0	52.58	0
28/1	265	3	0	0	3	4	275	96.36	1.09	0	1.09
15/102	34	0	11	0	0	9	54	62.96	0	20.37	0
15/3	287	0	0	0	2	0	289	99.31	0	0	0.69
15/13	275	0	2	0	0	0	277	99.28	0	0.72	0
15/14	259	0	0	0	0	0	259	100	0	0	0
15/19	256	1	7	0	1	2	267	95.88	0.37	2.62	0.37
15/Z	339	0	2	0	3	2	346	97.98	0	0.58	0.87
15/Y	260	0	4	0	2	0	266	97.74	0	1.5	0.75
15/X	217	1	41	1	9	0	269	80.97	0.37	15.3	3.36
15/W	261	1	37	0	4	1	304	85.86	0.33	12.17	1.32
15/L	213	1	53	1	0	4	272	78.6	0.37	19.56	0
15/96	244	1	6	0	6	4	261	93.49	0.38	2.3	2.3
15/S	284	0	5	0	2	0	291	97.59	0	1.72	0.69
15/98	262	0	41	0	1	0	304	86.18	0	13.49	0.33
15/Q	321	4	1	0	0	2	328	97.87	1.22	0.3	0
15/100	274	3	0	0	1	1	279	98.21	1.08	0	0.36
35/2	2	0	15	0	0	0	17	11.76	0	88.24	0
35/3	306	0	0	1	1	6	314	97.76	0	0	0.32
30/106	335	0	1	0	0	3	339	98.82	0	0.29	0
30/1	92	0	229	7	34	5	367	25.56	0	63.61	9.44
30/3	135	0	180	26	4	3	348	41.93	0	55.9	1.24
30/104	250	0	58	24	0	3	335	80.39	0	18.65	0
33/1	272	0	99	16	1	4	392	72.34	0	26.33	0.27
31/5	327	0	2	0	6	17	352	92.9	0	0.57	1.7
33/4	340	4	0	0	3	4	351	96.87	1.14	0	0.85
21/Z	34	11	1	0	9	2	57	59.65	19.3	1.75	15.79
21/66	289	1	0	0	0	1	291	99.31	0.34	0	0
21/68	255	0	0	0	0	0	255	100	0	0	0
21/3	285	5	2	0	6	2	300	95	1.67	0.67	2
21/7	277	0	1	0	0	0	278	99.64	0	0.36	0
21/9	234	1	3	1	31	5	275	85.4	0.36	1.09	11.31
21/91	59	0	81	80	1	2	223	41.26	0	56.64	0.7
21/57	11	1	137	96	1	0	246	7.33	0.67	91.33	0.67
21/50	244	2	5	0	23	0	274	89.05	0.73	1.82	8.39
21/77	306	4	0	0	3	2	315	97.14	1.27	0	0.95
24/51	3	0	0	0	313	0	316	0.95	0	0	99.05
24/50	331	0	0	0	2	1	334	99.1	0	0	0.6
24/1	345	1	5	0	8	2	361	95.57	0.28	1.39	2.22
24/2	120	0	1	0	3	0	124	96.77	0	0.81	2.42
24/4	264	1	74	22	20	4	385	72.73	0.28	20.39	5.51
24/57	324	1	2	0	1	4	332	97.59	0.3	0.6	0.3
24/5	376	5	1	3	2	6	393	96.41	1.28	0.26	0.51
48/6	31	28	13	0	0	19	91	34.07	30.77	14.29	0
47/4	50	3	10	0	1	5	69	72.46	4.35	14.49	1.45
47/5	174	14	26	0	1	11	226	76.99	6.19	11.5	0.44
47/6A	28	0	1	0	0	1	30	93.33	0	3.33	0
46/1C	259	7	0	0	0	1	267	97	2.62	0	0
43/A1	17	0	145	87	0	1	250	10.43	0	88.96	0
44/4	45	0	111	83	20	27	286	22.17	0	54.68	9.85
49/14	27	0	131	121	1	4	284	16.56	0	80.37	0.61
49/5	305	7	0	0	4	3	319	95.61	2.19	0	1.25
49/16	311	0	1	0	7	3	322	96.58	0	0.31	2.17
49/100	280	3	0	1	0	0	284	98.94	1.06	0	0

APPENDIX D.1. Sample preparation technique for XRD bulk mineral analysis.



