BIOSTRATIGRAPHY OF THE CRETACEOUS-TERTIARY PINDOS SERIES OF CRETE

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ABSTRACT

This thesis concentrates on the planktonic foraminiferal content of the Upper Cretaceous to Lower Eocene strata of the Pindic-Ethia Series in Crete. The project became feasible when preliminary field investigation showed that this series contains abundant microfossils which are dominated by diverse taxa of the Globigerinida.

Detailed sampling of the Pindic-Ethia Series was carried out only in 2 regions, namely (i) the Asiderotos Ori and (ii) the Asterousia Ori. As the bulk of the samples were collected from indurated limestones, examination of the microfossils was restricted to thin-section study only.

A total of 12 biozones based on the first appearances and extinctions of specific taxa of the Globigerinida were established to reflect the characteristic changes in the microfaunal assemblages observed throughout the interval from Upper Cretaceous to Lower Eocene. The proposed zonation faciliates correlation of the sections examined here with other Pindic outcrops in Crete and in mainland Greece.

A similar faunal change was also observed in the assemblages of the larger benthonic foraminifera. The presence of these fossils in association with other shallow-water calcareous allochems (especially fragments of echinoderms and mollusks) and minor amounts of fine terrigenous material in the calciturbidites indicate that the Pindic-Ethia basin was receiving derived materials from an adjacent reefal complex or complexes during this

period of its depositional history. On faunal and sedimentological evidence, the Tripolitza Series, classically considered to be the source of the derived materials in the Pindic-Ethia basin, is ruled out.

Finally, an attempt is made to reconstruct the geological evolution of the Pindic-Ethia basin in Crete.

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1.0 INTRODUCTION

1.1 GEOGRAPHY

1.1.1 General

The island of Crete is the largest island in the Eastern Mediterranean (fig. 1a). From east to west it is approximately 200 km long, but its width measured from north to south is highly variable. It lies just above 35° N and is situated directly south of mainland Greece but north of the African States of Egypt and Libya. Its capital is Khania.

1.1.2 Climate

Crete experiences a typical mediterranean climate. In the summer months, the island is hot and dry, with temperatures averaging 26° C at sea-level. During winter, temperatures in the lowlands fall to around 12° C while in the mountains, snow may occur. Rainfall is characteristically seasonal, varying from low in summer to high (up to 100 mm per month) in winter.

The climate favours the proliferation of aromatic shrubs and bushes. Trees, with the exception of olives, providing shade from the heat and glare are generally lacking. However, in western Crete, due to the higher amount of rainfall received annually, the landscape is more densely wooded.

Crete produces and exports a wide range of fruits (grapes, peaches, melons etc.) and vegetables (cucumber, tomatoes etc.). In addition, the climate encourages the rearing of a large population of goats and sheep.

Figure 1

Fig. 1a Map showing the present tectonic setting of Crete (after Le Pichon et al, 1982).

Fig. 1b Map showing the main mountain ranges using the 500 meter contour.

Fig. 1c Map showing the main roads, major towns, and localities mentioned in the text.

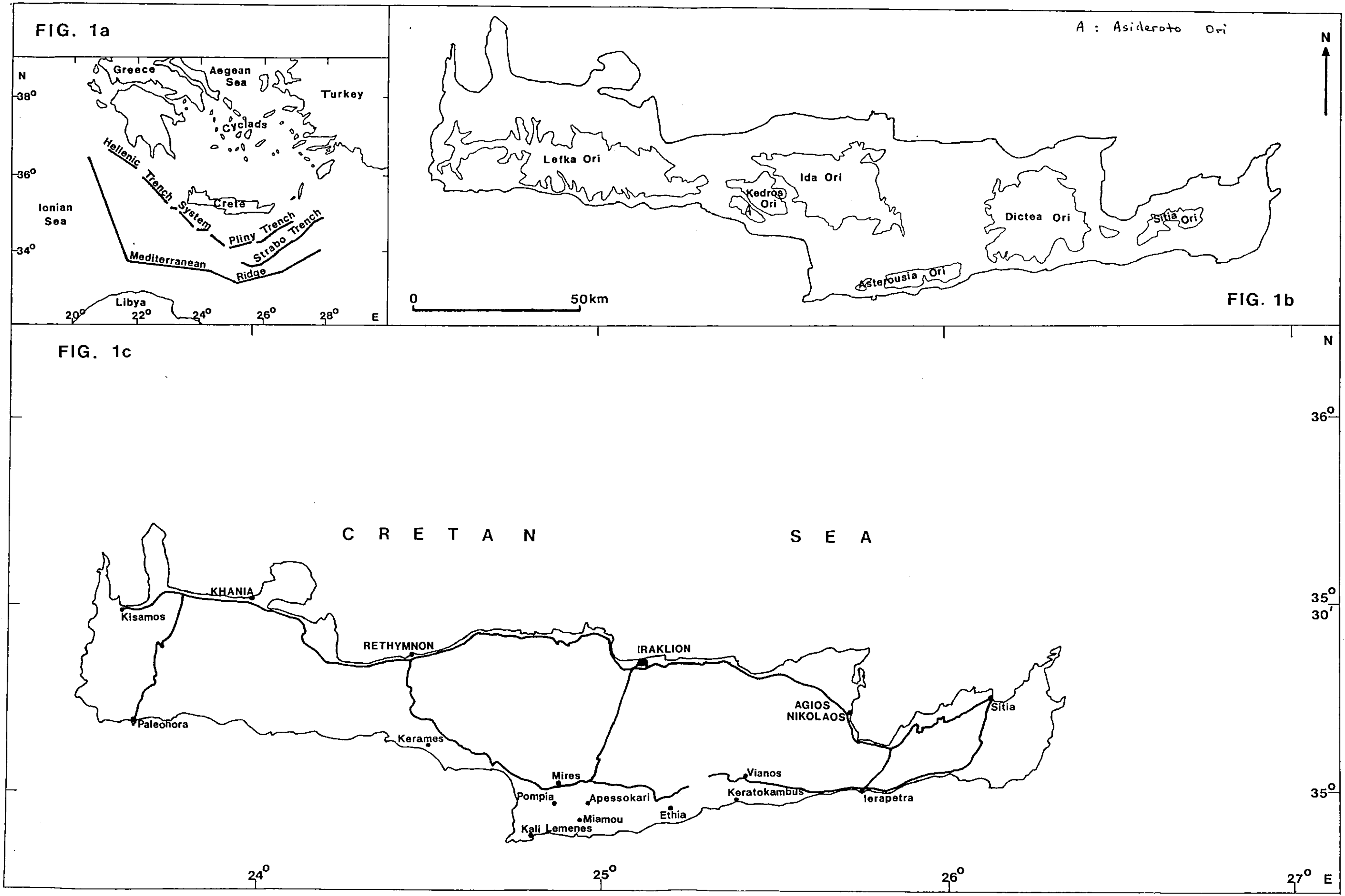


FIG. 1a
N
Greece
Aegean Sea
Turkey
Cyclads
38°
36°
34°
Hellenic Trench System
Ionian Sea
Crete
Pliny Trench
Strabo Trench
Mediterranean Ridge
Libya
20°
22°
24°
26°
28°
E
A : Asideroto Ori
N
Lefka Ori
Ida Ori
Kedros Ori
Dictea Ori
Sitia Ori
Asterousia Ori
0
50km
FIG. 1b
FIG. 1c
N
C R E T A N
S E A
36°
35° 30′
35°
KHANIA
Kisamos
RETHYMNON
IRAKLION
AGIOS NIKOLAOS
Sitia
Paleohora
Kerames
Mires
Pompia
Apessokari
Miamou
Kali Lemenes
Ethia
Vianos
Keratokambus
Ierapetra
24°
25°
26°
27° E

1.1.3 Topography

The island is well known for its rugged terrain and craggy mountain ranges (fig. 1b). In western Crete, Lefka Ori dominates the landscape. In central Crete, several ranges are found : in the south is the Asterousia Ori and in the north are the Kedros, Ida (Psilorites) and Dictea Ori. Eastern Crete is dotted with a series of smaller ranges and massifs, with Sitia Ori among the largest. The majority of these mountain ranges are composed of hard limestone or dolomite ranging in age from Permian to Lower Tertiary. They provide a wide range of scenery from spectacular gorges and caves to jagged peaks. Their surface terrain is generally rough and soil cover is usually lacking or minimal.

Less widespread than the limestone terrain but equally outstanding are the areas dominated by the softer flysch - molasse terrain. Chief among these is the famous Messara Plain, separating Asterousia Ori to the south from Ida Ori to the north. This Plain is an elongated graben, floored by Neogene molasse, and is one of the most fertile areas in Crete.

Scattered throughout the island are small outcrops of volcanic and metamorphic rocks. In Asterousia Ori, especially to the east, eye-catching, vivid, red-coloured rocks called the Arvi Unit dominates the landscape. It is composed of red shales associated with blackish, pillow lavas. The latter tend to form sharp, jagged peaks. Other eye-catching outcrops include sporadic exposures of dark green serpentinites and banded amphibolites.

1.1.4 Acess and Transport

Crete is directly accessible by air or sea. The main airport in Iraklion handles both national and international flights regularly. There is also a daily ferry service linking the port of Pireus in mainland Greece with Iraklion and Khania in Crete.

The island is served by a network of roads (fig. 1c). The major trunk road runs along the north coast linking Kisamos in the west to Sitia in the east. From Rethymnon a branch of this road verges southwards to link the towns in the Messara Plain and the south coast before returning northwards to rejoin the major trunk road at Sitia and north of Pachia Amnos respectively. In addition, there are a series of smaller roads linking the villages and smaller towns. In the more remote areas, metalled roads are replaced by dirt-tracks and crudely paved roads.

1.1.5 People and Culture

The Cretans are Greek nationals. Their population on the island is about ½ million. The majority of the Cretans are descended directly from the Hellenic stock; a minor proportion of the people are descended from Turkish immigrants. However, whatever their origins, the present Cretans are a fairly homogenous people. All of them speak the same language (i.e. Greek but with dialectic variations), they profess the same religion (i.e. Orthodox Christianity), and they practise more or less a similar life-style.

A large proportion of the population is settled in the main towns such as Iraklion, Khania and Rethymnon, engaging in small-scale commercial activities. Part of these cater directly for the tourist industry which has become very lucrative in recent years. Away from the bustle of the bigger towns, farming and animal husbandry become the major occupations. Farming is usually carried out on a small-scale. Most of the rural Cretans are a self-sufficient and hardy breed. They are generally very friendly and hospitable but are temperamental and extremely inquisitive with regard to a stranger's affairs. The older generation still adhere to their conservative life-style which centers on the man being the master of the house while the woman spends her entire life keeping house and tending the farm. However, with the influence of the mass-media and frequent contacts with tourists, this is slowly giving way to a more westernised life-style.

1.2 PRESENT GEOLOGIC SETTING

Crete is situated along the southern limit of the Aegean region (fig. 1a). Directly south of the island are 2 deep sea trenches, the Pliny Trench and the Strabo Trench, with depths of about 5 km. These linear structures are part of a larger, regional, arcuate feature, the Hellenic Trench System. On the basis of geophysical and geologic data, this feature is presently interpreted as a northwards dipping subduction zone (Le Pichon et al., 1982). It can be traced from off the west coast of Greece and Peloponesse southeastwards to the south of Crete, before curving northeast to Rhodes. Lying between the Hellenic Trench System and the north African coast is a topographic high called the Mediterranean Ridge which is interpreted as a compressional feature produced by the convergence of the African plate against the Eurasian plate (Rabinowitz and Ryan, 1970). Northwards of the

Hellenic Trench System, at about a distance of 150 km, is a volcanic arc, the Cyclads, which consists of several volcanic islands. Directly north of Crete, in the Cretan Sea, is a deep basin with water depths of up to 2 km. This basin, respectively called the North Cretan Basin or Cretan Trough, is interpreted by some as a backarc basin (Hsu, 1978).

The present morphology of Crete and the Aegean region is directly influenced by the Plio-Pleistocene tectonic activities of the Hellenic Arc - Trench System. These activities were reflected by a regime of normal faulting resulting in a mosaic of elevated and down-thrown blocks. The major fault trends are east-west, northeast-southwest, northwest-southeast, with minor north-south directions (Nesteroff et al., 1977).

1.3 PRESENT STUDY

The initial step towards the setup of the present research was taken in 1978 when D.J. Carter (Imperial College), M.G. Audley-Charles (Queen Mary College) and R. Hall (Queen Mary College) were awarded a NERC grant to conduct a regional study of the island of Crete. Two research students, namely A. Hussin (Queen Mary College) and myself, joined the group in late 1978 and early 1979 to participate in this project.

For the first 6 months, under the supervision of D.J. Carter, this author, without any previous knowledge of planktonic foraminifera, undertook a crash course on the study of the Upper Cretaceous and Tertiary Globigerinida. At the end of the course, she departed with the rest of the research group for Crete. During the following 3 months, the group conducted a general field reconnaissance to establish the general stratigraphical and structural relationship of the different nappes in Crete. In addition, a preliminary investigation of their fossil assemblages and their ages were carried out by D.J. Carter and myself.

Rocks in Crete fall mainly into 2 categories, namely (i) limestone-flysch associations and (ii) others such as volcanics and metamorphics. Of the former, 3 series (the Plattenkalk Series, the Tripolitza Series and the Pindos Series) were recognized. The Plattenkalk Series was found to be almost wholly recrystallized, whatever fossils there were are now lost and it is unsuitable for paleontological study. The Tripolitza Series contains a mainly shallow-water fauna and contains few planktonic fossils. Fortunately, the Pindos Series was found to contain abundant planktonic foraminifera ranging in age from Upper Cretaceous to Lower Tertiary. In addition, this series is very widespread in Crete and sampling could be carried out without too much difficulty.

At the end of the general field reconnaissance, this author spent a further 2 months studying and collecting samples from selected Pindos outcrops in the Asterousia Ori and the Asideroto Ori. These samples were later brought back to the laboratory for detailed study. The preliminary results were not very satisfactory due to the extensive age gaps found in the Upper Cretaceous Pindos. During the second field season in 1980, more Pindos outcroos were sought and studied. Further detailed sampling was carried out. All in all, close to 400 samples were collected for this study. The joint findings of both field seasons were then analysed and compiled. A summary of the results and the conclusions will be discussed in later chapters.

CHAPTER 2

2.0 GEOLOGICAL OUTLINE OF CRETE

2.1 REVIEW OF PUBLISHED LITERATURE

Investigations of the geology of Crete were prompted by studies of the Hellenides in the mainland Greece. Early workers have drawn attention to the similarity in the stratigraphy and the structural history of these regions. Renz (1947) correlated certain facies zones in Greece, namely the Tripolitza and the Olonos-Pindos, with similar rock types in Crete. His figure 13 showed that facies zones in Greece run parallel to one another along a NW-SE trend. In their southern parts, the facies zones form a broad curve eastwards into Crete.

Aubouin (1965) proposed that the Hellenides represent a geosyncline, with a typical ridge-furrow topography. He recognized 6 parallel isopic zones, aligned NNW-SSE. They are from west to east, the Apulian zone, the Ionian zone, the Gavrovo-Tripolitza zone, the Pindos zone, the Sub-Pelagonian zone and the Pelagonian zone. The Gavrovo-Tripolitza and the Pelagonian zones are visualized as ridges where sedimentation is neritic or even reefal. On the other hand, the Ionian and the Pindos zones are considered as furrows with pelagic sedimentation. The Ionian-Gavrovo-Tripolitza couple is considered to represent the miogeosynclinal realm, the Pindos-Pelagonian couple is taken to be the eugeosynclinal realm, while the Apulian zone is thought to represent the foreland. The evolution of the geosyncline is characterized by the so-called "geosynclinal polarity" which is reflected in the migration of both the orogenesis and the flysch from the eugeosyncline towards the miogeosyncline, the inclination of the majority of the tectonic structures towards the foreland, and the extrusion of ophiolites in the internal eugeosyncline. The miogeosynclinal realm is considered to be essentially autochthonous while the eugeosynclinal realm is allochthonous. The latter gave rise to nappes, namely the Pindos Nappe and the Sub-Pelagonian Nappe.

The concept of geosyncline was subsequently applied to Crete by Aubouin and Dercourt (1965). In a series of cross-island profiles, they recognized 3 superimposed structural units. From the base upwards is the autochthonous Gavrovo-Tripolitza Series, the Pindos Nappe and lastly, the Ophiolitic or Sub-Pelagonian Nappe. The direction of thrusting was reported to be from the north. As was the case in the Hellenides, the Pindos Nappe here was divided into an internal, an axial and an external facies. The internal facies was recorded in northern Crete and the external facies, - the "Ethia Facies" is present towards the south. Therefore unlike the Hellenides, the isopic zones in Crete were interpreted to run roughly east-west. To explain this, the southern parts of the isopic zones in Greece were believed to form a broad arc before passing eastwards into Crete. The end-result is remarkably similar to the facies map of Renz (1947, fig. 13).

More recent works on the geology of Crete were published primarily by the French and the Germans (Creutzburg and Seidel, 1975; Bonneau, 1976; Bonneau et al., 1977; Kopp, 1978). Despite some differences, the broad geological outline of Crete was agreed upon. They recognize 4 major nappes and an autochthonous series on Crete. From the base to the top, they are, the autochthonous Plattenkalk Series, and the Phyllite-Quartzite, Tripolitza, Pindos, and Ophiolite Series.

Plattenkalk Series Creutzburg and Seidel, 1975.

synonymous with :

Ida Series Bonneau, 1976.

Taleo Ori Series Epting et al., 1972.

This series has been reported to be more than 5000 meters thick (Kopp, 1978) in the Taleo Ori. The lower part of this series is made up of "Fusulina"-bearing limestones (Fodele Beds), which is overlain by oolitic dolomites and phyllites (Sisses Beds). The age of these beds was reported to be Upper Permian. An unconformity separates the Permian limestones from a massive dolomitic stromatolite of Norian age. Resting directly above the stromatolites is a sequence of recrystallized, platy limestones with chert bands and nodules. This sequence is generally referred to as the "Plattenkalk". In Kalavros, the top of the Plattenkalk passes into a transitional zone consisting of red and green phyllitic, marly limestones containing traces of Globigerina believed to be Eocene or even Oligocene in age (Bonneau, 1973). Locally the top of the transitional zone passes into flysch.

The whole series is believed to be affected by low grade metamorphism. It is considered by Creutzburg and Seidel (1975) to be an autochthon but Bonneau (1973), Bonneau et al.(1977) regarded it as a paraautochthon. The series is reported to be intensely folded with folds verging towards the south (Bonneau et al., 1977). This was confirmed by M. Audley-Charles and R. Hall (per. comm., 1982) and they reported flat-lying, tight to isoclinal folds with east-west axes. Therefore the total thickness of several thousand meters as recorded for this series by various authors is probably exaggerated due to repetition by folding and faulting.

Phyllite-Quartzite Series

(i) Tripali Unit Creutzburg and Seidel, 1975.

This unit is composed of coarse shallow-water carbonate breccias and rauhwacken. It was reported from western Crete where it rests discordantly on the Plattenkalk Series. Creutzburg and Seidel (1975) considered that the Tripali limestone passes concordantly upwards into the Phyllite-Quartzite Series and therefore they place the Tripali Unit together with the Phyllite-Quartzite Series into one tectonic unit. Bonneau (1976) did not consider the Tripali limestone as a separate unit. Areas mapped by Creutzburg and Seidel (1975, fig. 1) as the Tripali Unit were included by Bonneau (1976) as part of the Ida zone (equivalent to Plattenkalk Series) and the "phyllades" (equivalent to Phyllite-Quartzite Series).

(ii) Phyllite-Quartzite Series Creutzburg and Seidel, 1975.
synonym : "phyllades"

This series is composed of a metamorphic rock complex believed to have undergone a high pressure metamorphism. Glaucophane-bearing metabasalts found throughout the island were regarded by Creutzburg and Seidel (1975) to represent oceanic basalts. Bauman et al.(1975) interpreted this series as a melange. The age reported for this series range from probably Permian to Lower Triassic (Papastamatiou and Reichel, 1956; Epting et al., 1972). The Phyllite-Quartzite Series is thrust over the Plattenkalk Series and it is in turn overthrust by the Tripolitza

Series (Creutzburg and Seidel, 1975; Kopp, 1978). The French authors (Aubouin and Dercourt, 1965; Bonneau et al., 1977) regarded the Phyllite-Quartzite Series, which they termed as the "phyllades", to be the basement to the Tripolitza Series.

Tripolitza Series

The French geologists have consistently placed the "phyllades" as the basement to the Tripolitza limestones even though a decollement separates them (Aubouin adn Dercourt, 1965; Bonneau, 1973; Bonneau et al., 1977). They believed that the decollement is due to the presence of gypsum between the "phyllades" and the Tripolitza limestones which then acted as a lubricant separating what was once a sedimentary sequence. Creutzburg and Seidel (1975) disputed the sedimentary contact between the Phyllite-Quartzite Series and the Tripolitza Series based on the absence of metamorphism in the latter.

The Tripolitza Series is made up of shallow-water carbonates. From the base upwards are, banded dolomites and limestones of Triassic-Liassic age, Upper Jurassic limestones with Cladocoropsis, Lower Cretaceous limestones with Charophytes, Upper Cretaceous rudist limestones, Lower-Middle Eocene limestones rich in benthonic foraminiferal fauna (eg. Nummulites, Fasciolites, etc.), followed finally by a flysch of Upper Eocene to Oligocene age (Aubouin and Dercourt, 1965; Bonneau et al., 1977; Creutzburg and Seidel, 1975; Kopp, 1978; Leppig, 1978). In mainland Greece, the Gavrovo-Tripolitza Series is considered as an autochthon (Aubouin, 1965). Similarly, earlier workers (Aubouin and Dercourt, 1965) have regarded the Gavrovo-Tripolitza Series in Crete to be in an autochthonous position. Later workers however viewed the Gavrovo-

Tripolitza Series in Crete as a nappe. It has been reported to be thrust over the Plattenkalk Series (Creutzburg and Seidel, 1975; Bonneau, 1973) as well as over the Phyllite-Quartzite Series (Creutzburg and Seidel, 1975).

Pindos Series

This series is thrust over the Tripolitza Series and is internally imbricated. Renz (1930, 1955), Aubouin and Dercourt (1965), Bonneau and Fleury (1971), Bonneau et al. (1977) drew attention to the presence of a widespread limestone sequence in Crete which they believed to be different from the typical Pindos in northern Greece. They called this limestone sequence the "Ethia Facies" or the "Ethia Series." Renz (1930, 1955) placed the "Ethia Facies" in the Ionian zone but later workers proposed that the "Ethia Series" represents a flank deposit on the slope of the Tripolitza ridge bordering the Pindos furrow (Aubouin and Dercourt, 1965; Bonneau et al., 1977). They arrived at this conclusion based on the higher proportion of flank microbreccia-calciturbidite and the later arrival of the Tertiary flysch as compared to the Pindos facies in Greece.

A more or less similar facies, the "Mangassa Series", was also regarded as a flank deposit on the Tripolitza ridge facing the Pindos furrow (Bonneau and Zambetakis, 1975). Earlier workers originally placed this series on the flank of the Tripolitza ridge facing the Ionian furrow (Aubouin and Dercourt, 1965). The "Mangassa Series" is said by Bonneau and Zambetakis (1975) to occupy a more proximal position relative to the Tripolitza as compared to the "Ethia Series." They based their conclusion on the absence of radiolarites and the "Premier Flysch" from the

"Mangassa Series."

From bottom to top, the Pindic-Ethia nappe is composed of Upper Triassic sandy-pelitic sequence with intercalations of lavas, a thick series of red, Halobia-bearing cherty limestones of partly Triassic to partly Lower Jurassic age, calcareous turbidites and oolitic cherty limestones of Dogger-Malm age, radiolarite horizons, "Premier Flysch" of Upper Cenomanian (?) - Turonian - Campanian age, Globotruncana-bearing Upper Senonian platy limestones with intercalations of microbreccias and calciturbidites, passage beds with Globorotalia (s.l.) species, and finally Paleocene-Eocene flysch.

Ophiolite Series   Aubouin and Dercourt, 1965.

synonyms :

Asterousia Nappe   Bonneau, 1972.

Serpentinite-Amphibolite Association   Creutzburg and Seidel, 1971.

Volcano-Sedimentary Complex   Baumann et al., 1978.

This series is reported to be thrust over the Pindos Series (Aubouin and Dercourt, 1965). It is composed of serpentinites plus a heterogenous metamorphic assemblages indicating a high pressure-high temperature regime (Seidel et al., 1976). The serpentinites were reported to be above the metamorphic complex (Creutzburg and Seidel, 1975; Bonneau et al., 1977). In addition to this series, Bonneau et al. (1977) recognize an additional nappe which underlies his Asterousia Nappe. They called this the "Intermediate Nappes." This complex encompasses the Arvi Nappe, the Miamou Nappe and the Vato Schists. Creutzburg and Seidel (1975) interpreted the "Intermediate Nappes"as chaotically mixed blocks which were shaved off from the thrust mass of the Serpentinite-Amphibolite Association and subsequently carried along the thrust.

2.2 GENERAL CONCEPT OF THE PINDOS ZONE

The Pindos zone was originally defined as a sedimentary facies zone characterized by continuous sedimentation in a deep water facies from Middle Triassic to Eocene (Renz, 1947). Occurrences of Pindic facies were reported from mainland Greece (stretching from the north to the Peloponesse), Crete and other Greek islands (Renz and Reichel, 1945). Several distinct facies were identified. They are, from the base to the top, as follow (Renz and Reichel, 1945) :

(i) Variegated slates and cherts. The presence of *Halobia* species give a Carnian age.

(ii) Whitish grey to reddish chert-rich platy limestones.

(iii) Darkish red or grey *Orbitolina*-bearing limestone breccias of Cenomanian age. Planktonic fossils associated with these breccias include *Globigerina* species, radiolaria, *Globotruncana appennica* and *Globotruncana stephani*. Rudists and chert fragments were also present.

(iv) Dark red and grey, fine-grained, calcareous sandstones (with chert fragments) which contain *Globotruncana helvetica*, *Globotruncana lapparanti-coronata*, *Globigerina* species, and *Cuneolina* species. Age of this unit is said to be Lower Turonian.

(v) *Orbitoides*-bearing limestone breccias of Maastrichtian age. A mixed fauna of larger benthonic foraminifers (egs. *Orbitoides* spp ., *Siderolites* spp ., *Omphalocyclus* spp ., and *Lepidorbitoides* spp .) were reported. In addition to the breccias, pelagic limestones containing abundant *Globotruncana* of Lower Maastrichtian or possibly

Upper Campanian age were found.

As early as 1940, the Pindos zone was interpreted as a nappe which overrides the Ionian flysch, the Gavrovo zone and the Tripolitza zone (Renz, 1940).

Aubouin (1959, 1965), working essentially in northern Greece, concluded that the development of the Pindos zone followed an evolutionary scheme. The history of its sedimentation, igneous activity, tectonics and orogenesis was considered by Aubouin to reflect its formation within an eugeosynclinal furrow. According to the hypothesis he proposed, the Pindos trough developed in the Upper Triassic with the deposition of Halobia-bearing limestones and jaspers. During the Jurassic to the Lower Cretaceous, the trough deepened and a substantially thick sequence of radiolarites were formed (250-300 meters). Along the flanks of the trough, limestone microbreccias which were derived from the adjacent shallow-water ridges (egs. Tripolitza, Pelagonian and Sub-Pelagonian zones) were intercalated with the radiolarites. This variation in facies was thought to be sufficiently significant to warrant the division of the Pindos zone into an axial facies (containing only radiolarites) and two lateral facies (containing intercalations of limestones and radiolarites). During the Kimmeridgian, massive outpourings of ophiolites occurred in the Sub-Pelagonian zone. Thus, the ophiolites became interbedded with the radiolarites along the eastern flank of the Pindos trough. By Barremian to Aptian times, terrigenous facies termed the "Premier Flysch" spreaded partly across the trough; it is reported to be absent from its western flank. The flysch was said to be derived from the Pelagonian and the Sub-Pelagonian zones which were uplifted and eroding. Erosion of the latter zone also provided radiolarite microbreccias which were deposited along the eastern flank and the axis of the Pindos trough. Aubouin then drew attention to the association of ophiolites, radiolarite microbreccias and the coarsest flysch facies which is present only on the eastern flank of the Pindos zone. He called this the internal zone, while the western flank which lacks the above rock association is termed the external zone. When the deposition of the flysch ended, that of pelagic limestones (about 400 meters thick) resumed along the axis of the trough. From the base upwards are 100 meters of platy limestones and red jaspers, 200 meters of platy limestones with grey or black chert and finally another 100 meters of platy limestones without chert. Along the flanks of the trough, interbeds of limestone microbreccias which were once again derived from the adjacent shallow-water ridges were deposited. The pelagic microfauna (especially the Globotruncana species) identified from the limestones gave a Lower Senonian to Maastrichtian age. In the microbreccias, Orbitoides spp ., Siderolites spp ., and Lepidorbitoides spp . were also found (Aubouin et al., 1960). During the Maastrichtian, intercalations of pelagic limestones, limestone microbreccias and terrigenous facies were deposited throughout the trough. These beds, termed as the "Couches de Passage", have a thickness of about 50 to 100 meters and contained a rich assemblage of Globotruncana spp ., Guembelina spp ., and Globigerina spp . Deposited directly above the "Couches de Passage" is the second Pindic flysch of Eocene age. The source of this flysch was thought to be the Pelagonian and the Sub-Pelagonian zones which were once again uplifted and eroding. The Pindos zone was subsequently involved in orogenesis and was thrust over the Tripolitza zone.

After having established the geological sequences and events in northern Greece, Aubouin then applied his model to other Pindic occurrences in mainland Greece and produced a map showing the distribution of the axial and the lateral Pindic facies (Aubouin et al., 1960, fig. 1). Willis (unpub. Ph.D thesis, 1966), working on the Pindos zone in the Frangista-Karpenisia Region in western Greece, disagreed with the extension of the axial Pindic zone there by Aubouin et al. (1960). He showed that the lateral variations in the thickness of the radiolarite sequences across the Frangista-Karpenisia Region indicated that the axis of the trough should lie to the eastern part of the Karpenisia Region and not to the west as illustrated by Aubouin et al. (1960). His conclusion was based on Aubouin's proposal that the radiolarite sequence is thinnest along the axis of the Pindos trough and thickest along the flanks due to the influx of limestone breccias which increase the total thickness of the radiolarite sequence there. In the Frangista-Karpenisia Region, the radiolarite sequence thins towards the east. Loftus (unpub. Ph.D thesis, 1966) working in an area immediately south of Willis's study-area, concluded that there is no evidence for the division of the Pindos zone into an axial and lateral facies in his study-area. Previously, Aubouin et al. (1960) had placed the eastern part of Loftus's study-area under the internal Pindic zone, and the western part under the axial zone.

The Upper Cretaceous limestones in western Greece, estimated to be 330 meters thick, are composed predominantly of interbedded red calcilutites, white calcilutites and calciturbidites (Willis, 1966; Loftus, 1966). The basal part of these limestones consists mainly of interbedded red calcilutites and red shales, while in the upper part, intercalations of shale and sandstone also appear. Development of replacement chert (as nodules and layers) was said to be restricted to certain horizons. The age of these Upper Cretaceous limestones was reported to be from Santonian to Maastrichtian, and they were then overlain by the Pindos flysch whose basal part was said to be of Paleocene age (Willis, 1966; Loftus, 1966).

Paleocurrent directions of the Upper Cretaceous calciturbidites in the Frangista-Karpenisia Region were reported to fall mainly within the northwest quadrant, with some in the northeast quadrant (Willis, 1966). On the basis of these data, Willis suggested that the turbidity currents were of a longitudinal type and came from the north i.e. the paleoslope was to the south. However, he was unable to indicate from which zone or zones the carbonate clasts (consisting of fragments of echinoderms, Inoceramus, algaes and rudists) in the calciturbidites were derived. Presence of clasts of radiolarian chert and basaltic rocks in the calciturbidites was assumed by Willis to have been derived from the Sub-Pelagonian zone to the north of his study-area.

Similar paleocurrent results (i.e. from northwest to southeast) were also obtained from the Upper Cretaceous calciturbidites in the Peloponesse (Piper and Pi-Piper, 1980). Facies change within these calciturbidites showed that the coarsest beds (calcirudites and calcarenites) were restricted mainly to the west and that they become thinner and rarer to the east. Piper and Pi-Piper (1980) suggested that the paleocurrents and the facies change of the calciturbidites indicate either an axial transport (from northwest to southeast) or a lateral transport from the west. They also concluded that the facies change within the Premier Flysch showed a west to east passage, being proximal in the west and more distal in the east (in contrast to Aubouin's model which considers the Premier Flysch to come from the east).

Thus it become obvious that the classical eugeosynclinal model proposed by Aubouin (1959, 1960) for the Pindos zone could not explain the differences that are present in western Greece and the Peloponesse. It is possible that either the model is an oversimplification of the geology of the Pindos zone, or, that the configuration of the Pindos trough is not a simple linear structure.

In Crete, rock-types similar to those reported from the Pindos zone in mainland Greece were also found. Renz (1930) described a rock-series which he thought belong to the Ionian zone. He called it the "Ethia Series" and mentioned a limestone sequence which is composed of the debris of rudists, Orbitoides, Nummulites and Discocyclina; towards the top, the series passes into platy limestones containing Globorotalia. It is then overlain directly by the flysch. Renz also included an Orbitolina-bearing grey limestone in this series.

The "Ethia Series" was subsequently expanded by later workers to include a whole range of Pindic facies ranging in age from Upper Triassic to Eocene. They disagreed with Renz and considered the "Ethia Series" as a flank deposit in the external Pindic zone (Aubouin and Dercourt, 1965; Bonneau and Fleury, 1971).

Aubouin and Dercourt (1965) established an internal

Pindic facies in northern Crete, and an external facies or the so-called "Ethia Series" in southern Crete. The latter is said to be characterized by the absence of the "Premier Flysch" and by the extension of the Upper Cretaceous limestones into Lower Eocene. Thus the arrival of the second Pindic flysch here is much later (in Middle Eocene). They believed that these facts proved that the "Ethia Series" was deposited in the external Pindic zone. Bonneau and Fleury (1971) working on the "Ethia Series" in the Asfendilia mountain in central Asterousia, established for the first time the presence of the "Premier Flysch" there. They accepted the view that the "Ethia Series" is an external Pindic facies, and proposed that the "Premier Flysch" can exist in an extremely external position in contrast to the classical view that the "Premier Flysch" does not cross westwards beyond the axis of the Pindos trough. They argued that the younger ages obtained for the "Premier Flysch" here (Lower Turonian to possibly Lower Senonian) in contrast to the older ages (Barremian-Aptian) reported form the mainland, reflect its more external position. From the base upwards, the "Ethia Series" in the Asfendilia mountain consists of gravelly, oolitic limestones of Jurassic age, several chert and Orbitolina-bearing limestone breccia interbeds, a Lower Turonian to possibly Lower Senonian pelite-sandstone sequence (synonymous with "Premier Flysch") containing Globotruncana helvetica, Globotruncana stephani, Globotruncana schneegansi-sigali and Globotruncana cf. coronata (Bonneau and Fleury, 1971), followed finally by 300 meters of sublithographic limestones and limestone microbreccias of Senonian to Lower Eocene age. This series is overlain directly by the second Pindic flysch.

Seidel (1971) recorded an almost complete profile of Triassic to Paleocene Pindos sequence in the district of Paleohora in southwest Crete. The stratigraphy here is generally similar to the "Ethia Series" in the Asfendilia mountain. However, unlike the latter, Halobia-bearing beds (chert, limestone and shale) were found, the Jurassic gravelly-oolitic limestones were replaced by chert and limestone interbeds (oolitic and detrital beds occur in subordinate amount), the "Premier Flysch" is older here (the presence of Rotalipora appenninica gave a Cenomanian age), and, the top of the limestone section contained Globorotalia angulata which gave a Paleocene age.

Later, Bonneau (1976) extended the base of the "Ethia Series" to include Halobia-bearing limestones and marls. He also placed a massive rudist-rich limestone breccia found near Pirgos as one of the facies of the "Ethia Series." By this time, the earlier view of Aubouin and Dercourt (1965) (i.e. northern Crete is represented by internal Pindic facies while southern Crete is represented by the "Ethia Series") was replaced by the opinion that the "Ethia Series" is the dominant Pindic facies in both western and central Crete (Aubouin et al., 1976). A reinterpretation of the geology of the Aegean Region by Aubouin et al. (1976) suggested that during the Cretaceous, the extreme southern limit of the north-northwest trending Pindos zone began to form two diverging arms. The two arms were said to be separated by a shallow-water complex; the interior arm trends roughly northeast-southwest while the exterior arm runs in an east-west direction and terminates eastwards into a blind alley. The "Ethia Series" and its neritic equivalent (termed as the "Mangassa Series") were interpreted to be formed in the exterior Pindic arm. This interpretation was put forward to explain the presence of the "Mańgassa Series" in eastern Crete, the restriction of the "Ethia Series" to western and central Crete, and the absence of these facies from the mainland.

The "Mangassa Series" was said to be formed in the Upper Triassic with the deposition of Halobia-bearing marls, sandstones and bioclastic limestones. These were followed, in ascending order by, gravelly and oolitic limestones of Jurassic age, Lower Cretaceous dolomites and limestones which contained Orbitolina species in the upper part, Upper Cretaceous-Eocene pelagic limestones and limestone breccias containing a mixed planktonic and benthonic fauna, and, finally, by Upper Lutetian passage beds with Nummulites and Discocyclina. The series is overlain conformably by flysch of Priabonian age. "Premier Flysch" and radiolarites were said to be absent from this series and clasts with facies similar to the Tripolitza limestones were found in the limestone breccias. On the basis of this, Bonneau and Zambetakis (1975) regarded the "Mangassa Series" as having once occupied a paleogeographic position closer to the Tripolitza ridge than any other known Pindic occurrences. This view was modified by Aubouin et al. (1976) who proposed that the "Mangassa Series" was formed in the easternmost extreme of the exterior Pindic arm where it was bordered by the shallow-water complexes of the Gavrovo zone and the Kalilimni-Archangelos zone.

During post-Eocene times, the Ethia-Mangassa rock-types in Crete were thrust over the Tripolitza zone. Scattered remains of these Pindic facies were informally termed as the "Pinde-Ethia Nappe" by the French geologists. With regard to the occurrences of the internal Pindic facies in Crete, the earlier concept that they existed only in northern Crete was discarded. Instead, Aubouin et al. (1976) proposed that the internal Pindic facies on Crete existed as an independent nappe resting directly above the Pinde-Ethia Nappe. They identified the Arvi Unit to be the internal Pindic facies and it is said to be composed of cherty limestones of Triassic to Jurassic age, radiolarites, *Globotruncana*-bearing limestones and Maastrichtian red marls which were intruded by extensive accumulations of spilites.

During the field seasons of 1980-1981, members of the Cretan Project, on the basis of field evidence (such as overturned folds), concluded that the directions of thrusting of the Pindic-Ethia nappe over the Tripolitza zone is to the present west, and that subsequently during Oligocene or post-Oligocene, the Tripolitza Series with the Pindic-Ethia nappe on its back was thrust towards the present south.

CHAPTER 3

3.0 THE PROBLEM

A review of the published literature on the Pindos Series in mainland Greece and Crete has highlighted two aspects of its geology in which information is either lacking or incomplete.

Firstly, despite the presence of abundant planktonic foraminifera in the Upper Cretaceous-Eocene limestones, not much is known about the faunal content of this thick sequence. This is because most workers have restricted their investigation to specific horizons; as a result, the ages of the base and top of this sequence are generally known while the bulk of it remains undated. In this work, the author will attempt to zone the Upper Cretaceous-Eocene limestone sequence of the Pindic-Ethia Series in Crete. Zonation is based on the presence of *Globotruncana* species and *Globorotalia* (s.l.) species in these rocks. In addition, wherever possible, correlation with other Pindos outcrops or sections will be made.

Secondly, the Pindic-Ethia Series in Crete contains a relatively high proportion of calciturbidites, calcbreccias and calcarenites. Unlike the pelagic limestones, these beds are composed of shallow-water calcareous materials with minor amounts of siltsone-sandstone, volcanic and metamorphic clasts. In the classical view, the Tripolitza zone has always been assumed to provide the shallow-water microbreccias into the "Ethia Series" by virtue of its proximity. Aubouin (1965) believed that these microbreccias are *homogenous* in the sense that they are of the same age as the pelagic sediments of the basin into which they were deposited. He emphasized that such microbreccias are indicative of the instability of the shallow-water ridge involved, and that they do not contain land-derived materials. However, as land-derived materials are definitely present together with the shallow-water calcareous debris in the Pindic-Ethia breccias, the question remains whether the Tripolitza zone is the source of these materials as envisaged by the geosyncline model. To help solve this problem a comparison of the composition of these breccias and the Tripolitza limestones was carried out. In addition, variations in the proportion and thickness of the Pindic-Ethia breccias in various outcrops were noted for the development of any facies trend.

CHAPTER 4

4.0 FIELD LOCALITIES AND DESCRIPTION OF SECTIONS

4.1 INTRODUCTION

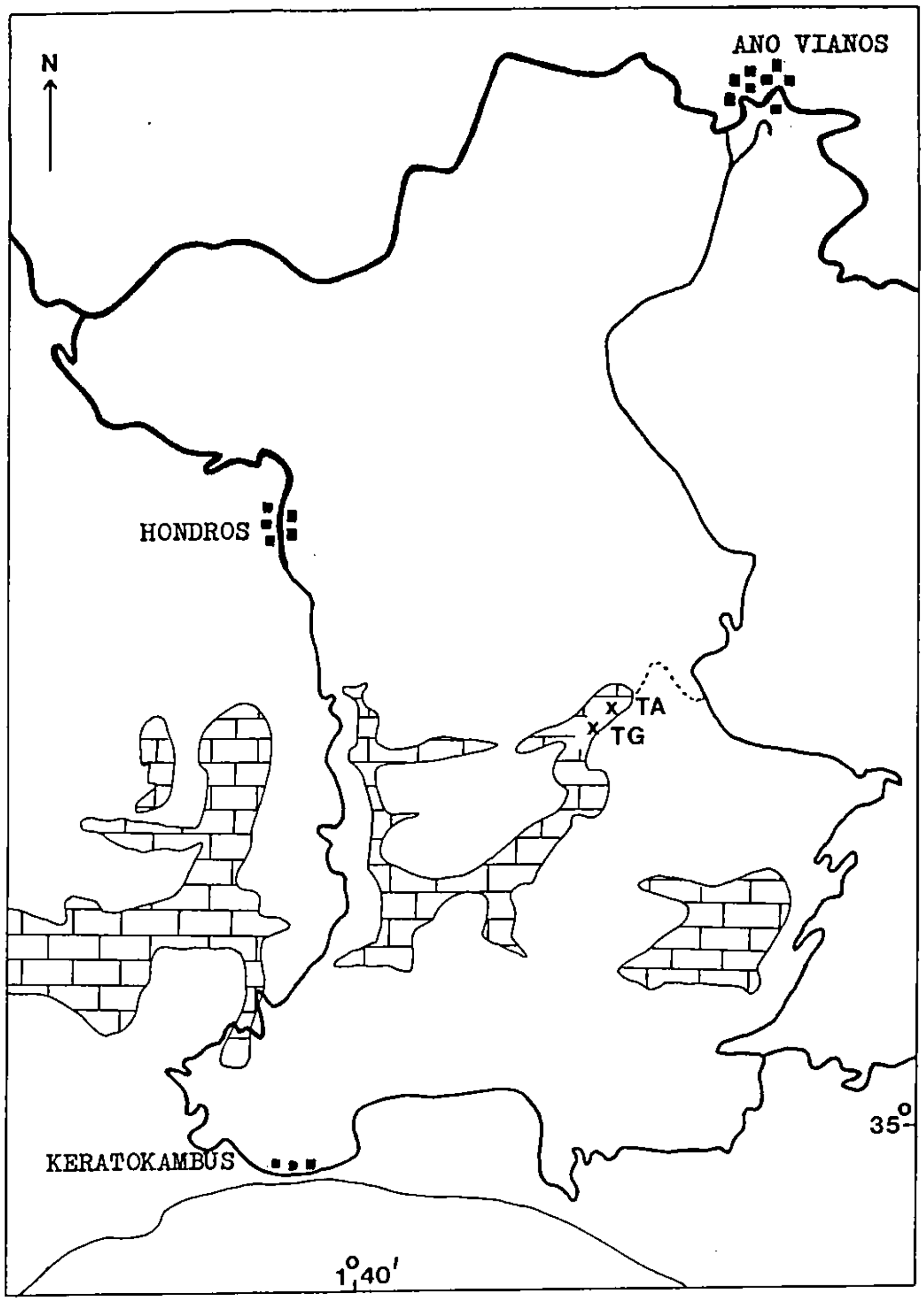
8 major outcrops of the Pindic-Ethia Series were studied and sampled in detail. Seven of the outcrops are located in the Asterousia Ori and one in the Asideroto Ori. These outcrops were selected for the variations in their lithofacies and ages. Of the 8 outcrops, section TE(1) had previously been investigated by Bonneau and Fleury (1971) but no details were given regarding the faunal content of the Upper Cretaceous-Eocene limestones (their "Sublithographic limestones and limestone microbreccias").

Outcrops were sampled at regular intervals, usually at spacing of 4 or 2 meters. Where planktonic microfauna are restricted to specific horizons within a limestone sequence that is generally unfossiliferous, close sampling of these horizons was carried out at cm-intervals.

In addition to sample collection, the strikes and the dips of the beds, colour of the strata, rock-types, vertical variations in lithofacies, variation in bed thickness, and other features such as presence or absence of chert nodules, stylolites, laminations etc. were noted.

4.1.1 Section TA (Plate 1, fig. A; Plate 2, figs. A, B)
Locality (fig. 2) : The outcrop is situated approximately mid-way between Ano Vianos and Keratokambos. It is located in a narrow valley trending southwest. It is accessible via a path leading off the main road from Ano Vianos to Keratokambos.

Fig. 2 - Locality map of Sections TA and TG.



Scale - 1 : 30,000

Description of section :

The section forms a steep valley wall facing south-southeast. It can be divided into 3 units (fig. 3).

Unit 1 - From the floor of the valley upwards, the section is composed of well-bedded, 10-20 cm thick, grey calcilutites, calcisiltites and calcarenites. The calcilutites may contain thin laminae of arenite-sized carbonate grains. Some of the calcarenites show load structures, planar lamination, small-scale cross-lamination, and grading from arenite to lutite sizes. Such calcarenites are interpreted as calciturbidites. Some black chert nodules and bands are also present. Stylolites are well developed and coincide with the bedding planes. Beds are generally poorly fossiliferous and are dipping at about 10-20^{o} towards south-southeast. The thickness of this unit is about 40 meters.

Unit 2 - Thrust directly above unit 1 is a 10-15 meters thick, bedded unit composed of brecciated limestones with abundant secondary calcite veins. No fossils were observed. The thrust plane strikes northwest-southeast and dips 20-30^{o} towards northeast.

Unit 3 - These limestones are well-bedded and their lithologies agree with the description given for unit 1. In addition, two massive breccia beds (about 4 m and 1.5 m thick respectively) containing a shallow-water fauna (Orbitoides, miliolids, etc.) were observed. Sporadic occurrences of Globotruncana species are present throughout this unit. Several recumbent folds with axes trending approximately east-northeast - west-southwest were noted. As the axes of these folds run roughly parallel to the face of the section studied, repetition of beds by folding was not readily discerned in the field. Folds with axes trending northwest-southeast and

Fig. 3 - Sketch of Section TA.

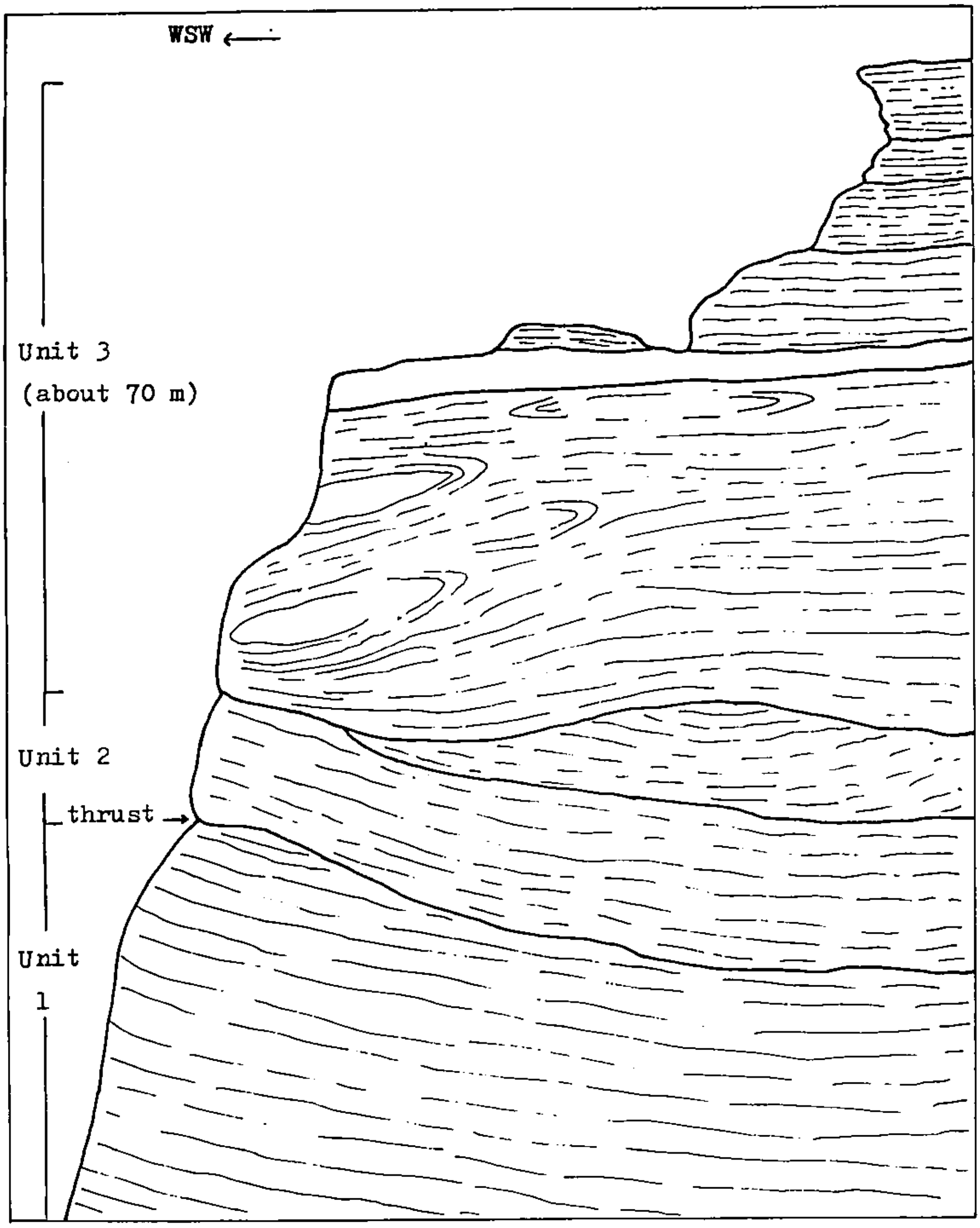


Plate 1

fig. A Section TA

a - massive bed composing predominantly of shallow-water limestone clasts.

fig. B Section TN

a - massive limestone breccia of unit 5 (about 98 meters thick).


a
A


B

Plate 2

fig. A — Upper Cretaceous limestone sequence in Section TA. Folds overturning to the west were observed. Stylolites are well-developed.

fig. B — Upper Cretaceous limestone sequence in Section TA. a, b, c show the presence of recumbent folds with axes running (trending) roughly east-northeast.

