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OLIGO-MIOCENE STRATIGRAPHY OF MALTA AND GOZO

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ABSTRACT

The Tertiary marine sediments of Malta and Gozo are divided into 5 formations for which type sections were designated: from base to top, the Lower Coralline Limestone (Late Chattian), Globigerina Limestone (Aquitanian-Langhian), Blue Clay (Langhian-Serravallian), Greensand (Serravallian-Early Tortonian), Upper Coralline Limestone (Early Tortonian). The sediments were deposited in a marine area in which sea depth increased until Langhian-Serravallian time to 150–200 metres to decrease again in the later part of the Miocene. Besides these relative sea-level changes the area was gradually transformed from a sheltered gulfal realm or intra-reefal basin to a shallow platform in open sea. Numerous faunal and sedimentary breaks occur. *Miogypsinoides complanatus*, *Lepidocyclina praemarginata*, uniserial *Uvigerina*, *Planorbulinella* and several planktonic species enable correlations to the type sections of the Tertiary stages and to Crete, SW Spain and SW France.

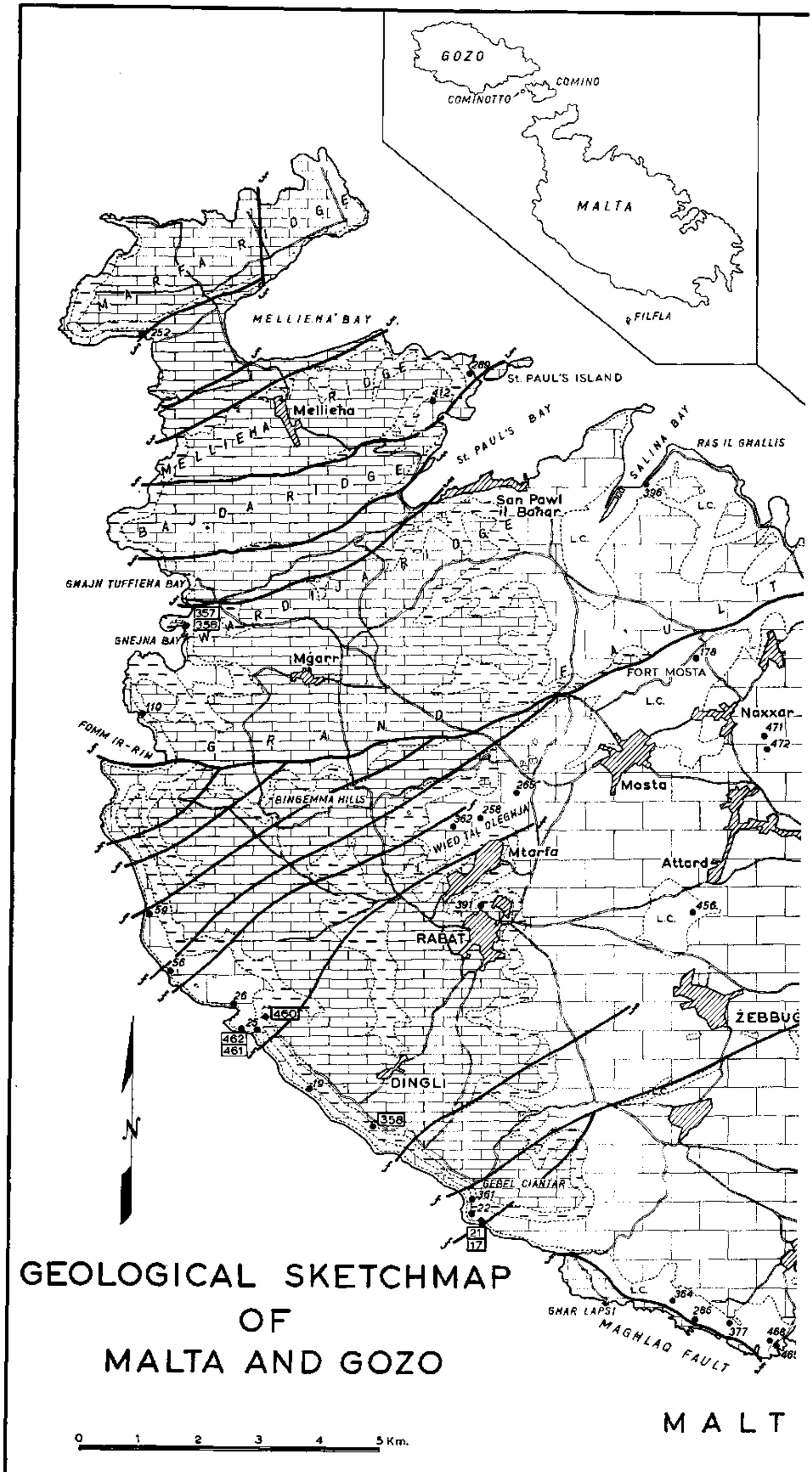
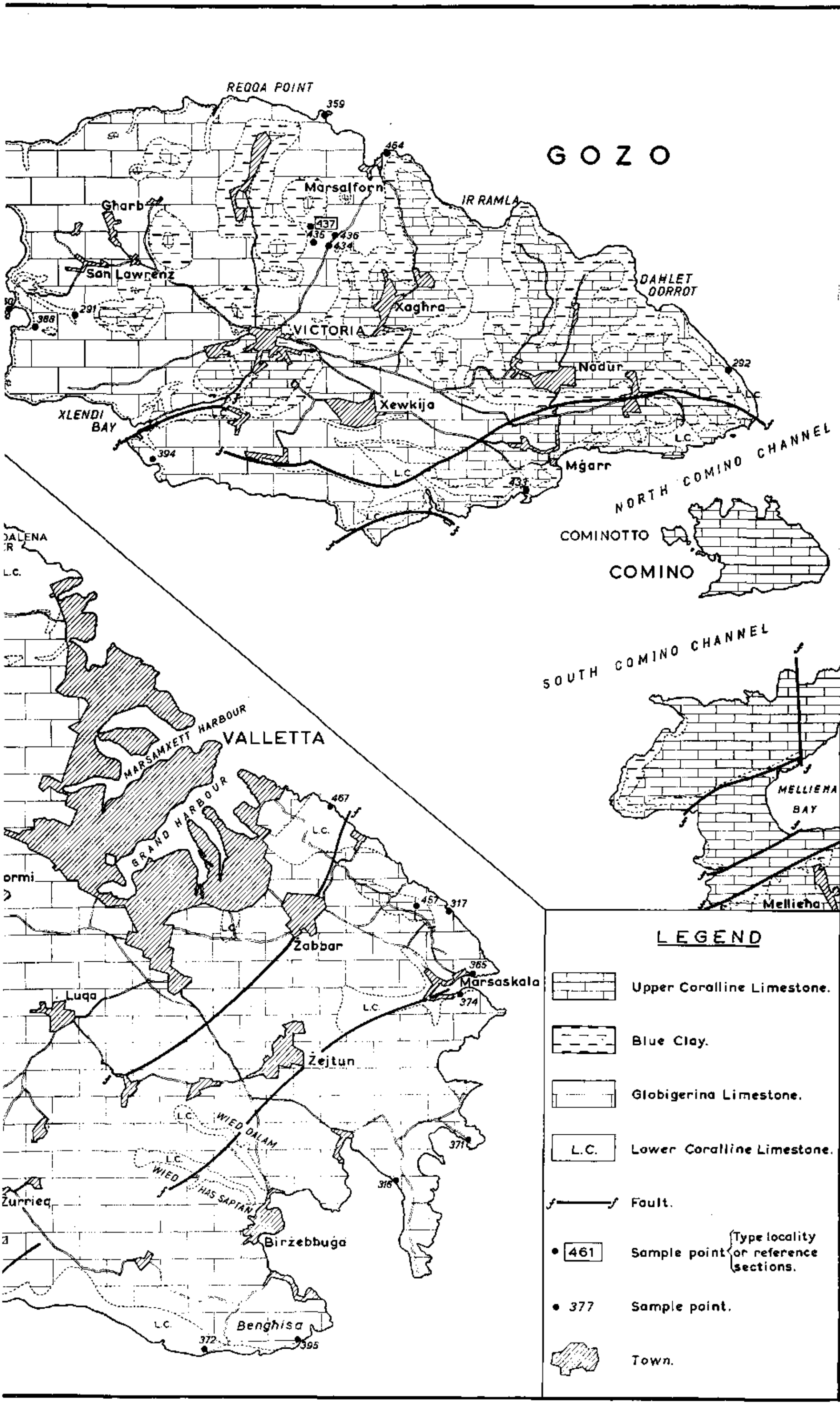