APPENDIX D.2. Results of the XRD bulk mineral analysis; sample material is analysed in cavity mounts. Values are intensities measured for calcite at d=3.036Å, clay at d=4.47-4.5Å, quartz at d=3.34Å.

sample	age(Ma)	intensity calcite	intensity clay	intensity quartz
15/102	66	150	160	335
15/3	58	2756	71	140
15/13	52	2760	67	111
15/19	49	3085	0	52
15/33	48	1154	0	741
15/Y	47.5	2903	57	71
15/X	47	2830	60	67
15/W	46	3100	44	48
15/L	42.5	2663	86	137
15/95	38	3030	45	59
15/96	37	2697	52	42
15/R	23	2890	61	62
15/Q	20	2218	124	429
18/1	53	2826	67	148
18/2	52.6	3029	53	81
18/8	52.3	3349	44	35
18/7	52	3003	49	77
18/23	50.5	2835	43	57
28/D	49	3155	40	42
28/C	46	2712	68	75
28/E	28	3171	61	73
28/A	18	2969	53	67
28/1	17.5	2852	67	87
24/1	53	3170	46	51
24/2	52	2669	56	75
24/4	43	2900	54	59
24/5	34	2964	65	64
35/2	66	150	219	727
35/3	53	2265	58	113
30/1	49	2494	77	81
30/2	46	2313	87	92
30/4	43	2345	93	100
30/104	42.5	2611	61	92
33/1	37	2760	59	70
31/5	36.5	2895	54	52
31/2	36	2759	73	113
31/1	23	2736	70	113
33/4	19	2449	66	117
48/3	66	171	242	649
48/6	55	2381	82	128
47/4	54.5	2160	101	146
47/6	54	2289	96	156
47/1	53.5	1886	83	89
46/1	53	2847	59	156
43/10	51.5	2250	84	90
43/13	51	2524	63	88
43/1	49	2161	90	85
44/4	43	2344	80	80
49/8	36	2893	56	63
49/100	23	2414	70	188

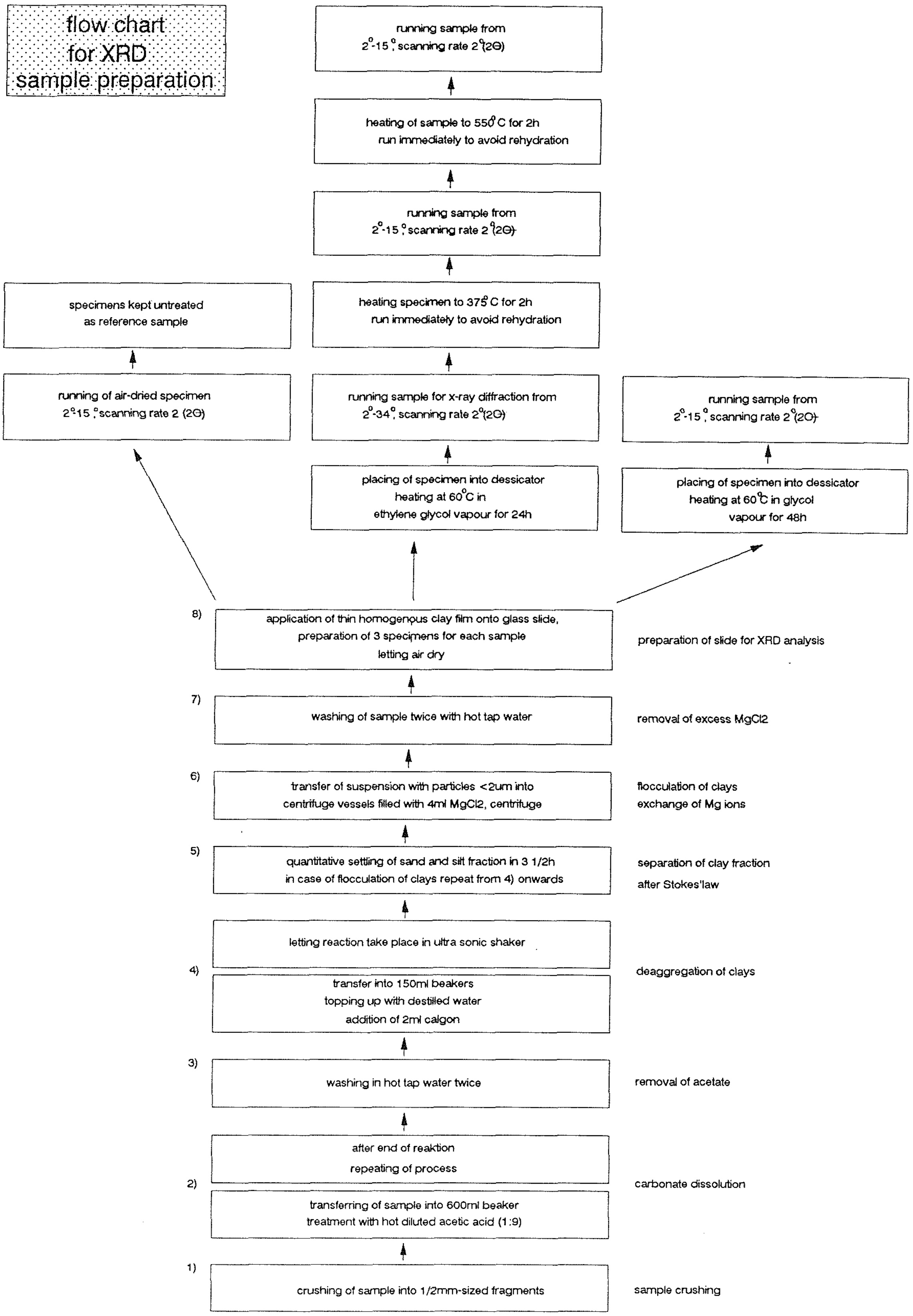
APPENDIX D.3. Carbon measurements using the Elemental Analyser EA 1108 Carlo Erba instruments; calcium carbonate percentages calculated from atomic weight percentage ratios in the compound.