A and B belong to Unit 3 of Section TA.


A


a
b
c
B

overturning to southwest are also found. The estimated thickness of this unit is 68 meters. The actual thickness is much less due to repetition of beds by folding.

The top of section TA is faulted against siliciclastics ("Tertiary Pindos Flysch").

4.1.2 Section TG

Locality (fig. 2): The outcrop is located about 120 meters directly southwest of section TA. It is separated from section TA by a narrow gulley trending southwest.

Description of section (fig. 4) :

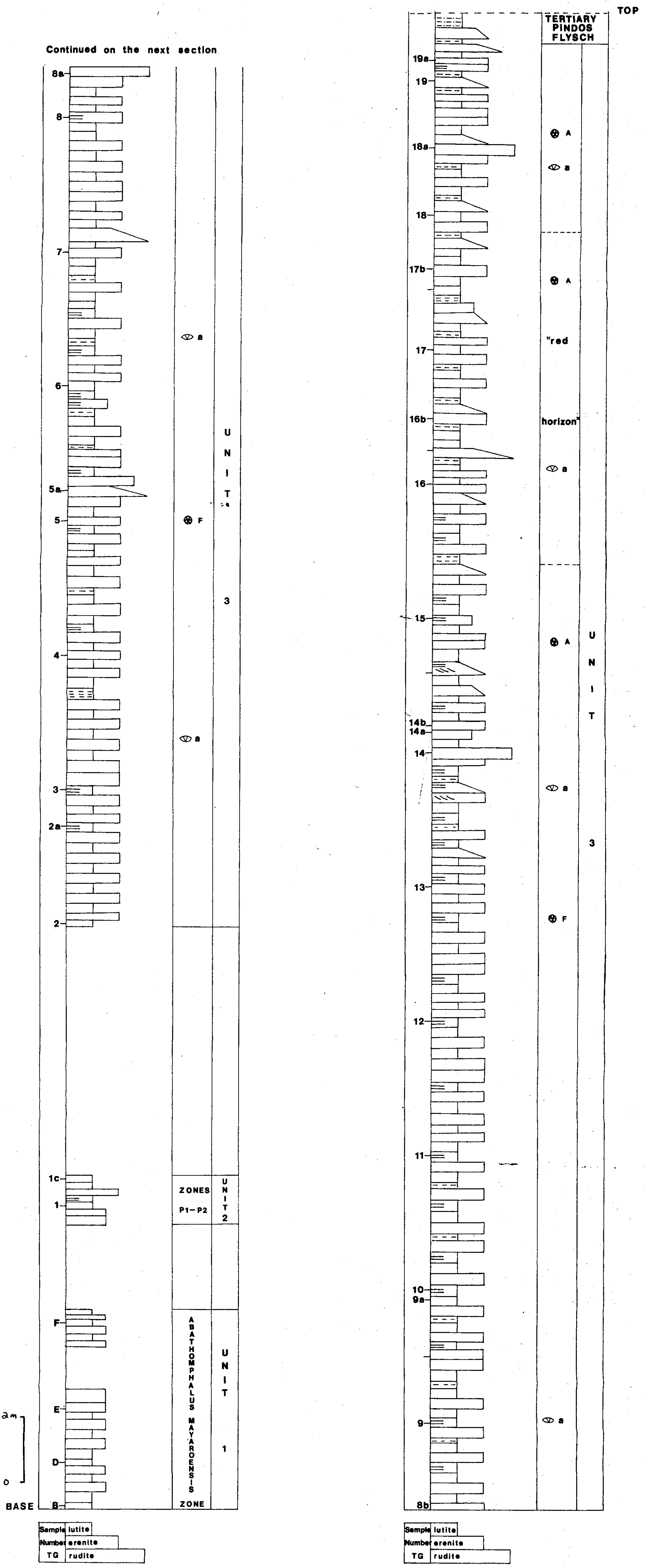
The cliff face shows a well-bedded limestone sequence dipping at about 20° towards the southeast. Throughout the section, stylolites and black chert nodules and bands are well developed.

Unit 1 - The basal part of the section consists of grey, Globotruncana-bearing calcilutites that pass upwards into generally non-fossiliferous beds. The thickness of this unit is about 5 meters.

Unit 2 - A 2.5 meter gap separates the last bed in unit 1 from an overlying sequence of fossiliferous calcilutites and calcisiltites. The calcilutites are thinly-bedded and some are laminated. A graded calcarenite was also observed. The fossils identified in the field consist mainly of Turborotalia species. This unit is thus of early Tertiary age.

Unit 3 - Another gap (7.5 meter wide) separates unit 2 from the base of a thick limestone sequence consisting predominantly of interbedded, grey, calcilutite and calcarenite with minor amounts of intercalated shale. A few beds of coarse limestone breccia are also found.

FIG. 4 PINDIC-ETHIA SERIES —— SECTION TG



The calcilutites may be laminated while the calcarenites include laminated, graded, cross-laminated and partly recrystallized beds. Fossils, both benthonics and planktonics, are common throughout this unit. The planktonics are dominated by Acarinina and Morovozella species, while the benthonics include Discocyclina spp ., Nummulites spp . and Fasciolites spp . The upper part of the unit is characterized by the presence of thin red shale intercalations. Even the calcilutites at this 'red' level have a reddish to pinkish tint. The red shales are not fossiliferous. The thickness of the 'red horizon' is estimated to be 12 meters. About 5 to 6 meters directly above the top of the 'red horizon', the limestone beds were replaced by Pindos flysch. The flysch here consists mainly of grey, fissile, non-fossiliferous shales although a few beds of graded calcarenite and calcilutite are still present in its basal portion. The contact between the Tertiary limestones and the flysch here is conformable. The total thickness of unit 3 is about 65 meters.

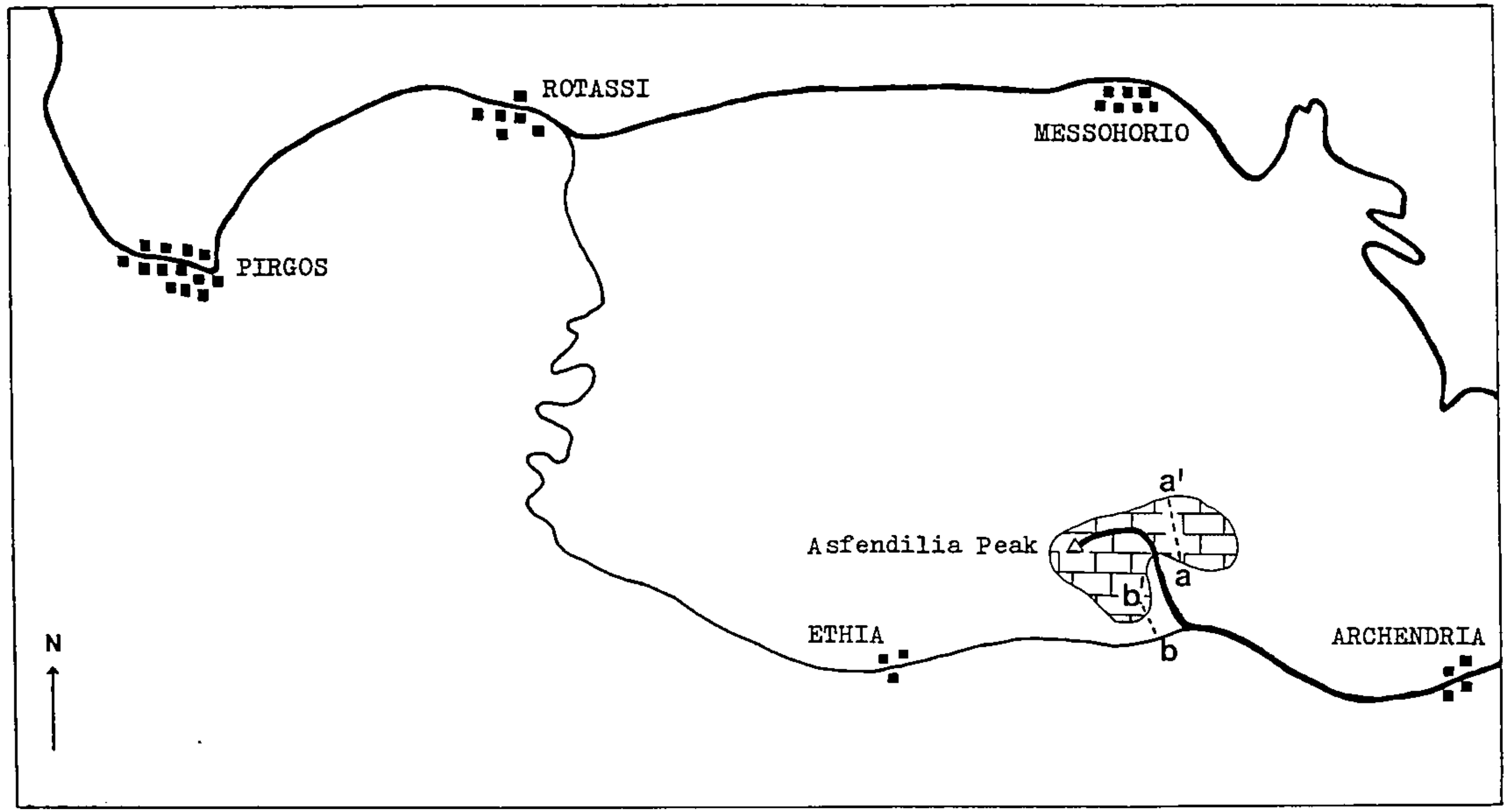
4.1.3 Section TE

Locality (fig. 5) : The study area is bordered directly on the west by the Asfendilia Peak and on the south by the Achendria - Ethia road. An offshoot of this road leading to the Television Station on the summit of Asfendilia separates the limestone beds of the study area from the limestone outcrop of section TE(1).

Description of section (fig. 6a) (Plate 3; Plate 4, figs. A-C; Plate 5, figs. A-D; Pl. 6, figs. A, B)

The outcrop consists of well-bedded limestones dipping about 30° to 40° towards the north. The section chosen for study extends right across the outcrop along a south-southeast to north-northwest traverse line.

Fig. 5 - Locality map of Sections TE and TE(1)



Scale - 1 : 30,000

a'-a traverse across Section TE

b'-b traverse across Section TE(1)

Plate 3 : Panoramic view of the Asfendilia Mountain. Section TE lies directly eastwards of the roading leading to the Television Station (located at the summit of the Asfendilia Mountain).


SSW
NNE

Throughout the section, stylolites were well developed. Black chert nodules are generally absent except towards the upper part of the section. Folding in the limestone beds was also observed. The folds are more abundant higher up in the section. The main types of flexure seen are open to closed chevron folds. Isoclinal and open asymmetrical folds are present but are not common. The majority of the fold axes trend north-south; near the top of the section, the folds plunge quite steeply (about 40^{o}) towards the north.

Unit 1 - The section commences with a massive, 10-12 meter thick conglomeratic limestone.

Unit 2 - Overlying the conglomerate is a sequence of cm-bedded calcilutites, calcarenites with minor amounts of calcirudites. The calcilutites are generally laminated, and the calcarenites include graded, laminated and partly recrystallized beds. The calcirudites or limestone conglomerates tend to be thick-bedded and graded. They are composed of coral fragments, rudist fragments, ooliths-pisoliths, black chert clasts and limestone clasts. In the lower part of this unit, fossils are usually minute; higher upwards, Globotruncana species become more common. The total thickness of this unit is about 101.7 meters.

Unit 3 - Unit 2 is overlain by a series of dm-thick calcarenites. Most of the calcarenites are coarse, sand-sized; partly recrystallized and graded beds were also seen. Laminated calcilutites and calcirudites occured only at certain horizons; these beds form only a small proportion of the whole unit. Fossils are generally absent from, or are badly preserved in the calcarenites. Globotruncana species were observed from the calcilutites and calcirudites. The unit here is about 80 meters thick.

Unit 4 - The calcarenite sequence of unit 3 passes directly into another series of interbedded calcilutite and calcarenite similar to those seen in unit 2. A few beds of calcirudites were also seen. Globotruncana spp. and Orbitoides spp. are present throughout the unit. A narrow horizon of grey, non-fossiliferous, bedded, calcareous sandstone and siltstone divides this unit roughly into two parts. The lower part is about 66 meters thick while the upper part is nearly 77 meters thick. The top 24 meters of this unit is poorly exposed.

Unit - The succession of Cretaceous Globotruncana-bearing limestone beds continue without a distinct break into the Tertiary. The transition from Cretaceous to Tertiary is poorly exposed and could not be determined in the field. Beds with definite Tertiary fossils were recorded for the first time at level TE 120. Throughout the unit, planktonic fossils such as Acarinina, Subbotina and Morozovella species are common. Benthonics include Discocyclina, Nummulites and Fasciolites species. Black chert and bands are well developed. The unit is composed mainly of calcilutites and calcarenites with subordinate amounts of grey and red shales, and limestone breccias. Laminated, graded and partly recrystallized beds are interspersed throughout the unit. As in other limestone sections of Tertiary age, red shale intercalations are found towards the top 15 meters. The thickness of the portion containing red shale is about 10 meters. The total thickness of this unit is not estimated due to poor exposure and probable repetition of beds due to folding. Resting directly on its top is a flysch sequence. The basal part of the latter is dominated by grey, fissile shales with a few limestone and sandstone interbeds. The latter are generally laminated and/or cross-bedded. The

FIG. 6a PINDIC-ETHIA SERIES —— SECTION TE

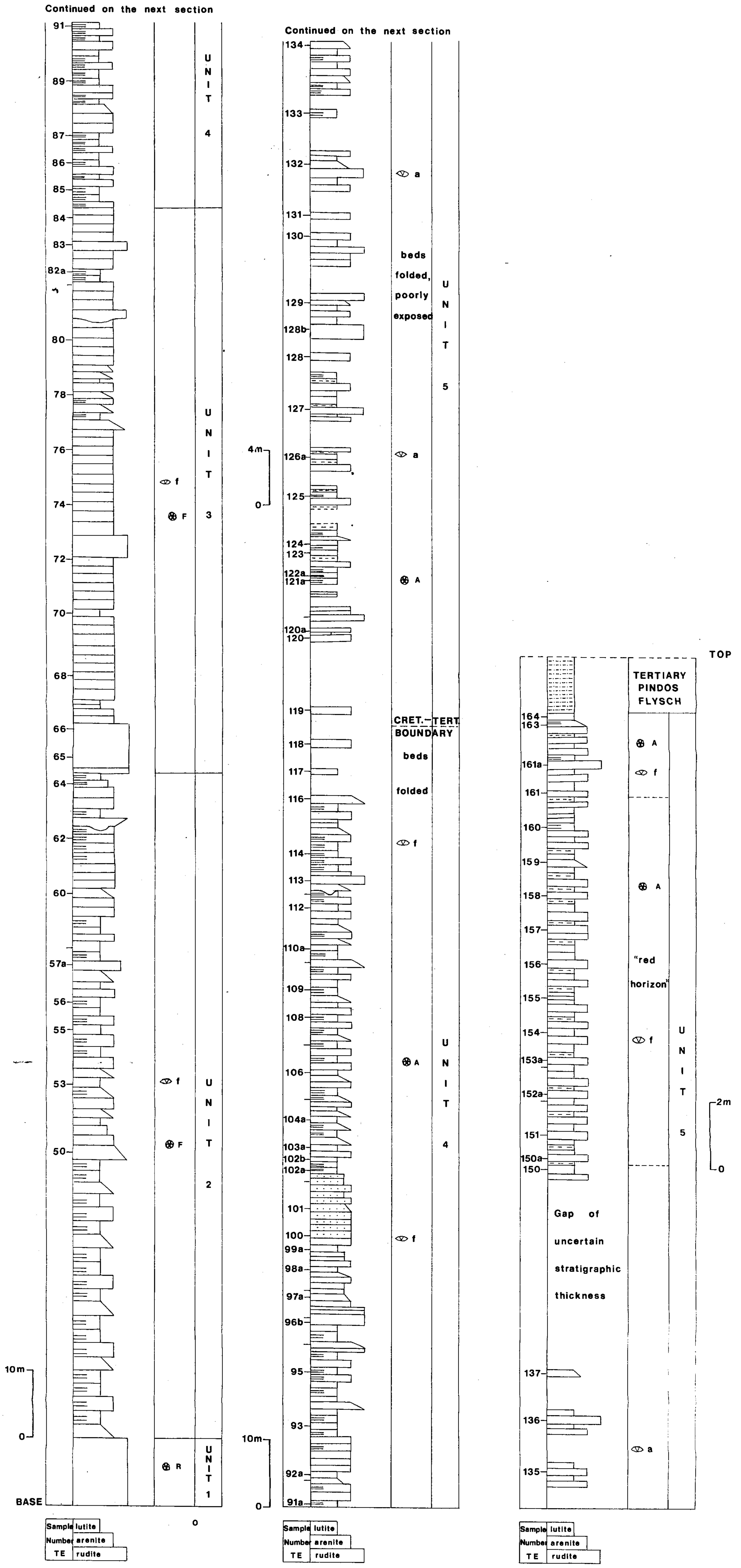


Plate 4

fig. A — Thick calcarenite and limestone breccia (conglomerate) beds of Unit 3 in Section TE.

fig. B — Calcirudite bed. Arrow points to a small-scale channel. Locality : Section TE

fig. C — Calcirudite bed showing grading. Clasts are composed predominantly of carbonate. Locality : Section TE


A


B


C

Plate 5

fig. A Calcirudite containing coarse carbonate clasts and black chert grains. Locality : Section TE

fig. B Calcirudite showing grading and planar laminations. Locality : Section TE

fig. C Laminated calcilutites. Laminae are composed of arenite-sized carbonate grains. Pen points to a channel. Locality : Section TE

fig. D Basal portion of the "Tertiary Pindos Flysch." Locality : north of the Asfendilia Peak.

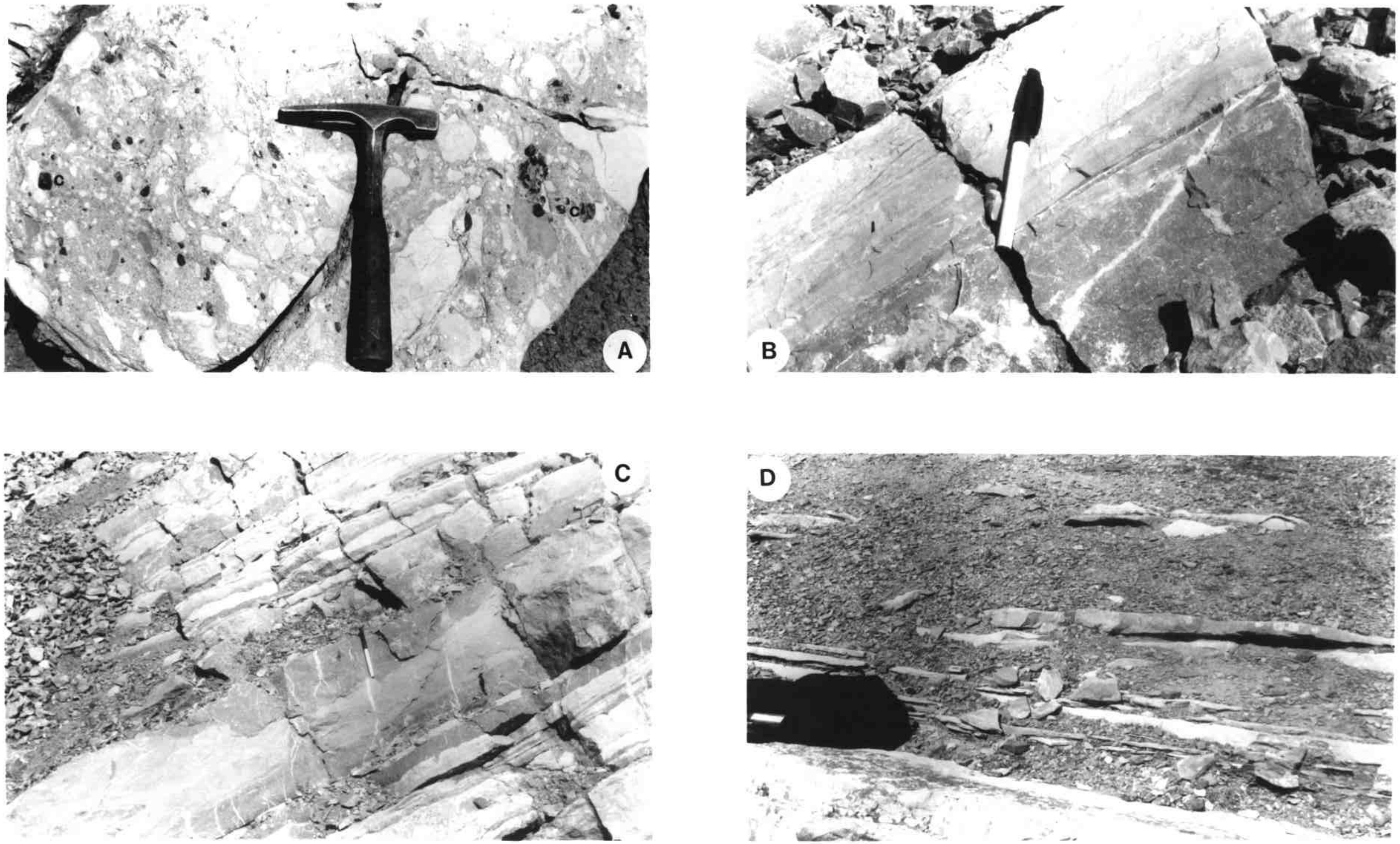

A
B
C
D

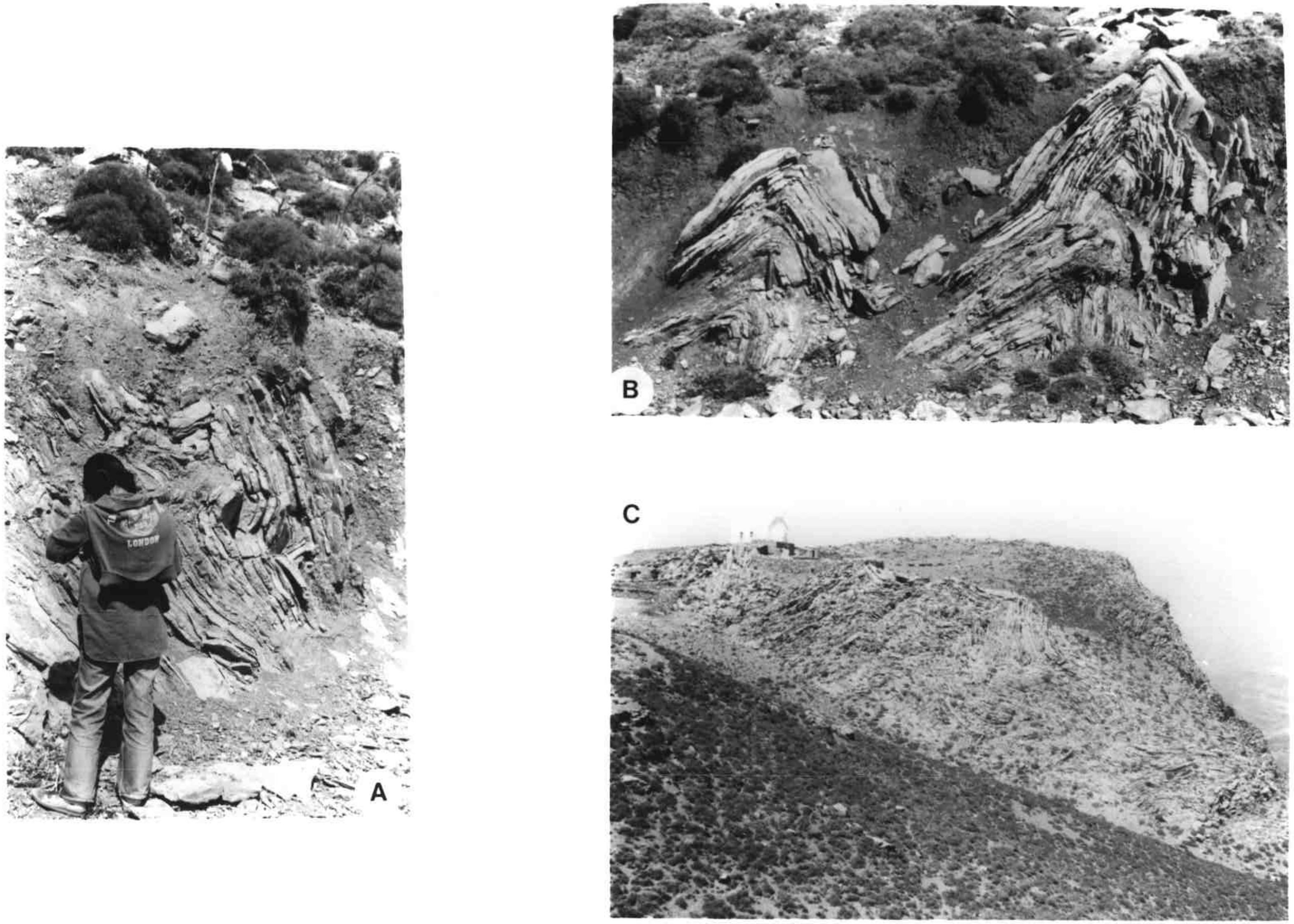
Plate 6

figs. A - C Folded limestone sequence (Lower Tertiary age) in the Pindic-Ethia Series.

Localities :

A, B - Section TE

C - north of the Asfendilia mountain


A
LONDON
B
C

limestone beds are non-fossiliferous.

4.1.4 Section TE(1)

Locality (fig. 5) : The outcrop forms the lower part of the south-eastern foothill of the Asfendilia Peak. It is bordered on the south by the Archendria - Ethia road.

Description of section (Plate 3) :

The section studied corresponds in part to the section investigated by Bonneau and Fleury (1971). The traverse b-b' extends from the road-cut (Archendria-Ethia road) to the base of the Upper Cretaceous limestone sequence. From the road-cut upwards, one finds (fig. 6b) :

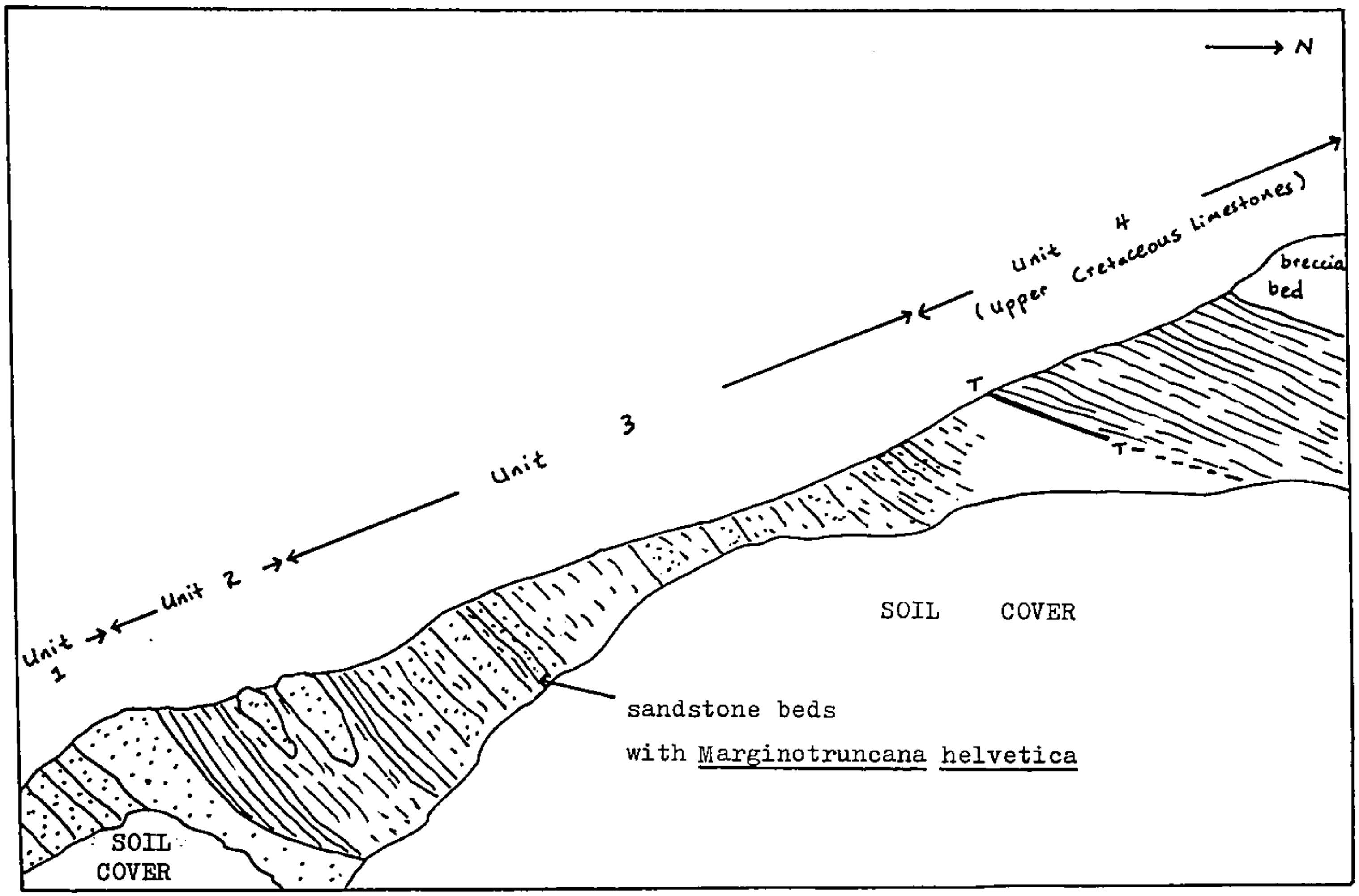
Unit 1 - A sequence of disrupted cm-thick sandstone and siltstone beds with minor amounts of shales. This passed sharply upwards into a massive sandstone bed (1.5 - 2 m thick), followed by more cm-thick sandstone beds. The sandstone beds in this unit are generally graded, and their lower bedding planes are sharp. On the surfaces of the lower bedding planes, scour and fill structures were observed. These beds are interpreted as turbidites. The surfaces of the beds here are badly weathered; fresher surfaces are grey in colour. The beds are non-fossiliferous and they dip 55^{o} to 65^{o} towards the north-northeast and east-northeast. The thickness of this sequence is about 4.5 meters.

Unit 2 - The sandstone-siltstone sequence of unit 1 is truncated along a curving surface by a series of thin centimetric beds of grey radiolarian calcilutites (partly silicified), laminated green chert and weathered shales. These pass upwards into more laminated grey to red shales. Associated with the red shales are some disrupted beds of steeply dipping red-coloured sandstone. The sandstones show a well developed lineation of coarse calcareous lenses. Higher up, grey, radiolarian calcilutites and calcarenites appear. Throughout this unit, beds continue to dip at about 60° towards the northeast.

Unit 3 - Resting directly on unit 2 is a sequence dominated by shales, siltstones and sandstones. The shales are fissile and they range from grey to red in colour. Two types of siltstone-sandstone were observed. One consists of bluish-grey coloured, graded beds that are rich in carbonaceous remains, and the other is characterized by its red colour and the presence of lineations. In the latter, coarser beds contain calcareous lenses. The beds in the lower part of this unit dip about 50-60° towards the north-northeast, but higher up towards the Cretaceous limestones, dips of about 20° were recorded. This unit is overlain by the Upper Cretaceous limestone sequence.

Unit 4 - The contact between the Upper Cretaceous limestones and the shale-sandstone sequence of unit 3 is displaced by numerous small faults. The limestone beds at the contact are not sheared or badly fractured and they dip about 20° to 30° towards the north-northeast. They appear to be conformable with the upper part of the underlying shales and sandstones. However within the shale-sandstone sequence, the basal part has a much steeper dip compared to the top part. Due to the lack of a good section, it could not be determined in the field whether the contact is conformable or thrust. A detailed micropaleontological study is being carried out to solve this problem. At the base, the Upper Cretaceous limestones consist mainly of graded calcarenites and laminated calcilutites. These beds contain minute fossils and some black

Fig. 6b Sketch of section TE(1)



T - thrust

chert nodules. The thickness of this basal part is about 16 meters. Resting directly on the calcarenite-calcilutite series is a massive, coarse, limestone breccia (10-12 meters thick) similar to the one recorded from the base of the section TE. The section above this coarse breccia was not examined.

4.1.5 Section TN

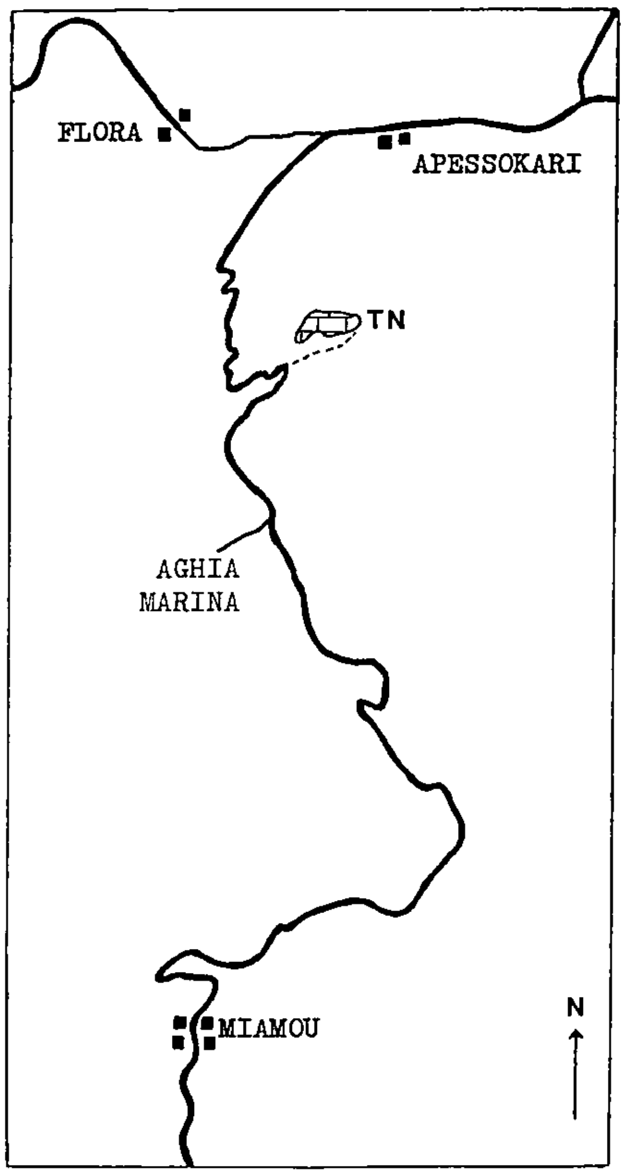
Locality (fig. 7) : The outcrop is situated roughly midway between Apessokari and Aghia Marina, in a small valley lying to the east of the main road from Apessokari to Miamou. It is partly bordered on the south by a sharp hairpin loop formed by the main road.

Description of section : (Plate 1, fig. B)

The section forms a steep to almost vertical cliff. The cliff face reveals a well-bedded sequence of terrigenous and limestone beds. These beds dip about 8-10^{o} towards the east. The base of the sequence is not exposed. From the bottom of the cliff face upwards, one finds (fig. 8) :

Unit 1 - Graded, grey coloured calcareous sandstones interbedded with fissile, grey, silty shales. These beds are right way up. The sandstones are generally thick, usually measuring about 40 to 50 cm. Components of the sandstone include angular quartz grains (about 15 %), carbonaceous streaks and some micas. No fossils were observed in the sandstones or in the shales. A graded limestone bed was found in the lower part of this unit; this contains minute fossils. Towards the top of the unit, the sandstone-shale sequence was interbedded with thin bands of red, silty shale, pale, grey, laminated calcilutites and greenish grey, calcareous siltstone.

Fig. 7 - Locality map of Section TN.



Scale - 1 : 30,000

Unit 2 - Directly above unit 1 is a succession of thinly bedded, (2-5 cm thick) grey calcarenites, calcisiltites and calcilutites. Some of the calcisiltites and calcilutites are finely laminated. Interbeds of red, silty shale and light grey and light purple calcilutites appear higher up in this unit. Minute fossils were observed in the calcilutites. Some black chert nodules were developed throughout this unit.

Unit 3 - The lower part of this unit is made up of thinly bedded (3-7 cm thick), greenish-grey, calcareous siltstone and shale. Varying amounts of carbonaceous remains were observed in these beds. The upper part of this unit is dominated by a massive, grey, calcareous sandstone bed (65-75 cm thick) showing small scale channelling. Angular quartz grains, black and red chert grains, volcanic grains and some mud pebbles were identified in the sandstone. No fossils were observed in this unit.

Unit 4 - Overlying the massive sandstone conformably is a thick limestone sequence dominated by calcilutites. Also present in lesser proportion are calcarenites, coarse limestone breccias, red silty shales, and grey, calcareous sandstone-siltstone.

(i) The limestone breccias were located at two levels. The first breccia beds were found at the base of the unit. The total thickness of these beds is 75 cm. The second breccia beds were situated about halfway-up the unit and have a total thickness of 3.2 meters. The components of both breccias are essentially similar, and include rudist fragments, mud clasts, quartz grains, chert grains, volcanic grains and ooliths.

(ii) Interbedded grey calcarenites occur throughout the unit. Some of the calcarenites are recrystallized, and some are graded.

(iii) Several types of calcilutites were observed. Those lying between the two coarse limestone breccias are generally interbedded in the red silty shales. Colours of these calcilutites range from pale grey, white, pink to purplish grey, and khaki-coloured. Some of the calcilutites are laminated and most contain minute fossils and radiolaria. Chert nodules and bands are rare in these beds. Directly above the second breccia, the unit is dominated almost entirely by laminated calcilutites with well developed red chert nodules and bands. Striking colours of pale pink, light yellow, white and pale grey characterized these calcilutites. Radiolaria is quite abundant in these beds and rare double-keeled, flat Globotruncana species were also observed.

(iv) A few beds of calcareous sandstone and siltstone showing grading and lamination were found in the lower half of this unit. Most of the beds contain variable amounts of carbonaceous material but are otherwise non-fossiliferous. The typical colour of the sandstone-siltstone is grey to greenish-grey but a red-coloured sandstone grading into red, silty shales has also been observed.

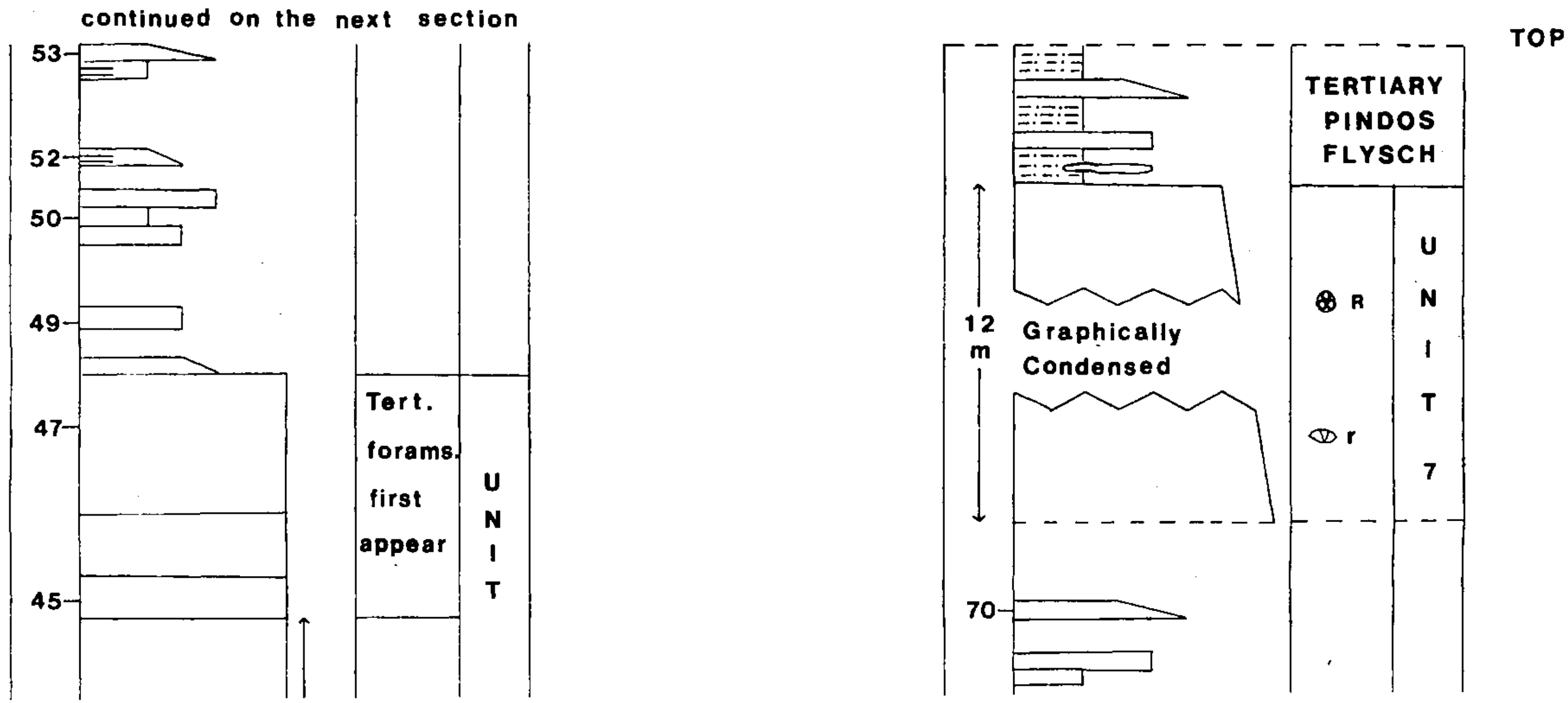
The total thickness of unit 4 is 37.6 meters.

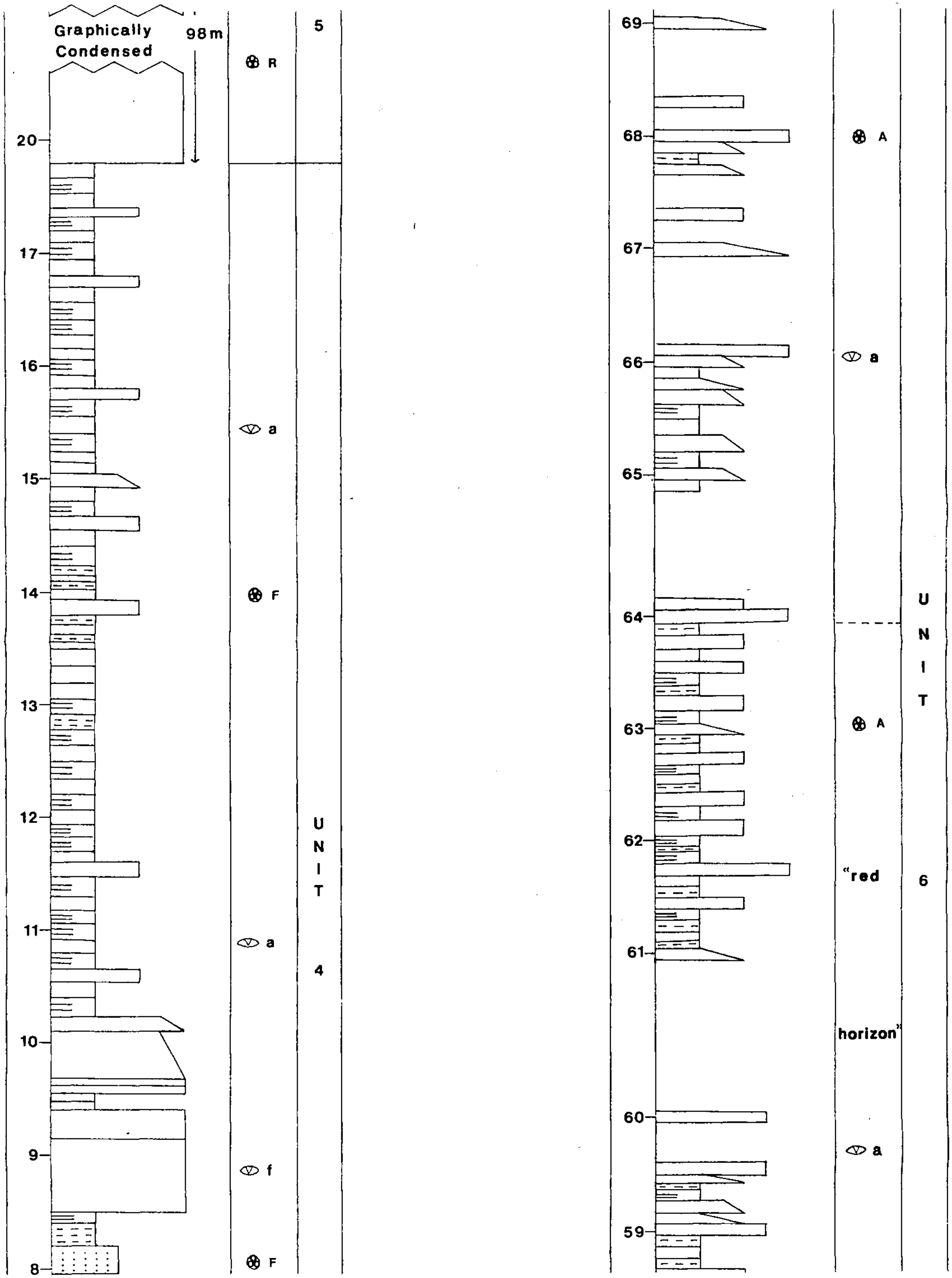
Unit 5 - Resting directly above unit 4 is a massive sequence of coarse limestone breccias. The contact between the breccia and the underlying unit is sharp and conformable. The angle of dip is 10^{o} towards the east. Bedding were not observed in the breccia except near the top of the unit. Components identified in the field include ooliths, rudist fragments, corals, quartz grains, chert grains, siltstone clasts, volcanic clasts and lime-mud clasts. A large proportion of the breccias is recrystallized and show no traces of faunal elements. At the top of this unit, Discocyclina species were recorded from 3 thick breccia beds. The total thickness of this unit is 98 meters.

Unit 6 - Directly overlying the massive breccias is a succession of cm-thick, fossiliferous limestone beds of Tertiary age composing of interbedded, grey limestone breccias, calcarenites, calcisiltites and calcilutites. The breccias here are rich in rudist fragments, corals, pisoliths and Discocyclina species. Planktonic fossils are generally absent. The calcarenites are common throughout the unit. Some of the beds are partly recrystallized and some are graded. Planktonic fossils are present but are not well preserved. The calcisiltites and the calcilutites are usually laminated and are very fossiliferous. Fossils are well preserved in these beds and include Acarinina, Morozovella and Subbotina species. At about 16.7 meters above the base of the unit, thin beds of red, fissile shales appear between the limestone beds. This interval of limestone with red shale interbeds could be traced vertically for another 11.5 meters. No fossils were observed in the shales. Above the red shale-limestone interval are more calcarenites with minor amounts of calcilutite and calcibreccia. These beds yielded abundant planktonic and benthonic fauna as described earlier. Throughout this unit, stylolites and black chert nodules-bands are well developed.