sample	age (Ma)	%C	%CaCO3
18/1	53	10.09	84.15
18/2	52.6	10.53	87.82
18/7	52	10.78	89.91
18/23	50.5	10.95	91.32
28/C	46	9.5	79.23
28/A	19	10.54	87.9
28/1	17.5	10.16	84.73
15/3	58	9.85	82.15
15/13	52	9.63	80.31
15/19	49	11.66	97.24
15/24	48.5	11.02	91.91
15/Y	47.5	10.45	87.15
15/W	46	10.97	91.49
15/R	23	10.72	89.4
15/Q	20	6.89	57.46
21/1	53	8.45	70.47
21/5	50.5	10.85	90.49
21/8	49	9.19	76.64
21/9	45	9.98	83.23
21/10	19	9	75.06
30/1	49	8.71	72.64
30/4	43	7.54	62.88
31/5	36.5	10.66	88.9
31/1	23	9.98	83.23
24/1	53	11	91.74
24/2	52	9.74	81.23
24/4	43	10.34	86.24
24/5	34	10.46	87.24

Appendix D.4. Acid soluble/insoluble proportion of the sediment (% wt).

SAMPLE	AGE	sediment	dissolved	residue	dissolved	residue
	(Ma)	(g)	(g)	(g)	(%)	(%)
15/103	66	10.33	0.9	9.43	8.7	91.3
15/3	58	11.95	9.91	2.04	82.9	17.1
15/24	48.5	9.59	8.65	0.94	90.2	9.8
15/Y	47.5	16.55	14.74	1.81	89.1	10.9
15/X	47	23.9	20.43	3.47	85.5	14.5
15/W	46	18.23	16.53	1.7	90.7	9.3
15/95	38	14.51	13.17	1.34	90.8	9.2
15/96	37	22.47	20.24	2.23	90.1	9.9
15/R	23	18.86	15.93	2.93	84.5	15.5
15/100	18	19.4	15.88	3.52	81.9	18.1
35/2	66	14.52	1.65	12.87	11.4	88.6
35/3	53	14.46	11.62	2.84	80.4	19.6
30/106	52	9.86	8.89	0.97	90.2	9.8
32/1	50.5	28.35	23.36	4.99	82.4	17.6
30/2	46	11.77	7.91	3.86	67.2	32.8
30/4	43	13.42	9.06	4.36	67.5	32.5
30/104	42.5	11.9	9.38	2.52	78.8	21.2
33/1	37	11.38	9.64	1.74	84.7	15.3
31/5	36.5	13.68	12.35	1.33	90.3	9.7
31/2	36	20.14	15.69	4.45	77.9	22.1
31/1	23	19.95	16.34	3.61	81.9	18.1
33/4	19	17.21	14.12	3.09	82	18
48/3	66	8.91	1.27	7.64	14.3	85.7
48/6	55	16.68	10.03	6.65	60.1	39.9
47/4	54.5	12.43	7.23	5.2	58.2	41.8
47/6K	54	13.26	9.27	3.99	69.9	30.1
47/1	53.5	14.96	8.78	6.18	58.7	41.3
46/1B	53	16.24	12.59	3.65	77.5	22.5
43/10	51.5	11.73	7.97	3.76	67.9	32.1
43/13	51	15.09	12.13	2.96	80.4	19.6
43/A1	49	13.49	8.73	4.76	64.7	35.3
44/4	43	10.13	6.92	3.21	68.3	31.7
49/8	36	13.71	11.71	2	85.4	14.6
49/100	23	12.74	9.82	2.92	77.1	22.9

APPENDIX E.1. Prepatation technique for clay mineral analysis. Samples are run with copper radiation.



Appendix E.2. D-spacing (Å) of clay minerals detected. Values are taken from measurements in ethylen glycole for smectite d-spacings are given for glycerol-ethylen glycol-air dried samples, secondary peaks are in brackets, vermiculite (??) are glycerol values.

sample	smec.	paly.	sepio.	chlorite	ill.	verm.	zeol.
15/102	17.88 17.125 15.08	---	12.222---	---	9.935	14.209	8.934
15/3	17.74 16.61 14.3	10.601 (6.52)	12.044 (?)	7.138 (?)	9.913	14.301	8.934
15/24	17.961 16.674 15.081	10.576 (6.501)	12.011	7.173 (14.209)	9.98	14.255	8.952
15/X	18.108 17.258 15.237	10.476 (?)	---	---	---	---	---
15/95	17.395 17.06 14.63	10.627 (6.53)	11.978	---	---	14.164	---
15/96	17.82 17.125 15.03	10.652	---	---	9.913 (?)	14.074	---
15/Q	18.49 17.059 15.081	---	---	7.126	9.936	14.394	8.898

35/2	17.06 17.191 14.78	10.601	12.109	7.104	9.935	14.255	8.988
35/3	17.670 16.610 14.800	10.576 (6.549)	12.076	7.092 (3.900)	9.980	14.300	8.988
30/2	17.395 17.125 14.929	10.576	---	7.161 (13.81?)	---	14.301	8.880
30/4	18.352 17.326 15.614	10.476	12.277	7.184	trace	14.489	---
30/104	17.700 17.326 15.300	10.551	---	7.243	9.958	14.441	8.898
33/1	18.034 17.060 15.133	10.526	trace	7.161 (13.640)	9.958	14.209	9.044
31/2	17.961 17.191 15.133	10.576	---	7.092	9.913	14.441	8.916
33/4	17.530 16.993 14.979	10.526	---	7.149 (13.770)	9.913	14.164	8.952

48/3	16.994 16.929 14.829	10.602	---	7.081	9.936	14.209	8.934
48/6	16.929 16.737 14.536	10.602 (6.511)	12.109	7.092 (13.985)	9.914	14.301	8.934
47/4	17.464 16.674 14.489	10.551 (6.539)	12.011	7.196	9.914	14.301	8.916
47/6K	17.259 16.800 14.584	10.576 (6.530)	12.143	7.070 (13.941)	9.914	14.119	8.934
47/1	18.034 17.060 15.030	10.476	12.076	---	9.869	14.301	9.025
46/1B	17.464 16.864 14.441	10.602 (6.549)	12.243	7.093 (13.941)	9.981	14.441	8.989
43/10	17.744 17.192 15.133	10.551	12.044	---	9.936	14.536	8.934
43/13	17.464 16.864 15.081	10.576	12.044	---	9.981	14.394	---
43/A1	17.400 17.060 15.237	10.476	12.210	7.115	---	14.119	---
44/4	17.603 16.929 14.929	10.526	11.978	7.149	10.05	14.348	---
49/8	17.533 17.060 14.878	10.653	---	---	9.981	14.255	8.952
49/100	17.259 16.929 14.829	10.476	---	7.173	9.936	14.441	---

APPENDIX E.3. Weight factors for percentage estimations of clay mineral assemblages. Factors are to be multiplied with refraction intensities (Piper, 1978).