Unit 7 - In the study section, a meter of soft ground separates the last bed of the underlying unit from the base of a massive, 12 meters thick, limestone breccia. In adjacent sections at the same locality, the breccia rests directly on the underlying unit conformably. The basal part of the breccia is made up of rounded, flattened cobbles. The majority of these are composed of grey calcilutites and crystalline calcarenites containing fragments of rudists and corals. A few cobbles are composed of calcareous

FIG. 8 PINDIC - ETHIA SERIES —— SECTION TN





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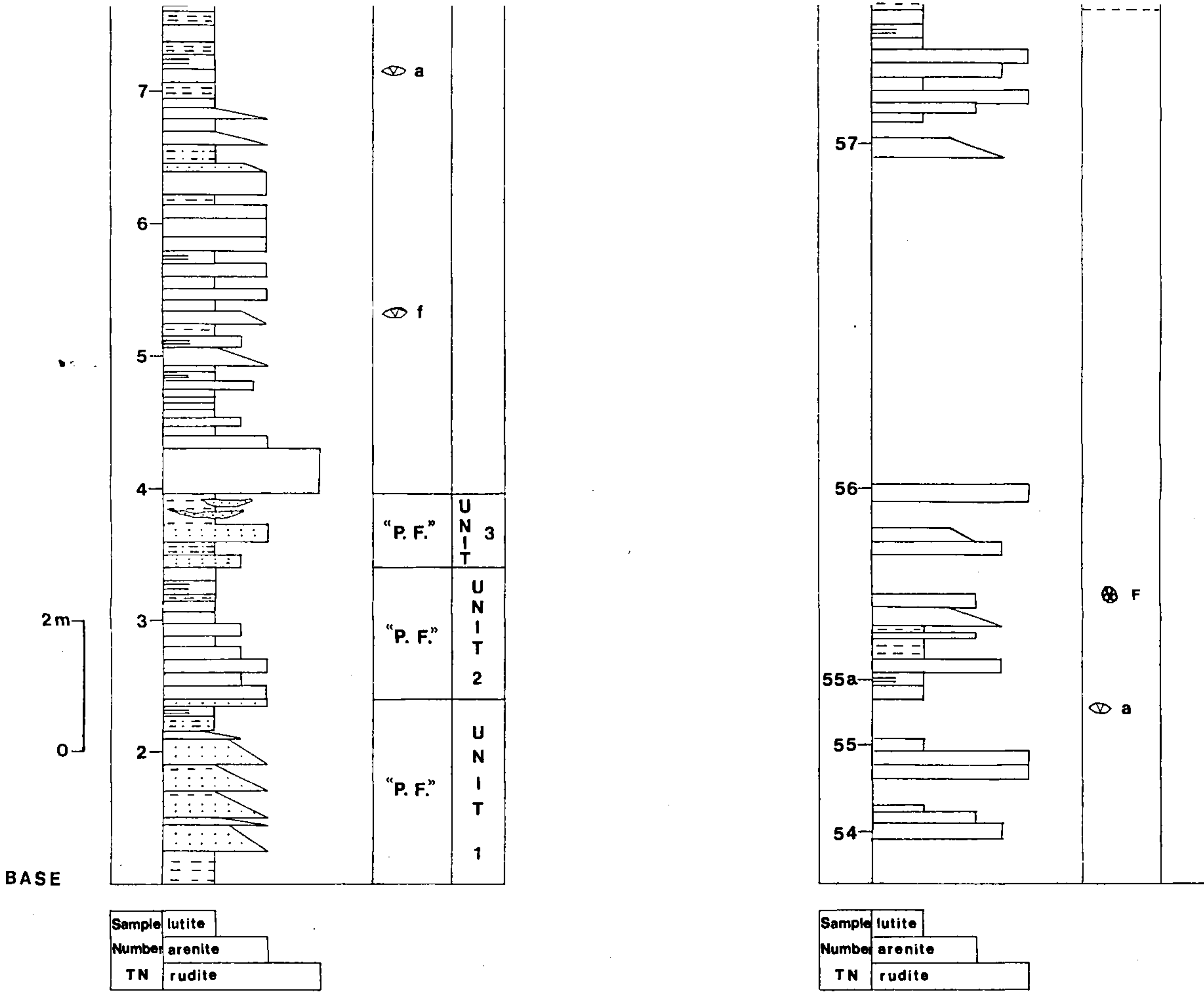
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sandstone, black chert, volcanics and quartzite. The cobbles pass upwards into pebble-sized, limestone breccias with lithologies similar to those of the cobbles. Nummulites, rudist fragments, corals and rare planktonic foraminifera are scattered throughout the breccia.

Unit 8 - Resting on the massive 12 meter breccia is the Tertiary Pindos flysch. The basal part of the flysch is made up of predominantly grey, fissile, and occasionally laminated shales containing a few beds and lenses of graded calcarenite, calcibreccia, and calcilutite. The coarser limestone beds contain Fasciolites spp ., Nummulites spp . and rudist fragments. Planktonic foraminifera are absent from the beds here. A more detailed study of the flysch is currently being done by A.H. Hussin from Queen Mary College.

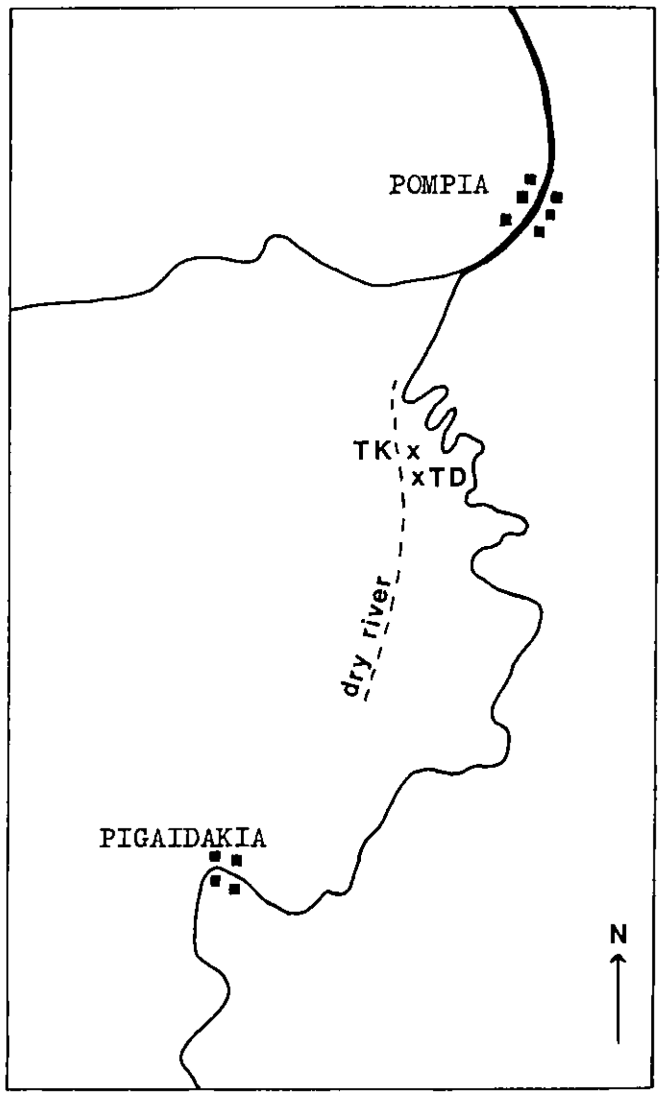
4.1.6 Section TK

Locality (fig. 9) : The outcrop is situated about 1 km south-southwest of Pompia. It is located on the eastern wall of a narrow gully trending south-southwest. It is accessible by a path leading off the first hairpin loop formed by the main road from Pompia to Pigaidakia.

Description of section :

The gully here is floored and walled by well-bedded limestones. Numerous faults trending north-south, northwest-southeast, and northeast-southwest transect the gully. The limestone section exposed along the eastern wall of the gully could be traced laterally despite slight displacement on small faults, while the section along the western wall is more disrupted and

Fig. 9 - Locality map of Sections TK and TD.



Scale - 1 : 30,000

discontinuous. Study was restricted to the section along the eastern wall of the gully. The beds here dip about 25-40° towards the east-northeast. From the gully floor upwards, one finds (fig. 10) :

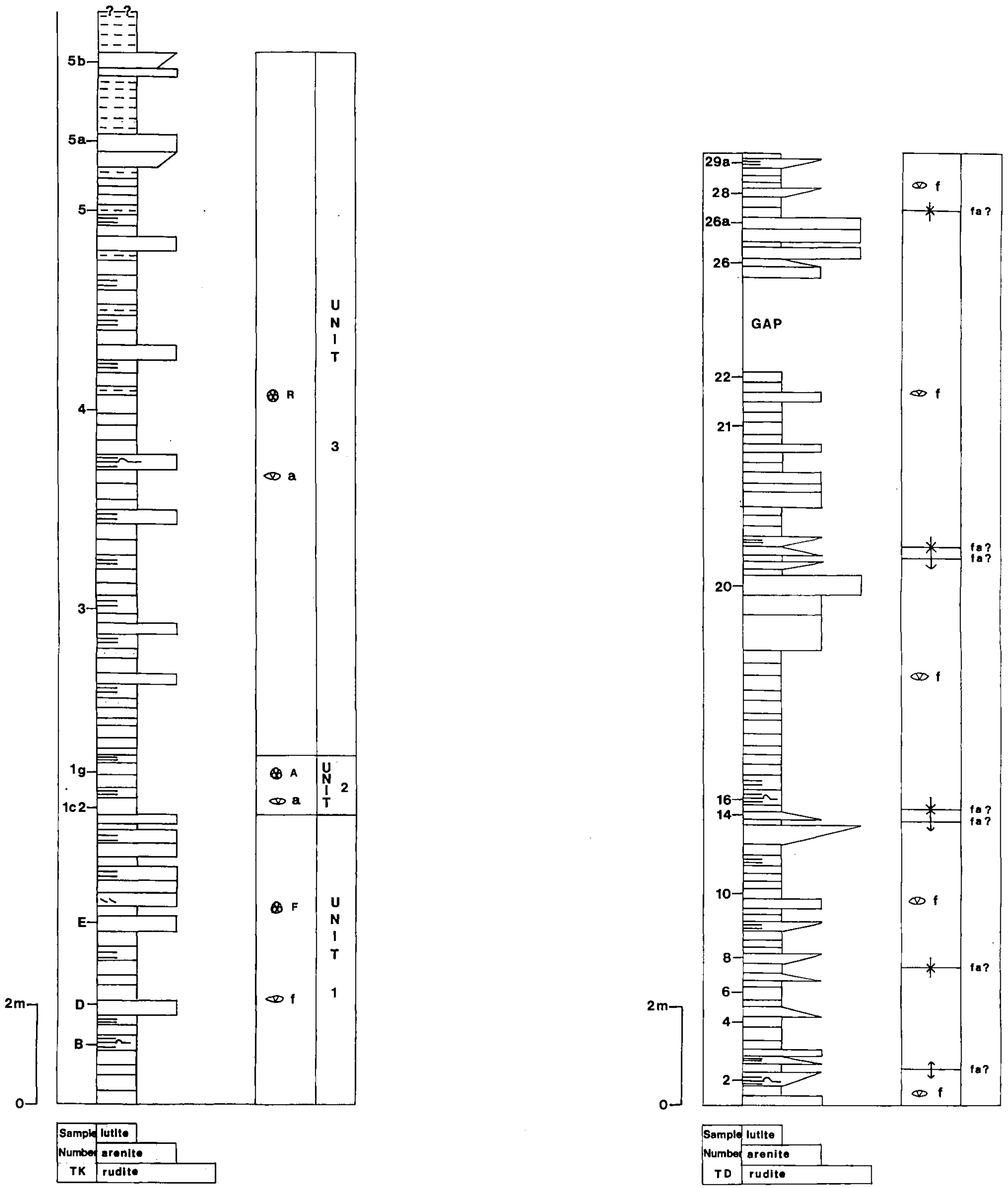
Unit 1 - cm-thick beds of calcilutites and calcarenites. The former may be laminated, and the latter increases in proportion upsection. Stylolites are well developed throughout the section. Some black chert nodules were also observed. Loading features indicate that beds are inverted.

Unit 2 - Overlying unit 1 is a sequence of very fossiliferous, Globotruncana-bearing and Marginotruncana-bearing, grey to blackish-grey calcilutites. Beds are generally laminated and grading within some of the laminae indicate that beds are inverted. Black chert nodules and bands are well developed. The thickness of this unit is about 1 meter.

Unit 3 - Directly above unit 2 is a distinct horizon of varied coloured calcilutites with minor amounts of grey calcarenites. The colours of the calcilutites range from pink, beige, light grey, to white. Beds are generally non-fossiliferous. Laminations and red, or black, chert nodules and bands are common. The upper part of this unit is dominated by red shales and red limestones. Towards the top of the red shales, exposures become poor. Soil with traces of grey shales was generally observed. Higher up in the section, two more calcarenite beds were found interbedded with fissile, greenish-grey shales. Grading within some of the calcarenites in this unit indicate that beds here are inverted.

The grey shales at the top of this section are covered by blocks of sandstone belonging to the blocky flysch. Contact between the shales and the flysch could not be determined in the

FIG. 10 PINDIC ETHIA SERIES — SECTIONS TK AND TD



field. Micropaleontological study and field evidence show that section TK is inverted and unit 3 is the oldest of the three units studied.

4.1.7 <u>Section TD</u>

Locality (fig. 9) : The outcrop is located on the eastern side of the same gully in which section TK is found. It is about 90 meters south-southeast of section TK.

Description of section (fig. 10) :

The limestone outcrop here stands as a small hillock on the eastern flank of the dried-up river gully. The base of the sequence is not exposed. The section studied consists of well-bedded, grey to pale grey calcilutites, calcarenites and calcirudites. The calcilutites dominate the section; they constitute over 50 % of the total bulk of the limestone beds.

The dip recorded for the beds in this section is about 30^{o} towards the northeast-northnortheast. Thicknesses of the individual bed range from 5 to 15 cm. Throughout the section, stylolites are well developed; they are formed parallel to, or coincident with, the bedding planes. Chert nodules and bands are present but are poorly developed.

The calcilutites are usually fossiliferous and some are finely laminated. The laminae are made up of fine calcareous grains. Some calcilutites may be bioturbated. The calcarenites in general lack fossils and show various degree of recrystallization. Sedimentary features associated with the calcarenites include grading, loading structures, lamination, and scour marks, and they indicate that some of the calcarenites in this section are calciturbidites. Calcirudites are rare in this section but they are generally fossiliferous and thicker beds may be graded.

A study of the grading, scour marks and loading features, show that inverted beds are repeatedly associated with beds in a right-way up position throughout the section. The author believes that such an association would suggest a tightly folded sequence with fold axes trending roughly parallel to the strike of the beds. However, no folds were directly observed in the field.

4.1.8 Section TP

Locality (fig. 11) : Outcrop forms the northeastern foothill of the Asideroto Ori. It is located on the eastern flank of a gully trending roughly northeast-southwest, and is accessible by a small path linking Vatos to Kerames.

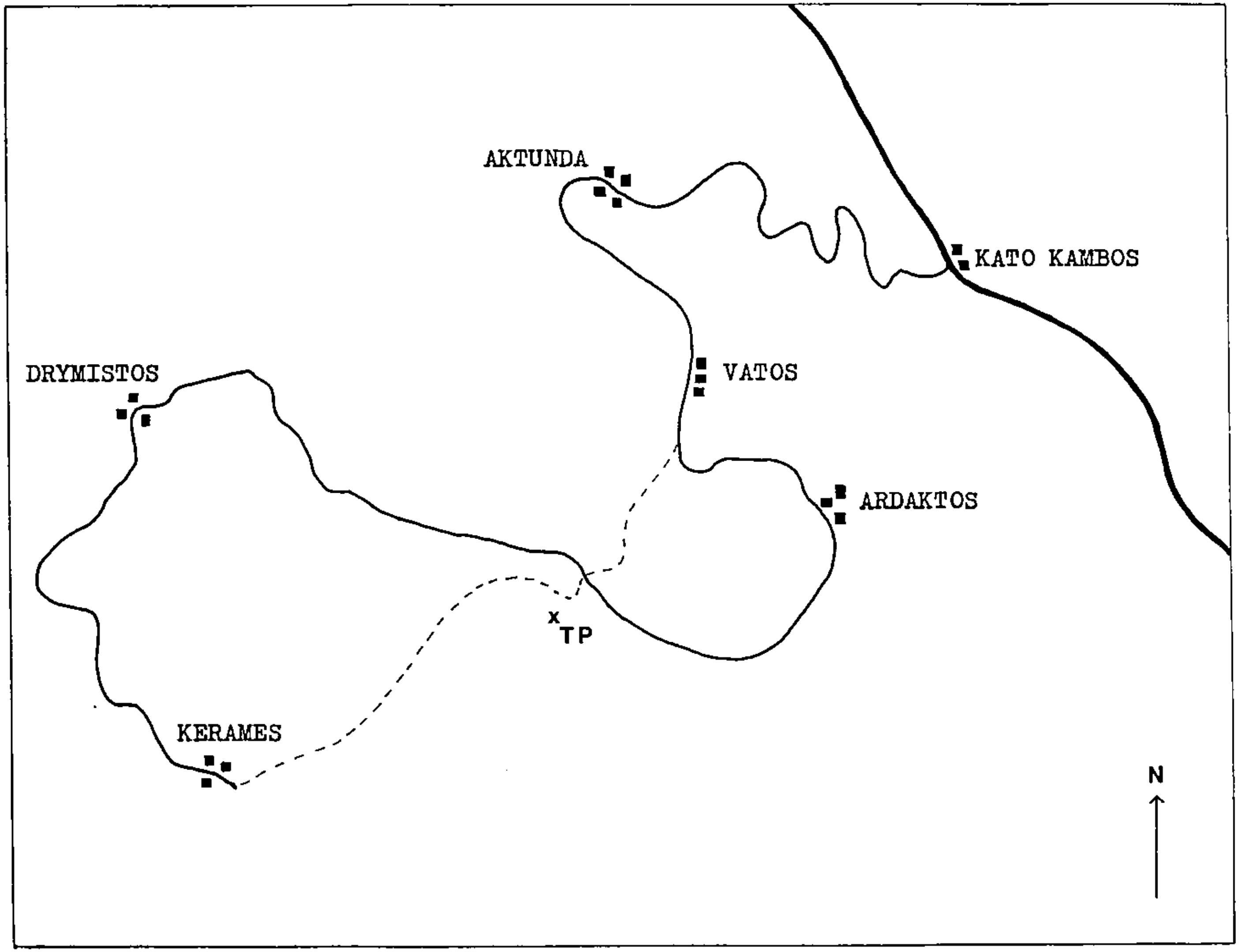
Description of section :

The section forms a relatively steep cliff face. It is composed of imbricate slices of the Pindic-Ethia Series which were thrust over the Tripolitza limestones. The thrust plane strikes 92° and dips 30-60° towards the north. From the thrust plane upwards, one finds (fig. 12) :

Unit 1 - Sequence of sheared, black, carbonaceous shale and sandstone intercalations with calcareous nodules containing *Halobia* (s.l.). Lenticular blocks of sandstone and *Globotruncana*-bearing calcilutite are tectonically mixed into this sequence. Several small-scale recumbent folds with axes trending east-west were recorded.

Unit 2 - Sequence of cm-bedded, red, radiolaria-bearing, silicified

Fig. 11 - Locality map of Section TP.



Scale - 1 : 30,000

shales, grey, Halobia-bearing calcarenites and calcilutites, and red, radiolaria- and Halobia-bearing calcilutites. Beds show pinch and swell structures. Several recumbent folds with axes trending east-west were observed.

Unit 3 - Tectonically mixed unit composed of blocks of Globotruncana-limestones, Globorotalia (s.l.)-bearing limestones and sandstone-siltstone of Turonian age (presence of Marginotruncana helvetica in some sandstones). At the basal part of this unit, sandstone-siltstone predominate, while in the upper part, limestones are more common. Blocks range from centimeter to meter-sized; the largest block measures at least 10 m by 15 m. Shape of these blocks tend to be lenticular. The sandstone-siltstone shows grading, planar and cross-lamination and are interpreted as turbidites. They are correlated with the "Premier Flysch." Within the larger limestone blocks, isoclinal folds with axes trending northwest-southeast were observed. The limestones are composed of calcilutites, calcisiltites and calcarenites. Some laminations and occasional black chert nodules-bands were also observed in the limestones.

Unit 4 - A thick sequence of cm-dm bedded, grey calcilutites and calcarenites with well developed black chert bands. Beds at the base of this unit contain planktonic foraminifera of Upper Santonian age. Recumbent folds with axes trending north-south were noted. Upper parts of this sequence was not sampled due to the difficulty in scaling the cliff face.

The contacts between units 1 to 4 are interpreted as low-angle thrust. Thickness of each unit varies from place to place and fig. 12 shows their approximate thicknesses as seen on the

Fig. 12

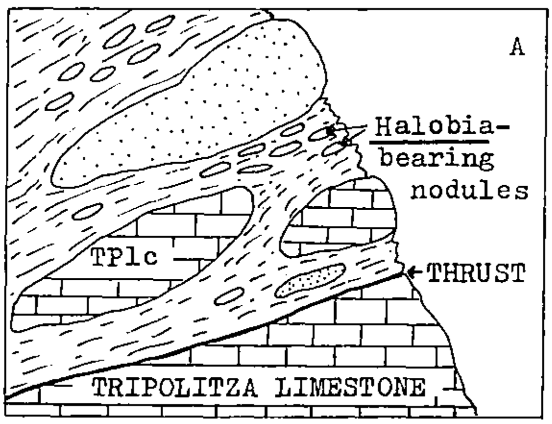
A - sheared shale-sandstone matrix containing Halobia-bearing nodules and blocks of Globotruncana-bearing limestone (B) and sandstone.

B - slices and blocks of Globotruncana-bearing limestone.

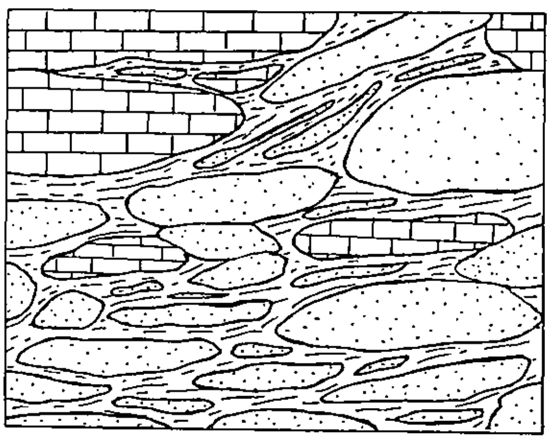
C - slice of Halobia-bearing limestone.

D - red shale-chert-radiolarite horizon.

E - shaly matrix with blocks and slices of "Premier Flysch" sandstone, Globotruncana-bearing limestone, and Globorotalia (s.l.)-bearing limestone.

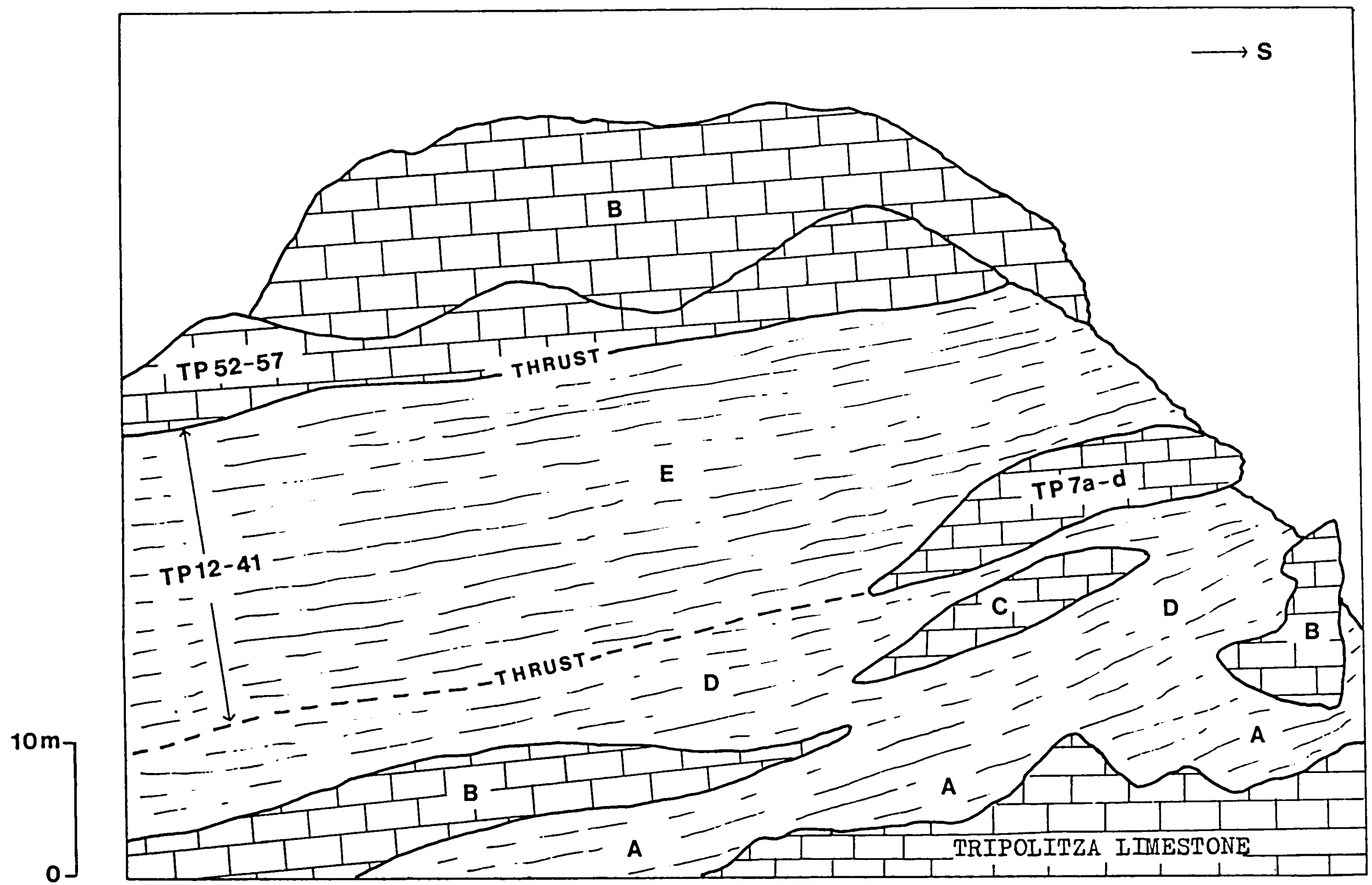


Detailed sketch of level A.



Detailed sketch of level E.

Fig. 12 - Sketch of Section TP.



cliff face. As rocks of different ages were tectonically mixed, the method of sampling at regular intervals was abandoned in favour of random spot-sampling.

CHAPTER 5

5.0 PETROLOGY

5.1 INTRODUCTION

In the field, the Pindic-Ethia limestones were grouped into 3 categories, namely, the calcilutites, calcarenites and calcirudites on the basis of their grain sizes. An additional group, the calciturbidites, were recognized on the basis of their sedimentary features such as the Bouma elements, scour marks, etc. However, these field-terms were found to be inadequate to describe the microfacies revealed by thin-section studies. An alternative classification which takes into account the grain sizes, the grain-matrix relationship and the types of grains was adopted. Emphasis is also placed on the environmental significance of the derived and non-derived constituents of the limestones.

5.2 LIMESTONE CLASSIFICATION

The classification scheme in use here is modified after Folk (1959). In this scheme, 3 compositional end-members are recognized. They are (a) terrigenous constituents, (b) allochemical constituents, and (c) orthochemical constituents. As the terrigenous constituents in the Pindic-Ethia limestones fall well below 10 %, for the sake of simplicity, they are hereby ommited from the classification. The limestones can then be classified according to the types and the proportion of the allochems and orthochems. Limestones in which the allochems exceed 10 % are distinguished from those in which the allochems constitute less than 10 %. A further division of the former category based on the types of orthochems and allochems would result in several varieties of limestones as shown in Table I.

5.2.1 Terrigenous constituents

They are defined as constituents derived from the erosion of source lands outside basin of deposition and transported as solids to the sediments. In the Pindic-Ethia limestones, terrigenous constituents form a very minor but significant fraction. They consist of siltstone-sandstone clasts, micas, quartz grains, chert fragments, volcanic clasts and metamorphic rock fragments. Metamorphic rock fragments are rounded and the dimensions of the clasts generally fall into the sand to pebble sizes. Only two types of metamorphic clasts are found in the Pindic-Ethia limestones. They are the quartzite and the quartz-mica schist clasts. Volcanic clasts are characterized by "variolitic texture" in which feldspar or pyroxene crystals occur in delicate brush-like clusters. The clasts are sand- to pebble-sized and are generally rounded. Quartz grains include both the monocrystalline and the polycrystalline varieties. The former varies from angular to euhedral-shaped, and the latter usually occur as rounded grains.

5.2.2 Allochemical constituents

They are defined as discrete particles that originated within the basin of deposition, and, for the most part, have suffered some transportation. Folk (1959) recognized 4 types of allochems. They are :

(i) Intraclasts (Pl. 9, fig. A) - They are defined as fragments of penecontemporaneous, weakly consolidated carbonate sediment which are reworked from within the area of deposition. Erosion products of older carbonates are specifically excluded from the definition.

Table 1 - Limestone Classification (after Folk, 1959)

Volumetric Allochem composition	> 10 % Allochems Allochemical Rocks		< 10 % Allochems Microcrystalline Rocks		
	Sparry calcite cement > Microcrystalline ooze cement	Microcrystalline ooze matrix > sparry calcite cement	1-10 % Allochems		< 1 % Allochems
	Sparry Allochemical Rocks	Microcrystalline Allochemical Rocks			
> 25% Intraclasts	Intrasparudite Intrasparite	Intramicrudite Intramicrite	Most Abundant Allochem	Intraclasts : Intraclast-bearing micrite	Micrite
< 25 % Intraclasts; > 25 % Oolites	Oosparudite Oosparite	Oomicrudite Oomicrite		Oolites : Oolite-bearing micrite	
< 25 % Intraclasts; < 25 % Oolites; Volume ratio of fossils to pellets > 3:1	Biosparudite Biosparite	Biomicrudite Biomicrite		Fossils : Fossiliferous micrite	
< 25 % Intraclasts; < 25 % Oolites; Volume ratio of fossils to pellets 3:1 - 1:3	Biopelsparite	Biopelmicrite		Pellets : Pelletiferous micrite	
< 25 % Intraclasts; < 25 % Oolites; Volume ratio of fossils to pellets < 1:3	Pelsparite	Pelmicrite			

They may or may not contain skeletal fragments. In the Pindic-Ethia limestones, the proportion of intraclasts is usually low but in certain samples, they can form up to 30-40 % of the rock. The majority of the intraclasts are composed of micrite (lime-mud) and may contain some fine calcareous debris and a few planktonic fossils. However, pellet-bearing, miliolid-bearing, and agglutinated foraminifer-bearing intraclasts were also present. Sizes of intraclasts vary from arenite to rudite dimension. They are usually rounded but can also be partly squashed. In some, the micrite is partially recrystallized into microspar.

(ii) Ooliths-pisoliths (Pl. 7, fig. A) - Spherical to ovoid-shaped particles characterized by a concentric lamellar cortex about a detrital nucleus. They are frequently found in very minor amount in the Pindic-Ethia limestones. However in the older beds, they can form up to 10-15 % of the rock.

(iii) Pellets - These are generally absent from the Pindic-Ethia limestones. However they do occur as pellet-rich intraclasts or laminae.

(iv) Fossils - They include a wide range of skeletal remains.

(a) Echinodermata (Pl. 7, fig. B) - Echinodermal fragments are recognized by their typical single crystal structure. Under crossed-nicols, each fragment or grain extinguishes uniformly. In general, echinodermal fragments retain their porous structures which have a dusty appearance. They also tend to have syntaxial calcite overgrowth whose clarity distinguishes it from the outline of the original grain. Echinodermal fragments are significant contributors to the Pindic-Ethia limestones. They are usually concentrated in the calcarenites and calcirudites.

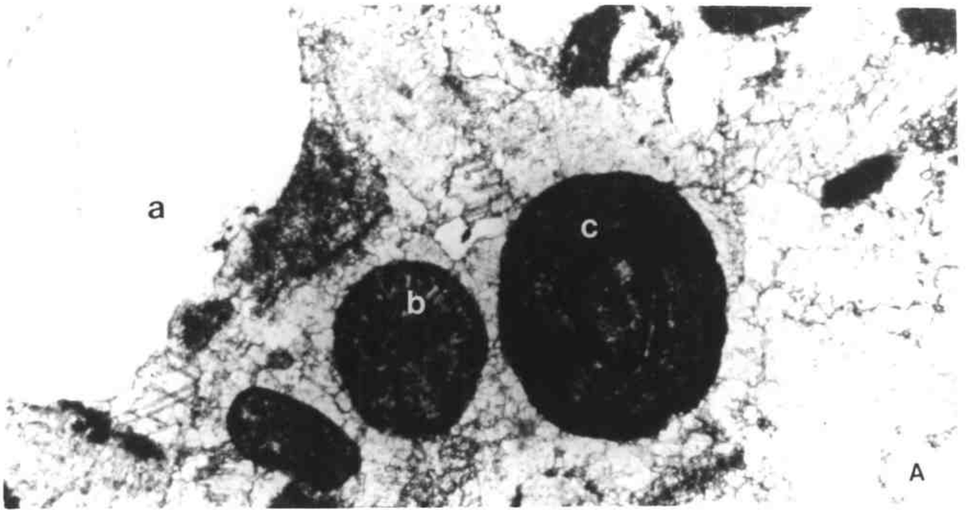
(b) Benthonic calcareous algae (Pl. 7, fig. C) - Two algal families,

Plate 7

fig. A Biosparite containing quartz grains (a) and ooliths (b showing radial structure and c showing concentric structure). X 68

fig. B Biosparite containing clasts of echinoderms (showing syntaxial growth (a)), Nummulites (b) and micritic limestone (c). X 26

fig. C Biosparite showing a partly dolomitized coralline algae clast (the cellular structure of the algae is still preserved). X 58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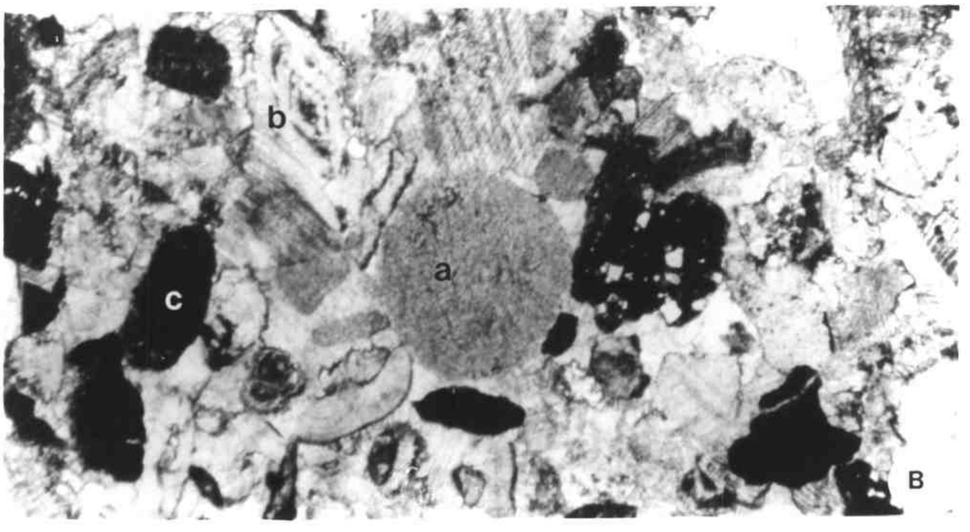
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B


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the Corallinaceae and the Dasycladaceae, are found in the Pindic-Ethia limestones. The former is characterized by a fine, regularly arranged cellular structure, and the latter can be identified as a calcified cylindrical body with a central cavity from which numerous porous tubes radiated. Algal grains are present in very minor amount in the calcarenites and calcirudites.

(c) Byrozoa (Pl. 8, fig. A) - Bryozoan fragments are sporadically scattered throughout the coarser fraction of the Pindic-Ethia limestones. Each fragment consists of a cluster of zooecia which lack radiating septal walls. The zooecia are filled with calcite crystals and the walls are composed of thin, laminated or fibrous calcite.

(d) Mollusca (Pl. 8, fig. B; Pl. 9, fig. B; Pl. 10, fig. A) - Identification of molluscan fragments in the Pindic-Ethia limestones is based entirely on their microscopic shell structures and the gross morphology of the shells. The most common microscopic shell structure observed here is prismatic. Homogenous and cross-lamellar structures are also present but are not common. Another important group of molluscs, the rudists, are recognized by their regularly arranged, vesicular, box-work texture to cellular, primatic structure. Molluscan fragments are the main constituents of the coarser Pindic-Ethia limestones, especially in calcarenites and calcirudites. In the calcilutites, they are either concentrated in laminae, or are randomly scattered. More common in these beds are Inoceramus prisms. In the Triassic strata, thin, long valves, identified as Halobia (s.l.) were also observed.

(e) Foraminiferida

Benthonic foraminifers - The majority of the benthonic foraminifers found in the Pindic-Ethia limestones belong to the following

Plate 8

fig. A	Bryozoa X 110
fig. B	Rudist X 57
fig. C	Dissolution fabrics in which the outlines of the original grains are preserved as micritic envelopes. The internal structures are obliterated and the grains are infilled with calcite spar. X 25

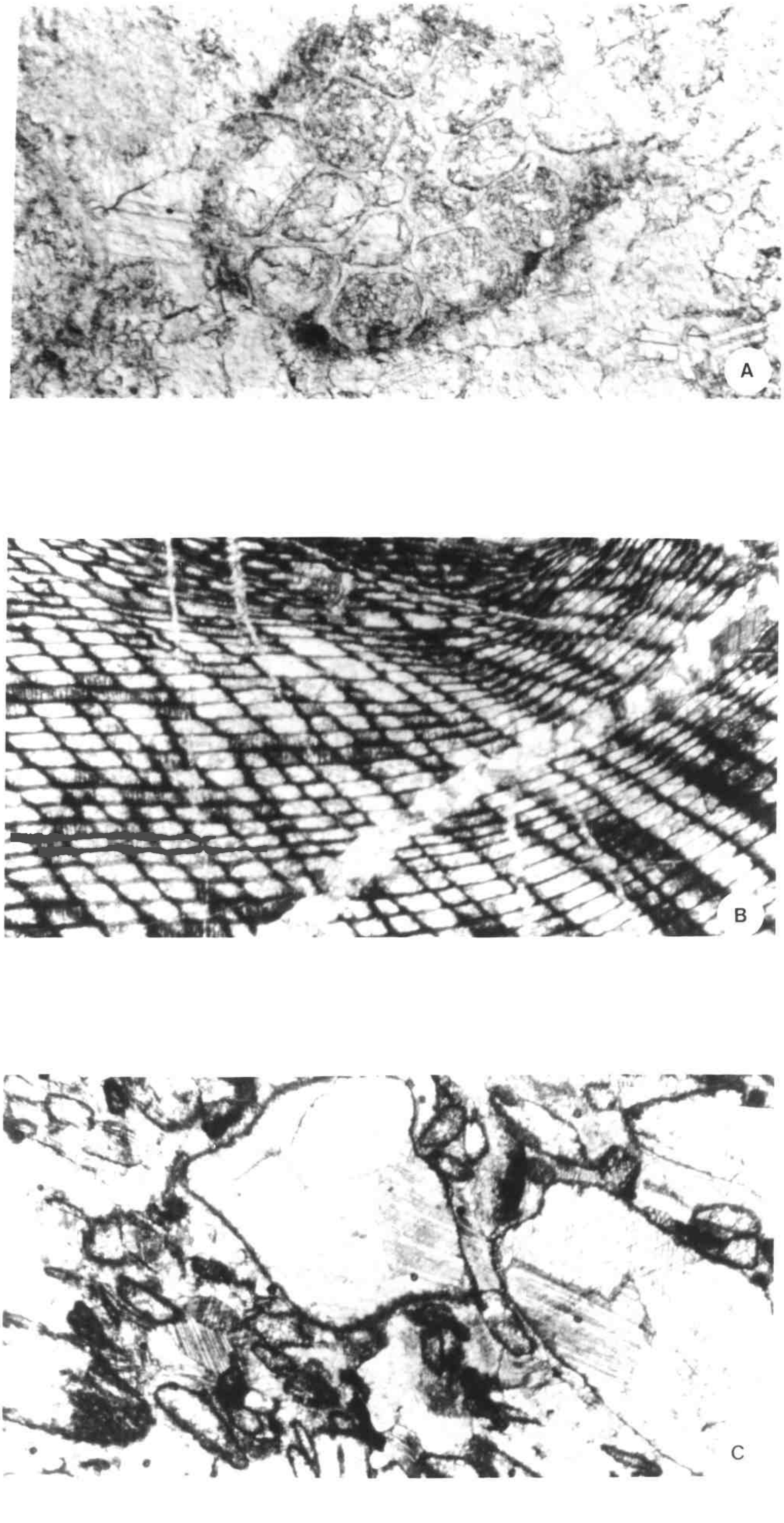
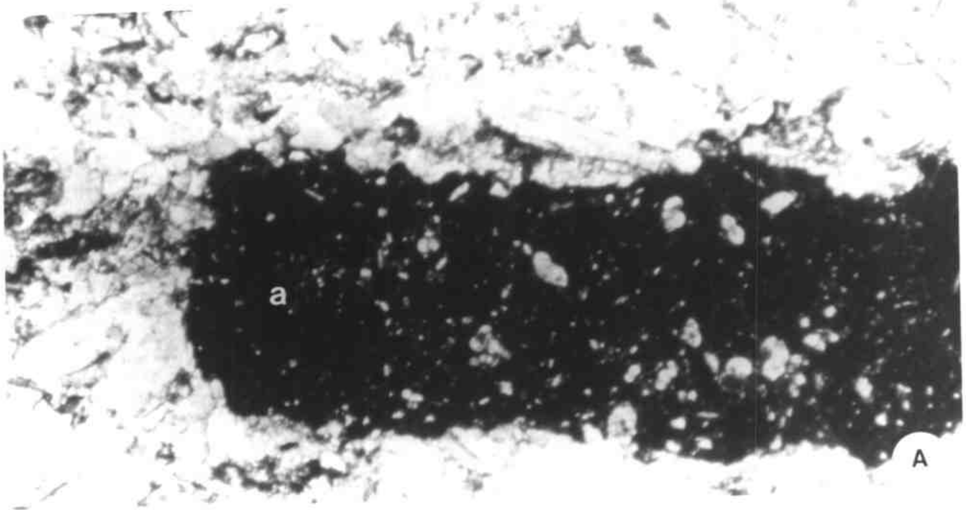

A
B
C

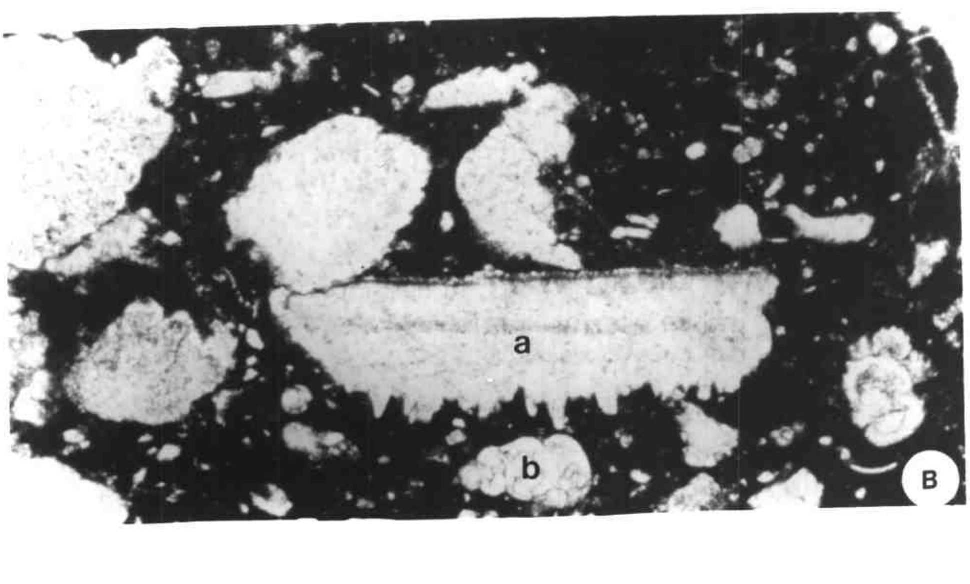
Plate 9

fig. A Intraclast (a) X 22

fig. B Biomicrudite containing fragments of molluscs ((a), showing neomorphic calcite growth in the form of saw-toothed crystals) and planktonic foraminifera (b). X 72

fig. C Biomicrite showing the outlines of two burrows (a). X 42


a
A


a
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B

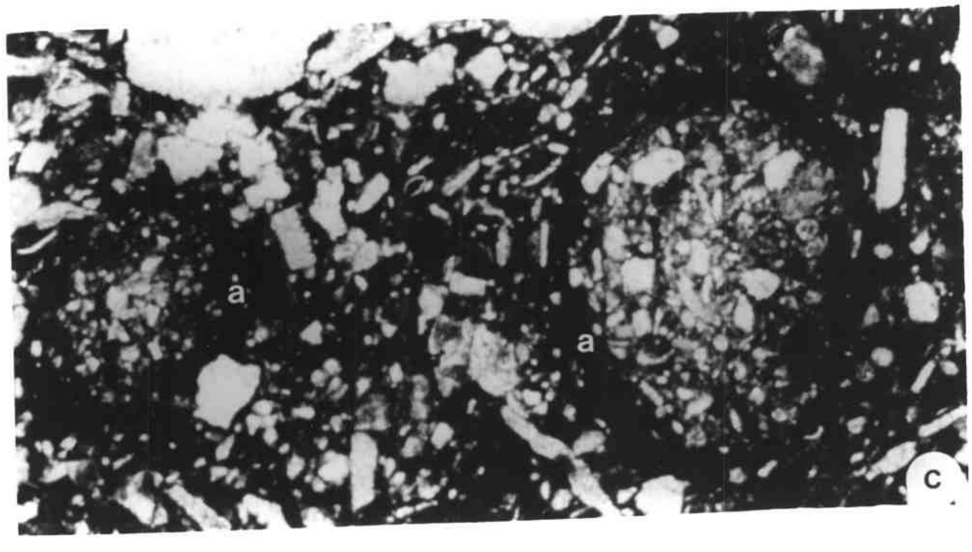
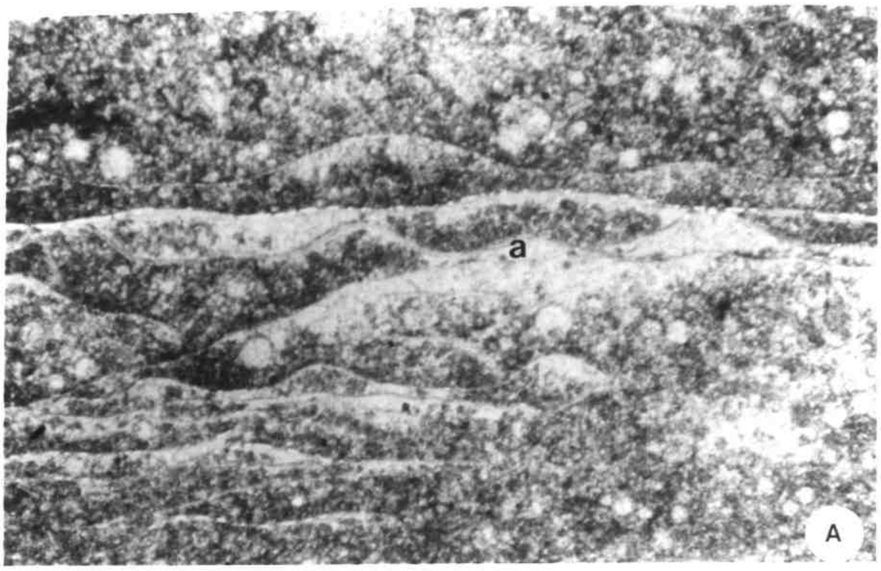

a
a
C

Plate 10

fig. A Halobia (s.l.)-bearing calcilutite. X 14
a - Halobia (s.l.)

fig. B Calcilutite containing calcareous filaments (a) and radiolaria (b). X 22

fig. C Calcilutite containing calcareous filaments (a), calcite grains and echinodermal fragments (b). X 14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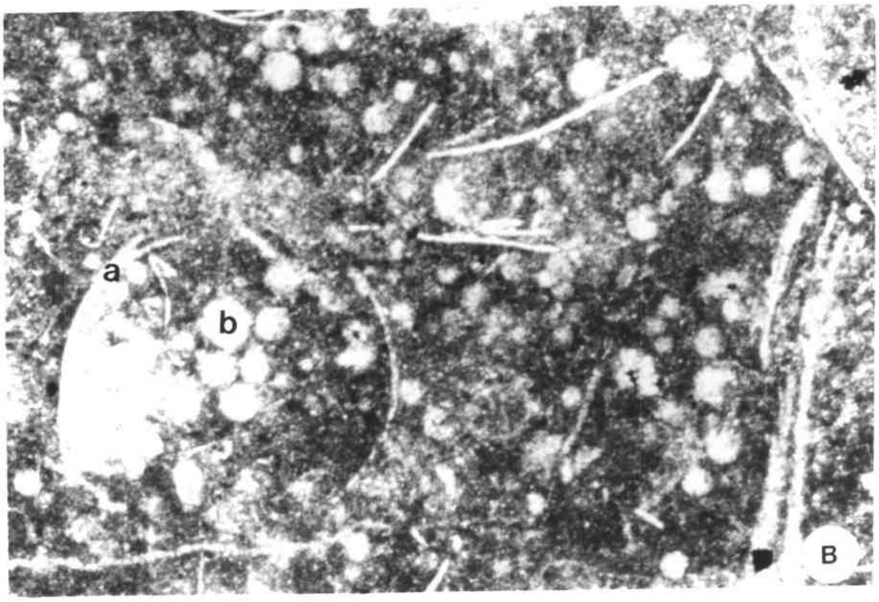
A


a
b
B


a
b
C

Superfamilies : Lituolacea, Miliolacea, Rotaliacea, and Orbitoidacea. Lituolacea - Agglutinated foraminifers present in the limestones here belong to several genera, of which, _Cuneolina_ (Pl. 11, fig. B), _Valvulina_, _Pseudolituonella_ and _Textularia_ are common. They occur in abundance in the older calcarenites and calcirudites, but form only a very minor fraction in the younger beds (Upper Senonian to Lower Tertiary). They are also found in some of the intraclasts. Miliolacea (Pl. 11, figs. D, E) - This Superfamily contains foraminifers with porcellaneous tests. When examined under transmitted light, the test is composed of micrite. The genera commonly encountered here are _Triloculina_ and _Quinqueloculina_. _Fasciolites_ are found only in the Upper Paleocene to Eocene calcarenites and calcirudites. This group of foraminifers generally constitute only a very minor fraction of the Pindic-Ethia limestones.

Rotaliacea (Pl. 12, figs. e, g, i, j) - Forms found in the Pindic-Ethia beds are generally robust with sizes in the arenite-rudite range. Their walls are composed of laminated radial calcite crystals which show extinction perpendicular to the test-wall under crossed-nicols. The most common forms present here are _Rotalia_ sp., _Nummulites_ sp., _Operculina_ sp., and _Siderolites_ sp., and they are frequently found in the calcarenites and calcirudites.

Orbitoidacea (Pl.11, figs. A, F; pl. 12, figs. a-d, g-h) - Foraminifers found in the Pindic-Ethia limestones belong mainly to the families Orbitoidae and Discocyclinidae. They are characterized by forms having an equatorial layer which is bordered on either side by lateral chambers. In some species, lateral chambers are not developed. Forms are robust and large (arenite-rudite sizes). The most common genera found here are the _Discocyclina_ and _Orbitoides_. Also

Plate 11

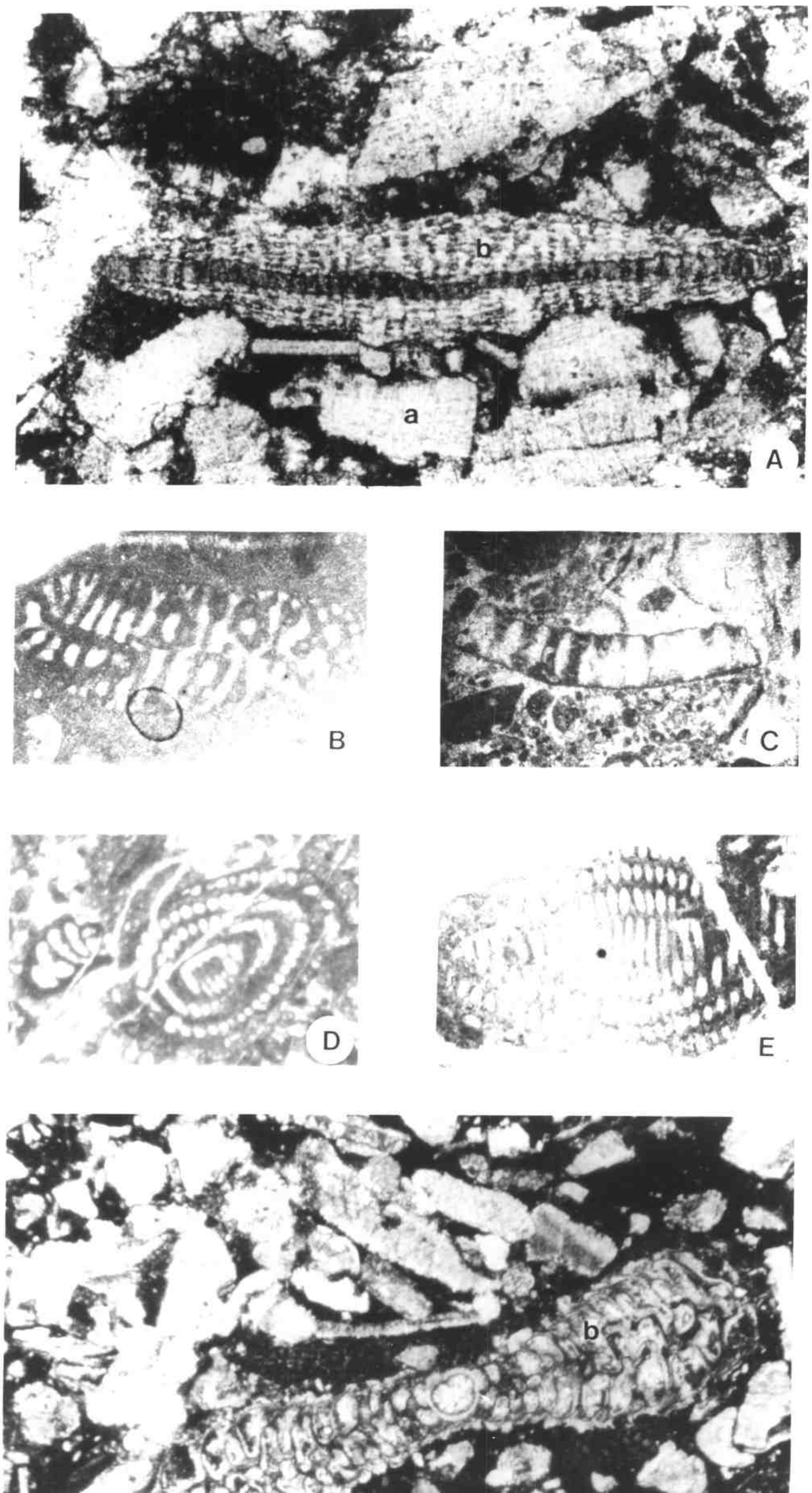
fig. A — Biomicrudite containing clasts of <u>Discocyclina</u> sp. (b), mollusc (a) and echinoderm. X 51

fig. B — <u>Cuneolina</u> sp. X 58

fig. C — Dasyclad-bearing clast. X 32

figs. D, E — <u>Fasciolites</u> spp.
D - X 22
E - X 42

fig. F — Biomicrudite containing clasts of <u>Omphalocyclus macroporus</u> (b), molluscs (a) and echinoderms. X 22


b
a
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C
D
E
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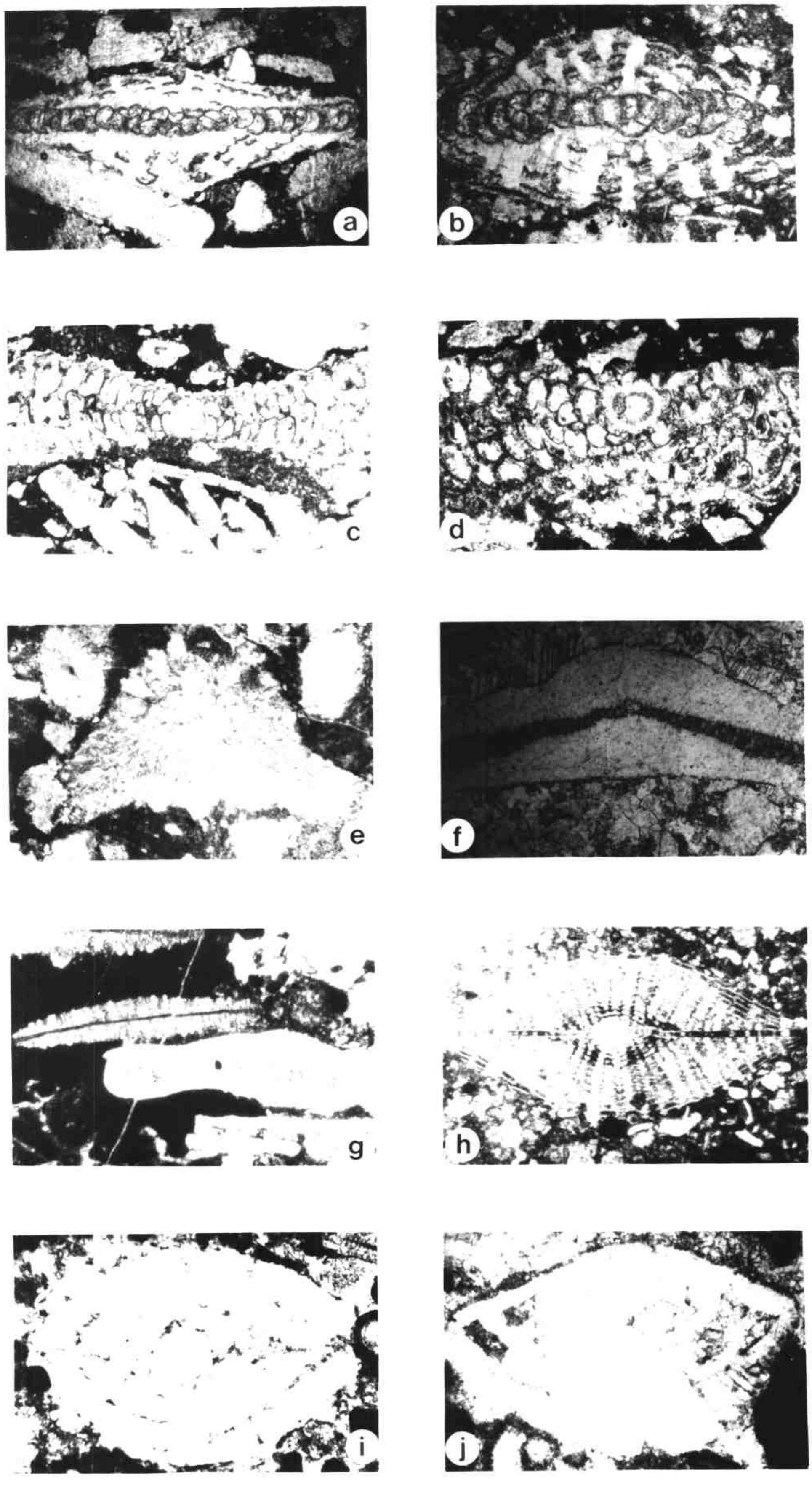
a
F


a
b
c
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i
j

Plate 12

figs. a, b	*Orbitoides* spp. a - X 29 b - X 45
figs. c, d	*Omphalocyclus macroporus* c - X 16 d - X 25
fig. e	*Siderolites calcitrapoides* X 41
fig. f	*Hellenocyclina beotica* X 40
fig. g	*Discocyclina* sp. and *Operculina* sp. X 7
fig. h	*Discocyclina* sp. X 7
fig. i	*Nummulites* sp. X 31
fig. j	*Rotalia trochidiformis* X 46

present in lesser numbers are Lepidorbitoides, Omphalocyclus and Hellenocyclina species. In the Tertiary calcarenites and calcirudites, Discocyclina spp. together with Rotalia and Nummulites spp. constitute a major fraction of the limestones. Orbitoides and Siderolites spp. are significant only in beds of Campanian-Maastrichtian age.

Planktonic foraminifers - Foraminifers of the Superfamily Globigerinacea are abundant in the Pindic-Ethia limestones. Calcilutites are generally flooded with them. In the calcarenites and calcirudites, they are found mixed with a shallow-water benthonic fauna. In the majority of limestones here, the planktonic foraminifers are relatively well preserved. They show perforated tests which are composed of lamellar radial calcite. In the Upper Cretaceous Pindic-Ethia beds, 3 families of planktonic foraminifers, namely, Heterohelicidae, Globotruncanidae and Rotaliporidae predominate. In the Tertiary beds, Globorotalidae and Eoglobigerinidae replace the families mentioned above. Identification, distribution and zonation of the planktonic foraminifera will be discussed more fully in later chapters.

(f) Radiolaria (Pl. 10, figs. A, B) - Radiolarian tests are generally found in association with Halobia-bearing or planktonic foraminifera-bearing calcilutites.

5.2.3 Orthochemical constituents

They are defined as normal precipitates formed within the basin of deposition, and, showing little or no evidence of transportation. Two types of precipitates are recognized.

(i) Micrite or microcrystalline calcite ooze - This is composed of calcite grains whose average sizes fall within 1 to 4 microns.

Carbonates composed predominantly of micrite have been variously referred to as lithographic, sublithographic, or porcellaneous limestones. Pindic-Ethia beds referred to as calcilutites in the field are either wholly or partially composed of micrite.
(ii) Sparry calcite cement - These are precipitated in voids and intergranular spaces. Calcite crystals are characterized by their clarity and coarser sizes (usually exceeding 10 microns). In general, two generations of spar were observed.

5.3 PETROLOGY OF THE CALCILUTITES

The term "calcilutite" was used in the field to describe porcellaneous, sublithographic and lithographic limestones. In thin-sections, they are composed predominantly of micrite. Allochems are present in varying proportion but not to the extent that they form the framework of the carbonates. In general, most allochems have sizes in the fine arenite range. The chief constituents of the allochems here are the skeletal remains. Thus calcilutites are hereby classified as biomicrite , fossiliferous micrite and micrite. Several varieties of limestones are found :
Micrite - These limestones have less than 1 % allochems. This variety is generally rare.
Biomicrite I / Fossiliferous micrite I - Calcilutites here are characterized by abundant planktonic fossils. Other types of allochems are absent except fine arenite-sized calcareous debris which is difficult to identify because of its small size. Terrigenous constituents are extremely rare; only mica flakes and quartz grains were found. Planktonic fossils consist of radiolaria and foraminifers. In beds of Turonian to Santonian age, _Marginotruncana_ spp. and _Hedbergella_ spp. were identified. These

were replaced by *Globotruncana* spp., *Heterolix* spp., *Globigerinelloides* spp., *Pseudotextularia* spp., *Racemiguembelina* sp. and *Gublerina* sp. which are common in beds of Upper Senonian age. In beds of Paleocene to Eocene age, a different assemblage consisting of *Acarinina* spp., *Morozovella* spp., *Subbotina* spp., and *Globorotalia* spp. were found. Orientation of the planktonic fossils in these limestones is usually random but in some samples, the fossils were preferentially aligned parallel to the bedding.

Biomicrite II / Fossiliferous micrite II - Calcilutites in this category are characterized by the diversity of allochems. The most abundant allochems are tabular-shaped shell fragments and planktonic fossils. Also present are minor amount of ooliths, intraclasts, rudist fragments, echinodermal fragments, and *Orbitoides* fragments. The planktonic fossils are similar to those found in the Upper Senonian biomicrites I / Fossiliferous micrite I. Terrigenous constituents, consisting of a few volcanic clasts, siltstone clasts and some quartz grains, were also present.

Laminated Biomicrites III / Fossiliferous micrite III - Calcilutites showing mm-cm thick laminations are treated separately because individual lamina differs from each other in their allochemical and orthochemical constituents. Three categories were commonly recognized. Category (a) consists of fossiliferous calcilutites in which laminae composed only of planktonic fossils alternate with those that either lack or contain very few planktonic fossils. In category (b), the allochems in each lamina are the same but the orthochems are different, resulting in an alternation of micrite- with sparite-lamina. Allochems here consist mainly of planktonic fossils and minute calcareous grains. In category (c), each lamina has allochemical and orthochemical constituents different from those in subjacent and surjacent laminae. For example, calcilutites in which biomicrite-lamina alternate with pelbiosparite-lamina belong to this category. Terrigenous grains are absent. In some of the coarser laminae, loading features were observed.

5.4 PETROLOGY OF THE CALCARENITES

The term "calcarenite" was used in the field to describe limestones in which the allochems are so abundant as to support each other (i.e. they form the framework of the carbonate). The uppermost size limit of the allochems is set at 1.0 mm. In thin-sections, void spaces between allochems are either occupied by micrite or by a mosaic of calcite spar. In the majority of calcarenites whose void spaces are presently filled with spar there is evidence that the spar was formed by the recrystallization of micrite. Such rocks are hereby termed micsparites. Based on the orthochemical constituents, 2 categories of calcarenites were recognized.

Biomicrite IV - Limestones in this category were found only in the Tertiary Pindos. Allochems consist predominantly of shell fragments and planktonic foraminifers. Echinodermal fragments and larger benthonic foraminifers (especially Discocyclina spp.) are common. Smaller benthonics (i.e. Anomalina spp.) are also abundant. Planktonic foraminifers include Morozovella spp., Acarinina spp., and Subbotina spp. Terrigenous constituents are a few angular quartz grains and some micas.

Biosparites - Calcarenites belonging to this category are present in Upper Cretaceous as well as in the Tertiary Pindos. Biosparites of Tertiary age carry essentially the same types of allochems as described for biomicrite IV. The Upper Cretaceous biosparites are composed mainly of shell and echinodermal fragments. Micrite patches are present, and in some samples, they form up to 10-15 % of the rock. No planktonic fossils were observed. Terrigenous constituents consist of some angular quartz grains and mica flakes.

5.5 PETROLOGY OF THE CALCIRUDITES

Sizes of allochems fall into the rudite range (exceed 1.0 mm). Void spaces are occupied either by micrite or by calcite spar. Four categories of calcirudites are recognized here.

Biosparudite - Shell fragments are most abundant. Echinodermal fragments and rudists are usually present. In addition, one finds minor amount of coralline algae, bryozoa, ooliths, intraclasts and larger benthonic foraminifers. In the Upper Cretaceous beds, the larger benthonic foraminifers consist mainly of *Orbitoides* spp. and *Siderolites* spp. In the Tertiary beds, they consist of *Discocyclina* spp., *Rotalia* spp., *Operculina* spp., and *Nummulites* spp., as well reworked *Orbitoides* spp. and *Siderolites* spp. The proportion of shell fragments decreases in the Tertiary beds while the larger benthonic foraminifers become more abundant. Planktonic foraminifers are generally absent. Terrigenous constituents consist of quartz grains, metamorphic clasts, volcanic clasts and siltstone-sandstone clasts.

Bioosparudite - These rocks predominantly contain shell fragments and ooliths. Echinodermal and rudist fragments may be present in minor quantities. No planktonic fossils were found. Terrigenous constituents consist of quartz grains, chert grains, quartz-mica schist and volcanic clasts.

Biointrasparudite-Intrabiosparudite - This contains roughly equal proportions of shell fragments, agglutinated foraminifers and intraclasts. Several types of intraclasts were observed; they are of micrite, biosparite (containing agglutinated foraminifers), pelsparite, and biopelsparite (containing agglutinated foraminifers and miliolids). Minor quantities of rudist and echinodermal fragments are also present. Planktonic foraminifers are generally absent or rare. Agglutinated foraminifers include such genera as <u>Cuneolina</u>, <u>Pseudolituonella</u> and <u>Valvulina</u>. Terrigenous constituents include quartz grains, rare red chert grains and a few volcanic and metamorphic clasts.

Biomicrudite - These contain abundant shell and echinodermal fragments. Intraclasts vary from rare to common and include several types (micrite, pelmicrite, pelbiosparite (containing miliolids), oosparite, biosparite (containing miliolids), and biomicrite (containing radiolaria)). Other allochems present in small quantities are rudists, ooliths, coralline algae, bryozoa, planktonic foraminifers and larger benthonic foraminifers. Of the latter, Upper Cretaceous forms include <u>Orbitoides</u>, <u>Siderolites</u>, and <u>Omphalocyclus</u> species, while those from the Tertiary consist of <u>Discocyclina</u>, <u>Rotalia</u>, <u>Nummulites</u> and <u>Fasciolites</u> species. Terrigenous constituents include quartz grains, sandstone clasts, metamorphic clasts and volcanic clasts.

5.6 PETROLOGY OF THE CALCITURBIDITES

The term was used in the field to describe limestone beds that are graded. In some beds, the graded portions pass upwards into thin planar lamination and ripple lamination. The majority of the calciturbidites are graded from rudite to arenite size, or, from arenite to lutite size. In the coarser fractions, the allochems are similar to those describedfrom the calcirudites and calcarenites. The finer portions consist mainly of planktonic fossils and fine calcareous debris. Terrigenous constituents are usually absent. . In a few samples, minor quantities of quartz grains and sandstone clasts were observed.

5.7 DIAGENETIC FEATURES

The dominant diagenetic process operative in the carbonates here is compaction. On a macroscopic scale, this is reflected in the extensive development of stylolites along planes parallel or subparallel to the bedding. The occurrence of stylolites in carbonates irrespective of whether the rock is a calcilutite, calcarenite or calcirudite, have been noted in the chapter on field localities and description. On a microscopic scale, pressure-solution also occurred along the boundaries of allochems, resulting in the penetration of one allochem into another. This fabric is well developed in carbonates in which allochems form the supportive framework. The overall effect of compaction is a significant reduction in the total volume of the original Pindic-Ethia sediments.

In some calcarenitesand calcirudites , allochems were cemented by calcite spar. The spar is characterized by plane intercrystalline boundaries and by the absence of floating relics composed of micritic patches. Where echinodermal fragments are present, the calcite cement is added on as a syntaxial overgrowth which is in optical continuity with the grain. In a few samples, two generations of spar were observed, in which the earlier spar formed a thin coating round the allochems, and latter spar then filled the remaining voids.

In carbonates referred to as biomicsparites, a micritic groundmass is believed to have been partly or totally recrystallized into microspar and spar. Unlike calcite cement, the calcite spar and microspar generally have irregular to wavy intercrystalline boundaries. Floating relics of micritic patches are usually present. Recrystallization of this type has also been observed in some intraclasts and in chambers of planktonic foraminifers. In the latter, lime-mud (micrite) that once filled the chamber cavities show gradations into microspar and spar (Pl. 20, figs. g, h, j; Pl. 25, figs. a-j). Another type of replacement of micrite is shown by echinodermal and certain shell fragments found in the biomicrites. The former developed syntaxial calcite rims and the latter developed saw-toothed margins (Pl. 9, fig. B). Though these features are similar to cement rims, the fact that they were embedded in micritic groundmass ruled out the possibility of cementation. In must be assumed then that these calcite rims grew at the expense of the micritic groundmass.

Dissolution fabrics are commonly found in the biosparudites. Here, the affected skeletal grains had been leached or dissolved away. What remain of the original grains are their grain boundaries which are preserved as micritic envelopes (Pl. 8, fig. C). Leached grains were later infilled with calcite cement. Identification of these grains is therefore based on their gross shapes. Works on recent carbonate environments (Bathurst, 1971) have shown that skeletal grains suffering this type of dissolution-precipitation process were originally aragonitic and that they were replaced by low-Magnesium, sparry calcite cement.

Dolomitization has also been observed but only selective allochems were affected. Allochems most susceptible to this alteration are the coralline algae (Pl. 7, fig. C), followed to a much lesser degree by porcellaneous foraminifers, Discocyclina spp. and some intraclasts. Growth of dolomite rhombs appear to be random and they tend to destroy the original fabric of the affected allochems. In some cases, the internal structure of the allochems is preserved. The author believes that affected allochems were dolomitised before being washed into the Pindic-Ethia basin. The reasons for this opinion are based on two indirect evidence, (a) pelagic limestones originating in the basin are not dolomitised, and (b) affected allochems were derived from environments (i.e. tidal flats and reefal complex) that are favourable for dolomitization.

5.8 ENVIRONMENT OF ACCUMULATION

Carbonates accumulated in the Pindic-Ethia basin can be broadly distinguished into 2 major facies.

(i) Pelagic facies - These are represented by calcilutites that contain abundant planktonic fossils (radiolaria and foraminifers). Beds may or may not be laminated, and they generally contain chert nodules and bands. Terrigenous and shallow-water carbonate constituents are absent. Therefore, such calcilutites are interpreted as pelagic calcareous oozes which were slowly deposited above CCD.

(ii) Mixed facies - Unlike the pelagic facies, carbonates here are characterized by the presence of mixed faunal assemblages, in which planktonic foraminifers are found in association with abundant shallow-water skeletal remains. Beds may show grading and/or laminations. Chert nodules and bands are common. The occurrence of these carbonates in association with the pelagic facies indicate that shallow-water carbonate allochems were being washed into the basin where they became mixed with pelagic sediments accumulating there. Field evidence have shown that a proportion of these beds were deposited from turbidity currents. However, some of these carbonates may also have been deposited by processes such as sliding, slumping and debris flow. The thickness and proportion of these 'mixed facies' carbonates, measured along an east-west line traverse across the Asterousia Ori, increase towards the present west. This would imply that the western portion of the Pindic-Ethia sediments in the Asterousia Ori were accumulated closest to the shallow-water complex, in contrast to the eastern region where sediments were accumulated in a more distal environment. Thus, the paleoslope of the Pindic-Ethia basin would be towards the present eastern quadrant.

The Pindic-Ethia limestones are here interpreted as having been accumulated at the toe of a carbonate slope facing the present eastern quadrant and where extensive overlapping of slope sediments with basinal sediments could occur.

5.9 ENVIRONMENTS OF THE SOURCE AREAS OF THE DERIVED CARBONATE CONSTITUENTS

The description and types of allochems found in the Pindic-Ethia limestones have already been discussed in an earlier section. What is of interest here is their ecologic or environmental value. Works on ancient and recent shallow-water carbonate complexes have yielded a wealth of data on the types of environments found in such complexes, and the assemblages of allochems associated with each of these environments. By comparing the types of allochems present in the Pindic-Ethia limestones with existing data, it is possible to postulate the original environments in which the allochems were formed or found.

(i) Ooliths - They are reported to be formed only in shallow, turbulent sea-waters such as in areas of shoals. Extensive oolith facies are found in the Great Bahama Bank (Purdy, 1963) and in the Gulf of Batabano, Cuba (Hoskins, 1964). Optimum depth for oolith formation is reported to be 1.8 meters below low water (Newell et al., 1960).

(ii) Porcellaneous foraminifers (eg. Triloculina, Fasciolites, etc.) - They thrive well in warm shallow marine waters. They are reported to be abundant especially in back-reef lagoons and in littoral areas (Henson, 1950; Greiner, 1970; Heckel, 1974).

(iii) Algae

Crustose coralline algae - They are predominantly found in reefal, back-reefal, and fore-reefal areas where they help to bind loose sediments or reefal debris (Johnson, 1954; Heckel, 1974).

Dasyclad algae - Like all other species of green algae, dasyclads are restricted to the photic zone. They are common in back-reefs (Heckel, 1974).

(iv) Rudists - They are important reef-builders during the Cretaceous, forming either small reef patches or more extensive reef build-ups. They are reported to be common in the Tethyan region, especially in the Mediterranean Sea and the Gulf of Mexico (Heckel, 1974).

(v) Larger benthonic foraminifers - Benthonic foraminifers of the families, Orbitoididae, Calcarinidae, Discocyclinidae and Nummulitidae are reported to be robust and abundant in fore-reef shoals (Henson, 1950; Heckel, 1974). Upper Cretaceous fore-reef shoal limestones dominated by Orbitoides, Omphalocyclus and Loftusia have been found in the Middle East (Henson, 1950); similarly, during the Tertiary, fore-reef shoals and carbonate build-ups were said to be dominated by Nummulites (Heckel, 1974).

(vi) Molluscs - They are significant contributors of skeletal debris in back-reefs (such as lagoons) and in open littoral environments. In Libya and the Middle East, oyster-reef patches were formed in lagoons and shell-banks were reported from open littoral seas (Henson, 1950; Selley, 1970).

(vii) Echinodermal remains - They are commonly found in several environments. They are reported to be abundant in back-reefs (eg. lagoons), open littoral seas, reef-talus slopes and in fore-reef shoals (Henson, 1950). In back-reefs and open littoral seas, they are generally found in association with molluscs, Alveolinellidae, miliolids and peneroplids. In reef-talus slopes and fore-reef shoals, they occur amidst reefal debris (rudists, corals, etc.) and larger benthonic foraminifers.

(viii) Agglutinated foraminifers - Recent works by Phleger (1965) and Greiner (1970) on the distribution of agglutinated foraminifers have shown that they predominate in near-shore to estuarine areas and in the deeper waters of the continental slope. The absence of these fossils from the pelagic Pindic-Ethia limestones, and their usual association with other derived shallow-water allochems would suggest that the agglutinated foraminifers here were derived from near-shore to estuarine areas.

From the recorded distribution, the author concludes that the source areas of the derived carbonate allochems constitute a reefal complex. Three major environments are distinguished, namely, back-reefs, reef-proper and fore-reef shoals. Calcareous debris formed in these environments were believed to be constantly subjected to wave actions and water currents. Some of the debris were thus removed and transported into the Pindic-Ethia basin where they become intercalated with the pelagic sediments.

5.10 DISCUSSION

When Aubouin's geosyncline model was put forward to explain the geology of Crete, the Pindic-Ethia Series became identified as an external facies of the Pindos zone. As it is believed to be situated closer paleogeographically to the Tripolitza zone, it was assumed that the calcareous breccias and microbreccias found in the external facies were derived from the Tripolitza limestones. Petrographic analysis carried out by this author on the allochemical constituents of the Pindic-Ethia limestones indicate that the environments of the source areas is a reefal complex. The question is - could this reefal complex be the Tripolitza Series ? To solve this problem, the lithofacies and fossil contents of the Tripolitza Series (obtained from published reports) are compared with the derived materials found in the Pindic-Ethia limestones (i.e. allochemical and terrigenous constituents).

Figure 13 shows the lithofacies and fossil content of the Tripolitza Series in northern Peloponesse (Dercourt, 1960) and northern Crete (Leppig, 1978), and the Pindic-Ethia Series in the Asterousia Ori, southern Crete. It shows that during the

FIG. 13 : COMPARISON OF THE LITHOFACIES AND FAUNAL CONTENT OF THE TRIPOLITZA SERIES AND THE DERIVED MATERIALS IN THE PINDIC ETHIA SERIES.

Tripolitza Series in northern Peloponesse, Dercourt (1960).

Lithofacies	Fossil content	Age
Flysch		
Neritic Limestones	Nummulites Alveolina Discocyclina	EOCENE
Rudist Limestones	Orbitoides Siderolites Globotruncana Textularids Miliolids	UPPER CRETACEOUS
Massive Algal Limestones	Clypeina Trocholina Valvulinella Textularids Valvulinids	L. CRET. — U. JUR.
Banded Dolomites and Limestones		LIAS — TRIAS

Tripolitza Series in northern middle Crete, Leppig (1978).

Lithofacies	Fossil content	Age
Flysch		
Alveolina-bearing Limestones calcarenites	Alveolina	L. EOC. — U. PAL.
Stromatolitic dolomites		L-M. PAL.
Rudist Limestones	Orbitoides cf. media Laffitteina Broeckinella Rhapydionina	MAAS — CAMP
	Murciella Accordiella	CAMP — L. TUR.
calcarenites	Pseudolituonella, Nezzazata, Coxites, Reissella.	L TUR — L CEN
Stromatolitic dolomites	Coskinolina	L. CRET
Stromatolitic dolomites (marbles) Passage Beds	Clypeina Cladocoropsis Pseudocyclammina	
Phyllites		

Pindic-Ethia Series in Asterousia Ori, southern Crete; present work.

Lithofacies	Derived materials	Age
Flysch		
red shales calcilutites calcarenites calcirudites calciturbidites	Discocyclina Nummulites Fasciolites echinoderms, molluscs, rare ooliths, intraclasts, siltstone, quartz, sandstone, volcanics, metamorphics.	L. EOC. — PAL.
calcilutites calcarenites calcirudites calciturbidites	Orbitoides Siderolites Omphalocyclus Hellenocyclina molluscs, rudists, echinoderms, ooliths, intraclasts, quartz, volcanics, metamorphics, sandstone, siltstone.	MAAST. — CON.
"Premier Flysch"	Not discussed.	TUR.
calcilutites, calciturbs. (oolitic and pisolitic), shales, polymictic conglomerates | thick to massive oolitic, pisolitic, pebbly limestones, polymictic conglomerates	intraclasts, echinoderms, miliolids, Nautiloculina, Trocholina, ooliths, quartz, volcanics, metamorphics, micas, red and green chert.	L. CRET. — JUR.
calcilutites red shales radiolarites chert	volcanics, micas.	TRIAS

Jurassic and Lower Cretaceous, the Pindic-Ethia Series were dominated by oolitic-pisolitic limestones which form massive calcarenites (in one locality, they form slump sheets) and cm-bedded calciturbidites. However, in the Tripolitza limestones, the corresponding period is represented by algal limestones. Recent works on the Great Bahama Bank and the Persian Gulf (Bathurst, 1971) have shown that ooliths are formed only in shallow turbulent seas (strong tidal currents with flood velocities of up to 150 cm/sec. were recorded) such as in areas of shoals, and that algal stromatolites are found only in sheltered intertidal areas where severe wave actions and strong tidal currents are absent. Therefore the large quantities of ooliths and pisoliths found in the Pindic-Ethia beds could not have been derived from the Tripolitza limestones. In addition, terrigenous constituents which consist of rounded pebbles of black chert and quartz, sandstone clasts, shale clasts and basic volcanic clasts are found in polymictic conglomerates that were intercalated with the oolitic-pisolitic beds (Azhar, per. com., 1982). Seidel (1971) also reported the presence of basic volcanic clasts (which he called ophiolites) in the oolitic and detrital limestones belonging to the Jurassic-Lower Cretaceous Pindos sequence in Paleohora District, southwest Crete. So far, the author has not come across any published literature which acknowledges the presence of terrigenous constituents in the Tripolitza Series. In the Upper Cretaceous, the derived allochems in the Pindic-Ethia beds are composed mainly of shell fragments and varying proportions of echinoderms, rudists, Orbitoides, Siderolites, Omphalocyclus, Hellenocyclina, agglutinated foraminifers, intraclasts and ooliths. Occasionally associated with these constituents are small quantities of quartz grains, micas, sandstone clasts, siltstone clasts, volcanic clasts and metamorphic clasts. During the same period, Tripolitza Series is represented by rudist limestones which contain abundant lituolids. Towards its upper part (Campanian to Maastrichtian age), Orbitoides, Siderolites, and even Globotruncana species were found. Though the majority of the allochems in the Pindic-Ethia limestones could be correlated with constituents in the Tripolitza limestones, yet one cannot ignore the absence of terrigenous constituents in the latter. During Paleocene to Lower Eocene time, derived allochems in the Pindic-Ethia carbonates remained essentially similar to those present in the Upper Cretaceous beds, except that Discocyclina, Operculina, Nummulites and Fasciolites appeared for the first time and became quite abundant. In addition, reworked fossils of Orbitoides, Siderolites and rudists were found. Also associated with these allochems are minor quantities of quartz grains, volcanic, metamorphic, and sandstone-siltstone clasts. In the Tripolitza Series, a minor regression appear to have occurred during Lower to Middle Paleocene; this was followed by a slight trangression which resulted in the formation of Nummulites-, Alveolina- and Discocyclina-bearing limestones. According to D.J. Carter (per. com., 1981), Upper Lutetian Tripolitza limestones outcropping to the west of Apostoli, eastern Crete, belong to a deeper water facies which contain Nummulites and Discocyclina in addition to planktonic foraminifers. Globigerina tripartita were found in the overlying flysch. This shows that trangression continued at least up to Middle Eocene or Priabonian. During the regressive period, erosion of parts of the underlying rudist limestones belonging to the Tripolitza Series would yield reworked Orbitoides, Siderolites and rudists into the Pindic-Ethia basin. However it could not explain the presence of terrigenous constituents and Discocyclina (known to inhabit fore-reef shoals) in the Pindic-

Ethia Series. With the advance of the trangressive period, correlations of the allochems in the Pindic-Ethia Series with the constituents of the Tripolitza Series became possible.

Though similarities between some lithofacies and some of the fossil content of the Tripolitza Series and some of those in the Pindic-Ethia Series exist, very significant differences (especially with regard to terrigenous constituents) prompts the author to rule out the Tripolitza Series as their source area. The author believes that although the Tripolitza Series is paleogeographically well situated to provide the shallow-water allochems to the Pindos basin, it has been too rigidly conceptualized and the consideration of an alternative and more probable reef complex source area has been neglected.

CHAPTER 6

6.0 PLANKTONIC FORAMINIFERA ZONATION

6.1 INTRODUCTION

Since the earliest studies of the Pindic-Ethia Series of Crete, attempts were made to date these strata in accordance with the Standard European Stages. Insofar as the Upper Cretaceous-Lower Eocene strata here are concerned, the presence of planktonic foraminifera in these rocks have permitted successive workers to recognize the Campanian, Maastrichtian and Eocene Stages. No further attempts were made to subdivide these stages to give a better age resolution. However since then, major advances made in using planktonic foraminifera as zonal indicators have met with worldwide success. In view of this development, the biostratigraphy of the Pindic-Ethia Series in Crete need to be revised. In the course of this study, exposures of the Pindic-Ethia Series in Crete were sampled in detail; more information was collected, and the analysis of these data show that Pindos Series can be successfully zoned.

6.2 THE PROPOSED ZONAL SCHEME

The aims of erecting a zonal scheme here are twofold : they effectively summarize the paleontological findings of the Pindic-Ethia Series, and permit direct comparison with other localities carrying a similar fauna content reported from mainland Greece.

The biozones established here are based on the range zones and the concurrent range zones of selected taxa of the Globigerinida. Within the Upper Cretaceous-Lower Eocene Pindic-Ethia Series, a total of 12 zones are recognized (Table 2). These zones are compiled from paleontological data obtained from several

Table 2 - Santonian to Lower Eocene foraminiferal zonal scheme for the Pindic-Ethia Series, Crete.

ABS. AGE (m.y.)	AGE	ZONES
	LOWER EOCENE	G.(M.) aragonensis / G.(A.) bullbrooki (P7-P8?)
		G.(M.) subbotinae (s.l.) (P6)
54	PALEOCENE	G.(G.) pseudomenardii / G.(M.) velascoensis (s.l.) (P4-P5)
		G.(M.) angulata / G.(T.) pusilla (P3)
		G.(T.) uncinata (P2)
		G.(T.) pseudobulloides (P1)
65	MAASTRICHTIAN	Abathomphalus mayaroensis
		Racemiguembelina fructicosa / Gtr. contusa
71	CAMPANIAN	Gtr. fornicata/Gtr. tricarinata
		Globotruncana elevata
78	SANTONIAN	D. carinata / Gtr. elevata
		Dicarinella carinata

localities in the Asterousia Ori, southern Crete, and in the vicinity of Kerames, southwest end of central Crete. In most of the localities or sections studied, part of the proposed zones are missing due to intense thrusting and imbrication within the Pindic-Ethia Series. Along the western part of the Pindic-Ethia nappe in Asterousia Ori (section TN), biozones are poorly established because of an overwhelming influx of fore-reefal to lagoonal detritus throughout a large part of the depositional history.

6.3 UPPER CRETACEOUS PINDIC-ETHIA SERIES

Present work on this series is concentrated mainly on the thick limestone sequence overlying the "Premier Flysch". Microfossils identified from the latter include *Marginotruncana helvetica*, *Marginotruncana pseudolinneiana*, *Marginotruncana* cf. *imbricata* and *Hedbergella delrioensis - planispira*, thus giving it at least a Turonian age.

The basal section of the Upper Cretaceous limestone sequence is composed of unfossiliferous calcilutites. About 6.5 meters above its base, the first fossiliferous horizon was found. Within this horizon (about 1 m thick), three zones were established, namely, (i) upper part of the *Dicarinella carinata* zone, (ii) the *Dicarinella carinata* / *Globotruncana elevata* zone, and (iii) lower part of the *Globotruncana elevata* zone. These zones are recognized only in sections TK and TP. The oldest age of the horizon indicated here is Santonian. On the basis of its stratigraphic position, the basal section of the Upper Cretaceous limestone sequence, which is sandwiched between Turonian flysch and Santonian limestone strata, is therefore assumed to be Coniacian in age.

The rest of the Upper Cretaceous limestone sequence can be further divided into 3 zones. From the base to the top are the Globotruncana fornicata / Globotruncana tricarinata zone, the Racemiguembelina fructicosa / Globotruncana contusa zone, and the Abathomphalus mayaroensis zone.

6.4 CRETACEOUS - PALEOGENE TRANSITION

Stratigraphic transition between Upper Cretaceous and Paleogene strata was observed in three of the sections (i.e. TE, TN, and TG). In the field, this transition is detected through a change in faunal content. Upper Cretaceous planktonic taxa such as Globotruncana, Rugoglobigerina, Racemiguembelina and Abathomphalus disappeared abruptly to be replaced by assemblages of Globorotalia (s.l.) and Subbotina. A similar change was also observed in the assemblages of the larger benthonic foraminifera. Species of Discocyclina and Nummulites (s.l.) appear for the first time in the Paleogene strata.

6.5 PALEOGENE PINDIC-ETHIA SERIES

The first strata bearing abundant species of Globorotalia (Turborotalia) pseudobulloides was located 7.6 meters above uppermost Maastrichtian strata containing Abathomphalus mayaroensis (observed in section TG). This would represent the Globorotalia (Turborotalia) pseudobulloides zone or P1 (Berggren, 1969; Blow, 1979). In the other sections examined, this zone is not well developed; in section TE, Globorotalia (Turborotalia) pseudobulloides is poorly preserved in strata containing reworked Upper Cretaceous planktonic fauna, and in section TN, no planktonic foraminifera are found during this interval.

A total of 6 zones are recognized. From the base to the top are (i) the G.(T.) pseudobulloides zone (P1), (ii) the G.(T.) uncinata zone (P2), (iii) the G.(M.) angulata / G.(T.) pusilla zone (P3), (iv) the G.(G.) pseudomenardii / G.(M.) velascoensis (s.l.) zone (P4-5), (v) the G.(M.) subbotinae zone (P6), and (vi) the G.(M.) aragonensis / G.(A.) bullbrooki zone (P7-P8?). The assemblages characterising these zones clearly display distinct, morphologic trends. Planktonic foraminifera in zones P1 and P2 belong to the so-called rounded Globorotalia (s.l.) assemblage. These are replaced upwards by the keeled Globorotalia (s.l.) assemblage (P3-P5), to be followed by an assemblage containing highly spinose or rugose Globorotalia (s.l.) spp. which may or may not be keeled (P6-P8?).

The top of the Paleogene limestone sequence is thus shown to be of Ypresian age. Immediately overlying the limestone is the Pindos flysch, the study of which is outside the scope of this research. However, preliminary field examination of the basal portion of this flysch shows the absence of planktonic foraminifera.

6.6 DEFINITIONS OF THE BIOZONES

Dicarinella carinata zone (partial range zone)

The base of this zone cannot be established due to the absence of planktonic foraminifera from the underlying beds in the section examined. The top of this zone is placed stratigraphically below the first occurrence of Globotruncana elevata and coincides with the disappearance of Dicarinella concavata.

Other taxa found in this zone include Marginotruncana angusticarenata, Marginotruncana coronata and Marginotruncana pseudolinneaina.

Dicarinella carinata / Globotruncana elevata zone (concurrent range zone)

The base of this zone coincides with the first occurrence of Globotruncana elevata; the top is placed below the first occurrence of Globotruncanella havanensis.

The taxa found in the underlying Dicarinella carinata zone are present throughout this zone. Globotruncana elevata become abundant here.

Globotruncana elevata zone (partial range zone)

The top of this zone could not be determined due to the lack of exposures in section TK where the lower part of this zone was established.

Globotruncanella havanensis, Globotruncana linneiana, Globotruncana arca and Pseudotextularia sp. appear for the first time here. The basal portion of this zone still contains Marginotruncana angusticarenata, Marginotruncana coronata, Marginotruncana pseudolinneiana, as well as Globotruncana fornicata.

Globotruncana fornicata / Globotruncana tricarinata zone (concurrent range zone)

Due to the limitation of the available data for this particular horizon, this zone is based on the absence of Globotruncana elevata (a species common in Lower Campanian strata) from its lower part and the presence of Globotruncana ventricosa and Globotruncana tricarinata in its upper part. This zone is placed above the Globotruncana elevata zone but below the

Racemiguembelina fructicosa / Globotruncana contusa zone.

Globotruncana fornicata, Globotruncana arca, Globotruncana linneiana, Globotruncana stuarti-stuartiformis, Globotruncanella havanensis, Rugoglobigerina rugosa and Pseudotextularia sp. are common throughout this zone. In the upper part of this zone, transitional forms between Globotruncana fornicata and Globotruncana contusa, Gublerina specie and Rugoglobigerina rotundata are observed.

Unfortunately this zone has a relatively wide range, covering both Upper Campanian and Lower Maastrichtian ages and the boundary between the Campanian and Maastrichtian Stages cannot be determined.

Racemiguembelina fructicosa / Globotruncana contusa zone (concurrent range zone)

The base of this zone is placed at the first occurrence of Globotruncana contusa and Racemiguembelina fructicosa, while the top is placed immediately below the first occurrence of Abathomphalus mayaroensis.

Taxa associated in this zone include Globotruncana gansseri, Globotruncana aegyptica, Globotruncana conica, Globotruncana stuarti-stuartiformis, Rugoglobigerina rotundata, Gublerina specie as well as the longer ranging Globotruncana arca, Globotruncana linneiana, Globotruncanella havanensis and Rugoglobigerina rugosa.

Abathomphalus mayaroensis zone (total range zone)

The base of this zone coincides with the first occurrence of the zonal fossil, and its top lies immediately below the first occurrence of Paleogene fauna.

This zone contains a rich assemblage of planktonics similar to those found in the underlying _Racemiguembelina_ _fructicosa_ / _Globotruncana_ _contusa_ zone.

Globorotalia (_Turborotalia_) _pseudobulloides_ zone (P1) (partial range zone)

The base of this zone is placed at the first occurrence of the zonal fossil, and its top is drawn immediately below the first occurrence of _Globorotalia_ (_Turborotalia_) _uncinata_.

Taxa associated here include _G._(_T._) _compressa_, _Subbotina_ _triloculinoides_ and transitional forms between _G._(_T._) _pseudobulloides_ and _G._(_T._) _compressa_. _G._(_T._) _pseudobulloides_ is abundant throughout this zone.

Globorotalia (_Turborotalia_) _uncinata_ zone (P2) (partial range zone)

The base of this zone coincides with the first occurrence of the zonal fossil; its top is placed immediately below the first occurrence of _G._(_M._) _angulata_.

_G._(_T._) _pseudobulloides_, _G._(_T._) _compressa_, _G._(_T._) _uncinata_ and _Subbotina_ _triloculinoides_ are also present. Unlike those forms in the underlying zone, species of _G._(_T._) _pseudobulloides_ here have coarser perforations and more distinct surface ornamentation. Transitional forms between _G._(_T._) _uncinata_ and _G._(_M._) _angulata_ are also observed.

Globorotalia (_Morozovella_) _angulata_ / _Globorotalia_ (_Turborotalia_) _pusilla_ zone (P3) (concurrent range zone)

The base is placed at the first occurrence of

G.(M.) angulata and its top below the first occurrence of G.(G.) pseudomenardii and G.(M.) velascoensis (s.l.).

G.(T.) chapmani, G.(G.) ehrenbergi, G.(T.) pusilla, G.(G.) laevigata, G.(M.) angulata, G.(M.) aequa, G.(M.) occlusa and G.(M.) cf. acutispira first appear within this zone. G.(T.) pseudobulloides and G.(T.) compressa disappear within this zone.

Globorotalia (Globorotalia) pseudomenardii / Globorotalia (Morozovella) velascoensis (s.l.) zone (P4 - P5) (concurrent range zone)

The base of this zone is placed at the first occurrence of G.(G.) pseudomenardii and G.(M.) velascoensis (s.l.); its top is determined by the disappearance of these zonal fossils from strata containing G.(M.) subbotinae.

This zone is not subdivided further owing to the general absence of G.(M.) velascoensis from the sections examined, but it is roughly equivalent to the G.(G.) pseudomenardii zone and the G.(M.) velascoensis zone established by Bolli for Trinidad. However, the range of G.(G.) pseudomenardii is much longer in Crete.

G.(M.) cf. acutispira is common throughout this zone. G.(A.) cf. esnaensis and G.(M.) subbotinae appear for the first time here, while G.(M.) angulata disappear from its upper part.

Globorotalia (Morozovella) subbotinae zone (P6) (partial range zone)

G.(M.) subbotinae, G.(M.) cf. acutispira and G.(A.) cf. esnaensis persist into this zone. G.(M.) aequa develops coarse, blunt spines over its entire test surface.

The top of this zone is drawn immediately below the first occurrence of *G.* (*A.*) *bullbrooki* and highly spinose, keeled forms which are here referred to as *G.* (*M.*) cf. *aragonensis*.

Globorotalia (*Morozovella*) *aragonensis* / *Globorotalia* (*Acarinina*) *bullbrooki* zone (P7 - P8?) (concurrent range zone)

Top of this zone cannot be defined because the limestone sequence of the Pindic-Ethia Series is replaced by flysch lacking a planktonic fauna.

Throughout this zone, *G.* (*A.*) *bullbrooki*, *Subbotina linaperta* and *G.* (*M.*) cf. *aragonensis* are common and well developed. Sporadic occurrences of *G.* (*M.*) *crater* - *caucasica* are also found.

Table 3 - Distribution of planktonic foraminifera in Section TK.

SECTION TK / SAMPLE NUMBER	PLANKTONIC FORAMINIFERA														ZONES	AGE
	M. angusticarenata	M. coronata	M. helvetica	M. pseudolinneiana	D. carinata	D. concavata	Gtr. arca	Gtr. elevata	Gtr. fornicata	Gtr. linneiana	Gl. havanensis	Pseudotextularia sp.	H. delrioensis	H. planispira		
E							O			O		O			Gtr. elevata	L. CAMP.
1c2	O	O		O			O	O	O							
1d	O	O		O					O		O					
1e	O	O		O	O			O							Gtr. elevata — D. carinata	SANTONIAN
1f	O			O				O								
1g	O	O		O	O			O								
1h	O			O	O	O									D. carinata	
1i	O	O		O												
1L	O	O		O												
UNFOSSILIFEROUS HORIZON																
5			O	O											M. helvetica	TUR.
5b													O	O		

TABLE 4 - DISTRIBUTION OF PLANKTONIC FORAMINIFERA IN SECTION TP.

SECTION TP / SAMPLE NUMBER	PLANKTONIC FORAMINIFERA																				ZONES	AGE
	M. angusticarenata	M. coronata	M. helvetica	M. pseudolinneiana	D. carinata	Gtr. arca	Gtr. conica	Gtr. contusa	Gtr. elevata	Gtr. fornicata	Gtr. gansseri	Gtr. linneiana	Gtr. stuarti (s.l.)	Gl. havanensis	Gublerina sp.	Pseudotextularia sp.	Rgu. fructicosa	Rgl. rugosa	G.(T.) pseudobulloides	G.(M.) angulata		
56				O					O	O											Gtr. elevata — D. carinata	U. SANT.
54				O	O				O	O												
52				O					O	O												
T H R U S T																						
39						O				O			O		O	O	O				Rgu. fructicosa / Gtr. contusa	MAST.
38						O						O	O	O	O	O	O					
T H R U S T																						
36						O	O	O		O			O	O	O	O	O				Rgu. fructicosa / Gtr. contusa	MAST.
34															O	O	O					
T H R U S T																						
28						O		O		O			O			O	O	O			Racemiguembelina fructicosa / Globotruncana contusa	MAST.
27							O	O		O			O			O	O	O				
26													O			O	O					
24						O	O			O			O			O	O					
T H R U S T																						
19	O		O																		Marginotruncana helvetica	TUR.
17	O		O																			
T H R U S T																						
7d										O	O		O		O	O					Racemiguembelina fructicosa / Gtr. contusa	MAST.
7a								O		O	O	O	O		O	O	O					
T H R U S T																						
13																			O	O	P3	PAL.
T H R U S T																						
1c													O			O	O	O			Rgu. fructicosa / Gtr. contusa	MAST.