Clay mineral	Multiplication factor
Montmorillonite	3.00
Palygorskite	9.20
Sepiolite	2.00
Illite (mica)	6.00
Chlorite	4.95
Clinoptilolite	1.56

APPENDIX E.4. Intensities of diffraction counts for clay minerals; background subtracted.

SAMPLE	Ma	paly	smec	illite	chlor	zeol	sepio
15/102	66	0	769	109	0	224	0
15/3	58	863	1072	235	21	163	179
15/24	48.5	624	692	199	48	81	280
15/X	47	83	939	0	0	0	0
15/95	38	275	1293	0	39	0	138
15/96	37	142	1120	0	0	0	0
15/Q	20	0	1785	226	39	0	0
35/2	66	46	683	66	25	142	21
35/3	53	790	705	254	78	114	268
30/2	46	169	897	0	74	89	0
30/4	43	58	492	45	37	0	41
30/104	42.5	88	582	80	28	51	0
33/1	37	111	373	73	34	50	25
31/2	36	159	1270	251	51	173	0
33/4	19	179	1065	292	472	97	0
48/3	66	212	1783	147	71	181	0
48/6	55	449	749	149	33	322	223
47/4	54.5	561	778	204	32	204	315
47/6K	54	754	1608	441	238	392	712
47/1	53.5	194	697	144	0	154	150
46/1B	53	609	815	249	120	147	131
43/10	51.5	331	647	71	0	70	72
43/13	51	382	782	123	67	0	138
43/A1	49	52	525	0	43	0	49
44/4	43	128	843	79	0	0	73
49/8	36	124	1436	170	0	189	0
49/100	23	193	1336	203	64	0	0

APPENDIX E.5. Percentages of clay minerals; for weight factors see Appendix E.3.

SAMPLE	age (Ma)	%palygors	%smectite	%illite	%chlorite	%zeolite	%sepiolite
15/102	66	0	69.7	19.8	0	10.6	0
15/3	58	59.8	24.2	10.6	0.8	1.9	2.7
15/24	48.5	57.8	20.9	12	2.4	1.3	5.6
15/X	47	21.3	78.7	0	0	0	0
15/95	38	36.8	56.4	0	2.8	0	4
15/96	37	28	72	0	0	0	0
15/Q	20	0	77.6	19.6	2.8	0	0
35/2	66	13	62.9	12.2	3.8	6.8	1.3
35/3	53	60.5	17.6	12.7	3.2	1.5	4.5
30/2	46	32.7	56.6	0	7.7	2.9	0
30/4	43	21	58	10.6	7.2	0	3.2
30/104	42.5	24.9	53.7	14.8	4.3	2.4	0
33/1	37	35.5	38.9	15.2	5.9	2.7	1.7
31/2	36	20	52.2	20.6	3.5	3.7	0
33/4	19	18.1	35.2	19.3	25.7	1.7	0
48/3	66	22.1	60.7	10	4	3.2	0
48/6	55	49.3	26.8	10.7	1.9	6	5.3
47/4	54.5	52.5	23.8	12.5	1.6	3.2	6.4
47/6K	54	39.4	27.4	15	6.7	3.5	8.1
47/1	53.5	33.8	39.6	16.4	0	4.5	5.7
46/1B	53	52.7	23	14.1	5.6	2.2	2.5
43/10	51.5	53.8	34.3	7.5	0	1.9	2.5
43/13	51	48.8	32.6	10.2	4.6	0	3.8
43/A1	49	20.2	66.6	0	9	0	4.1
44/4	43	27.2	58.5	11	0	0	3.4
49/8	36	16.9	63.7	15.1	0	4.4	0
49/100	23	24.3	54.8	16.6	4.3	0	0