Table 5 - Distribution of planktonic foraminifera in Section TD.

SECTION TD / SAMPLE NUMBER	PLANKTONIC FORAMINIFERA: Gtr. arca	Gtr. conica	Gtr. fornicata	Gtr. linneiana	Gtr. cf. petalliformis	Gtr. stuarti-stuartiformis	Gtr. tricarinata	Gtr. ventricosa	Globigerinelloides sp.	Pseudotextularia sp.	Rugoglobigerina rugosa	ZONES	AGE
29a	0		0	0	0	0				0		Gtr. fornicata — Gtr. tricanata	LOWERMOST MAAST.
29			0			0				0			
28	0		0	0	0	0			0	0			
26		0		0					0				
21	0		0	0	0	0							
20	0		0		0				0				
16			0	0	0								
14			0	0		0		0	0				
6			0		0	0				0	0		
5	0		0	0					0	0	0		
4			0	0		0	0		0		0		
3	0		0	0		0				0			
2			0	0									

TABLE 6 - DISTRIBUTION OF UPPER CRETACEOUS PLANKTONIC FORAMINIFERA IN SECTION TE.

SECTION TE / SAMPLE NUMBER	Gtr. cf. aegyptica	Gtr. arca	Gtr. calcarata	Gtr. conica	Gtr. contusa	Gtr. fornicata	Gtr. gansseri	Gtr. linneiana	Gtr. cf. petalliformis	Gtr. stuarti-stuartiformis	Gtr. tricarinata	A. mayaroensis	Gl. havanensis	Globigerinelloides sp.	Gublerina sp.	Pseudotextularia sp.	Rgu. fructicosa	Rgl. rotundata	Rgl. rugosa	Rgl. scotti	ZONES	AGE
	PLANKTONIC FORAMINIFERA																					
118							O			O											ABATHOMPHALUS MAYAROENSIS	UPPER MAASTRICHTIAN
114																O		O				
113					O				O	O		O				O	O	O				
112a												O			O	O						
112									O								O					
110a				O						O			O		O		O					
106														O								
104a		O			O					O					O		O	O				
104	O				O					O		O	O		O	O	O	O	O			
103a	O			O	O				O	O			O	O		O	O	O	O			
102b										O				O	O		O		O			
102a		O				O				O				O	O	O			O	O		
100								O		O			O	O		O						
99a	O					O		O		O					O	O	O					
99					O	O	O		O	O			O		O	O	O					
98a	O			O	O					O			O			O	O					
97a		O							O	O						O						
97			O rw		O				O	O		O		O		O	O					
96b					O					O						O	O					
93					O				O	O		O	O	O		O	O					
92a		O		O	O	O			O	O		O	O	O		O	O					
91a													O	O							GTR. FORNICATA — GTR. TRICARINATA	LOWERMOST MAAST.
87		O				O									O							
86													O	O								
82a						O				O				O	O	O		O				
78a										O												
70						O				O						O		O				
64a						O		O		O	O			O	O	O						
57a											O		O									
53a		O				O				O						O						
53						O								O								

rw - reworked

TABLE 7 - DISTRIBUTION OF LOWER TERTIARY PLANKTONIC FORAMINIFERA IN SECTION TE.

SECTION TE / SAMPLE NUMBER	G.(T.) chapmani	G.(T.) compressa	G.(T.) pseudobulloides	G.(T.) pusilla	G.(T.) uncinata	G.(G.) albeari	G.(G.) ehrenbergi	G.(G.) pseudomenardii	G.(M.) aequa	G.(M.) angulata	G.(M.) cf. acutispira	G.(M.) cf. aragonensis	G.(M.) cf. occlusa	G.(M.) subbotinae	G.(M.) velascoensis (s.l.)	G.(A.) bullbrooki	G.(A.) cf. esnaensis	M. mckannai	S. linaperta	S. triloculinoides	ZONES	AGE
160												O				O			O		P7 - P8?	LOWER EOCENE
159												O				O			O			
158																			O			
157												O				O			O			
154												O				O			O			
153a												O				O						
152a												O				O						
151												O				O						
150a												O				O						
150												O				O						
134									O					O			O	O			P6	L. EOC. TO U. PALEOC.
133											O			O								
132											O			O								
131									O					O			O					
128b	O					O		O							O						P4 - P5	
128									O													
127											O											
126a											O			O								
125								O			O			O			O					
124							O	O		O			O		O							
123a	O	O	O	O		O	O			O										O	P3	M. PALEOCENE
123			O				O													O		
122a							O		O	O	O									O		
121a	O		O	O			O		O	O										O		
120a		O	O		O															O	P2	
120		O	O		O																	
119			O																			

TABLE 8 - DISTRIBUTION OF PLANKTONIC FORAMINIFERA IN SECTION TG.

SECTION TG / SAMPLE NUMBER	G.(T.) compressa	G.(T.) pseudobulloides	G.(M.) cf. acutispira	G.(M.) aequa	G.(M.) angulata	G.(M.) cf. aragonensis	G.(M.) cf. crater-caucasica	G.(M.) subbotinae	G.(M.) velascoensis (s.l.)	G.(A.) bullbrooki	G.(A.) cf. esnaensis	M. mckannai	M. cf. senni	S. linaperta	S. triloculinoides	ZONES	AGE
																PLANKTONIC FORAMINIFERA	
18b				O		O	O			O						P7 - P8?	L. EOCENE
18a						O	O			O							
17b						O	O			O							
16b										O			O	O			
16						O				O			O				
15a						O				O				O			
14b						O				O	O			O			
14a											O		O	O			
9a								O						O		P3 - P6 (zones are poorly developed)	PALEOCENE
8b								O									
8a								O			O			O			
7					O												
5a			O								O						
4			O		O							O					
3aa				O				O	O		O						
3								O			O						
2a					O												
1c	O	O															
1b		O													O	P1 - P2	PALEOC.
1a		O															
1		O															

Table 9 - Distribution of Lower Tertiary planktonic foraminifera in Section TN.

SECTION TN / SAMPLE NUMBER	PLANKTONIC FORAMINIFER													ZONES	AGE
	G.(T.) chapmani	G.(T.) compressa	G.(G.) ehrenbergi	G.(M.) cf. acutispira	G.(M.) aequa	G.(M.) angulata	G.(M.) cf. aragonensis	G.(M.) subbotinae	G.(M.) velascoensis (s.l.)	G.(A.) bullbrooki	G.(A.) cf. esnaensis	M. mckannai	S. triloculinoides		
70							O			O				P7-P8?	L. EOCENE
69							O			O					
67a										O					
66										O					
65										O					
63					O					O	O				
62			O rw			O rw								P6	L. EOCENE to U. PALEOCENE
59a						O rw									
59					O			O	O		O				
58				O							O			P4-P5	
56				O							O	O			
55a		O rw			O	O									
55	O					O							O		
52a						O							O		
52					O	O							O		
50						O							O		
49				O		O			O				O		
45													O		

rw – reworked

CHAPTER 7

7.0 CONCLUSIONS

7.1 GENERAL PALEONTOLOGICAL FINDINGS

(i) Established for the first time the existence of Santonian and Lower Campanian Pindic-Ethia strata in Crete based on planktonic microfauna. Previous records of these strata were based not on the faunal content of these rocks but on their stratigraphic position which was defined by the overlying fossiliferous Campanian-Maastrichtian strata ("couches de passage") and the underlying Cenomanian-Turonian "Premier Flysch" (Aubouin and Dercourt, 1965; Bonneau and Fleury, 1971; Seidel, 1971).

(ii) Recorded for the first time a complete transition of Lower Paleocene to Lower Eocene planktonic foraminifera in the limestones overlying the Upper Maastrichtian of the Pindic-Ethia Series. Earlier workers have generally accepted an overall Eocene age for these strata (Aubouin and Dercourt, 1965; Bonneau and Fleury, 1971) with the exception of Seidel (1971) who reported the presence of Globorotalia angulata 10 meters above strata containing Abathomphalus mayaroensis. In most instances, no faunal list was given to substantiate the proposed ages of these strata.

(iii) The transition from Uppermost Maastrichtian (i.e. Abathomphalus mayaroensis zone) to Lowermost Paleocene is not sharply defined in the Pindic-Ethia Series of the Asterousia Ori. Zones M. 18 (Blow, 1979) (equivalent to the Globigerina eugubina zone Luterbacher and Premoli-Silva, 1964) and P. α (Blow, 1979) are not established here owing to lack of a suitable microfauna. This transition is marked by a narrow zone (about 5 meters thick) of poorly exposed microbreccias, calcilutites and black chert beds which are poorly fossiliferous; a few Globotruncana spp. and badly preserved traces of probable Globorotalia (Turborotalia) pseudobulloides might be present.

(iv) A total of 12 biozones based on planktonic foraminifera were proposed for the Upper Cretaceous to Lower Eocene Pindic-Ethia Series in Crete.

(v) The age of the "Premier Flysch" in the Asterousia Ori and Asideroto Ori is at least Turonian to possibly Coniacian.

7.2 CORRELATION

Correlation with other Pindic outcrops in Crete and in mainland Greece is often hindered by the lack of complete published faunal lists. In most cases, previous authors tend to concentrate on the faunal assemblages of specific stratigraphic horizons while ignoring the rest. As a result, only the planktonic foraminifera of the "couches de passage" and the "Premier Flysch" were given emphasis and elaborated in detail (Aubouin and Dercourt, 1965; Bonneau and Fleury, 1971; Seidel, 1971).

Despite these shortcomings, Table 10 shows that general correlation with other Pindic outcrops can be achieved.

7.3 GENERAL GEOLOGICAL FINDINGS

(i) The Pindic-Ethia Series found in the Asterousia Ori and the Asideroto Ori are fragments of the Pindic-Ethia nappe that was overthrust onto the Tripolitza nappe. The zone of detachment or decollement of the Pindic-Ethia nappe coincided with the Triassic

TABLE 10: CORRELATION CHART FOR THE PINDIC-ETHIA SERIES IN CRETE AND MAINLAND GREECE.

Age	Zonation proposed for this thesis	Auboin and Dercourt (1965), Crete		Seidel (1971)	Loftus (1966)
		Locality: Dictea Massif	Locality: Asideroto Ori	Loc. Paleohora, SW Crete	Navpaktos-Thermon region, Western Greece
L. EOCENE	G.(M.) cf. aragonensis/ G.(A.) bullbrooki		Flysch said to be Maastrichtian to Eocene age. No faunal list was given.	No other younger taxa of the Globigerinida were mentioned in the "transitional zone."	Flysch said to be of Paleocene to Eocene in age. No faunal list was given.
	G.(M.) subbotinae				
PALEOCENE	G.(M.) velascoensis / G.(G.) pseudomenardii				
	G.(M.) angulata / G.(T.) pusilla			First occurrence of Globorotalia angulata.	
	G.(T.) uncinata			No mention of other microfossils.	
	G.(T.) pseudobulloides				
MAAST.	Abathomphalus mayaroensis			First occurrence of Abathomphalus mayaroensis	Gtr. stuarti, Gtr. arca, Gtr. contusa, Gtr. gansseri, Gtr. cf. mayaroensis, Gtr. cf. linneiana, Gtr. cf. elevata stuartiformis, Racemiguembelina, Gublerina, Pseudotextularia elegans, Rugoglobigerina.
	Gtr. contusa / Rgu. fructicosa	Microfauna said to be Campanian-Maastrichtian age : Gtr. stuarti, Gtr. contusa, Gtr. arca, Gtr. linnei, Gtr. lapparanti, Gtr. lugeoni, Gtr. stuarti-stuartiformis.	Microfauna said to be Maastrichtian age : Gtr. stuarti, Gtr. contusa, Gtr. arca, Gtr. cf. tricarinata, Gtr. lugeoni Gtr. stuarti-stuartiformis Guembelina, Globigerina.	No faunal list was given but the Globotruncanae were said to be typical of Upper Campanian to Maastrichtian age.	Gtr. stuarti, Gtr. elevata stuartiformis, Gtr. arca, Gtr. cf. contusa, Gtr. cf. gansseri, Gtr. cf. linneiana, Racemiguembelina, Pseudotextularia elegans.
CAMP.	Gtr. fornicata / Gtr. tricarinata				Gtr. calcarata, Gtr. arca, Gtr. fornicata-caliciformis, Gtr. conica.
	Gtr. elevata	NeoCretaceous Limestone. No faunal list was given.	NeoCretaceous Limestone. No faunal was given.	No detailed faunal list was given; said to contain Globigerina and Globigerinelloides.	Microfossils said to indicate age close to Santonian-Campanian boundary : Gtr. elevata, Gtr. linneiana, Gtr. linneiana coronata, Gtr. fornicata, Gtr. cf. ventricosa, Gtr. cf. rosetta, Gtr. elevata-stuartiformis Gtr. cf. linneiana bulloides.
SANT.	Gtr. elevata / D. carinata				
	D. carinata				Microfossils said to give at least Santonian age : Gtr. cf. linneiana, Gtr. cf. linneiana coronata, Gtr. cf. angusticarenata, Gtr. tricarinata, Heterohelix.

sediments of the Pindic-Ethia Series. Therefore, no pre-Triassic Pindic-Ethia rocks have been identified, and consequently, the nature of the basement of the Pindic-Ethia basin remains unknown.

(ii) The Pindic-Ethia Series is generally not intact due to internal imbrication and thrusting. The most complete unit of this series is the Coniacian to Ypresian limestone sequence, while the "Premier Flysch" and the Triassic-Lower Cretaceous sequences are least intact. The contact between the Upper Cretaceous-Lower Eocene limestones and the "Premier Flysch" (conformable in sections TK and TN) is generally thrust (egs. in sections TE(1) and TP); thrust contacts are usually difficult to discern in the field but detailed micropaleontological work shows a distinct stratigraphic break across such contacts.

(iii) The series is composed predominantly of carbonate sediments ranging in age from Triassic (Renz and Reichel, 1945) to Lower Eocene (this thesis), with 2 episodes of siliciclastic sedimentation occuring respectively during Turonian ("Premier Flysch") and Ypresian or post-Ypresian ("Tertiary Pindos Flysch").

(iv) The series is folded. Fold axes recorded from the Upper Cretaceous-Lower Eocene limestone sequence in section TE are predominantly NNW-SSE. These folds include open to tight folds, chevron folds, and asymmetrical to symmetrical folds whose axial surfaces are either overturned or upright. In the Kerames section (section TP), strata close to the Pindos thrust (especially the Halobia-bearing beds, red shales and radiolarites) show mainly east-west fold axes, while strata away from the thrust plane (i.e. the Upper Cretaceous limestones) show mainly north-south and northwest-southeast fold axes.

(v) A comparison of the proportion and thickness of the calcbreccias and calcarenites of the Coniacian-Ypresian limestones across the Asterousia Ori show that the calcbreccias and calcarenites are thickest and most abundant in the west, indicating that the direction of transport of these materials was from the present western quadrant. The paleoslope of the Pindic-Ethia basin during this period of its depositional history was thus dipping towards the present eastern quadrant. Azhar (per. com., 1982) on comparing the proportion, thickness and the facies distribution of the Lower Eocene Pindos siliciclastics ("Tertiary Pindos Flysch") concluded that the transport direction of these siliciclastics was from the present eastern quadrant.

(vi) The Tripolitza Series, classically thought of as the source of the Pindic-Ethia calcbreccias and calcarenites, is here considered to be too rigidly conceptualized and have thus failed to fulfil the criteria expected from the source area of the Pindic-Ethia calcbreccias. According to the geosyncline model applied to Crete (Aubouin and Dercourt, 1965), the Tripolitza Series is confined to an east-west trending isopic zone which is located immediately south of the Pindos isopic zone, thus implying that the direction of sediment transport (i.e. carbonate clastics) is from the south. Such a paleogeographic position fails to account for the field evidence collected by this author which show that the source area of the calcbreccias in the Pindic-Ethia basin should be to the west of the Asterousia Ori. Minor terrigenous, volcanic and metamorphic clasts found in these calcbreccias indicate that the carbonate and non-carbonate constituents of these beds came from the same source area.

No terrigenous constituents were reported from published literature on the Tripolitza Series.

7.4 GEOLOGICAL EVOLUTION OF THE PINDIC-ETHIA BASIN

The model proposed here for the geological evolution of the Pindic-Ethia basin is based on evidence collected from outcrops located along an east-west traverse across the Asterousia Ori, from Apessokari in the west to Keratokambus in the east. Due to the absence of pre-Triassic Pindic-Ethia rocks throughout Crete and mainland Greece, the nature of the basement of the basin is not postulated here.

During Triassic to possibly Lower Jurassic, thick successions of Halobia(s.l.)-bearing calcilutites, red chert, red radiolarites, subordinate shales, limestone conglomerates-breccias and oolitic-pisolitic calciturbidites were deposited in the Pindic-Ethia basin. The actual depth of the basin remains uncertain. Current theories on the formation of bedded chert provide contrasting views regarding its depth of formation (Garrison, 1973). However, the dominance of red coloured strata, abundance of pelagic fossils (radiolaria and Halobia (s.l.)), and the absence of any neritic benthonic fauna in these strata (with the exception of reworked faunas found in the calciturbidites and calcbreccias) indicate that the basin was relatively well oxygenated, calm, with depth exceeding the neritic zone. Within the limestone conglomerates-breccias and oolitic-pisolitic calciturbidites are derived shallow-water constituents (such as fragments of echinoderms and molluscs, ooliths, pisoliths), minor amounts of sandstone, volcanic and metamorphic clasts, red chert clasts and Halobia-bearing calcilutite clasts. The presence of derived shallow-water constituents indicates the existence of an adjacent shallow-water complex. The similarity of the red chert and Halobia-bearing calcilutite clasts to parts of the Pindic-Ethia strata suggest the possibility that these clasts might be derived from the erosion of parts of the Pindic-Ethia strata.

One plausible explanation to account for the introduction of the derived materials into the basin is that the shallow-water complex and the slope which linked this complex with the deeper parts of the Pindic-Ethia basin were affected by block-faulting. This mechanism would cause certain portions of the basin, the slope and the shallow-water complex to be preferentially uplifted and eroded thereby providing materials to be washed into the deeper parts of the basin. Minor constituents such as sandstone, volcanics and metamorphics were interpreted by Azhar (per. com., 1982) to be the eroded portions of partly exposed basement of the shallow-water complex or of the slope. He noted that the volcanic clasts were basaltic and the metamorphic clasts were composed of quartzite and quartz-mica schists. Due to the lack of evidence showing sediment transport direction in the calcbreccias and calciturbidites, the source area of the shallow-water and terrigenous constituents in these beds is not known.

During Upper Jurassic to Lower Cretaceous, the presence of massive and slumped oolitic-pisolitic limestones in the Pindic-Ethia calcilutite-calciturbidite sequence indicate that the geologic events that shaped the depositional history of the Trias-Lower Jurassic period persisted into this period. The top of the Lower Cretaceous carbonate sequence is characterized by an irregular, fissured surface filled with polymictic breccias with clasts similar to those found in the limestone conglomerates-breccias of the underlying sequence, with the exception that the proportion of terrigenous and volcanic clasts here is higher. Similar features described elsewhere as "Neptunian dykes" were observed throughout the Triassic-Jurassic Alpine-Mediterranean region (Bernoulli and Jenkyns, 1974; Wood, 1981) and were interpreted as fossilised submarine-highs and seamounts produced by block faulting and regional subsidence of a carbonate platform. In the Pindic-Ethia Series, this fissured surface was followed immediately by deposition of red chert-radiolarite-shale sequence with subordinate calciturbidites, indicating that the basin was deepening. Therefore, it appeared that block-faulting persisted throughout Triassic-Lower Cretaceous time.

Directly above the red chert-radiolarite-shale sequence is a conformable succession of siliciclastics, informally named by the French workers as "Premier Flysch". In many places in the Asterousia Ori, this succession is incomplete due to thrusting or shearing. It is composed predominantly of fine to coarse-grained sandstones and shales with subordinate amount of red chert, radiolarites, calcilutites and calcbreccias. The source area and the direction of transport of these siliciclastics are not known due to the lack of paleocurrent data and the absence of any sedimentological trend (sandstone-shale ratio, sandstone thickness variation, etc.). Presence of _Marginotruncana helvetica_ in some of the limestone beds here indicates that the age of the siliciclastics is Turonian.

Overlying these siliclastics is a thick succession of fossiliferous Coniacian to Ypresian calcilutites, calcarenites, calcbreccias and subordinate shales. The calcilutites contain a rich assemblage of calcareous planktonic foraminifera indicating deposition in an open sea above CCD. The calcarenites and calcbreccias are composed predominantly of reworked shallow-water allochems especially fragments of echinoderms, molluscs and rudists. Orbitoides, Siderolites, Discocyclina, Nummulites, Fasciolites, bryozoa, coralline algae, ooliths, pisoliths and planktonic foraminifera are also present in varying amounts. The presence of these reworked shallow-water constituents in the Pindic-Ethia basin indicate the presence of an adjacent reefal complex, a picture that is consistent with the geologic setting proposed for the older strata. A comparison of the proportion and thickness of calcbreccias and calcarenites in three of the sections located across the Asterousia Ori show that the bulk of these beds are concentrated in the western Asterousia Ori. This suggests that the likely source of these breccias was to the present west of the Asterousia Ori and that the paleoslope of the Pindic-Ethia basin in the Asterousia Ori is towards the present east. Minor proportions of sandstone-siltstone and volcanic and metamorphic clasts were also distributed throughout the sequence. The similarity of these clasts to those observed in the older strata indicate the possibility that they came from the same source area. Therefore it is probable that the morphology of the Pindic-Ethia basin had remained essentially similar since Triassic times.

By the Ypresian, shale intercalations become more frequent in the limestone sequence of the Pindic-Ethia Series until the limestones were gradually replaced by shales and sandstones of the "Tertiary Pindos Flysch."

Fold axes of the Pindic-Ethia Series fall into 2 major clusters, a NNW-SSE and a E-W. The NNW-SSE folds are predominant in the Upper Cretaceous-Lower Eocene limestones while the E-W folds are predominant in the older strata, especially those closest to the Pindos thrust. In the Asterousia Ori, Azhar (per. com., 1982) found that the NNW-SSE axes are also common in the older strata and in the Tertiary Pindos Flysch. This shows that the NNW-SSE folds are found throughout the whole of the Pindic-Ethia Series. He also confirmed that the E-W folds are predominant in thin-bedded strata (such as shales and calcilutites) close to the Pindos thrust and in the Tertiary Pindos Flysch. In a few places, he found evidence that the NNW-SSE folds were refolded by the east-west folds. This shows that the NNW-SSE folding event occurred earlier than the east-west folding episode and that the former which affected the whole of the Pindic-Ethia Series took place after the end of the "Tertiary Pindos Flysch" sedimentation. Azhar (per. com., 1982) and R. Hall et al. (in prep., 1982) postulate that the NNW-SSE folding was directly related to the thrusting of the Pindic-Ethia Series onto the Tripolitza nappe. Azhar further suggested that the east-west folds were probably formed during the emplacement of the Phyllite-Quartzite Series, Tripolitza Series and Pindos Series onto the Plattenkalk Series in Oligocene time.

N.B.

In the citation of synonyms, this author is in error for failing to acknowledge the author who first published the name of the species concerned before the name of a later author who has also described the species.

For example : in this thesis -

Globotruncana fornicata Postuma, 1971; Manual of Planktonic Foraminifera, p. 38-39.

SHOULD RIGHTLY BE -

Globotruncana fornicata Plummer, Postuma, 1971; Manual of Planktonic Foraminifera, p. 38-39.

CHAPTER 8

8.0 SYSTEMATICS

8.1 INTRODUCTION

The most popular approach to foraminiferal classification is based on the gross features of the test morphology. The type of characters used in taxonomy and their relative importance in classification vary from one worker to another (see review by Loeblich and Tappan, 1964). In general, the criteria proposed by Bolli et al. (1957) and by Loeblich and Tappan (1964) for the taxonomic separation of the planktonic foraminifera are broadly followed here.

In this work, the family GLOBOTRUNCANIDAE (Brotzen, 1942) is expanded to include the following genera : *Globotruncana* (Cushman, 1927), *Rugoglobigerina* (Bronnimann, 1952), *Abathomphalus* (Bolli, Loeblich and Tappan, 1957), *Globotruncanella* (Reiss, 1957), *Marginotruncana* (Pessagno, 1967) and *Dicarinella* (Porthault, 1970). In addition, the Cainozoic genus *Globorotalia* (Cushman, 1927) is divided into 4 subgenera, namely, *Globorotalia* (*Globorotalia*), *Globorotalia* (*Turborotalia*), *Globorotalia* (*Acarinina*) and *Globorotalia* (*Morozovella*).

Most of the samples collected for this research consist of hard limestones whose fossil content could not be released by either mechanical or chemical means. Therefore, only thin-section examinations were carried out. Close to 600 thin-sections were studied by the author in the course of this research. Most of the thin-sections were made from slices cut perpendicular to the bedding planes of the samples. In the majority of cases, this orientation passed axially through the tests of the planktonic foraminifera found in the samples, revealing features such as (i) wall structure (unless destroyed by recrystallization), (ii) the mode of coiling (trochospiral, planispiral, etc.), (iii) chamber form (globular, angular-truncate, etc.), (iv) shape of test, and (v) type of surface ornamentation. Due to the number of samples collected, usually only one thin-section per sample was made.

8.2 LIMITATIONS OF THIN-SECTION STUDY

Unlike the study of whole fossil specimens, thin-section examination suffers from several drawbacks. One of the most obvious is the absence of a three-dimensional perception of the fossil. Thus, the study of the apertural characters and their modifications, criteria that determine to a large degree the separation of the various families in the Globigerinacea, could not be carried out.

In addition, certain generic and specific characters which are easily discerned on whole specimens are not readily observed. These include (i) outline of chambers both dorsally and ventrally (crescentic, trapezoidal, etc), (ii) number of chambers per whorl and their rate of increase, (iii) nature of both dorsal and ventral sutures (radial, curved, depressed, etc.), and (iv) the arrangement of surface ornamentation (meridional or random).

As a result, the description of planktonic foraminifera given in this work is at best incomplete because the only features described are those observed directly from thin-sections. Identification of these fossils is made by comparison with published thin-section figures or photographs. To ensure that the concept of the holotype is adhered to, the taxonimic notes accompaning these published figures or photographs are checked against the descriptions of the respective holotypes. Despite the uncertainties involved in this method of identification, a comparison of the published works of different authors shows that the results obtained by this means are remarkably consistent and reliable, and it even permits the identification of the planktonic foraminifera up to species-level. Literature on thin-section study of planktonic foraminifera is still relatively scarce. Some of the papers dealing in this subject include those of Bolli (1944), Lehmann (1962), Luterbacher (1964), McGowran (1968), Pessagno (1967), Postuma (1971), Reichel (1952), Renz (1936) and Wonders (1979).

8.3 SYSTEMATIC DESCRIPTION

Order : FORAMINIFERIDA Echwald, 1830.

Suborder : ROTALIINA Delage and Herouard, 1896.

Superfamily : GLOBIGERINACEA Carpenter, Parker and Jones, 1862.

Family GLOBOTRUNCANIDAE Brotzen, 1942.

Genus MARGINOTRUNCANA Hofker, 1956.

Type species - Rosalina marginata Reuss, 1845.

Remarks :

This genus has a trochospiral test with well-developed single or double keels, a primary aperture that is extraumbilical-umbilical in position, and a primitive tegilla system that shows only infralaminal accessory supplementary apertures.

Marginotruncana cf. angusticarenata (Gandolfi, 1942)

(Pl. 15, figs. e-h)

Globotruncana linnei var. angusticarenata Gandolfi, 1942; Riv. Ital. diPaleontologia; p. 127; fig. 40, nos. 3a-c; table 4, figs. 17, 30.

Marginotruncana angusticarenata Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 300-301, pl. 98, figs. 5, 9-11.

Globotruncana angusticarenata Postuma, 1971; Manual of Planktonic Foraminifera, p. 16-17.

Thin-section description :

Test trochospirally coiled; unequally biconvex, the dorsal side being more convex. Chambers angular-truncate with two, moderately spaced, peripheral keels. In some specimens, the keels tend to become closer in the later chambers of the last whorl. Umbilicus wide. Surface of test smooth.

Remarks :

Caron and Luterbacher (1969) noted that the holotype of this species has been lost. On examining specimens in Gandolfi's collection labelled as "Globotruncana angusticarenata," they found that in general they have fewer chambers (6) than those figured originally by Gandolfi. In addition, they noted that specimens intermediate to Globotruncana renzi were frequent. Barr (1972) considered Globotruncana angusticarenata and Globotruncana renzi to be closely related and that they differ only in the number of chambers found in the final whorl. Therefore, he tentatively regarded the two conspecific.

Premoli Silva and Boersma (1976) proposed that this species is the direct ancestor of Globotruncana arca but Barr (1972) believed it to have evolved into Globotruncana fornicata *manaurensis*.

Forms here identified as *Marginotruncana* cf. *angusticarenata* have axial profiles that are similar to those of *Globotruncana arca*; they differ in having entirely different stratigraphic ranges.

Range :

The *Dicarinella carinata* zone to the lower part of the *Globotruncana elevata* zone (i.e. Santonian to lowermost Campanian).

Common in sections TK and TP, in association with specimens of *Dicarinella concavata*, *D. carinata*, *Marginotruncana pseudolinneiana*, *Marginotruncana coronata* and *Globotruncana elevata*. Elsewhere, this species has been reported from Turonian strata (Gandolfi, 1942; P.Silva and Boersma, 1977; Barr, 1972).

Marginotruncana coronata (Bolli, 1944)

(Pl. 14, figs. c-f)

Globotruncana lapparenti coronata Bolli, 1944; Eclog. Geol. Helv., v. 37, p. 233, fig. 1, nos. 21-22; pl. 9, figs. 14, 15.

Globotruncana cf. *coronata* Lehmann, 1962; Notes Serv. Geol. Maroc, t. 21, no. 156, text-fig. 2, no. m; pl. 4, fig. 3; pl. 5, fig. 3; pl. 8, figs. 2-3.

Globotruncana linneiana coronata Barr, 1962; Paleont., v. 4, p. 572-573, pl. 70, figs. 1a-c; pl. 72, figs. 3, 4.

Marginotruncana coronata Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 305-306, pl. 65, figs. 11-13; pl. 100, fig. 6.

Globotruncana coronata Postuma, 1971; Manual of Planktonic Foraminifera, p. 32-33.

Marginotruncana coronata Hart et. al., 1981; Strat. Atlas Foss. Foram., p. 210-211, pl. 7.19, figs. 6, 7.

Thin-section description :

Test a low trochospire, characterized by having a large, compressed, nearly biconvex or lenticular shape. Chambers of the earlier whorls globigerine-like; all later chambers angular-truncate and double keeled. Peripheral keels are relatively well spaced but with a tendency to become closer on the later chambers of the final whorl. Fusion of the two keels on the final chamber has been reported but was not observed here.

Remarks :

This species was originally described as a subspecies of Globotruncana lapparenti (Bolli, 1944). It was later placed in the genus Marginotruncana. Occurrences of this species from Upper Turonian to Santonian strata have been reported in many places.

Range :

Commom throughout the Dicarinella carinata zone to the lower part of the Globotruncana elevata zone.

Marginotruncana helvetica (Bolli, 1944)

(Pl. 13, figs. e-g; Pl. 14, figs. a-b)

Globotruncana helvetica Bolli, 1944; Eclog. Geol. Helv., v. 37, p. 226-227, text-fig. 1, nos. 9-12; pl. 9, figs. 6-8.

Globotruncana helvetica Hagn and Zeil, 1954; Eclog. Geol. Helv., v. 47, pl. 5, figs. 5-6.

Globotruncana helvetica Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 56, pl. 13, figs. 1a-c.

Globotruncana helvetica Lehmann, 1962; Notes Serv. Geol. Maroc, t. 21, no. 156, text-fig. 2h; text-figs.3g, 3h; pl. 3, figs, 1a-c.

Marginotruncana helvetica Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 306, pl. 53, figs. 9-13; pl. 54, figs. 1-3; pl. 99, fig. 4; pl. 100, fig. 4.

Praeglobotruncana helvetica Douglas, 1969; Micropaleont., v. 15, no. 2, p. 169-170, pl. 4, figs. 4-5.

Globotruncana helvetica Postuma, 1971; Manual of Planktonic Foraminifera, p. 44-45.

Praeglobotruncana helvetica Barr, 1972; Micropaleont., v. 18, no. 1, p. 15, pl. 2, figs. 8a-c.

Helvetoglobotruncana helvetica Wonders, 1979; Proc. Kon. Ned. Akad. Weten., Sers. B, v. 82(2), pl. 7, figs. 5, 8, 9.

Praeglobotruncana helvetica Hart et. al., 1981; Strat. Atlas Foss. Foram., p. 214-215, pl. 7.21, figs. 9, 10.

Thin-section description :

Test trochospirally coiled, plano-convex; dorsal side nearly flat, ventral side strongly vaulted or convex. Early chambers small and globigerine-like. Chambers of the last whorl strongly inflated, globular in shape, with a peripheral keel. Umbilicus wide and deep. Umbilical shoulders typically rounded.

Remarks :

This diagnostic species is a good index fossil for the Turonian. Specimens of this species were only found in strata in the "Premier Flysch."

Marginotruncana cf. imbricata

(Pl. 13, figs. h-j)

Globotruncana imbricata Mornod, 1950; Eclog. Geol. Helv., v. 42, no. 2, p. 589-590, text-fig. 5, nos. 2a-c, 3a-d; pl. 15, figs. 21-34.

Globotruncana imbricata Postuma, 1971; Manual of Planktonic Foraminifera, p. 46-47.

Range :

Rare in carbonate interbeds in the "Premier Flysch."

Found in association with Hedbergella delrioensis, Hedbergella planispira and Marginotruncana pseudolinneiana. The age of this species is usually given as Turonian (Pessagno, 1967).

Marginotruncana pseudolinneiana Pessagno, 1967.

(Pl. 14, figs. g-j; pl. 16, figs. h-j)

Marginotruncana pseudolinneiana Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 310, pl. 65, figs. 24-25; pl. 76, figs. 1-3.

Globotruncana pseudolinniana Douglas, 1969; Micropaleont., v. 15, no. 2, p. 185, pl. 3, figs. 2-4; text-fig. 6.

Marginotruncana pseudolinneiana Wonders, 1979; Proc. Kon. Ned. Akad. Weten., Sers. B, v. 82(2), pl. 8, figs. 5, 7, not 8.

Marginotruncana pseudolinneiana Hart et. al., 1981; Strat. Atlas Foss. Foram., p. 210-211, pl. 7.19, figs. 8, 9.

Thin-section description :

Test a low trochospire; dorsal and ventral sides nearly flat or biplanar. Earlier chambers globigerine-like; all later chambers angular-truncate to rectangular in axial profile. Widely-spaced double keels present along the peripheral margins of the later chambers. Umbilicus shallow and wide. Surface of test smooth.

Remarks :

This species was previously identified with Globotruncana linneiana or lapparenti because of its close morphological similarity. However, it was pointed out that species referred to Globotruncana linneiana in rocks of Turonian to Santonian age should rightly be assigned to Marginotruncana pseudolinneiana (Pessagno, 1967; Douglas, 1969) because their apertural characters differ from those species of Globotruncana.

Range : Common throughout the Dicarinella carinata zone to the lower part of the Globotruncana elevata zone (i.e. Santonian to lowermost Campanian). Specimens ofthis species were also observed together with Marginotruncana helvetica in the "Premier Flysch." Therefore, its range is extended downwards into the Turonian.

Genus DICARINELLA Porthault, 1970.

Type species - Globotruncana indica Jacob and Sastry,1950.

Remarks :

The test is trochospiral with double peripheral keels. The primary apertures are extraumbilical-umbilical in position. The ventral sutures are radial and depressd. The tegilla shows only infralaminal accessory apertures.

Dicarinella carinata (Dalbiez, 1955)

(Pl. 15, figs. b-d; Pl. 16, fig. a)

Globotruncana (Globotruncana) ventricosa carinata Dalbiez, 1955 : Micropaleont., v. 1, no. 2, p. 168-169, text-figs. 8a-d.

Globotruncana concavata aff. Globotruncana carinata Lehmann, 1962 : Notes Serv. Geol. Maroc, t. 21, no. 156, text-figs. 2q-r; text-fig. 3s, pl. 6, fig. 4b.

Marginotruncana concavata Pessagno, 1967 : Paleont. Amer., v. 5, no. 37, p. 304-305, pl. 58, figs. 3-6; pl. 99, figs. 1, 3; pl. 95, fig. 7.

Globotruncana carinata Postuma, 1971 : Manual of Planktonic Foraminifera, p. 24-25.

Globotruncana concavata concavata Barr, 1972 : Micropaleont., v, 18, no. 1, p. 18-19, pl. 8, figs. 3-4.

Globotruncana concavata carinata P. Silva and Boersma, 1977 : Ini. Reps. DSDP, v. 39, pl. 2, figs. 6a-b.

Marginotruncana carinata Wonders, 1979 : Proc. Kon. Ned. Akad. Weten., Sers. B, v. 82(2), pl. 9, figs. 4-5.

Thin-section description :

Test trochospirally coiled, plano-convex. Dorsal side slightly concave with a gently raised central cone formed by the earlier whorls; ventral side strongly convex. Chambers of earlier whorls globular but becoming partly truncate in the later part of the penultimate whorl. Chambers of the final whorl nearly angular conical in shape, with two distinct but relatively closely-spaced peripheral keels, and a periumbilical keel along the umbilical shoulders. Umbilicus wide and deep. Surface of test smooth.

Remarks :

This species is closely related to Dicarinella concavata but the latter possesses chambers that are ventrally more inflated and rounded, and lack a periumbilical keel.

Barr (1972) proposed that this species evolved directly from Globotruncana concavata cyrenaica (regarded here as synonymous with Dicarinella concavata), and he erected a Globotruncana concavata concavata zone based on the stratigraphic range of that species which he assigned to the Upper Coniacian. Other workers (P. Silva and Boersma, 1977; Wonders, 1979) have also recognized the zonal value of this species but gave its range as either late Santonian or Upper Santonian.

Range :

The Dicarinella carinata zone to the Globotruncana elevata / Dicarinella carinata zone. In the Pindic-Ethia Series, this species appears to be restricted to strata of Santonian age.

Dicarinella concavata (Brotzen, 1934)

(Pl. 15, fig. a)

Rotalia concavata Brotzen, 1934; Zeitschr. Deutsch. Ver. Palaestinas, v. 57, p. 66, pl. 3, fig. b.

Globorotalia assymetrica Sigal, 1952; 19th. Congress Geol. Internat., Monograph Reg. Alger, Ser. 1, no. 26, p. 35, text-fig. 35.

Globotruncana (Globotruncana) ventricosa ventricosa Dalbiez, 1955 ; Micropaleont., v. 1, no. 2, p. 168, text-figs. 7a-d.

Globotruncana concavata Bolli, 1957 ; U.S. Nat. Mus. Bull. 215, p. 57, pl. 13, figs. 3a-c.

Globotruncana concavata Lehmann, 1962; Notes Serv. Geol. Maroc, t.21, no. 156, text-figs. 2n-p, 3m, 3o-q; pl. 6, figs. 2a-c, 3a-c.

Marginotruncana concavata Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 304-305, pl. 58, figs. 7-9.

Globotruncana concavata Postuma, 1971; Manual of Planktonic Foraminifera, p. 26-27.

Globotruncana concavata cyrenaica Barr, 1972; Micropaleont., v. 18, no. 1, p. 19, pl. 8, figs. 1-2.

Globotruncana concavata concavata P. Silva and Boersma, 1977; Ini. Reps. DSDP, v. 39, pl. 2, figs. 7a-b.

Marginotruncana concavata Wonders, 1979; Proc. Kon. Ned. Akad. Weten., Sers. B, v. 82(2), pl. 9, fig. 7.

Dicarinella concavata Hart et. al., 1981; Strat. Atlas Foss. Foram., p. 186-187, pl. 7.7, figs. 9, 10.

Thin-section description :

Test trochospirally coiled, plano-convex, ventral side strongly convex; dorsal side of the last whorl slightly concave, while the earlier whorls form a slightly raised central cone. Earlier chambers globular; later ones are inflated, subconical, with rounded umbilical shoulders, bearing 2 distinct but closely-spaced peripheral keels. Umbilicus wide, relatively deep. Surface smooth.

Remarks :

Dalbiez (1955) regard *Rotalia concavata* Brotzen and *Globorotalia assymetrica* Sigal as synonyms of *Globotruncana (Globotruncana) ventricosa ventricosa* White. Bolli (1957), after comparing some specimens of *Globotruncana ventricosa* from White's original collection with specimens of *Globotruncana concavata* obtained from Israel, Tunisia and Trinidad, concluded that these two species are different and that they have different stratigraphic ranges.

Due to its short stratigraphic range, *Dicarinella concavata* has been used by many workers as a zonal indicator for strata of Lower Santonian age (Bolli, 1957; Pessagno, 1967; Wonders, 1979). It has also been recognized as a direct ancestor of *Dicarinella carinata* (Dalbiez, 1955; Barr, 1972).

Range :

Rare in the *Dicarinella carinata* zone (Lower Santonian age).

Genus *GLOBOTRUNCANA* Cushman, 1927.

Type species - *Pulvinulina arca* Cushman, 1926.

Remarks :

The diagnostic characters of this genus are the trochospiral test, a primary aperture that is umbilical in position, the presence of a spiral system of tegilla with intralaminal and infralaminal accessory apertures, and the presence of a single or double peripheral keel.

Globotruncana cf. aegyptica

(Pl. 19, figs. e-g)

Globotruncana aegyptica Nakkady, 1950; Jour. Paleont., v. 24, no. 6, p. 690, pl. 90, figs. 20-22.

Globotruncana aegyptica Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 319-321, pl. 79, figs. 2-4; pl. 83, figs. 8-10; pl. 94, fig. 6; pl. 95, figs. 8, 9.

Range :

Rare in the Abathomphalus mayaroensis zone.

Globotruncana arca (Cushman, 1926)

(Pl. 17, figs. i-j)

Globotruncana arca Cushman, 1946; U.S. Geol. Surv. Prof. Paper 206, p. 150, pl. 62, figs. 4a-c, Not 5a-c.

Globotruncana arca Bronnimann and Brown, 1956; Eclog. Geol. Helv., v. 48, no. 2, p. 539, pl. 23, figs. 10-12.

Globotruncana (Globotruncana) arca Edgell, 1957; Micropaleont., v. 3, no. 2, p. 110-111, pl. 1, figs. 10-12; pl. 3, figs. 4-6.

Globotruncana arca Bolli, Loeblich and Tappan, 1957; U.S. Nat. Mus. Bull. 215, p. 44-46, pl. 11, figs. 6-11.

Globotruncana arca Olsson, 1964; Micropaleont., v. 10, no. 2, p. 162-163, pl. 4, figs. 1-3.

Globotruncana arca Douglas, 1969; Micropaleont., v. 15, no. 2, p. 176, pl. 9, figs. 1-3; pl. 10, figs. 4-7.

Globotruncana arca Postuma, 1971; Manual of Planktonic Foraminifera, p.18-19.

Globotruncana arca Barr, 1972; Micropaleont., v. 18, no. 1, p. 18, pl. 6, figs. 7a-c.

Globotruncana arca Wonders, 1979; Proc. Kon. Ned. Akad. Weten., Sers. B, v. 82(2), pl. 10, fig. 8.

Thin-section description :

Test moderately trochospiral; shape of test nearly biconvex; early chambers globigerine-like; later chambers angular-truncate with 2 distinct, moderately to widely spaced, peripheral keels. Umbilicus wide. Surface of test smooth.

Remarks :

The holotype of this species was examined by Bronnimann and Brown (1956) and was found to be characterized by the presence of 2 distinct peripheral keels throughout the chambers of the last whorl. Therefore, the single-keeled forms included by Cushman (1946) under this species do not belong here. It probably belongs to the Globotruncana stuarti group (Bolli, 1951; Bronnimann and Brown, 1956). Globotruncana arca differs from the rest of the double-keeled Globotruncana species in having a distinctly biconvex test.

Range :

Upper part of the Globotruncana elevata zone to the Abathomphalus mayaroensis (M. Campanian ? to Maastrichtian).

This species was reported to be best developed in the Upper Maastrichtian (Bronnimann and Brown, 1956; Olsson, 1964). In general, its range extends from Campanian to Maastrichtian (Edgell, 1957; Barr, 1972; Douglas, 1969; Wonders, 1979).

Globotruncana calcarata Cushman, 1927.

(Pl. 21, fig. j)

Globotruncana calcarata Cushman, 1927; Contr. Cushman Lab. Foram. Res., v. 3, pt. 2, p. 115, pl. 23, figs. 10a-b.

Globotruncana calcarata Postuma, 1971; Manual of Planktonic

Foraminifera, p. 22-23.

Globotruncana calcarata Wonders, 1979; Proc. Kon. Ned. Akad. Weten., Sers. B, v. 82(2), pl. 11, figs. 5-7.

Remarks :

Reworked into the Abathomphalus mayaroensis zone.

Globotruncana conica White, 1928.

(Pl. 20, figs. i-j)

Globotruncana conica White, 1928; Jour. Paleont., v. 2, no. 4, p. 285, pl. 38, fig. 7.

Globotruncana conica Bolli, 1951; Jour. Paleont., v. 25, no. 2, p. 196, pl. 34, figs. 13-15.

Globotruncana stuarti conica Gandolfi, 1955; Bull. Amer. Paleont., v. 36, no. 155, p. 65-66, pl. 5, figs. 8a-c.

Globotruncana conica Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 328-330, pl. 65, figs. 8-10; pl. 82, figs. 1-5; pl. 93, fig. 12, 13.

Globotruncana conica Postuma, 1971; Manual of Planktonic Foraminifera, p. 28-29.

Globotruncana conica Barr, 1972; Micropaleont., v. 18, no. 1, p. 19, pl. 6, figs. 2a-c.

Thin-section description :

Shape of test a high trochospire, unequally biconvex. Dorsal side distinctly conical in shape. Chambers angular-rhomboid with a well-developed peripheral keel. Umbilicus wide and relatively shallow. Surface of test smooth.

Remarks :

This species differs from the closely related forms of Globotruncana stuarti (s.s.) by being more convex dorsally and by having more chambers in the final whorl. It is believed to have evolved from Globotruncana stuarti (s.s.) during the early Maastrichtian (Bolli, 1951).

Range :

Upper part of the Globotruncana fornicata / Globotruncana tricarinata and the Abathomphalus mayaroensis zone (i.e. ranging throughout Maastrichtian).

Globotruncana contusa (Cushman, 1926)

(Pl. 18, figs. g-j)

Pulvinulina arca var. contusa Cushman, 1926; Contr. Cushman Lab. Foram. Res., v. 2, pt. 1, p. 23.

Globotruncana arca var. contusa Cushman, 1946; U.S. Geol. Surv. Prof. Paper 206, p. 150-151, pl. 62, fig. 6.

Globotruncana contusa Bolli, 1951; Jour. Paleont., v. 25, no. 2, p. 196, pl. 34, figs. 7-9, text-fig. 1f.

Globotruncana contusa Troelsen, 1955; Micropaleont., v. 1, no. 1, p. 76-82, text-figs. 1-2.

Globotruncana contusa contusa Gandolfi, 1955; Bull. Amer. Paleont., v. 36, no. 155, p. 53-54, pl. 4, figs. 3a-c.

Globotruncana (Globotruncana) contusa Edgell, 1957; Micropaleont., v. 3, no. 2, p. 111-112, pl. 2, figs. 10-12; pl. 3, figs. 7-9; pl. 4, figs. 1-3.

Globotruncana contusa Olsson, 1964; Micropaleont., v. 10, no. 2, p. 163-164, pl. 2, fig. 5; pl. 3, figs. 6, 9.

Globotruncana contusa Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 330-333, pl. 77, figs. 1-9; pl. 78, figs. 6-11; pl. 92, figs. 10-12; pl. 96, figs. 15-16.

Globotruncana contusa Postuma, 1971; Manual of Planktonic Foraminifera, p. 30-31.

Globotruncana contusa Barr, 1972; Micropaleont., v. 18, no. 1, p.

19, pl. 7, figs. 7a-c.

Globotruncana contusa Wonders, 1979; Proc. Kon. Ned. Akad. Weten., Sers. B, v. 82(2), pl. 12, figs. 2, 3, 6.

Globotruncana contusa Hart et. al., 1981; Strat. Atlas Foss. Foram., p. 200-201, pl. 7.14, figs. 6, 7.

Thin-section description :

Shape of test a high trochospire; dorsal side strongly domed or conical. Earliest chambers globigerine-like; later chambers angular-truncate, with a tendency for its dorsal faces to be slightly inflated and undulatory. Two distinct but relatively closely-spaced peripheral keels present. Umbilicus shallow and wide. Surface of test smooth.

Remarks :

Within the population of specimens referred to as Globotruncana contusa, 2 morphotypes were established (Troelsen, 1955; Pessagno, 1967). One group is characterized by a more or less polygonal-shaped test that is high-spired and by the presence of plications on the dorsal surface of the chambers. The other morphotypes are lower-spired and generally lack plications. Transition between these 2 groups is common in strata of Maastrichtian age. In the present work, only the extremely high-spired forms are considered as Globotruncana contusa. Forms with lower dorsal spire are regarded as transitional between Globotruncana fornicata and Globotruncana contusa and are here referred to Globotruncana cf. patelliformis.

Range :

Common throughout the Racemiguembelina fructicosa / Globotruncana contusa zone to the Abathomphalus mayaroensis zone.

Globotruncana elevata (Brotzen) sensu Dalbiez

(Pl. 15, figs. i, j; Pl. 16, figs. b-d)

Rotalia elevata Brotzen, 1934; Zeitschr. Deutsch. Ver. Palastinas, v. 57, p. 66, pl. 3, fig. c.

Globotruncana (Globotruncana) elevata elevata Dalbiez, 1955; Micropaleont., v. 1, no. 2, p. 169, text-figs. 9a-c.

Globotruncana elevata Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 336-338, pl. 78, figs. 12-14; pl. 80, figs. 1, 2, Not 3-6; pl. 81, figs. 9-14; pl. 93, figs. 1-3, Not 4, 5, 8.

Globotruncana elevata Postuma, 1971; Manual of Planktonic Foraminifera, p. 34-35.

Globotruncana elevata Barr, 1972; Micropaleont., v. 18, no. 1, p. 20, pl. 6, figs. 5a-c.

Globotruncana elevata Wonders, 1979; Proc. Kon. Ned. Akad. Weten., Sers. B, v. 82(2), pl. 9, fig. 1.

Thin-section description :

Test forming a low trochospire. Dorsal face of the last whorl slightly concave, but the earlier whorls form a low convex cone. Ventral side strongly convex. Chambers subangular to angular and single-keeled throughout. Umbilicus wide and relatively deep. Surface of test smooth.

Remarks :

Dalbiez (1955) noted the close relationship of forms comprising the Globotruncana elevata group and proposed a trinomial nomenclature for them. The first member of this group to appear was said to be Globotruncana elevata elevata, followed by Globotruncana elevata stuartiformis. The latter then developed into Globotruncana stuarti. Pessagno (1967), on the other hand, believed that Globotruncana elevata evolved from Globotruncana stuartiformis during the late Campanian. However, in places like Libya (Barr, 1972), Delaware (Olsson, 1964), and in the author's study area, Globotruncana elevata was found to appear much earlier than Globotruncana stuartiformis. In sections TK and TP, this species first appeared in association with species of Dicarinella carinata and Marginotruncana coronata; Globotruncana stuartiformis is absent from strata containing such assemblages.

Range :

The Globotruncana elevata / Dicarinella carinata zone to the Globotruncana elevata zone (i.e. Upper Santonian to Lower Campanian); abundant in Upper Santonian strata.

Globotruncana fornicata Plummer, 1931.

(Pl. 18, figs. a-d)

Globotruncana fornicata Plummer, 1931; Bull. Texas Univ. 3101, p. 198-199, pl. 13, figs. 4-6.

Globotruncana fornicata fornicata Gandolfi, 1955; Bull. Amer. Paleont., v. 36, no. 155, p. 40-41, pl. 2, figs. 2a-c.

Globotruncana fornicata manaurensis ibid; p. 41-42, pl. 2, figs. la-c, text-figs. 9 (la-c), 9 (2a-c).

Globotruncana fornicata Bronnimann and Brown, 1956; Eclog. Geol. Helv., v. 48, no. 2, p. 542, pl. 21, figs. 7, 14, 15.

Globotruncana (Globotruncana) fornicata Edgell, 1957; Micropaleont., v. 3, no. 2, p. 112, pl. 3, figs. 10-12.

Globotruncana fornicata Olsson, 1964; Micropaleont., v. 10, no. 2, p. 164-165, pl. 2, figs. 3-4; pl. 3, figs. 7-8.

Globotruncana fornicata Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 338-341, pl. 63, figs. 1-9; pl. 80, figs. 7-9; pl. 96, figs. 3, 4.

Globotruncana fornicata Postuma, 1971; Manual of Planktonic Foraminifera, p. 38-39.

Globotruncana fornicata Barr, 1972; Micropaleont., v. 18, no. 1, p. 20, pl. 7, figs. 4-5.

Globotruncana fornicata manaurensis ibid; p. 21, pl. 7, figs. 2a-c.

Globotruncana fornicata Wonders, 1979; Proc. Kon. Ned. Akad. Weten., Sers. B, v. 82(2), pl. 10, fig. 1.

Globotruncana fornicata Hart et. al., 1981; Strat. Atlas Foss. Foram., p. 200-201, pl. 7.14, figs. 8-10.

Thin-section description :

Test trochospirally coiled, forming a low to moderately high spire on the dorsal side. Early chambers globigerine-like; later ones angular-truncate with slight inflation on the dorsal faces of the chambers. Two moderately spaced peripheral keels present, tending to become closer on the later chambers of the last whorl. Umbilicus wide, varying from shallow to relatively deep. Surface of test smooth.

Remarks :

The evolution of this species into *Globotruncana contusa* (s.l.) during the Maastrichtian has been widely recognized. Similar trend was also noticed in the specimens here. Differentiation of *Globotruncana fornicata* from *Globotruncana contusa* (s.l.) in thin-section is judged mainly on the degree of spiral convexity. The degree of chamber crenulation or plication (well developed in *Globotruncana contusa*) cannot usually be determined visually in thin-section.

Range :

The *Globotruncana elevata* / *Dicarinella carinata* zone to the *Abathomphalus mayaroensis* zone. This species has one of the longest ranges i.e. from Upper Santonian to Maastrichtian. Forms tending towards *Globotruncana contusa* were first observed in the lowermost Maastrichtian.

Globotruncana gansseri Bolli, 1951.

(Pl. 19, fig. d)

Globotruncana gansseri Bolli, 1951; Jour. Paleont., v. 25, no. 2, p. 196-197, pl. 35, figs. 1-3.

Rugotruncana gansseri Bronnimann and Brown, 1956; Eclog. Geol. Helv., v. 48, p. 549-550, pl. 23, figs. 7-9, text-fig. 23.

Globotruncana gansseri Said and Kerdany, 1961; Micropaleont., v. 7, no. 3, p. 331, pl. 2, fig. 16.

Globotruncana gansseri Postuma, 1971; Manual of Planktonic Foraminifera, p. 42-43.

Globotruncana gansseri Barr, 1972; Micropaleont., v. 18, no. 1, p. 21, pl. 5, figs. 3-4.

Thin-section description :

Test trochospirally coiled, plano-convex. Dorsal side flat while the ventral side is strongly convex. Due to poor preservation, outlines of earlier chambers not observed. Chambers of the last whorl ventrally strongly inflated and subconical in shape. A peripheral keel present. Some rugosities observed on the ventral surfaces of the chambers. Umbilicus wide and deep.

Remarks :

This species superfically resembles Marginotruncana helvetica. Some authors (Pessagno, 1967; Smith and Pessagno, 1973) included in this species forms that contain narrow double keels which merge into a single keel in the last one or two chambers. However, the illustration and description of the holotype by Bolli show a single keel throughout the chambers of the last whorl. In addition, figures of axially sectioned specimens (Bronnimann and Brown, 1956; Postuma, 1971) confirm that the early chambers are also single-keeled. Therefore, in this work, all double-keeled gansseri-like forms are excluded from this species.

Range :

Rare in the Racemiguembelina fructicosa / Globotruncana contusa zone to the Abathomphalus mayaroensis zone.

Globotruncana linneiana (D' Orbigny, 1839)

(Pl. 17, figs. f-h)

Rosalina linnei type 1 De Lapparent, 1918; Mem. Carte Geol. France, p. 7, figs, 1a, 1c.

Globotruncana linnei typica Vogler, 1941; Paleontographica Supp. 4, p. 286-287, pl. 23, figs. 12-21.

Globotruncana lapparenti lapparenti Bolli, 1944; Eclog. Geol. Helv., v. 37, p. 230, text-fig. 1, nos. 15, Not 16; pl. 9, fig. 11.

Globotruncana linneiana Bronnimann and Brown, 1956; Eclog. Geol. Helv., v. 48, no. 2, p. 540-542, pl. 20, figs. 13-17; pl. 21, figs. 16-18.

Globotruncana linneiana linneiana Barr, 1962; Paleont., v. 4, p. 571-572, pl. 69, figs. 7a-c; pl. 72, fig. 5.

Globotruncana linneiana Olsson, 1964; Micropaleont., v. 10, no. 2, p. 166-167, pl. 2, figs. 6a-c, 8a-c, Not 7a-c.

Globotruncana lapparenti Postuma, 1971; Manual of Planktonic Foraminifera, p. 48-49.

Globotruncana linneiana Wonders, 1979; Proc. Kon. Ned. Akad. Weten., Sers. B, v. 82(2), pl. 10, fig. 6.

Globotruncana linneiana Hart et. al., 1981; Strat. Atlas Foss. Foram., p. 200-2ol, pl. 7.14, figs. 11-12.

Thin-section description :

Shape of test a low trochospire, characterized by flat dorsal and ventral sides. Early chambers globigerine-like; later ones angular-truncate to almost rectangular in axial profile, with 2 widely-spaced, peripheral keels. Umbilicus wide, shallow. Surface of test smooth.

Remarks :

This species has been commonly identified as either _Globotruncana linneiana_ or _Globotruncana lapparenti_. It was designated _Rosalina linnei_ type 1 (De Lapparant, 1918), but Brotzen (1936) renamed all the double-keeled forms identified by De Lapparant from the Hendaya Region as _Globotruncana lapparenti_ on the grounds that these forms differ from the original figure of _Rosalina linnei_ (D' Orbigny) in having ventral sutures that are not radial but curved. In addition, he noted that on the ventral side, the chambers of _Rosalina linnei_ are rounded while in the specimens identified by De Lapparant are characterized by elongated, overlapping chambers. Bolli (1944) accepted Brotzen's observations and proposed that _Rosalina linnei_ type 1 be renamed _Globotruncana lapparenti lapparenti_.

Bronnimann and Brown (1956), on noting that the holotype of _Rosalina linnei_ is lost, designated a neotype from among the specimens collected from recent beach sands of Cuba (believed to be the type area). Their figures of the neotype show similar morphological features to the forms illustrated by De Lapparant as _Rosalina linnei_ type 1. Therefore, in this work, _Globotruncana lapparenti lapparenti_ is treated as a junior synonym of _Globotruncana linnei_ type 1 which is commonly referred to as _Globotruncana linneiana_ or _Globotruncana linneiana linneiana_. This species is homeomorphic with _Marginotruncana pseudolinneiana_. It is also closely related to _Globotruncana tricarinata_ which differs mainly by being more convex ventrally.

Range :

Upper part of the Globotruncana elevata zone to the Abathomphalus mayaroensis zone.

Globotruncana stuarti (s.l.)

(Pl. 20, figs. f-h)

Rosalina stuarti De Lapparant, 1918; Serv. Carte Geol. Mem., p. 13-14, pl. 1, figs. 5-7, text-fig. 4, 5(?).

Globotruncana stuarti Renz, 1936; Eclog. Geol. Helv., v. 29, no. 1, pl. 6, figs. 35-41; pl. 8, fig. 6.

Globotruncana stuarti Bolli, 1944; Eclog. Geol. Helv., v. 37, p. 236, pl. 9, fig. 18, text-fig. 1, nos. 27-28.

Globotruncana stuarti Bolli, 1951; Jour. Paleont., v. 25, no. 2, p. 196, pl. 34, figs. 10-12.

Globotruncana stuarti Dalbiez, 1955; Micropaleont., v. 1, no. 2, text-figs. 4a-c.

Globotruncana stuarti stuarti Olsson, 1964; Micropaleont., v. 10, no. 2, p. 169-170, pl. 5, figs. 9.

Globotruncana stuarti stuarti El-Nagger, 1966; Bull. Brit. Mus. (Nat. Hist.), Geol., Supp. 2, p. 133-136, pl. 8, figs. 4a-d; pl. 9, figs. 1a-d.

Globotruncana stuarti Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 356-357, pl. 81, figs. 1-6; pl. 93, figs. 9-11; pl. 94, fig. 7.

Globotruncana stuarti Postuma, 1971; Manual of Planktonic Foraminifera, p. 60-61.

Globotruncana stuarti Barr, 1972; Micropaleont., v. 18, no. 1, p. 24-25, pl. 6, figs. 1, 3.

Thin-section description :

Test trochospirally coiled, generally biconvex in shape; in some specimens, the ventral side may be more convex or vice versa. Other than in the initial globigerine-like stage of development, all later chambers are distinctly angular-rhomboid, with a well-developed peripheral keel. Umbilicus deep and wide and bordered by acute umbilical shoulders. Surface of test smooth.

Remarks :

In the original description, Lapparant figured specimens whose chambers are distinctly trapezoidal in shape on the dorsal side. This feature has been used by many later workers to separate this species from closely related ones such as Globotruncana stuartiformis and Globotruncana conica.

Dalbiez (1955) proposed that Globotruncana stuarti evolved from Globotruncana elevata stuartiformis during the Upper Campanian through acquiring chambers that dorsally become trapezoidal in shape. Olsson (1964), Pessagno (1967) and Barr (1972) agreed with Dalbiez's interpretation but they believed the change occurred during the Upper Maastrichtian.

In this work, no distinction is made between Globotruncana stuarti (s.s.) and Globotruncana stuartiformis. This is because available thin-sections only show the axial cuts or profiles of the fossil and therefore, the criteria for separating the two related species based on the dorsal shape of the chambers could not be determined here. Some workers have suggested that the degree of ventral or dorsal convexity can be used for separating the two species but this feature does not give consistent results. Therefore, both species are treated as Globotruncana stuarti (s.l.) or Globotruncana stuarti-stuartiformis.

Range :

Common throughout the Globotruncana fornicata / Globotruncana tricarinata zone to the Abathomphalus mayaroensis zone.

Globotruncana *tricarinata* (Quereau, 1893)

(Pl. 17, fig. e)

Globotruncana *lapparanti* *tricarinata* Bolli, 1944; Eclog. Geol. Helv., v. 37, p. 232-233, text-fig. 1, nos. 19, 20.

Globotruncana *lapparanti* *tricarinata* Hagn and Zeil, 1951; Eclog. Geol. Helv., v. 47, pl. 6, figs. 6, 7.

Globotruncana *linneiana* *tricarinata* Barr, 1962; Paleont., v. 4, p. 573-574, pl. 70, figs. 2a-c.

Globotruncana *tricarinata* Olsson, 1964; Micropaleont., v. 10, no. 2, p. 171-172, pl. 5, figs. 2-5.

Thin-section description :

Test a low trochospire; dorsal side slightly convex; on the ventral side, early chambers of the last whorl nearly flat, but later ones becoming more protruding or convex. Chambers angular-truncate, with 2 distinct and relatively well-spaced peripheral keels. Periumbilical keel clearly visible in the later chambers. Umbilicus wide and shallow. Surface of test smooth.

Remarks :

This species was originally described from thin-sections. Later workers (Bolli, 1944; Barr, 1962) treated it as a subspecies of either *Globotruncana* *lapparenti* or *Globotruncana* *linneiana*. Others (Pessagno, 1967; Douglas, 1969) regarded it a junior synonym of either *Globotruncana* *linneiana* or *Globotruncana* *ventricosa*. In this work, *Globotruncana* *tricarinata* is treated as a valid species. It differs from *Globotruncana* *linneiana* by being more convex ventrally and in having double keels that ar closer together. It differs from *Globotruncana* *ventricosa* in being less convex ventrally.

Range :

Appears to be restricted to the Globotruncana fornicata / Globotruncana tricarinata zone.

Globotruncana ventricosa White, 1928.

(Pl. 17, figs. a-d)

Globotruncana canaliculata var. ventricosa White, 1928; Jour. Paleont., v. 2, no. 4, p. 284, pl. 38, fig. 5.

Globotruncana ventricosa Cushman, 1946; U.S. Geol. Surv. Prof. Paper 206, p. 150, pl. 62, fig. 3.

Globotruncana ventricosa Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 57, pl. 13, figs. 4a-c.

Globotruncana ventricosa Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 362-364, pl. 75, figs. 21-26; pl. 79, figs. 9-14; pl. 95, figs. 10, 11.

Globotruncana ventricosa Postuma, 1971; Manual of Planktonic Foraminifera, p. 64-65.

Globotruncana ventricosa Barr, 1972; Micropaleont., v. 18, no. 1, p. 25-26, pl. 8, figs. 6a-c.

Globotruncana ventricosa Wonders, 1979; Proc. Kon. Ned. Akad. Weten., Sers. B, v. 82(2), pl. 10, fig. 3; pl. 11, figs. 1-2.

Thin-section description :

Test trochospirally coiled; dorsal side is almost flat, ventral side strongly convex. Chambers angular-truncate, with 2 distinct, moderately spaced peripheral keels. Earlier chambers characterized by a linneiana-stage of development. Umbilicus wide and relatively deep. Surface of test smooth.

Remarks :

This species morphologically is quite similar to specimens of Dicarinella carinata. However, the latter is ventrally more inflated, it lacks a well-developed *linneiana*-stage of development, the double keels are closer, and it is found in stratigraphically older strata. According to Douglas (1969), axial thin-sections of *Globotruncana ventricosa* closely match the type figures of *Globotruncana tricarinata* and he proposed that these two species might be synonymous. In this work, specimens identified as Globotruncana ventricosa are ventrally more convex than *Globotruncana tricarinata*.

Range :

Found only in the *Globotruncana fornicata* / *Globotruncana tricarinata* zone.

Genus *RUGOGLOBIGERINA* Bronnimann, 1952.

Type species - *Globigerina rugosa* Plummer, 1927.

Remarks :

The trochospiral test is ornamented with costellae arranged in a meridonal pattern, the primary aperture is umbilical in position, and the tegilla system shows infralaminal and intralaminal accessory apertures.

Rugoglobigerina rotundata Bronnimann, 1952.

(Pl. 20, figs. a-c)

Rugoglobigerina rugosa rotundata Bronnimann, 1952; Bull. Amer. Paleont., v. 34, no. 140, p. 34-36, pl. 4, figs. 7-9; text-figs. 15, 16.

Globotruncana (Rugoglobigerina) rotundata rotundata Gandolfi, 1955; Bull. Amer. Paleont., v. 36, no. 155, p. 70, pl. 7, fig. 2.

Kuglerina rotundata Bronnimann and Brown, 1956; Eclog. Geol. Helv., v. 48, no. 2, p. 557.

Rugoglobigerina rotundata Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 365-366, pl. 65, figs. 1-3, 4; pl. 68, figs. 1-3.

Rugoglobigerina rotundata Postuma, 1971; Manual of Planktonic Foraminifera, p. 88-89.

Rugoglobigerina rotundata Barr, 1972; Micropaleont., v, 18, no. 1, p. 30, pl. 10, figs. 3a-c.

Thin-section description :

Test a low trochospire, subspherical in shape. Chambers globular to subglobular, ornamented with rugosities which become weaker in the later chambers of the final whorl. Chambers of final whorl axially elongated increasing in size rapidly in contrast to those of the earlier whorls. Umbilicus narrow and deep.

Remarks :

When this species was originally described, Bronnimann (1952) regarded the umbilical tegilla as absent. This view, shared by Bronnimann and Brown (1956), was used as one of the criteria for separating this species from *Rugoglobigerina*, and they designated it the genotype for their new genus *Kuglerina*. However, subsequent workers have observed umbilical tegilla with intralaminal and infralaminal accessory apertures on well preserved specimens (Pessagno, 1967; Barr, 1972). *Kuglerina* was thus considered a junior synonym of *Rugoglobigerina* (Pessagno, 1967). This species differs from other rugoglobigerines by having a large, almost subspherical test, chambers of the final whorl that are axially elongated, and a deep and small umbilicus.

Range :

Upper part of the *Globotruncana fornicata* /

Globotruncana tricarinata zone to the Abathomphalus mayaroensis zone (i.e. ranging throughout Maastrichtian).

The restriction of this species to Maastrichtian strata has been confirmed by Bronnimann (1952), Pessagno (1967) and Barr (1972).

Rugoglobigerina rugosa (Plummer, 1927)

(Pl. 22, figs. f-g)

Globigerina rugosa Plummer, 1927; Univ. Texas Bull. 2644, p. 38, pl. 2, fig. 10.

Rugoglobigerina rugosa Postuma, 1971; Manual of Planktonic Foraminifera, p. 90-91.

Range :

Found in the Globotruncana fornicata / Globotruncana tricarinata zone to the Abathomphalus mayaroensis zone.

Rugoglobigerina scotti (Bronnimann, 1952)

(Pl. 20, figs. d, e)

Trinitella scotti Bronnimann, 1952; Bull. Amer. Paleont., v. 34, no. 140, p. 57, pl. 4, figs. 4-6; text-fig. 30.

Trinitella scotti Bronnimann and Brown, 1956; Eclog. Geol. Helv., v. 48, no. 2, p. 555, pl. 23, figs. 13-15; pl. 24, fig. 3.

Trinitella scotti Olsson, 1964; Micropaleont., v. 10, no. 2, p. 173-174, pl. 6, fig. 10.

Rugoglobigerina scotti Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 367, pl. 74, figs. 9-14; pl. 76, figs. 4-6.

Rugoglobigerina scotti Postuma, 1971; Manual of Planktonic Foraminifera, p. 92-93.

Thin-section description :

Test a low trochospire. Chambers globular throughout except the later ones of the final whorl which become laterally compressed. These later ones are subangular in shape and are flattened dorsally. Surface rugosities are well developed on the earlier chambers but become weaker in the later ones. Keel not observed. Due to poor preservation of the wall, it cannot be determined whether an imperforate margin is present in place of a peripheral keel. Umbilicus shallow, relatively wide.

Remarks :

This species was originally designated the generotype of the genus Trinitella to distinguish the latter from Rugoglobigerina (Bronnimann, 1952). Bronnimann separated Trinitella scotti from other species of Rugoglobigerina on the basis of the dorsal flattening of its later chambers and the presence of a keeled, final chamber. However, he regarded Trinitella an offshoot of Rugoglobigerina. Pessagno (1967) removed this species from Trinitella and included it in Rugoglobigerina because he considered that the criteria given by Bronnimann for the separation of this species from Rugoglobigerina are merely variations generally present within the latter genus.

Published thin-section photomicrographs of Rugoglobigerina scotti show that the peripheral keel of the imperforate peripheral band is only weakly developed (Bronnimann and Brown, 1956; Postuma, 1971). Specimens found here do not appear to have a peripheral keel on the later chambers of the final whorl.

Range :

Rare in the Abathomphalus mayaroensis zone. It was first reported from Upper Maastrichtian strata (Bronnimann, 1952).

Genus GLOBOTRUNCANELLA Reiss, 1957.

Type species - Globotruncana citae Bolli, 1951.

Remarks :

The test is trochospiral with a primary aperture which is extraumbilical-umbilical in position, and a tegilla system with only infralaminal, accessory apertures.

Globotruncanella havanensis (Voorwijk, 1937)

(Pl. 21, figs. a-f)

Globotruncana havanensis Voorwijk, 1937; Proc. Kon. Ned. Akad. Weten., Sers. B, v. 40(2), p. 195, pl. 1, figs. 25, 26, 29.

Globotruncana citae Bolli, 1951; Jour. Paleont., v. 25, no. 2, p. 197, pl. 35, figs. 4-6.

Rugotruncana havanensis Bronnimann and Brown, 1956; Eclog. Geol. Helv., v. 48, no. 2, p. 552, pl. 22, figs. 4-6; pl. 24, figs. 5 (part), 10.

Globotruncana citae Gandolfi, 1955; Bull. Amer. Paleont., v. 36, no. 155, p. 51-52, pl. 3, figs. 11a-c.

Globotruncana (Globotruncana) citae Edgell, 1957; Micropaleont., v. 3, no. 2, p. 111, pl. 1, figs. 13-15.

Praeglobotruncana (Praeglobotruncana) havanensis Berggren, 1962; Stock. Contr. Geol., v. 9, no. 1, p. 26-30, pl. 7, figs. 1a-c.

Globotruncanella havanensis Pessagno, 1967; Paleont. Amer., v. 5 no. 37, p. 373, pl. 84, figs. 1-3.

Praeglobotruncana citae Postuma, 1971; Manual of Planktonic Foraminifera, p. 70-71.

Globotruncanella havanensis Barr, 1972; Micropaleont., v. 18, no. 1, p. 32, pl. 1, fig. 8.

Globotruncanella havanensis Wonders, 1979; Proc. Kon. Ned. Akad.

Weten., Sers. B, v. 82(2), pl. 10, fig. 2.

Thin-section description :

Test a low trochospire. Dorsal side moderately convex; ventral side tending to be slightly concave. Earlier chambers globular; chambers of the last whorl laterally compressed, becoming ovate to subangular in shape. Peripheral margins of the later chambers of the last whorl subacute to acute. Peripheral keel generally absent. Umbilicus relatively shallow and narrow. Test wall thin, covered with fine spines.

Remarks :

Bronnimann and Brown (1956) examined and compared the holotype of Globotruncana havanensis (Voorwijk) with typotypes of Globotruncana citae (Bolli, 1951) and concluded that the two species are synnonymous.

This species is also morphologically similar to the group Globotruncana (Rugoglobigerina) petaloidea - subpetaloidea (Gandolfi, 1955). The latter is said to differ from Globotruncanella havanensis by lacking a keel or imperforate peripheral band (Gandolfi, 1955). However, Olsson (1964) pointed out that though specimens of Globotruncanella petaloidea lack a keeled margin, they possess an imperforate peripheral band which can be detected under high magnification. Pessagno (1967) further noted that specimens referred to Globotruncanella havanensis may or may not possess an imperforate peripheral band; he also remarked on the similarity of this species to Globotruncanella petaloidea. Published thin-section photomicrographs of Globotruncanella havanensis (Bronnimann and Brown, 1956; Postuma, 1971; Wonders, 1979) lack a peripheral keel or an imperforate carinal band. Therefore, until further information is available to enable a clear distinction to be made between Globotruncanella havanensis and Globotruncanella petaloidea (s.l.), they are here tentatively regarded as conspecific and are referred to as Globotruncanella havanensis (s.l.).

Globotruncanella havanensis is considered the ancestor of Abathomphalus mayaroensis (Bolli, 1951; Berggren, 1962; Pessagno, 1967).

Range :

The Globotruncana elevata zone to the Abathomphalus mayaroensis zone. More frequent in Maastrichtian strata.

Genus ABATHOMPHALUS Bolli, Loeblich and Tappan, 1957.

Type species - Globotruncana mayaroensis Bolli, 1951.

Remarks :

The test is trochospiral with double keels, a primary aperture which is extraumbilical in position, and a tegilla system lacking intralaminal, accessory apertures.

Abathomphalus mayaroensis (Bolli, 1951)

(Pl. 19, figs. h-j)

Globotruncana mayaroensis Bolli, 1951; Jour. Paleont., v. 25, no.2, p. 198, pl. 35, figs. 10-12.

Rugotruncana mayaroensis Bronnimann and Brown, 1956; Eclog. Geol. Helv., v. 48, no. 2, p. 553-554, pl. 22, figs. 10-12.

Abathomphalus mayaroensis Bolli, Loeblich and Tappan, 1957; U.S. Nat. Mus. Bull. 215, p. 43, pl. 11, figs. 1a-c.

Praeglobotruncana (Praeglobotruncana) mayaroensis Berggren, 1962; Stock. Contr. Geol., v. 9, no. 1, p. 32-36, pl. 7, figs. 3a-c.

Abathomphalus mayaroensis Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 372, pl. 92, figs. 4-9; pl. 95, fig. 5.

<u>Globotruncana</u> <u>mayaroensis</u> Postuma, 1971; Manual of Planktonic Foraminifera, p. 50-51.

<u>Abathomphalus</u> <u>mayaroensis</u> Barr, 1972; Micropaleont., v. 18, no. 1, p. 26-28, pl. 5, figs. 1-2.

<u>Abathomphalus</u> <u>mayaroensis</u> P. Silva and Boersma, 1977; Ini. Reps. DSDP, v. 39, pl. I, fig. 2.

<u>Abathomphalus</u> <u>mayaroensis</u> Wonders, 1979; Proc. Kon. Ned. Akad. Weten., Sers. B, v. 82(2), pl. 12, figs. 1, 5.

<u>Abathomphalus</u> <u>mayaroensis</u> Hart et. al., 1981; Strat. Atlas Foss. Foram., p. 180-181, pl. 7.4, figs. 1-3.

Thin-section description :

Test a low trochospire. Dorsal side slightly to moderately convex; ventral side slightly concave with chamber walls that characteristically slope inwards into the umbilicus. Earliest whorl shows a <u>Globotruncanella</u> <u>havanensis</u> stage of development. In later whorls, chambers are angular-truncate (nearly box shaped) with two, widely spaced, peripheral keels. Umbilicus shallow and relatively wide. Surface of test smooth.

Remarks :

This species was originally considered as a <u>Globotruncana</u> (Bolli, 1951), but, Bronnimann and Brown (1956) placed it in the genus <u>Rugotruncana</u> because of the presence of traces of costellae on some of the chambers of the last whorl on the ventral side. Bolli, Loeblich and Tappan (1957) discovered that the primary apertures of this species are extraumbilical-umbilical in position and that the umbilicus is covered by a single tegillum that bears only infralaminal accessory apertures. Based on this evidence they proposed this species as the type of their new genus <u>Abathomphalus</u>. Berggren (1962), despite acknowledging the evidence presented by Bolli et al., felt that it belongs in the genus *Praeglobotruncana*. However, most later workers have assigned it to *Abathomphalus*.

Abathomphalus mayaroensis is believed to have evolved from *Globotruncanella havanensis* (Bolli, 1951; Berggren, 1962; Pessagno, 1967). It is recognized as an excellent zonal fossil for the Uppermost Maastrichtian (Bolli, 1957; Pessagno, 1967; Barr, 1972; P. Silva and Boersma, 1977; Wonders, 1979).

Family PLANOMALINIDAE Bolli, Loeblich and Tappan, 1957.

Globigerinelloides spp.

(Pl. 22, figs. a-e)

Family ROTALIPORIDAE Sigal, 1958.

Hedbergella delrioensis

(Pl. 13, figs. a-c)

Globigerina cretacea D' Orbigny var. delrioensis Carsey, 1926; Univ. Texas Bull. 2612, p.43.

Hedbergella cf. *planispira*

(Pl. 13, fig. d)

Globigerina planispira Tappan, 1940; Jour. Paleont., v. 14, no. 2, p. 12, pl. 19, fig. 12.

Family HETEROHELICIDAE Cushman, 1927.

Heterolix spp.

(Pl. 22, figs. i-j)

Gublerina sp.

(Pl. 21, fig. i)

Planoglobulina sp.

(Pl. 21, fig. h)

Pseudotextularia sp.

(Pl. 22, fig. h)

Genus *RACEMIGUEMBELINA* Gallitelli, 1957.

Type species - *Guembelina fructicosa* Egger, 1900.

Remarks :

Chambers initally biserially arranged, later portion of test characterized by a proliferation of chambers, forming a circular crown.

Racemiguembelina fructicosa (Egger, 1900)

(Pl. 19, figs. a-c)

Pseudotextularia varians Cushman, 1946; U.S. Geol. Surv. Prof. Paper 206; p. 110, pl. 47, figs. 4-7, 8(?).

Racemiguembelina fructicosa Gallitelli, 1957; U.S. Nat. Mus. Bull. 215; p. 142-143, pl. 32, figs. 14, 15.

Racemiguembelina fructicosa Said and Kerdany, 1961; Micropaleont., v. 7, no. 3, p. 334, pl. 2, fig. 17.

Racemiguembelina fructicosa Pessagno, 1967; Paleont. Amer., v. 5, no. 37, p. 270-271, pl. 90, figs. 14, 15.

Thin-section description :

Test conical shape. Early chambers biserially arranged, laterally compressed. Later part of test characterized by a proliferation of globular chambers which form a circular crown towards the top. All chambers carry well-developed longitudinal striae.

Remarks :

A detailed discussion of the taxonomic status of this species has been given by Montanaro Gallitelli (1957).

Range :

Common in the _Racemiguembelina_ _fructicosa_ / _Globotruncana_ _contusa_ zone to the _Abathomphalus_ _mayaroensis_ zone.

Family GLOBOROTALIIDAE Cushman, 1927.

Genus _GLOBOROTALIA_ Cushman, 1927.

Type species - _Pulvinulina_ _menardii_ (D' Orbigny) var. _tumida_ Brady, 1877.

Remarks :

The test is trochospirally coiled and the primary apertures are extraumbilical-umbilical in position.

This genus is subdivided into 4 subgenera.

Subgenus _GLOBOROTALIA_ (_TURBOROTALIA_) Cushman and Bermudez, 1949, emended Blow, 1979.

Type species - _Globorotalia_ _centralis_ Cushman and Bermudez, 1937.

Remarks :

The wall is smooth, the test shows rounded to subacute peripheral margins lacking an imperforate, peripheral keel.

Globorotalia (Turborotalia) chapmani Parr,
sensu Berggren, Olsson and Reyment, 1967.
(Pl. 24, figs. h-j)

Globorotalia chapmani Berggren et al., 1967; Micropaleont., v. 13, no. 3, p. 277, text-fig. 1, pl. 1, figs. 1-6; text-fig. 3, nos. 1a-c; text-fig. 4, nos. 1a-c.

Planorotalites chapmani McGowran, 1968; Micropaleont., v. 14, no. 2, pl. 4, figs. 13-18, 21.

Globorotalia (Turborotalia) chapmani Blow, 1979; The Cainozoic Globigerinida, p. 1059-1061, pl. 116, figs. 1-5; pl. 106, fig. 1; pl. 111, fig. 5.

Thin-section description :

Test a low trochospire, compressed. Dorsal side slightly concave because the earlier whorls are either flush with or situated slightly below the level of the dorsal face of the last whorl. Early chambers subglobular. Chambers of the final whorl becoming compressed, oval to ogyval in shape. Peripheral margins subrounded throughout. Keel not observed. Surface of test smooth. Umbilicus shallow.

Remarks :

According to Blow (1979), the holotype of this species could be a benthonic species belonging to the Valvulineridae. However, until more information is available, Berggren et al.'s (1967) concept of this species is followed here.

Range :

Sporadic occurrences in Zones P3 - P4/P5. Berggren et al. noted its range as from the Globorotalia pseudomenardii zone to the Globorotalia rex zone. Blow (1979) extended the range upwards to P7 (basal early Eocene), while Bolli and P. Silva (1973) reported its occurrence as early as P3 (i.e. their Globorotalia pusilla pusilla zone).

Globorotalia (Turborotalia) compressa (Plummer, 1926)

(Pl. 24, figs. c, d)

Globigerina compressa Plummer, 1926; Univ. Texas Bull. 2644, p. 135, pl. 8, figs. 11a-c.

Globorotalia compressa Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 77, pl. 20, figs. 21-23.

Globorotalia compressa Loeblich and Tappan, 1957; U.S. Nat. Mus. Bull. 215, p. 188, pl. 40, figs. 5a-c; pl. 42, figs. 5a-c; pl. 44, figs. 9a-10c; (?) pl. 41, figs. 5a-c.

Globorotalia (Turborotalia) compressa Berggren, 1962; Stock. Contr. Geol., v. 9(1), p. 94-96, pl. 14, figs. 5a-c; text-figs. 13 (1-6).

Planorotalites compressus McGowran, 1968; Micropaleont., v. 14, no. 2, pl. 4, figs. 10-11.

Globorotalia (Turborotalia) compressa Jenkins, 1971; N.Z. Geol. Surv. Paleont. Bull. 42, p. 113, pl. 9, figs. 227-229.

Globorotalia compressa Postuma, 1971; Manual of Planktonic Foraminifera, p. 186-187.

Globorotalia (Turborotalia) compressa compressa Blow, 1979; The Cainozoic Globigerinida, p. 1062-1064, pl. 75, figs. 10-11; pl. 78, figs. 5-10; pl. 248, figs. 1-3; pl. 254, figs. 1-3; pl. 257, figs. 5-7.

Thin-section description :

Test a low trochospire, biconvex. Early chambers globular, becoming progressively compressed laterally. Chambers of the final whorl become ogyval in shape. Peripheral margins rounded throughout. Surface of test smooth, finely perforated. Umbilicus narrow and shallow.

Remarks :

This species differs from Globorotalia (Turborotalia) pseudobulloides by having a laterally compressed test; unlike Globorotalia (Turborotalia) chapmani, the dorsal face of the earlier whorls is not depressed below the level of the last whorl; it differs from Globorotalia (Globorotalia) ehrenbergi in having peripheral margins that are rounded and non-carinate throughout.

Many authors have proposed that Globorotalia (Turborotalia) pseudobulloides is the direct ancestor of this species (Bolli, 1957; Berggren, 1962; Jenkins, 1971). Forms transitional between Globorotalia (Turborotalia) pseudobulloides and Globorotalia (Turborotalia) compressa have been found here (Pl. 24, figs. a, b).

Range :

Infrequent in Zones P1 - P3. This species was reported from the upper part of the type Danian (Troelsen, 1957; Berggren, 1962) as well as from the lower Paleocene of Trinidad (Bolli, 1957).

Globorotalia (Turborotalia) pseudobulloides Plummer, 1926
(Pl. 23, figs. a-j)

Globorotalia pseudobulloides Bolli, 1951; U.S. Nat. Mus. Bull. 215, p. 73, pl. 17, figs. 19-21.

Globorotalia pseudobulloides Olsson, 1960; Jour. Paleont., v. 34, no. 1, p. 46, pl. 9, figs. 19-21.

Globorotalia (Turborotalia) pseudobulloides Berggren, 1962; Stock. Contr. Geol., v. 9, no. 1, p. 88-93, pl. 14, figs. 3a-4c; text-figs. 12 (1a-7b).

Globorotalia pseudobulloides Postuma, 1971; Manual of Planktonic Foraminifera, p. 202-203.

Globorotalia (Turborotalia) pseudobulloides Blow, 1979; The

Cainozoic Globigerinida, p. 1096-1101, pl. 69, figs. 2, 3; pl. 71, figs. 4, 5; pl. 75, figs. 2, 3; pl. 248, figs. 6-8; pl. 225, figs. 1-6.

Thin-section description :

Test a low trochospire. All chambers globular and inflated. Surface of test perforate and finely pitted throughout. Umbilicus relatively shallow and narrow.

Remarks :

Specimens from younger strata show a tendency to develop thicker walls and coarser pitted surfaces.

Range :

Zones P1 - P3; most abundant in Zones P1 - P2. This species was first reported from type Danian (Troelsen, 1957; Berggren, 1962). Its restriction to strata of Lower Paleocene age has been confirmed from many localities (Bolli, 1957; Loeblich and Tappan, 1957; Olsson, 1960; Blow, 1979).

Globorotalia (Turborotalia) pusilla Bolli, 1957.

(Pl. 28, fig. a)

Globorotalia pusilla pusilla Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 78, pl. 20, figs. 8-10.

Globorotalia pusilla pusilla El-Naggar, 1966; Bull. Brit. Mus. (Nat. Hist.), Geol. Supp. 2, p. 232-233, pl. 17, figs. 11a-c.

Globorotalia pusilla Postuma, 1971; Manual of Planktonic Foraminifera, p. 206-207.

Globorotalia (Turborotalia) pusilla Blow, 1979; The Cainozoic Globigerinida, p. 1108-1109, pl. 83, figs. 9-10.

Thin-section description :

Test trochospirally coiled; biconvex. Early chambers subglobular to subangular, chambers of the final whorl more angular with subacute to acute peripheral margins. No keel observed. Umbilicus narrow, relatively deep. Umbilical shoulders broadly rounded. Surface of test smooth, wall thin.

Remarks :

This species is believed by many authors to be the ancestor of Globorotalia (Globorotalia) albeari (Bolli, 1957; El-Naggar, 1966).

Range :

Rare in Zone P3. It was originally found in the Globorotalia pusilla pusilla zone to lower part of the Globorotalia pseudomenardii zone in Trinidad (Bolli, 1957).

Subgenus GLOBOROTALIA (GLOBOROTALIA) Cushman, 1927; emended Blow, 1979.

Type species - Pulvinulina menardii (D' Orbigny) var. tumida Brady, 1877.

Remarks :

The wall is smooth and the chambers show an imperforate peripheral keel.

Globorotalia (Globorotalia) albeari Cushman and Bermudez, 1949.

(Pl. 28, fig. b)

Globorotalia (Globorotalia) albeari Cushman and Bermudez, 1949; Contr. Cushman Lab. Foram. Res., v. 25, p. 33, pl. 6, figs. 13-15.

Globorotalia pusilla laevigata Bolli, 1957; U.S. Nat. Mus. Bull.

215, p. 78, pl. 20, figs. 5-7.

Globorotalia pusilla laevigata El-Naggar, 1966; Bull. Brit. Mus. (Nat. Hist.), Geol., Supp. 2, p. 229-230, pl. 17, figs. 12a-c.

Globorotalia laevigata Postuma, 1971; Manual of Planktonic Foraminifera, p. 196-197.

Globorotalia (Globorotalia) albeari Blow, 1979; The Cainozoic Globigerinida, p. 883-885, pl. 92, figs. 4, 8, 9; pl. 93, figs. 1-4.

Thin-section description :

Test trochospirally coiled, biconvex. Chambers angular-rhomboid. Later chambers of the final whorl have a small peripheral keel. Umbilicus small and relatively deep. Umbilical shoulders subrounded. Surface of test smooth, wall thin.

Remarks :

Blow (1979) examined the holotypes of Globorotalia laevigata (Bolli, 1957) and Globorotalia (Globorotalia) albeari (Cushman and Ponton, 1949) and concluded that they are synonymous. On that basis, Globorotalia laevigata is here regarded as a junior synonym of Globorotalia (Globorotalia) albeari. Both Bolli and Blow recognize the close relationship of this species with Globorotalia (Turborotalia) pusilla from which it differs by having a peripheral keel.

Range :

Rare occurrences in Zones P3 - P4/P5. In Trinidad, this species is restricted to Globorotalia pseudomenardii zone (Bolli, 1957), but Blow (1979) reported that it has a more extensive range from the latest part of Zone P3, possibly to the earlier part of Zone P7.

Globorotalia (Globorotalia) ehrenbergi Bolli, 1957.
(Pl. 24, figs. e, f)

Globorotalia ehrenbergi Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 77, pl. 20, figs. 18-20.

Planorotalites chapmani ehrenbergi McGowran, 1968; Micropaleont., v. 14, no. 2, pl. 4, fig. 12.

Globorotalia ehrenbergi Postuma, 1971; Manual of Planktonic Foraminifera, p. 188-189.

Globorotalia (Globorotalia) ehrenbergi Blow, 1979; The Cainozoic Globigerinida, p. 888-889.

Thin-section description :

Test a low trochospire, biconvex. Earlier chambers subglobular, later ones laterally compressed, angular in shape with subacute to acute peripheral margins. A small peripheral keel may be present in the last chamber of the final whorl. Umbilicus narrow, shallow. Surface of test smooth.

Remarks :

This species is closely related to Globorotalia (Turborotalia) pseudomenardii. In thin-section, the latter differs by being more convex dorsally and by having a more developed peripheral keel.

Range :

Quite common in Zone P3 to basal part of Zone P4/P5.

Globorotalia (Globorotalia) pseudomenardii Bolli,1957.
(Pl. 24, fig. g)

Globorotalia pseudomenardii Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 77, pl. 20, figs. 14-17.

Globorotalia pseudomenardii Bolli and Cita, 1960; Riv. Ital. Paleont., v. 66, no. 2, pl. 35, figs. 2a-c.

Globorotalia pseudomenardii El-Naggar, 1966; Bull. Brit. Mus. (Nat. Hist.), Geol., Supp. 2, p. 227-229, pl. 17, figs. 7a-8c.

Planorotalites pseudomenardii McGowran, 1968; Micropaleont., v. 14, no. 2, pl. 4, figs. 5-9.

Globorotalia pseudomenardii Postuma, 1971; Manual of Planktonic Foraminifera, p. 204-205.

Globorotalia (Globorotalia) pseudomenardii Blow, 1979; The Cainozoic Globigerinida, p.892-896, pl. 89, figs. 1-5; pl. 94, figs. 1-5; pl. 105, figs. 3, 7-10; pl. 108, figs. 4-7; pl. 111, figs. 1-4; pl. 112, figs. 2, 3, 9, 10.

Thin-section description :

Test trochospirally coiled, unequally biconvex, dorsal side more strongly convex. Chambers are angular, compressed. A distinct peripheral keel is observed on the earlier chambers of the last whorl. Surface of test smooth. Umbilicus relatively narrow and shallow.

Range :

Appears to be restricted to Zone P4/P5; rare. This species has been recognized as one of the diagnostic Upper Paleocene fossils (Bolli, 1957; Berggren, 1962; Blow, 1979).

Subgenus GLOBOROTALIA (ACARININA) Subbotina, 1953; emended Blow, 1979.

Type species - Acarinina acarinata Subbotina, 1953.

Remarks :

The test is spinose with rounded peripheral margins and lacks an imperforate peripheral keel.

Globorotalia (Acarinina) bullbrooki Bolli, 1957.

(Pl. 29, figs. a-j)

Globorotalia bullbrooki Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 167-168, pl. 38, figs. 4a-5c.

Globorotalia bullbrooki Postuma, 1971; Manual of Planktonic Foraminifera, p. 180-181.

Globorotalia (Acarinina) bullbrooki Blow, 1979; The Cainozoic Globigerinida, p. 915-917, pl. 149, figs. 8, 9; pl. 155, figs. 1-8; pl. 171, figs. 1-3, 7-9.

Thin-section description :

Test a low trochospire. Dorsal side nearly flat to slightly convex, ventral side strongly convex. Earlier chambers subglobular, later ones become more angular-conical in shape. Peripheral margins of chambers generally subrounded; there is a tendency in the later chambers of the final whorl to become more compressed on the dorsal side, resulting in a subacute peripheral margin. Umbilicus narrow and deep. Umbilical shoulders subrounded to subacute. Surface of test covered with coarse blunt spines.

Range :

Abundant in Zone P7 - Zone P8(?). This species was first recorded from the lower part of Middle Eocene strata in Trinidad (Bolli, 1957). Blow (1979) gave its range as from Zone P8b to Zone P11.

Globorotalia (Acarinina) cf. esnaensis

(Pl. 32, figs. a-d)

Globigerina esnaensis Le Roy, 1953; Geol. Soc. Amer. Mem. 54, p. 31, pl. 6, figs. 8-10.

Globorotalia esnaensis Said and Kerdany, 1961; Micropaleont., v. 7, no. 3, p. 328, pl. 1, fig. 6.

Globorotalia esnaensis El-Naggar, 1966; Bull. Brit. Mus. (Nat. Hist.), Geol., Supp. 2, p. 210-213, pl. 21, figs. 6a-c.

Globorotalia (Acarinina) esnaensis Jenkins, 1971; N.Z. Geol. Surv., Paleont., Bull. 42, p. 82, pl. 3, figs. 84-88.

Acarinina esnaensis McKeel and Lipps, 1975; Jour. Paleont. Res., v. 5, no. 4, p. 258, pl. 1, figs. 5a-d.

Thin-section description :

Outline of test quadrate. Test a low trochospire. Dorsal side nearly flat, ventral side strongly convex. Chambers are subglobular, inflated throughout. Axial peripheral margins of chambers rounded. Umbilicus narrow, relatively deep. Surface of test covered with coarse blunt spines.

Range :

Found in Zones P4 - P6; rare in basal part of Zone P7-P8(?). This species was also recorded from Upper Paleocene (Said and Kerdany, 1961; El-Naggar, 1966) and basal Eocene strata (El-Naggar, 1966; Jenkins, 1971).

Subgenus GLOBOROTALIA (MOROZOVELLA) McGowran, 1964; emended Blow, 1979.

Type species - Pulvinulina velascoensis Cushman, 1925.

Remarks :

The test is spinose with subacute to acute peripheral margins and a peripheral keel formed by the fusion of spines.

Globorotalia (Morozovella) cf. acutispira

(Pl. 27, figs. a-f)

Globorotalia acutispira Bolli and Cita, 1960; Riv. Ital. Paleont., v. 66, no. 3, p. 375-377, pl. 35, figs. 3a-c.

Truncorotaloides (Morozovella) sp. aff. Truncorotaloides (Morozovella) acutispira McGowran, 1968; Micropaleont., v. 14, no. 2, pl. 2, figs. 6-10.

Thin-section description :

Test trochospirally coiled, nearly biconvex. Chambers angular-rhomboid in shape. A peripheral keel is present. Umbilicus generally narrow and deep. Umbilical shoulders subrounded to subacute. Surface of test finely spinose.

Range :

Zones P3 to P6.

Globorotalia (Morozovella) aequa Cushman and Renz, 1942.

(Pl. 26, figs. a-j)

Globorotalia crassata var. aequa Cushman and Renz, 1942; Contr. Cushman Lab. Foram. Res., v. 18, pt. 1, p. 12, pl. 3, fig. 3.

Globorotalia aequa Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 74-75, pl. 17, figs. 1-3; pl. 18, figs. 13-15.

Globorotalia aequa Gartner and Hay, 1962; Eclog. Geol. Helv., v. 55, p. 560-561, pl. 2, figs. 1a-2b.

Globorotalia aequa Luterbacher, 1964; Eclog. Geol. Helv., v. 57, p. 670-671, figs. 63-71.

Globorotalia aequa El-Naggar, 1966; Bull. Brit. Mus. (Nat. Hist.), Geol., Supp. 2, p. 190-193, pl. 21, figs. 4a-c.

Truncorotaloides (Morozovella) aequus McGowran, 1968; Micropaleont., v. 14, no. 2, pl. 1, figs. 3-7.

Globorotalia aequa Postuma, 1971; Manual of Planktonic Foraminifera, p. 168-169.

Globorotalia (Morozovella) dolabrata Jenkins, 1971; N.Z. Geol. Surv., Paleont. Bull. 42, p. 104-105, pl. 10, figs. 233-241.

Globorotalia (Morozovella) aequa aequa Blow, 1979; The Cainozoic Globigerinida, p. 975-977, pl. 96, figs. 4-9; pl. 99, fig. 5; pl. 102, figs. 6, 9-10; pl. 103, fig. 1.

Globorotalia (Morozovella) aequa lacerti ibid; p. 977-979, pl. 138, figs. 1-3.

Thin-section description :

Test a low trochospire, dorsal side nearly flat, ventral side strongly convex. Early chambers globigerine-like, later ones becoming angular-conical in shape with acute peripheral margins. Chambers of the last whorl may or may not have a small peripheral keel. Umbilicus narrow and deep. Umbilical shoulders broadly rounded to acute in rare cases. Surface of test finely to coarsely spinose. Generally, specimens found in the younger strata are more heavily ornamented and their spines are coarser.

Remarks :

Blow (1979) subdivided Globorotalia (Morozovella) aequa (s.l.) into 4 subspecies based on the tightness of coiling and the shape of the equatorial outline of the test. Such a division is not applicable in the present work.

Bolli (1957) noted the close relationship of this species with Globorotalia (Morozovella) subbotinae subbotinae (synonym Globorotalia rex) and Globorotalia (Morozovella) subbotinae gracilis (synonym Globorotalia gracilis) and proposed it the ancestor of the latter species. This was confirmed by other workers (Luterbacher, 1964; Blow, 1979).

1964; Blow, 1979).

Specimens found in the younger strata are characterized by a coarsely spinose test with a well-developed peripheral keel. In addition, the final chambers become more angular-conical in shape and less inflated.

Range :

Zones P3 - P7/P8(?).

Globorotalia (Morozovella) angulata (White, 1928)
(Pl. 25, figs. c-f)

Globigerina angulata White, 1928; Jour. Paleont., v. 2, p. 191-192, pl. 27, fig. 13.

Globorotalia angulata Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 74, pl. 17, figs. 7-9.

Globorotalia angulata abundocamerata ibid; p. 74, pl. 17, figs. 4-6.

Globorotalia angulata Luterbacher, 1964; Eclog. Geol. Helv., v. 57, p. 658-660, figs. 37-39.

Globorotalia conicotruncata ibid; p. 660-663; figs. 40-42.

Globorotalia angulata angulata El-Naggar, 1966; Bull. Brit. Mus. (Nat. Hist.), Geol., Supp. 2, p. 197-199, pl. 22, figs. 1a-c.

Globorotalia angulata abundocamerata ibid; p. 194-197, pl. 22, figs. 2a-c.

Globorotalia angulata Postuma, 1971; Manual of Planktonic Foraminifera, p. 170-171.

Globorotalia abundocamerata ibid; p. 166-167.

Globorotalia angulata Hofker, 1978; Jour. Foram. Res., v. 8, no. 1. p. 69-70, pl. 8, figs. 4-6.

Globorotalia (Morozovella) angulata angulata Blow, 1979; The Cainozoic Globigerinida, p. 984-986, pl. 86, fig. 9; pl. 87, fig. 1.

Globorotalia (Morozovella) angulata conicotruncata ibid; p. 986-988, pl. 87, fig. 3.

Thin-section description :

Test a low trochospire, dorsal side nearly flat to slightly convex, ventral side strongly convex. Early chambers globigerine-like, later ones become angular-conical in shape with subacute to acute peripheral margins. A peripheral keel may be developed on the later chambers. Umbilical shoulders broadly rounded to subacute. Umbilicus small and deep. Surface of test finely spinose.

Remarks :

No distinction is made here between forms referred to Globorotalia (Morozovella) angulata and Globorotalia (Morozovella) conicotruncata (synonym Globorotalia (Morozovella) angulata abundocamerata) as the main difference separating them is the number of chambers present in the last whorl, a feature that is not observed in axially sectioned specimens.

Range :

Zone P3 to lowermost Zone P4/P5; abundant in Zone P3. This species is generally regarded as characteristic of the Middle Paleocene (Bolli, 1957; Luterbacher, 1964; El-Naggar, 1966; Blow, 1979).

Globorotalia (Morozovella) cf. aragonensis

(Pl. 30, figs. a-j; Pl. 31, figs. a-j)

Globorotalia aragonensis Nuttall, 1930; Jour. Paleont., v. 4, no. 3, p. 288-289, pl. 24, figs. 6-8, 10, 11.

Globorotalia aragonensis Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 75, pl. 18, figs. 7-9.

Globorotalia aragonensis ibid; p. 167, pl. 38, figs. 1a-c.

Globorotalia aragonensis Pessagno, 1961; Micropaleont., v. 7, no. 3, p. 356, pl. 1, figs. 14-16.

Globorotalia aragonensis Luterbacher, 1964; Eclog. Geol. Helv., v. 57, p. 696-698, figs. 121-126, 128; G-31, nos. a, l, m, n, e.

Globorotalia aragonensis Postuma, 1971; Manual of Planktonic Foraminifera, p. 172-173.

Globorotalia (Morozovella) aragonensis Blow, 1979; The Cainozoic Glogiberinida, p. 990-993, pl. 134, fig. 6; pl. 141, figs. 1, 2, 4-9; pl. 146, figs. 1, 2; pl. 147, figs. 5-7; pl. 152, figs. 1-5; pl. 164, figs. 6-9; pl. 167, figs. 6-9.

Thin-section description :

Test a low trochospire, dorsal side slightly convex, ventral side strongly convex. All chambers angular with a distinct peripheral keel. Umbilicus relatively narrow and deep. Umbilical shoulders subrounded to subacute. Surface of test spinose, the earlier chambers in particular are densely covered with coarse spines.

Remarks :

Unlike all other keeled species of Globorotalia (Morozovella) found in the Pindos rocks, this species is characterized by a robust, heavily spinose test with a well-developed peripheral keel. Blow (1979) proposed that this species evolved from Globorotalia (Morozovella) lensiformis by increasing the numbers of chambers in the final whorl. The present work shows that the early forms of this species have a close morphological affinity with forms referred to Globorotalia (Morozovella) subbotinae.

Range :

Abundant in Zone P7-P8(?). This species is generally regarded as an index fossil for the upper part of Lower Eocene (Bolli, 1957; Berggren, 1969; Blow, 1979).

Globorotalia (Morozovella) cf. crater-caucasica group

(Pl. 25, figs. i, j)

Globorotalia (Morozovella) crater crater Jenkins, 1971; N.Z. Geol. Surv., Paleont. Bull. 42, p. 103-104, pl. 8, figs. 192-197.

Globorotalia (Morozovella) crater caucasica ibid; p. 103, pl. 8, figs. 189-191.

Remarks :

Jenkins (1971) drew attention to the homeomorphic relationship of this group and the Globorotalia (Morozovella) velascoensis group.

Range :

Rare in Zone P7-P8(?). In New Zealand, species of Globorotalia (Morozovella) crater-caucasica group were found in strata of Lower Eocene age (Jenkins, 1971).

Globorotalia (Morozovella) subbotinae Morozova, 1939.

(Pl. 27, figs. g-j)

Globorotalia rex Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 75, pl. 18, figs. 10-12.

Globorotalia subbotinae Luterbacher, 1964; Eclog. Geol. Helv., v. 57, p. 676-679, figs. 85-90.

Globorotalia (Morozovella) subbotinae subbotinae Blow, 1979; The Cainozoic Globigerinida, p. 1018-1021, pl. 102, figs. 1-5; pl. 111, figs. 6-8; pl. 115, figs. 3-5; pl. 119, figs. 4-10; pl. 127, figs. 6, 7; pl. 133, fig. 8.

Thin-section description :

Test a low trochospire, unequally biconvex. Dorsal side slightly convex, ventral side strongly convex. Chambers angular in shape. A distinct, thick peripheral keel is present on the chambers of the final whorl. Umbilicus narrow and deep. Umbilical shoulders subrounded to subacute. Surface of test spinose; spines coarser on the umbilical shoulders. Test relatively robust.

Remarks :

Globorotalia subbotinae Morozova, 1939, is regarded as the senior synonym of Globorotalia rex Martin, 1943 (Berggren, 1964; Luterbacher, 1964; Blow, 1979). This species is believed to be the ancestor of Globorotalia (Morozovella) subbotinae gracilis (Blow, 1979).

In thin-section, this species differs from Globorotalia (Morozovella) aequa in having a well-developed peripheral keel on all the chambers of the final whorl. Its chambers are also distinctly angular-rhomboid in shape in contrast to the more inflated ones of Globorotalia (Morozovella) aequa. Murray et al. (1981) also noted the strong keel and the very rugose surface.

Range :

Zone P4/P5 to Zone P6.

Globorotalia (Morozovella) velascoensis sensu lato

(Pl. 25, figs. g, h)

Pulvinulina velascoensis Cushman, 1925; Contr. Cushman Lab. Foram. Res., v. 1 pt. 1, p. 19, pl. 13, figs. 5a-c.

Globorotalia velascoensis Reichel, 1952; Eclog. Geol. Helv., v. 42, text-fig. 3f.

Globorotalia velascoensis Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 76, pl. 20, figs. 1-4.

Globorotalia velascoensis Loeblich and Tappan, 1957; U.S. Nat. Mus. Bull. 215, p. 196-197, pl. 64, figs. la-c.

Globorotalia velascoensis Luterbacher, 1964; Eclog. Geol. Helv., v. 57, p. 681-686, figs. 92-94, 98-99.

Truncorotaloides (Morozovella) velascoensis McGowran, 1968; Micropaleont., v. 14, no. 2, pl. 2, figs. 1, 2-4.

Globorotalia velascoensis Postuma, 1971; Manual of Planktonic Foraminifera, p. 218-219.

Globorotalia (Morozovella) velascoensis velascoensis Blow, 1979; The Cainozoic Globigerinida, p. 1027-1028, pl. 92, fig. 7; pl. 94, figs. 6-9; pl. 95, fig. 1, 2; pl. 99, figs. 3, 4; pl. 216, figs. 1-8; pl. 217, figs. 1-6; text-fig. B, figs. (i) and (ii).

Thin-section description :

Test a low trochospire, nearly plano-convex. All chambers are angular-conical in shape. Ventral-apertural faces of the chambers in the last whorl tend to be slightly concave. A peripheral keel is developed on all chambers. Umbilicus wide and deep. Umbilical shoulders subacute to acute and may be ornamented with coarse spines. Surface of test finely spinose.

Remarks :

This species is generally considered to be the central type for a variety of subspecies such as Globorotalia (Morozovella) parva, Globorotalia (Morozovella) pasionensis and Globorotalia (Morozovella) acuta (Bermudez, 1953; El-Naggar, 1966; Blow, 1979). The division of these subspecies is based on features such as the tightness of coiling, width of the umbilicus and the number of chambers in the final whorl. In this work, as only axially sectioned specimens were available, no attempt is made to subdivide Globorotalia (Morozovella) velascoensis (s.l.) based on the criteria listed above.

Range :

Rare occurrences in Zone P4/P5. This species is generally regarded as a diagnostic Upper Paleocene fossil (Bolli, 1957; Berggren, 1969; Bolli and P. Silva, 1973).

Family GLOBIGERAPSIDAE Blow, 1979.

Genus MURICOGLOBIGERINA Blow, 1979.

Type species - Globigerina soldadoensis Bronnimann, 1952.

Remarks :

Trochospirally coiled. Primary apertures interiomarginal, umbilical in position. Keel is absent. Test wall covered with dense muricae.

Muricoglobigerina mckannai (White, 1928)

(Pl. 32, fig. g)

Globigerina mckannai White, 1928; Jour. Paleont., v. 2, p. 194, pl. 27, fig. 16.

Globorotalia mckannai Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 79, pl. 19, figs. 16-18.

Globorotalia mckannai Gartner and Hay, 1962; Eclog. Geol. Helv., v. 55, p. 564-565, pl. 1, figs. 1a-c.

Truncorotaloides (Acarinina) mckannai McGowran, 1968; Micropaleont., v. 14, no. 2, pl. 3, figs. 7-10.

Globorotalia mckannai Postuma, 1971; Manual of Planktonic Foraminifera, p. 200-201.

Thin-section description :

Test trochospirally coiled, ventral side more strongly convex. Earlier chambers globular. Chambers of final whorl become more appressed, causing elongation of the chambers parallel to the axis of coiling. Axial peripheral margins of all chambers rounded. Umbilicus narrow, deep. Wall covered with coarse, long spines.

Range :

Within Zones P4 - P5. This species was said to be restricted to Middle and Upper Paleocene only (Bolli, 1957; Blow, 1979).

Muricoglobigerina cf. senni

(Pl. 32, figs. e, f)

Globigerina senni Loeblich and Tappan, 1957; U.S. Nat. Mus. Bull. 215, p. 163, pl. 35, figs. 10a-12.

Globigerina senni Postuma, 1971; Manual of Planktonic Foraminifera, p. 156-157.

Thin-section description :

Test trochospirally coiled, ventrally more strongly convex. Chambers globular, closely or tightly coiled. 4 chambers in final whorl, increasing slowly in size. Axial peripheral margins rounded. Umbilicus narrow, deep. Surface of test covered with thick, coarse spines.

Range :

Within Zone P7-P8(?). This species was also reported from Lower to Middle Eocene strata (Loeblich and Tappan, 1957) and even as high up as basal part of Zone P16 (Blow, 1979).

Family EOGLOBIGERINIDAE Blow, 1979.

Genus SUBBOTINA Brotzen and Pozaryska, 1961; emended Loeblich and Tappan, 1964; emended Blow, 1979.

Type species - Globigerina triloculinoides Plummer, 1926.

Remarks :

Test trochospiral; chambers globose, strongly inflated. Keel absent. Primary aperture interiomarginal, "asymmetrically umbilical-extraumbilical" (Blow, 1979), bordered by a porticus. Test wall perforated, bear interpore ridges. Genus is restricted to Paleogene.

Subbotina linaperta (Finlay, 1939)

(Pl. 28, figs. h-j)

Globigerina linaperta Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 70-71, pl. 15, figs. 15-17.

Globigerina linaperta Loeblich and Tappan, 1957; U.S. Nat. Mus. Bull. 215, p. 163, pl. 63, figs. 5a-b.

Subbotina aff. linaperta McGowran, 1968; Micropaleont., v. 14, no. 2, pl. 3, figs. 12, 14, 16.

Globigerina (Subbotina) linaperta Jenkins, 1971; N.Z. Geol. Surv., Paleont. Bull. 42, p. 159, pl. 18, figs. 551-554.

Subbotina linaperta Blow, 1979; The Cainozoic Globigerinida, p. 1276-1279; pl. 91, fig. 8; pl. 124, fig. 9; pl. 158, fig. 8; pl. 160, figs. 6-8; pl. 177, figs. 4-6; pl. 240, figs. 5, 6.

Thin-section description :

Test a low trochospire. Dorsal side slightly convex, ventrally strongly convex. 3½ chambers visible in the final whorl. All chambers globular, inflated. Axial peripheral margins rounded. Umbilicus narrow, relatively deep. Wall perforated, covered with fine, short spines.

Remarks :

This species is believed to be descended from Subbotina triloculinoides (Bolli, 1957; Blow, 1979).

Range :

Zone P7-P8(?); also found in Upper Paleocene strata. In New Zealand, this species is reported to be restricted to Middle to Upper Eocene beds (Jenkins, 1971). In other localities, its range extends downwards to Upper Paleocene (Bolli, 1957; Loeblich and Tappan, 1957), and even to Middle Paleocene (Blow, 1979).

Subbotina triloculinoides (Plummer, 1926)

(Pl. 28, figs. d-g)

Globigerina triloculinoides Bronnimann, 1952; Bull. Amer. Paleont., v. 34, no. 143, p. 172-173, pl. 3, figs. 13-18.

Globigerina triloculinoides Bolli, 1957; U.S. Nat. Mus. Bull. 215, p. 70, pl. 15, figs. 18-20; pl. 17, figs. 25-26.

Globigerina triloculinoides Olsson, 1960; Jour. Paleont., v. 34, no. 1, p. 43, pl. 7, figs. 22-24.

Subbotina triloculinoides McGowran, 1968; Micropaleont., v. 14, no. 2, pl. 3, fig. 13.

Globigerina triloculinoides Postuma, 1971; Manual of Planktonic Foraminifera, p. 160-161.

Subbotina triloculinoides triloculinoides Blow, 1979; The Cainozoic Globigerinida, p. 1287-1292, pl. 74, fig. 6; pl. 80, fig. 1; pl. 98, fig. 7; pl. 248, figs. 9, 10; pl. 255, fig. 9; pl. 257, fig. 9.

Thin-section description :

Test a low trochospire. Dorsal side nearly flat, ventrally strongly convex. Chambers globular, inflated. Four chambers in final whorl. Axial peripheral margins rounded. Umbilicus narrow, relatively deep. Wall perforated, covered with fine spines.

Remarks :

This species is morphologically similar to Subbotina triangularis and Subbotina linaperta. Bolli (1957) and Blow (1979) proposed that it evolves into Subbotina triangularis and Subbotina linaperta. Species identified by Bronnimann (19520 as Globigerina stainforthi, Globigerina finlayi, and Globigerina hornibrooki were included by other workers as synonyms of Subbotina triloculinoides (Bolli, 1957; Loeblich and Tappan, 1957; El-Naggar, 1966).

Range :

Found within Zones P1 to P5. This species was also recorded from upper part of type Danian (Troelsen, 1957; Berggren, 1962), Upper Danian to end of Paleocene (El-Naggar, 1966), and Blow (1979) gave its range as Zone P1b to top of Zone P6.

Plate 13

figs. a, b, c	<u>Hedbergella delrioensis</u> a - X230 b - X 215 c - X 170	
fig. d	<u>Hedbergella</u> cf. <u>planispira</u>	X 240
figs. e, f, g	<u>Marginotruncana helvetica</u> e - X 130 f - X 135 g - X 175	
figs. h, i, j	<u>Marginotruncana</u> cf. <u>imbricata</u> h - X 190 i - X 215 j - X 210	

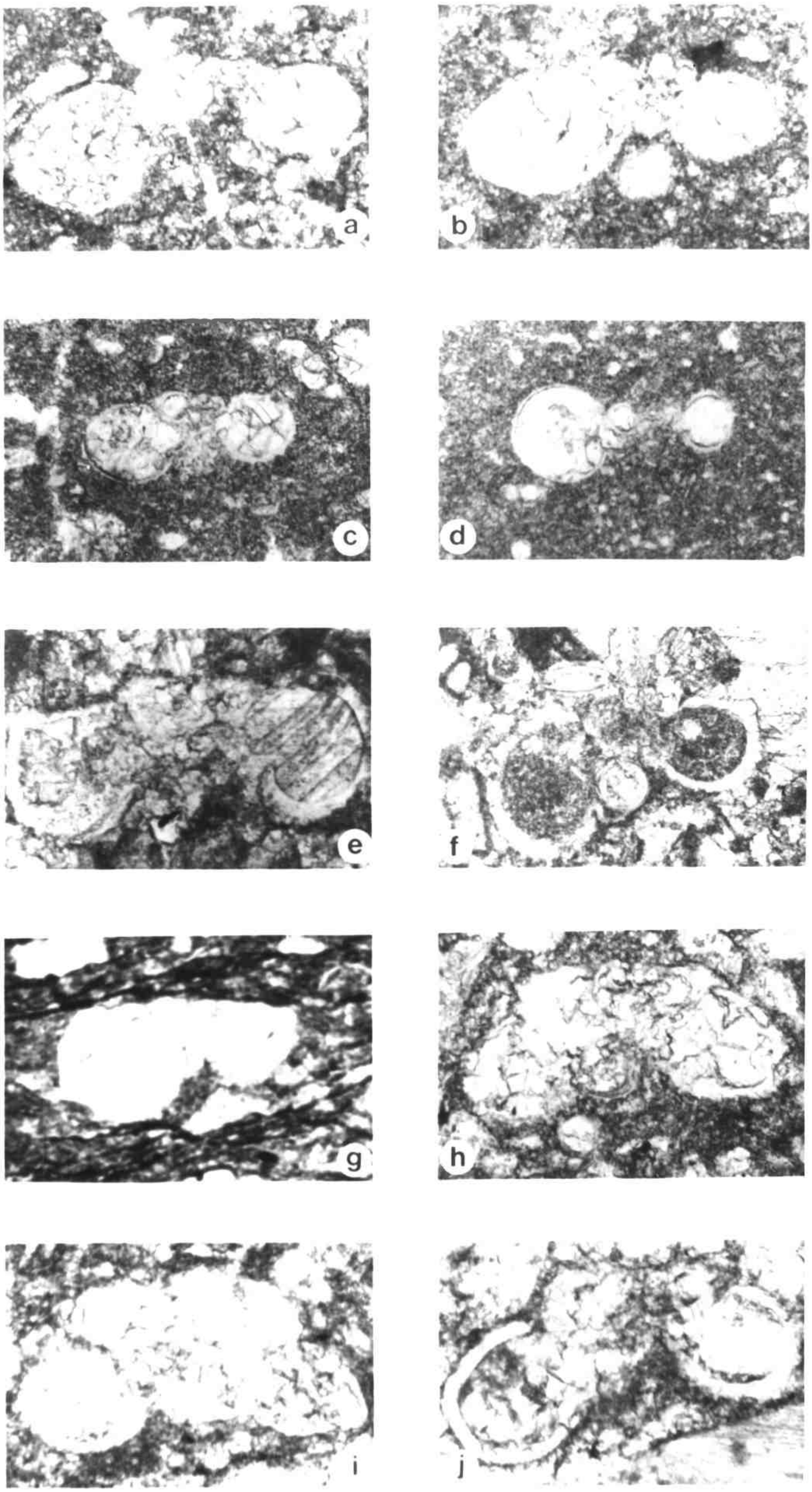
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Plate 14

figs. a, b	<u>Marginotruncana helvetica</u>	
	a - X 154	
	b - X 95	
figs. c, d, e, f	<u>Marginotruncana coronata</u>	
	c - X 75	
	d - X 95	
	e - X 95	
	f - X 75	
figs. g, h, i, j	<u>Marginotruncana pseudolinneiana</u>	
	g - X 75	
	h - X 95	
	i - X 95	
	j - X 75	

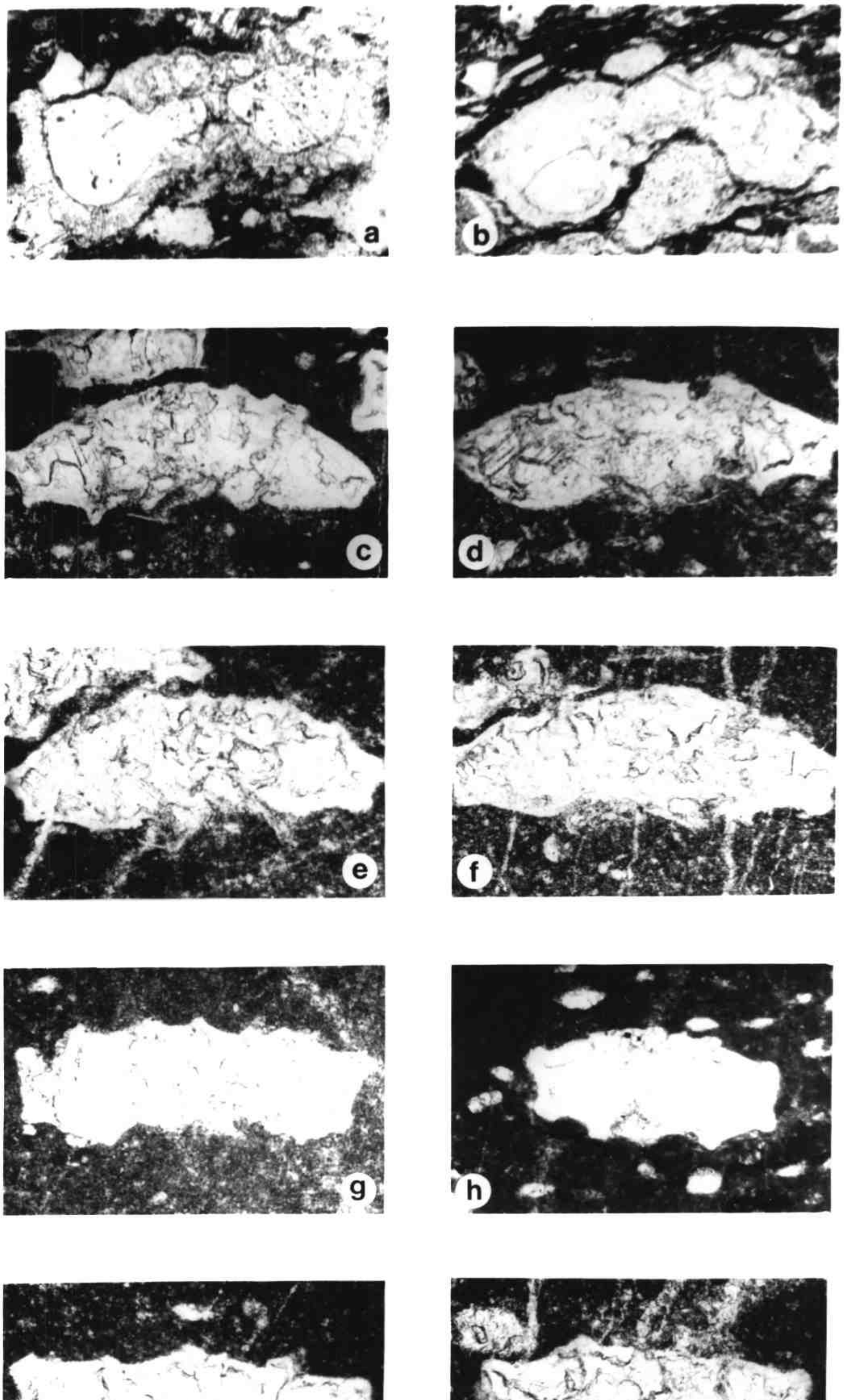
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Plate 15

fig. a	<u>Dicarinella</u> <u>concavata</u> X 132
figs. b, c, d	<u>Dicarinella</u> <u>carinata</u>
	b - X 95
	c - X 75
	d - X 95
figs. e, f, g, h	<u>Marginotruncana</u> cf. <u>angusticarenata</u>
	e - X 115
	f - X 60
	g - X 95
	h - X 60
figs. i, j	<u>Globotruncana</u> <u>elevata</u>
	i - X 60
	j - X 75

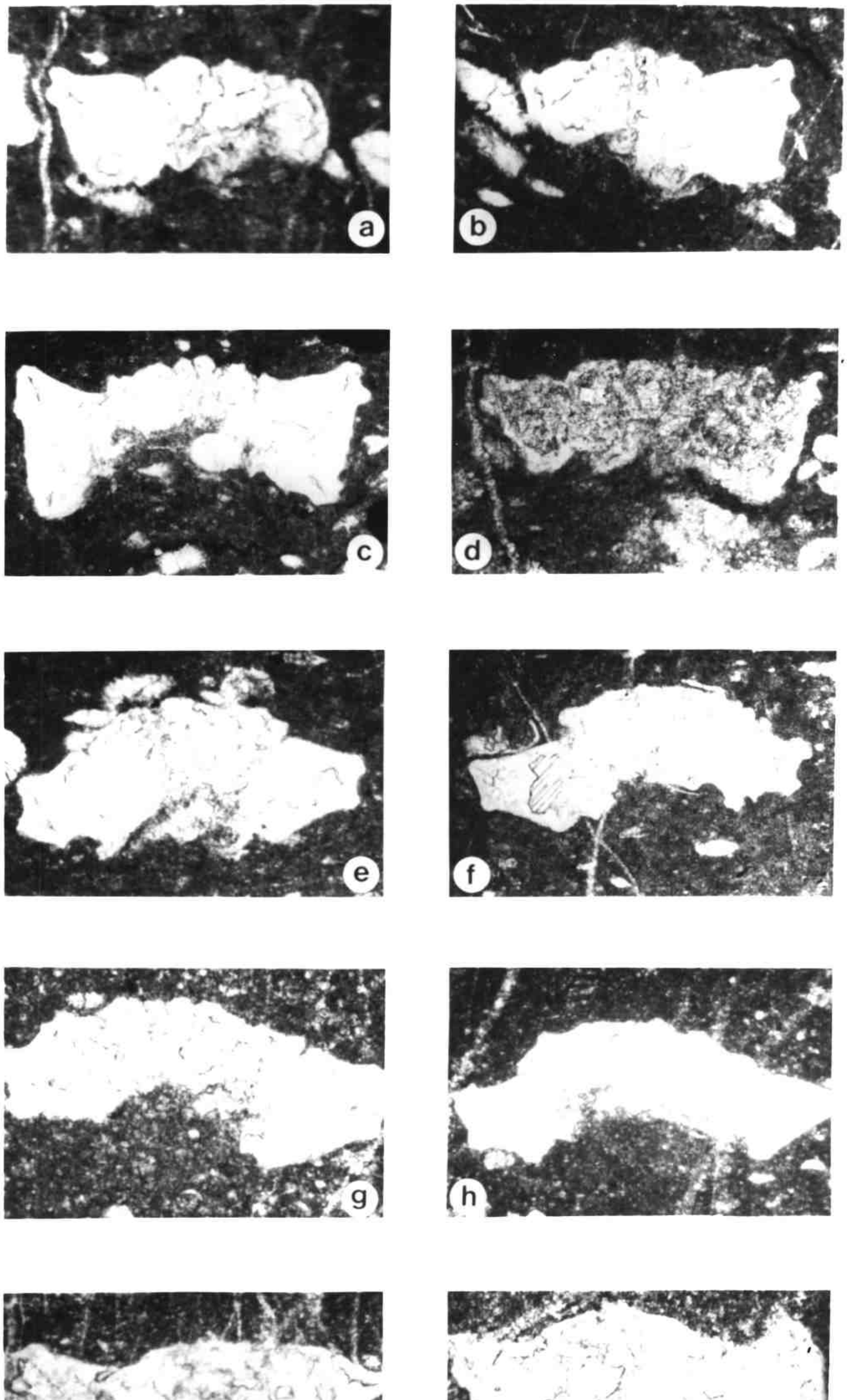
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Plate 16

fig. a	_Dicarinella carinata_ X 90
figs. b, c, d	_Globotruncana elevata_ b - X 90 c - X 90 d - X 75
figs. e, f	_Globotruncanella havanensis_ e - X 95 f - X 100
figs. h, i, j	_Marginotruncana pseudolinneiana_ h - X 100 i - X 150 j - X 95

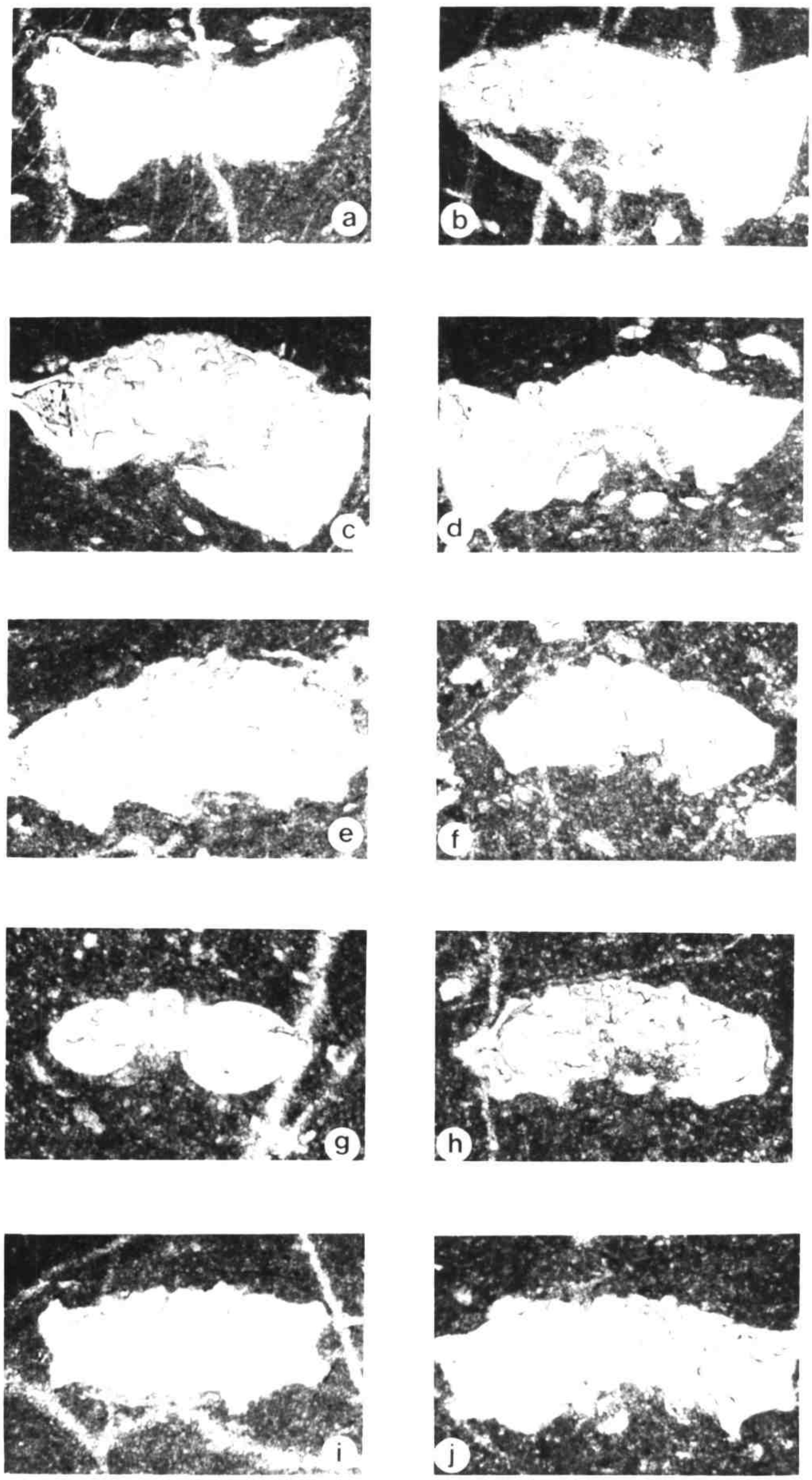
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Plate 17

figs. a, b, c, d	<u>Globotruncana</u> <u>ventricosa</u>	
	a - X 120	
	b - X 115	
	c - X 120	
	d - X 125	
fig. e	<u>Globotruncana</u> <u>tricarinata</u>	X 125
figs. f, g, h	<u>Globotruncana</u> <u>linneiana</u>	
	f - X 120	
	g - X 120	
	h - X 130	
figs. i, j	<u>Globotruncana</u> <u>arca</u>	
	i - X 120	
	j - X 120	

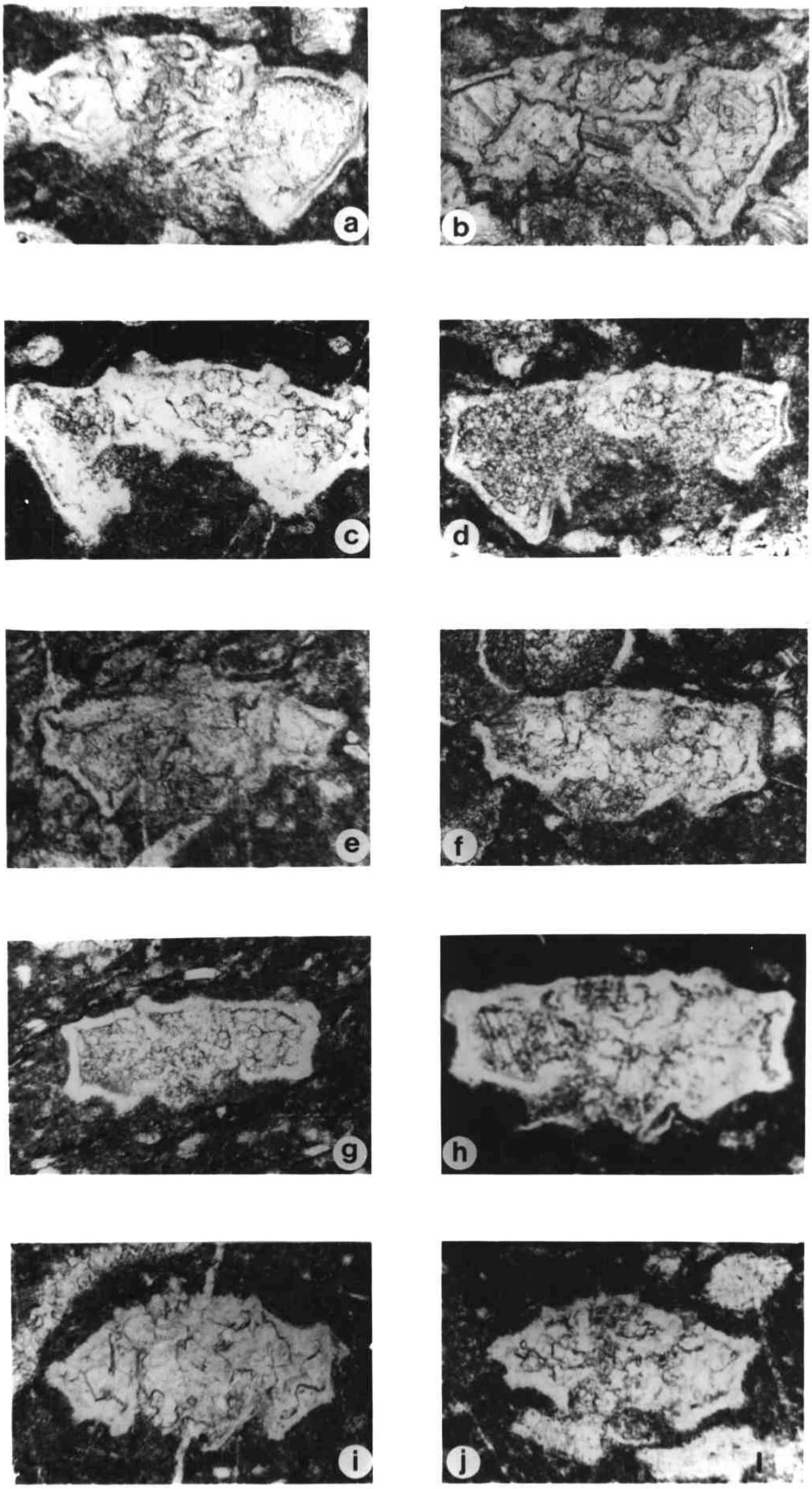
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Plate 18

figs. a, b, c, d	Globotruncana fornicata a - X 120 b - X 120 c - X 65 d - X 75
figs. e, f	Globotruncana fornicata -contusa transition or Globotruncana cf. patelliformis e - X 80 f - X 60
figs. g, h, i, j	Globotruncana contusa g - X 60 h - X 80 i - X 65 j - X 60

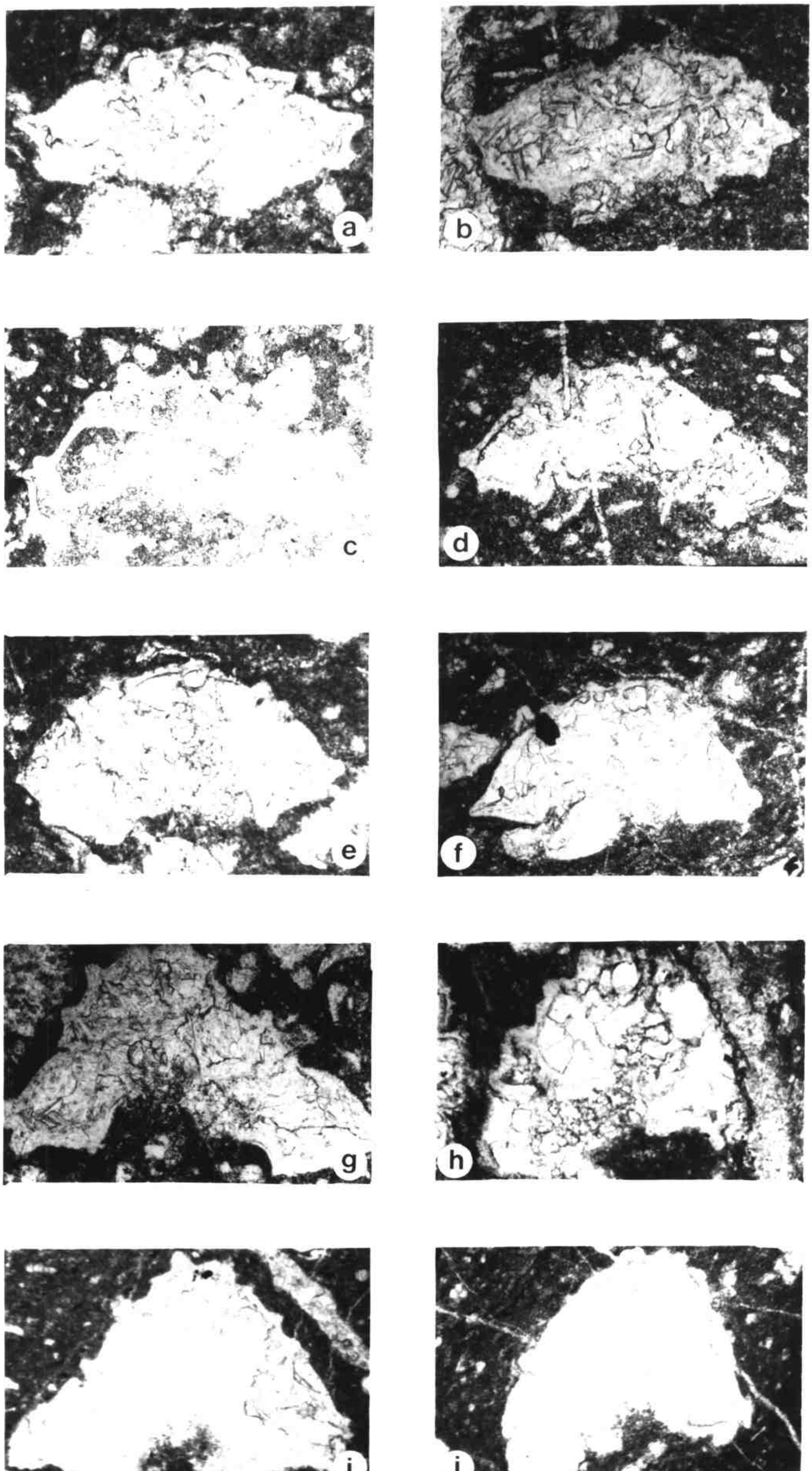
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Plate 19

figs. a, b, c	<u>Racemiguembelina</u> <u>fructicosa</u>
	a - X 75
	b - X 95
	c - X 80
fig. d	<u>Globotruncana</u> <u>gansseri</u> X 100
figs. e, f, g	<u>Globotruncana</u> cf. <u>aegyptica</u>
	e - X 110
	f - X 120
	g - X 120
figs. h, i, j	<u>Abathomphalus</u> <u>mayaroensis</u>
	h - X 95
	i - X 80
	j - X 80

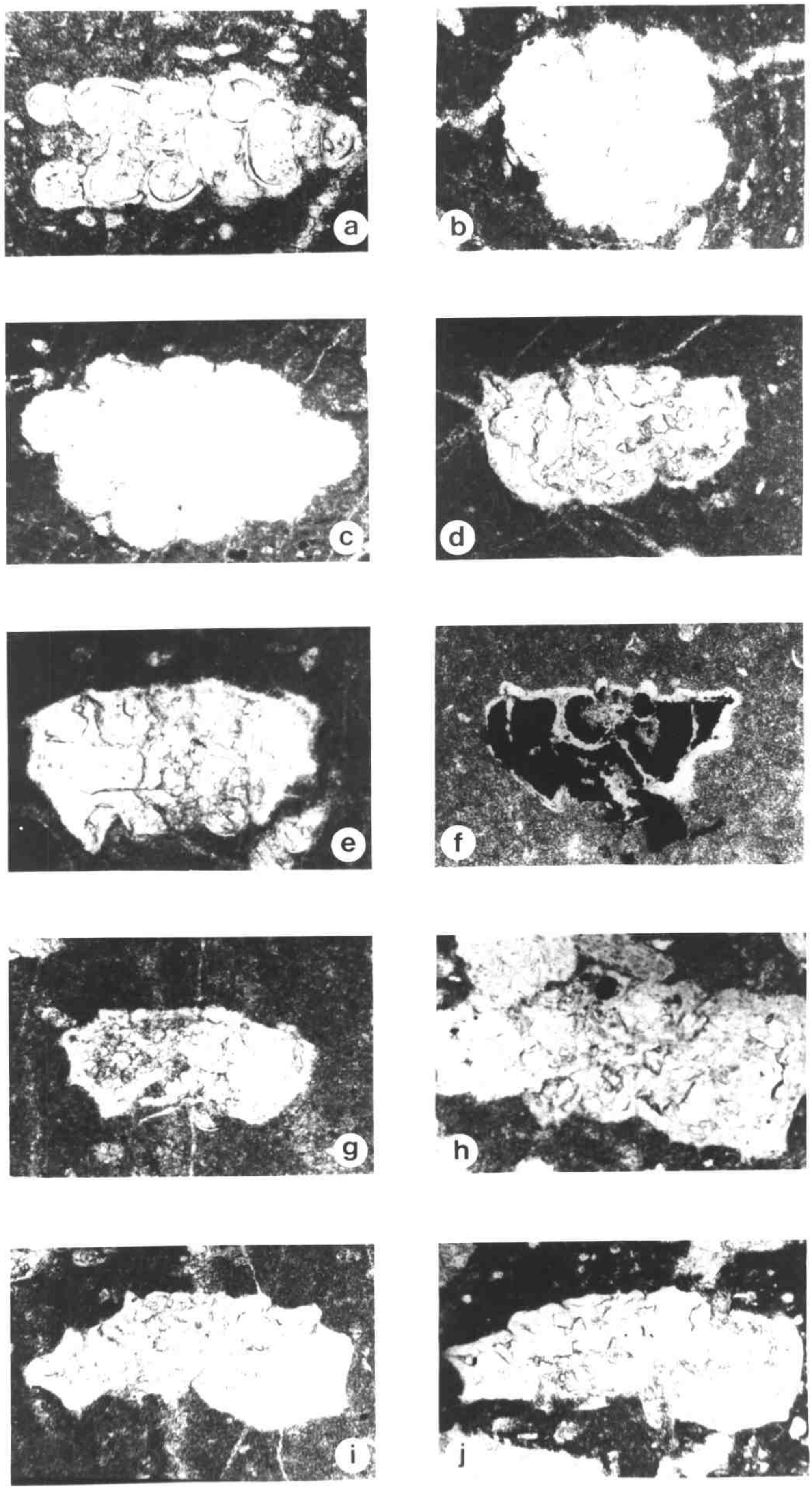
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Plate 20

figs. a, b, c	_Rugoglobigerina rotundata_
	a - X 120
	b - X 95
	c - X 110
figs. d, e	_Rugoglobigerina scotti_
	d - X 130
	e - X 150
figs. f, g, h	_Globotruncana stuarti_
	f - X 65
	g - X 80
	h - X 80
figs. i, j	_Globotruncana conica_
	i - X 90
	j - X 110

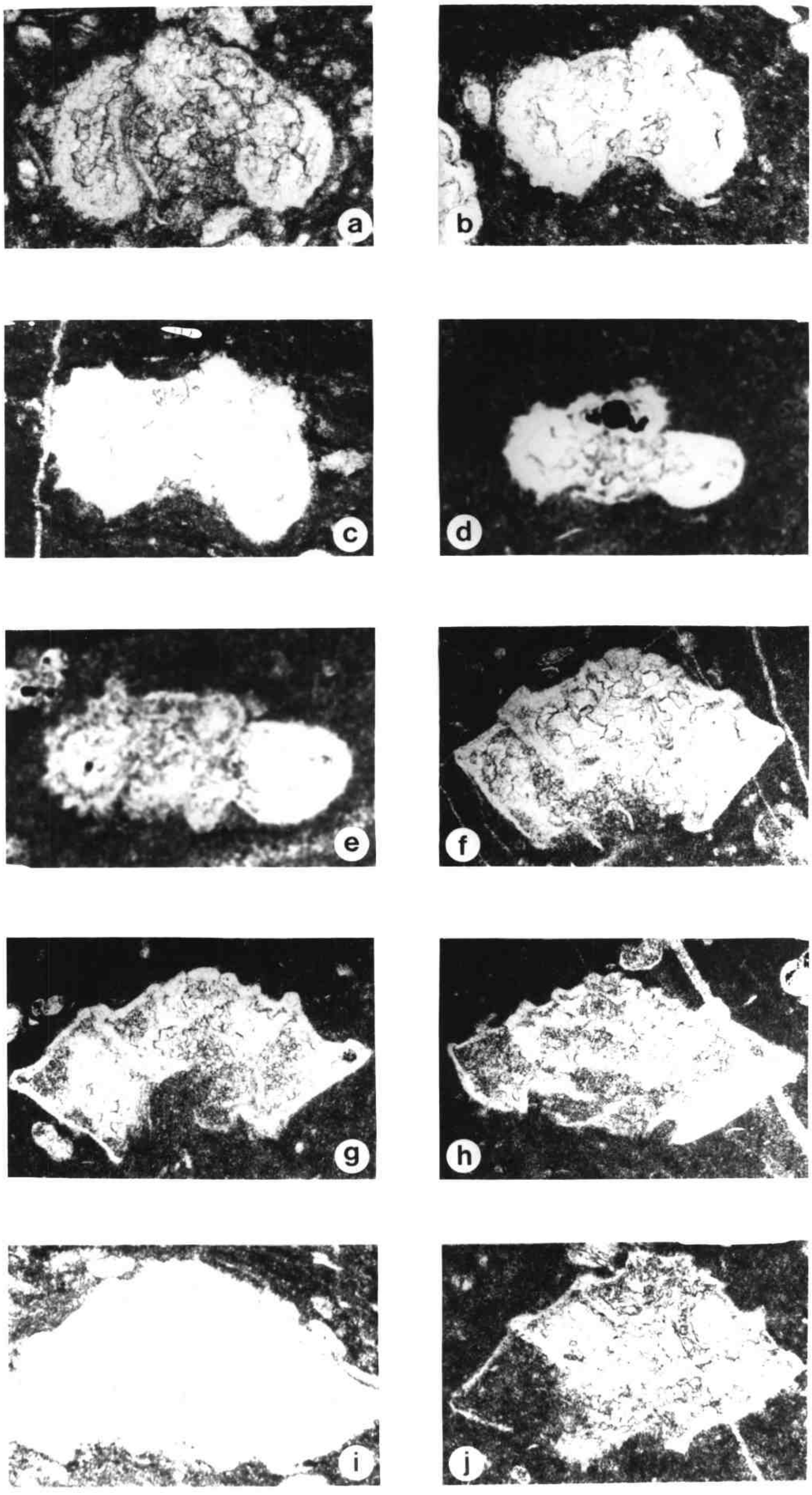
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Plate 21

figs. a, b, c, d, e, f	*Globotruncanella havanensis* a - X 120 b - X 120 c - X 120 d - X 110 e - X 110 f - X 120
fig. g	*Globotruncanella* aff. *petaloidea* X 100
fig. h	*Planoglobulina* sp. X 60
fig. i	*Gublerina* sp. X 70
fig. j	*Globotruncana calcarata* X 75

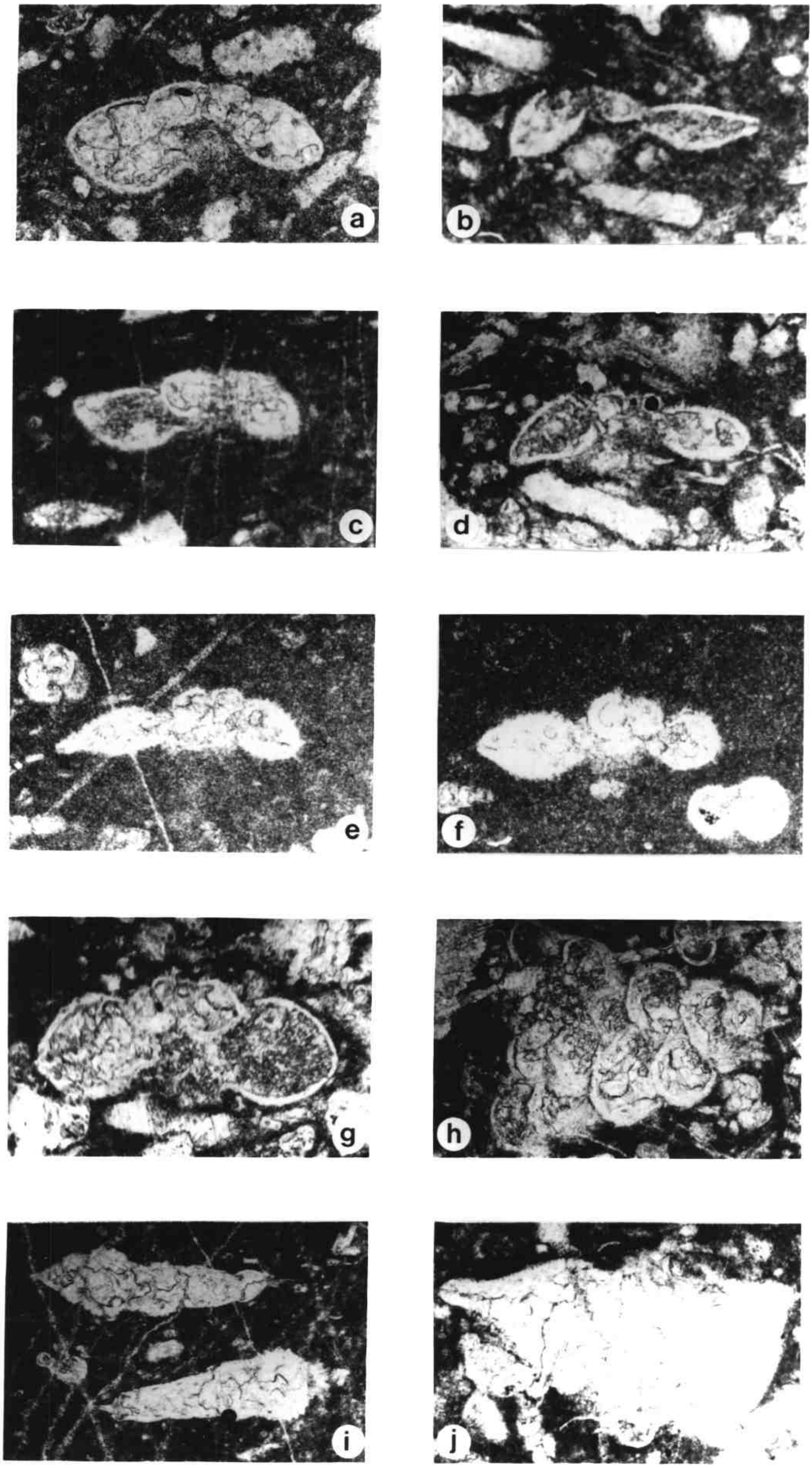
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Plate 22

figs. a, b, c, d, e	_Globigerinelloides_ spp. a - X 214 b - X 160 c - X 135 d - X 125 e - X 145
figs. f, g	_Rugoglobigerina_ _rugosa_ f - X 165 g - X 115
fig. h	_Pseudotextularia_ sp. X 60
figs. i, j	_Heterolix_ spp. i - X 115 j - X 120

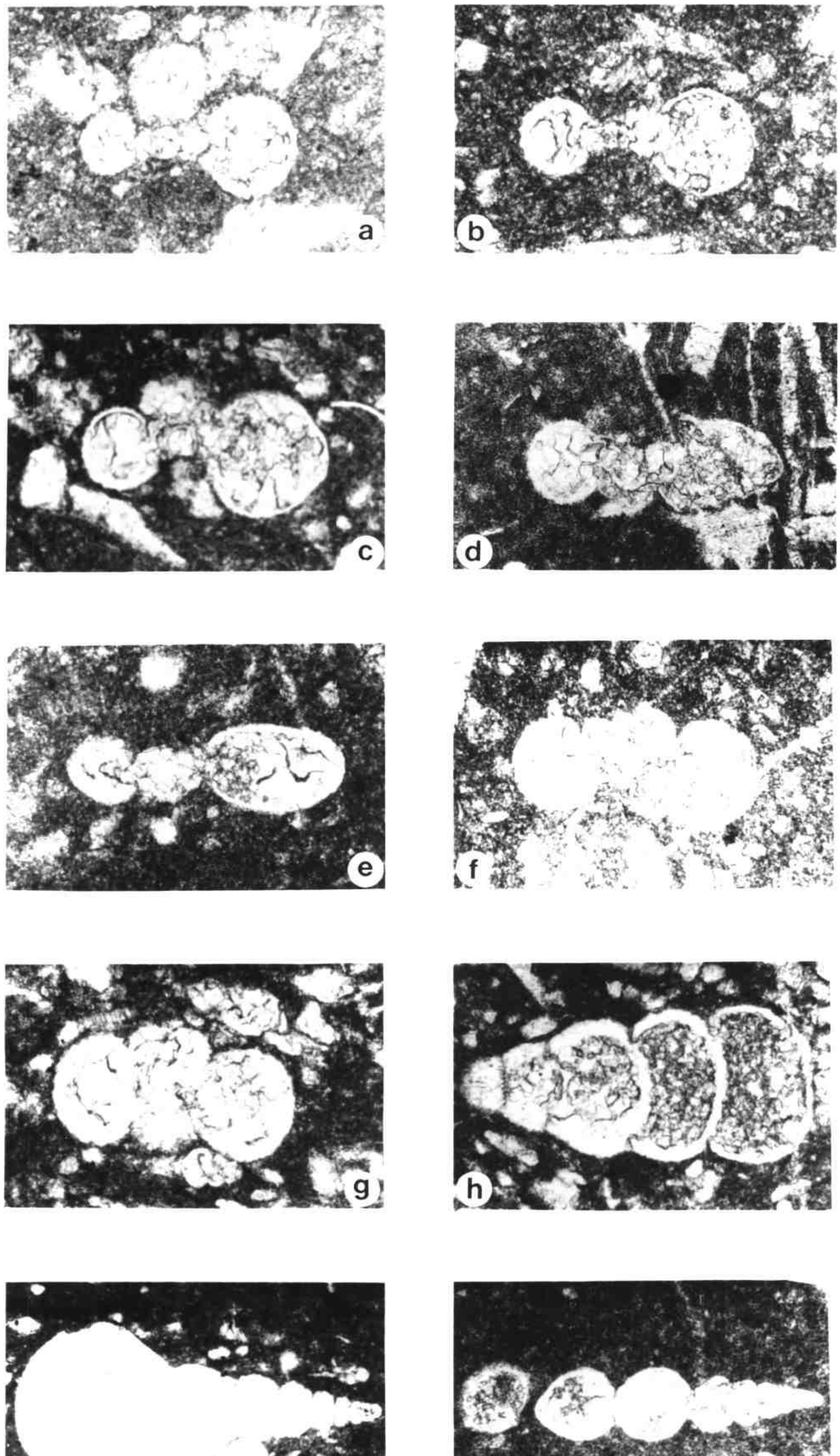
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Plate 23

figs. a - j

Globorotalia (*Turborotalia*) *pseudobulloides*

a - X 150

b - X 155

c - X 130

d - X 100

e - X 110

f - X 80

g - X 120

h - X 120

i - X 120

j - X 120

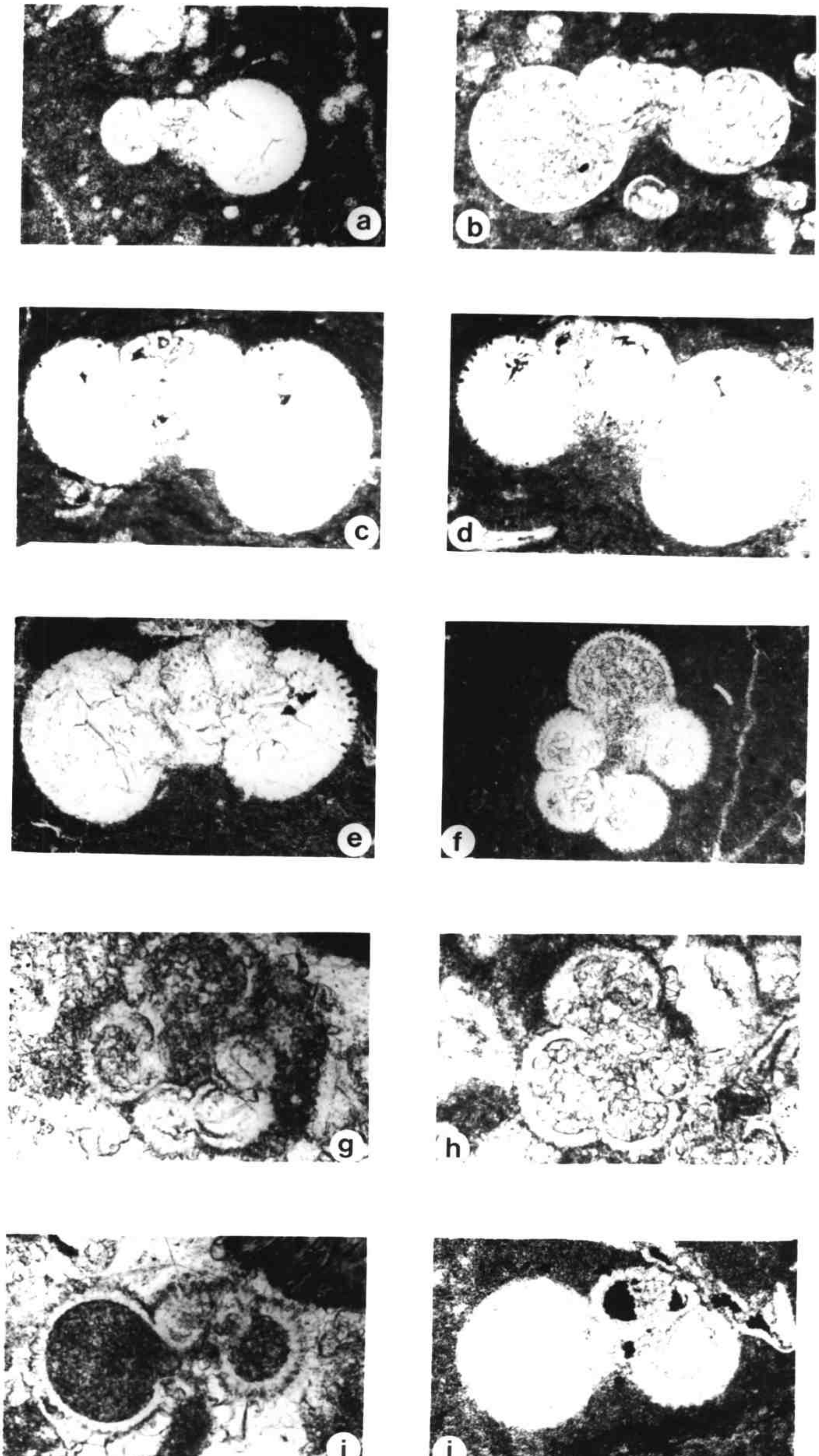
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Plate 24

figs. a, b	<u>Globorotalia</u> (<u>Turborotalia</u>) <u>pseudobulloides</u> - <u>compressa</u> transition a - X 200 b - X 200
figs. c, d	<u>Globorotalia</u> (<u>Turborotalia</u>) <u>compressa</u> c - X 157 d - X 204
figs. e, f	<u>Globorotalia</u> (<u>Globorotalia</u>) <u>ehrenbergi</u> e - X 200 f - X 260
fig. g	<u>Globorotalia</u> (<u>Globorotalia</u>) <u>pseudomenardii</u> X 130
figs. h, i, j	<u>Globorotalia</u> (<u>Globorotalia</u>) <u>chapmani</u> h - X 260 i - X 220 j - X 200

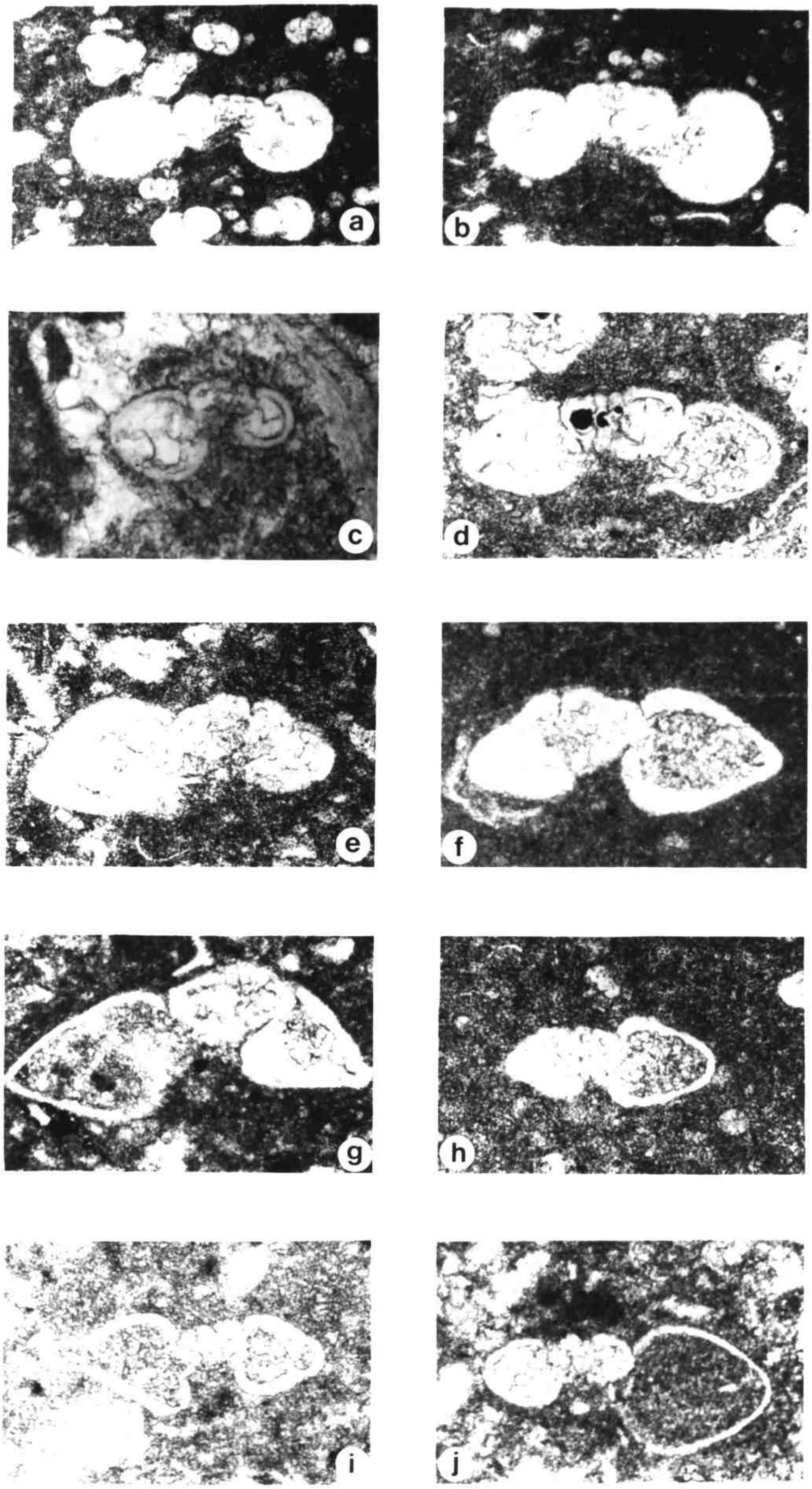
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Plate 25

figs. a, b	Globorotalia (Acarinina) uncinata - Globorotalia (Morozovella) angulata transition	a - X 110 b - X 120
figs. c, d, e, f	Globorotalia (Morozovella) angulata	c - X 120 d - X 210 e - X 110 f - X 100
figs. g, h	Globorotalia (Morozovella) velascoensis (s.l.)	g - X 110 h - X 80
figs. i, j	Globorotalia (Morozovella) cf. crater-caucasica	i - X 85 j - X 100

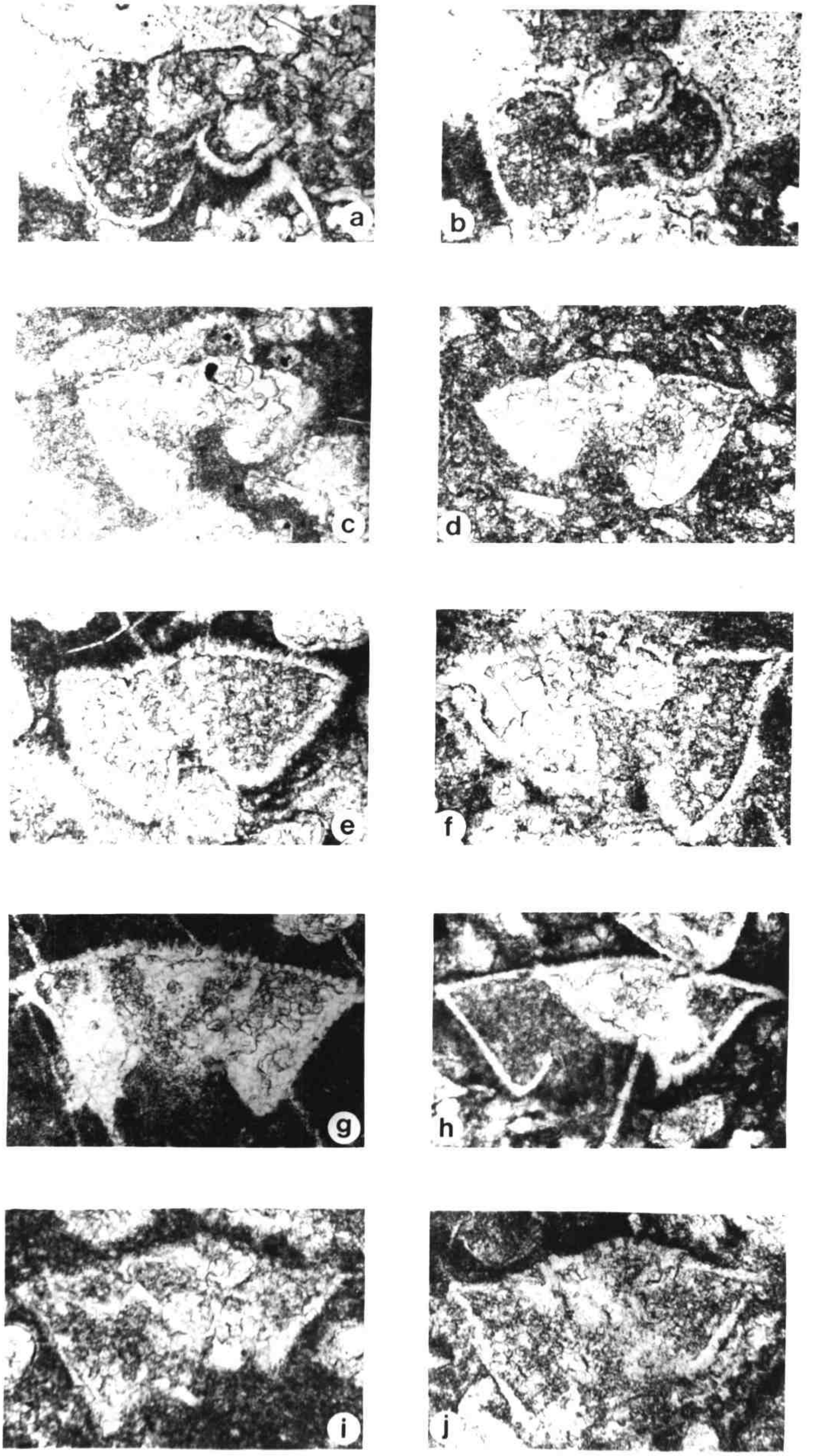
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Plate 26

figs. a - j

Globorotalia (Morozovella) aequa

a - X 120

b - X 110

c - X 110

d - X 130

e - X 130

f - X 140

g - X 140

h - X 130

i - X 140

j - X 120

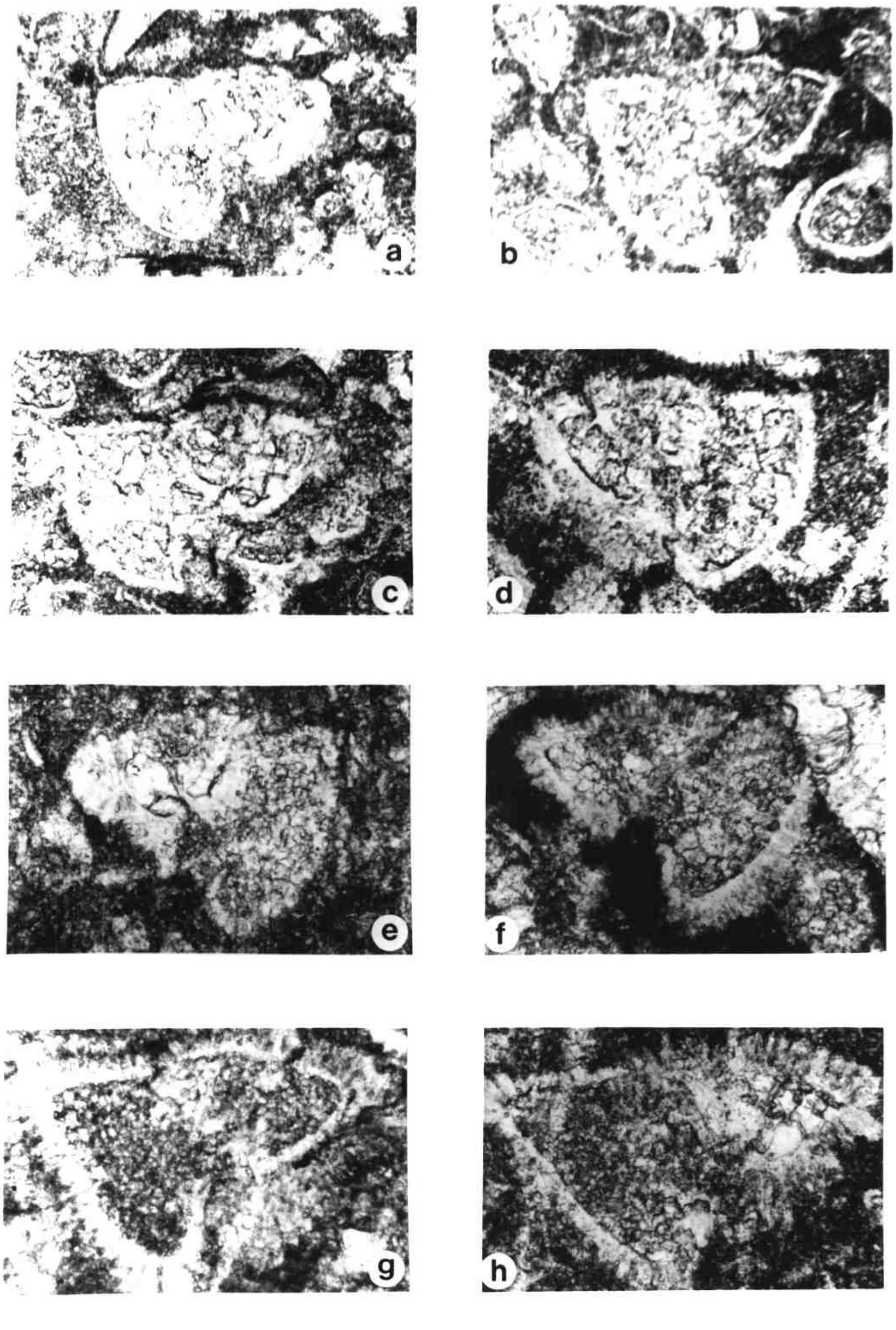
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Plate 27

figs. a - f	Globorotalia (Morozovella) cf. acutispira
	a - X 140
	b - X 140
	c - X 140
	d - X 85
	e - X 63
	f - X 200
	g - X 150
	h - X 180
	i - X 150
	j - X 150

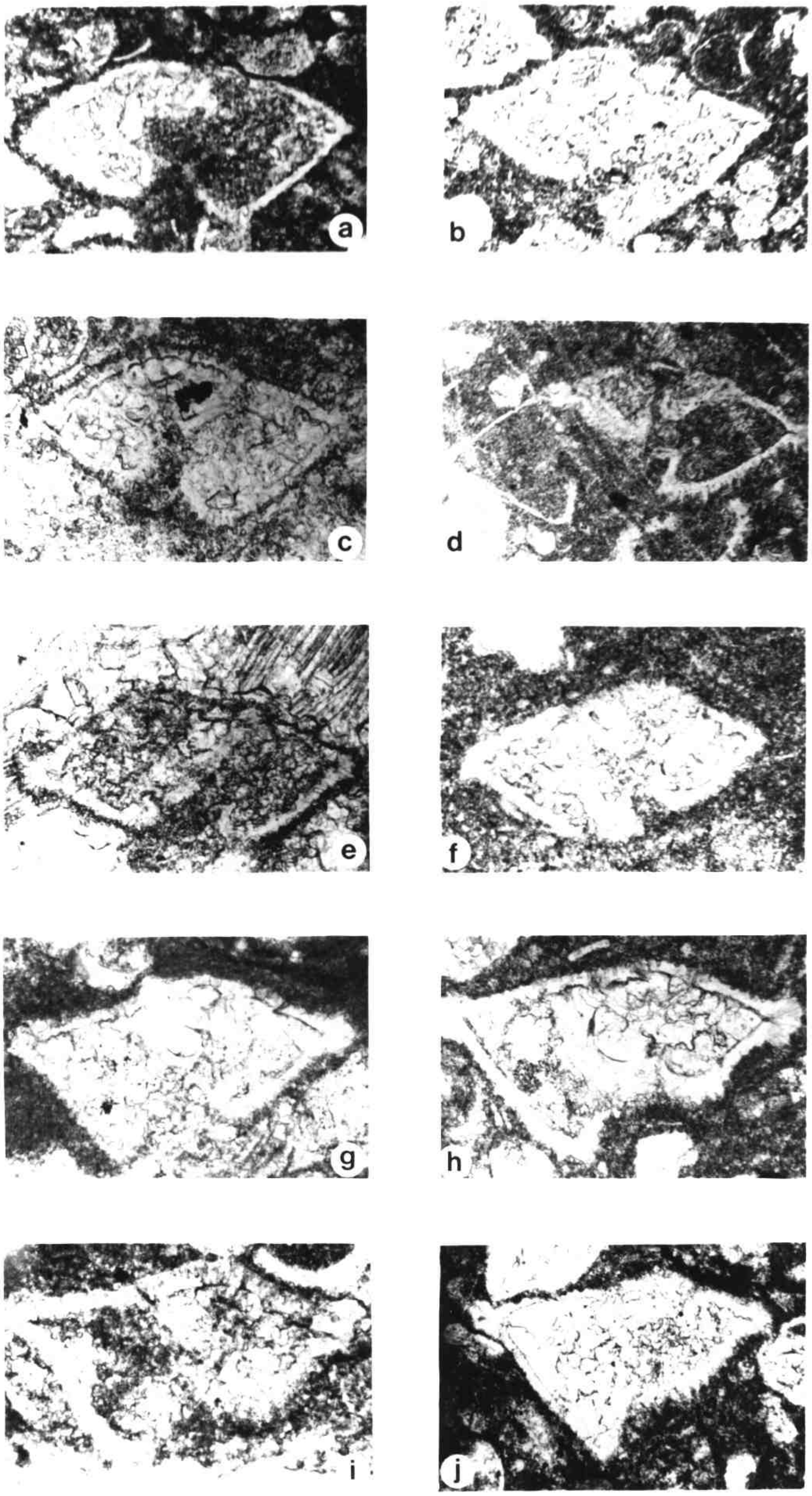
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Plate 28

fig. a	Globorotalia (Turborotalia) pusilla X 153
fig. b	Globorotalia (Globorotalia) albeari X 160
fig. c	Globorotalia (Morozovella) cf. occlusa X 170
figs. d, e, f, g	Subbotina triloculinoides d - X 80 e - X 130 f - X 190 g - X 200
figs. h, i, j	Subbotina linaperta h - X 190 i - X 200 j - X 100

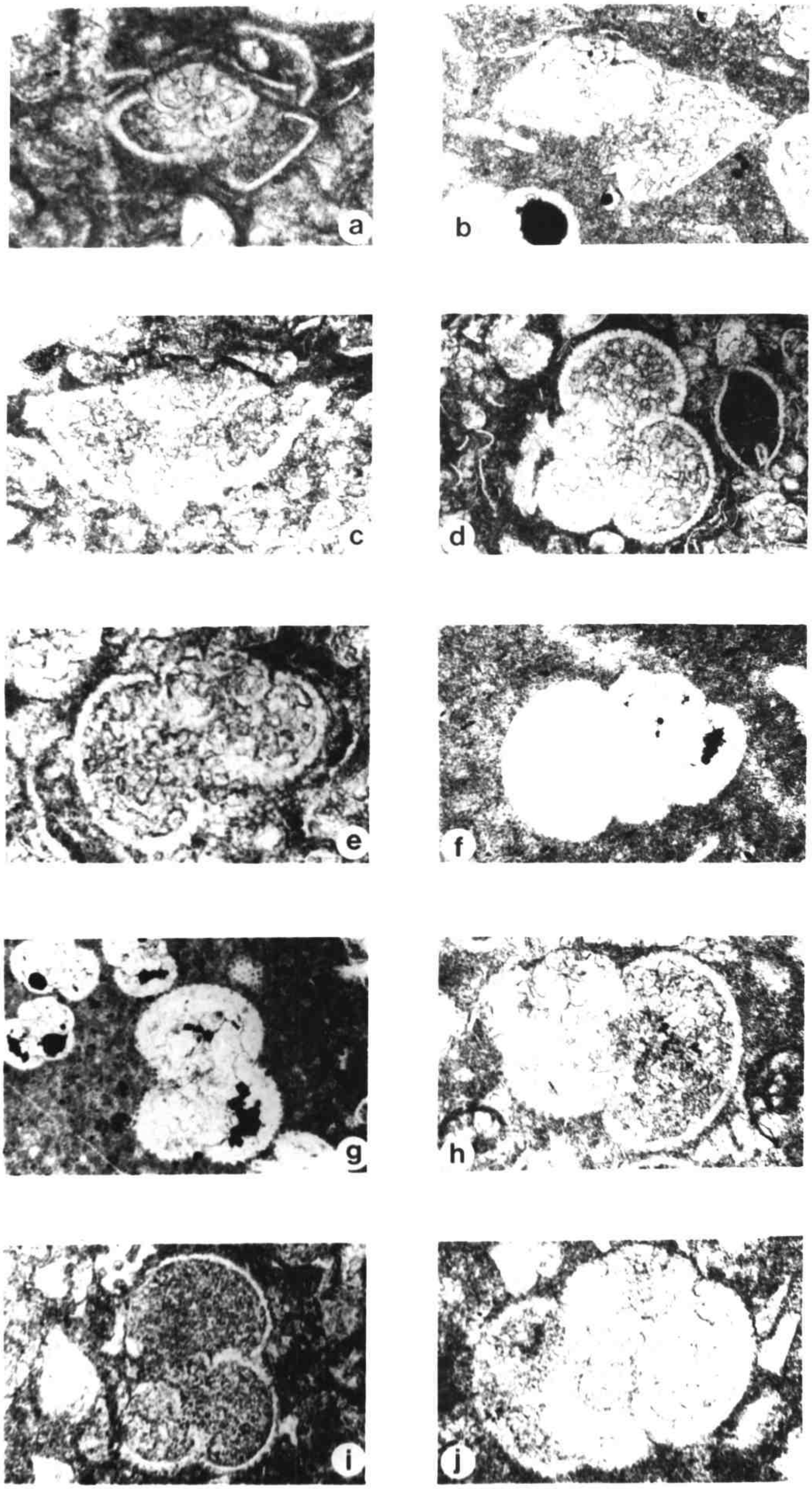
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Plate 29

figs. a - j

Globorotalia (Acarinina) bullbrooki

a - X 128

b - X 200

c - X 126

d - X 134

e - X 168

f - X 140

g - X 135

h - X 200

i - X 190

j - X 200

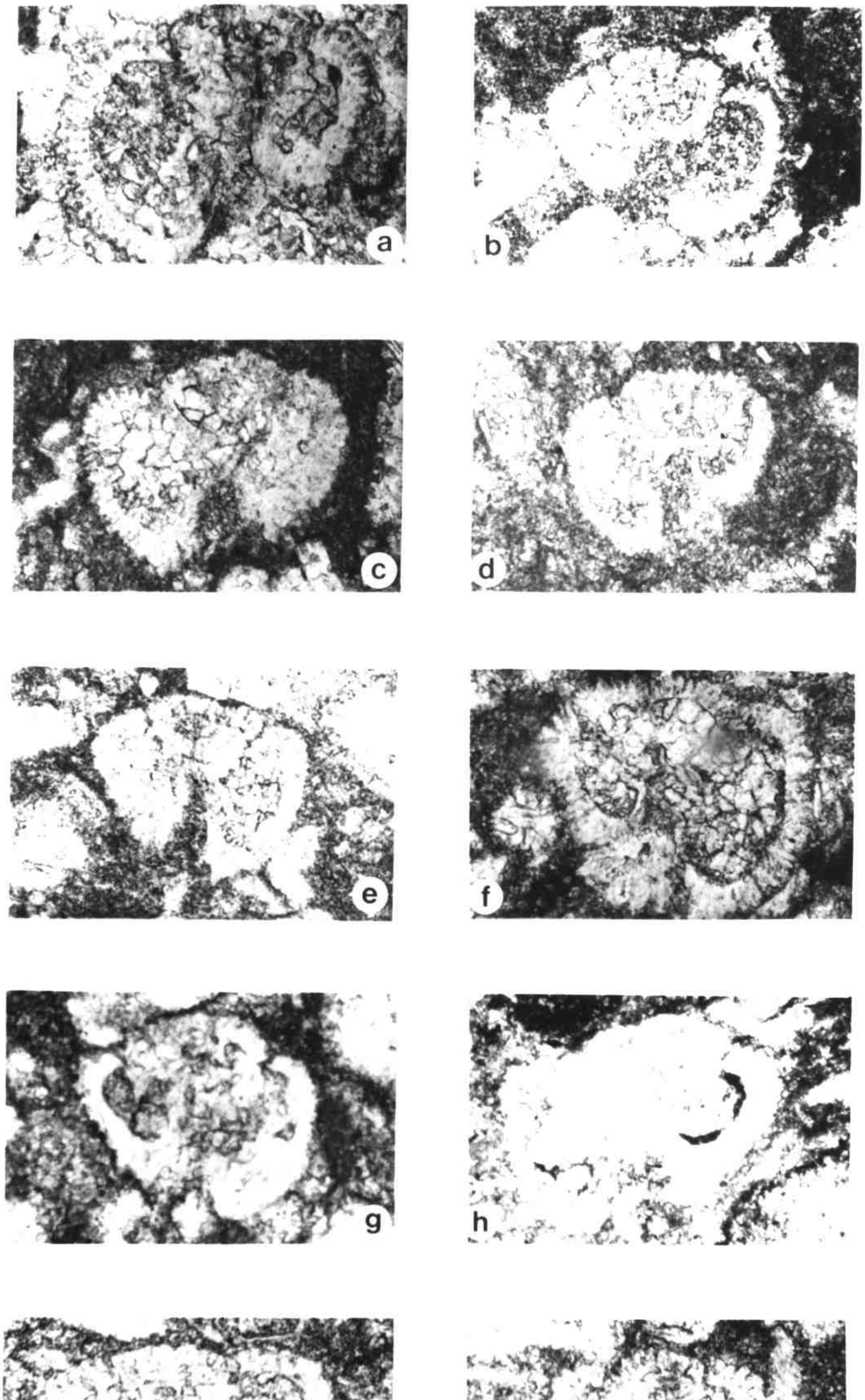
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Plate 30

figs. a - j — <u>Globorotalia</u> (<u>Morozovella</u>) cf. <u>aragonensis</u>

a - X 140
b - X 140
c - X 137
d - X 135
e - X 140
f - X 126
g - X 140
h - X 140
i - X 100
j - X 140

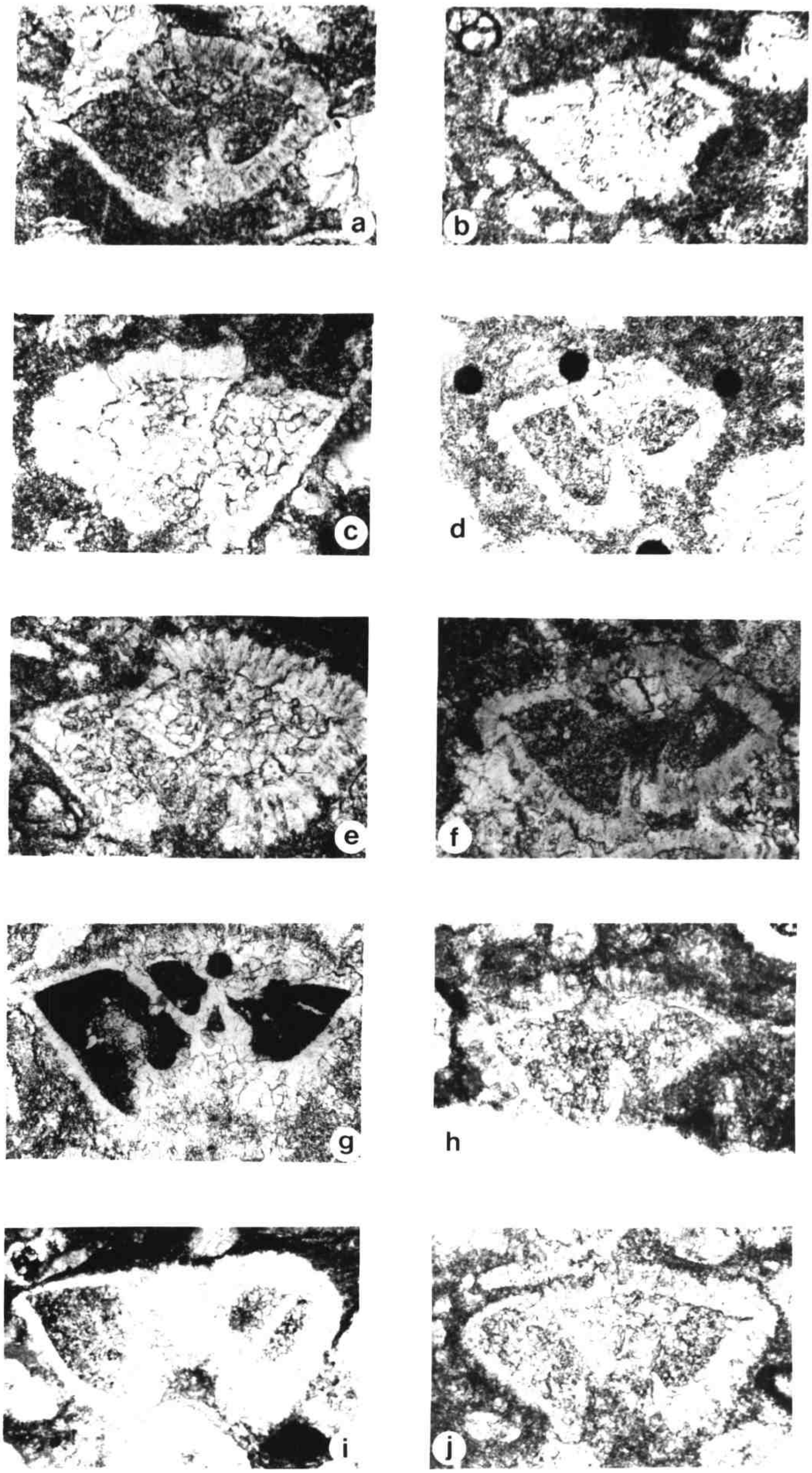
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Plate 31

figs. a - j — *Globorotalia* (*Morozovella*) cf. *aragonensis*

a - X 140
b - X 130
c - X 120
d - X 100
e - X 100
f - X 96
g - X 145
h - X 108
i - X 130
j - X 88

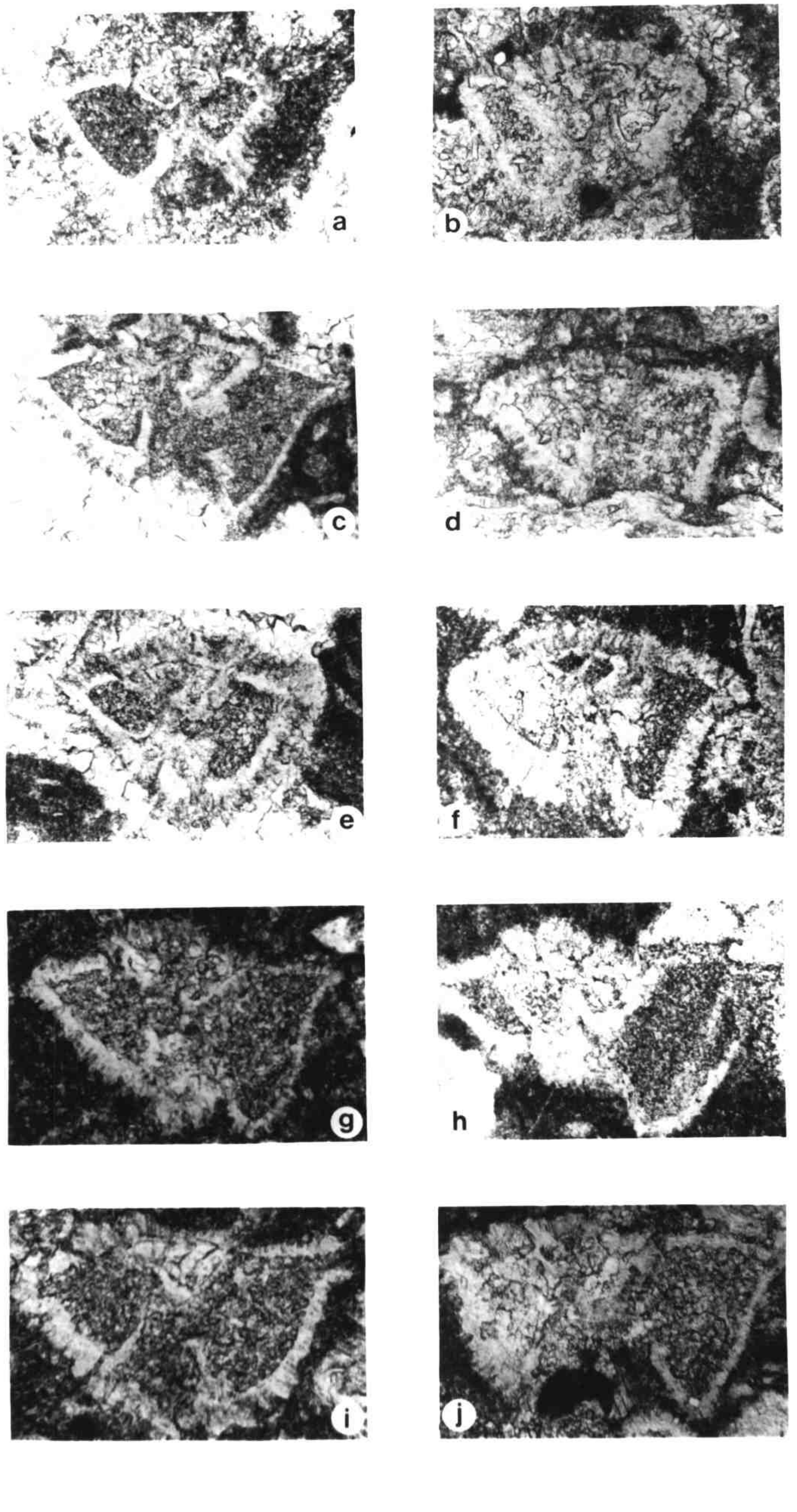
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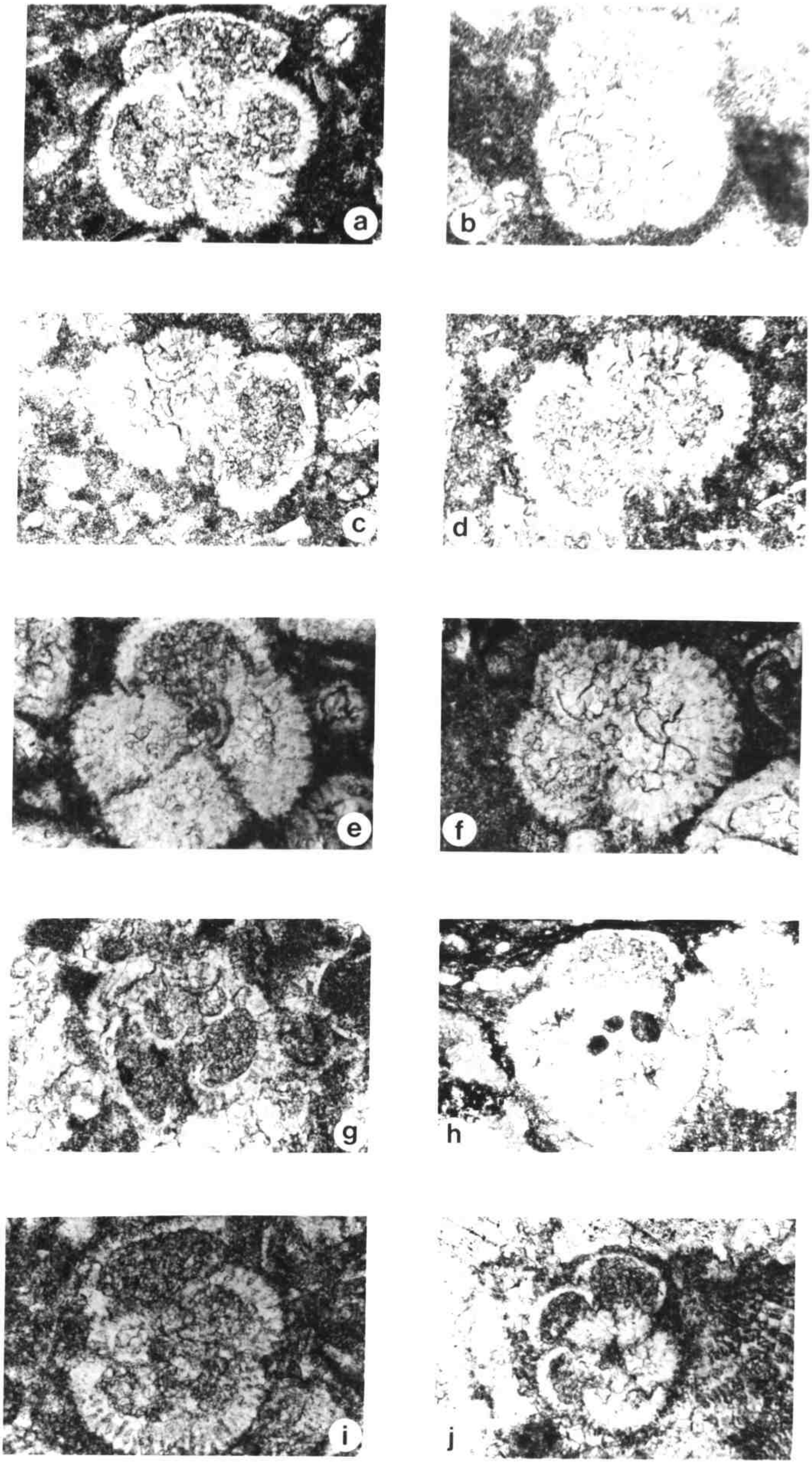
Plate 32

figs. a, b, c, d	*Globorotalia* (*Acarinina*) cf. *esnaensis* a - X 86 b - X 126 c - X 122 d - X 126
figs. e, f	*Muricoglobigerina* cf. *senni* e - X 126 f - X 132
fig. g	*Muricoglobigerina mckannai* X 147
figs. h, i	Spiral view of either *Muricoglobigerina* sp. or *Globorotalia* (*Acarinina*) sp. h - X 78 i - X 134
fig. j	Spiral view of *Globorotalia* (*Morozovella*) sp. X 126


a
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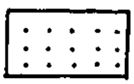
Explanation of the symbols used in figures 4, 6a, 8 and 10 :

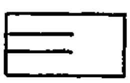
 limestone

 shale

 silty shale

 sandstone

 graded bed

 laminated bed

 bed with scour mark

 bed with channel

 chert nodules and/or bands

a - abundant

f - few

 pelagic foraminifera

A - abundant

F - few

R - rare

"P. F." Premier Flysch