FIG. 1. Geological sketchmap of Malta and Gozo


GOZO
REQQA POINT
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464
Marsalforn
IR RAMLA
Gharb
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435
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San Lawrenz
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QORROT
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LEGEND
Upper Coralline Limestone.
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Globigerina Limestone.
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Fault.
461
Sample point
Type locality or reference sections.
377
Sample point.
Town.

1. INTRODUCTION

1.1. General remarks

The subject of this paper is the marine Tertiary sediments of the Maltese Islands and their foraminiferal faunas. They were thought to enable some refinement of Oligo-Miocene stratigraphy in the Mediterranean. In addition some specific problems of Maltese stratigraphy deserved special attention such as:

1. The environmental history of the sedimentary sequence, with the Globigerina Limestone in between two coralline limestones. The latter units are likely to be of shallow water origin, whereas the Globigerina Limestone by its name and its phosphatic pebbles (Murray & Renard, 1884; Murray, 1890) suggests a considerable depth of sea during its deposition.
2. The remarkable order of occurrence of *Orbulina* and *Miogypsina*, reported by Blow (1957).
3. The question whether the Lower Coralline Limestone of Malta and the Ragusa Limestone of Sicily are synchronous deposits of Aquitanian Age, formed on the same platform (Eames et al., 1962).

The Maltese marine deposits were studied in the field during the summer seasons of 1960–1962 and in the spring of 1965. Laboratory work was carried out at the Department of Micropaleontology of the State University of Utrecht, The Netherlands. The collected samples and the figured specimens are stored in the collection of the same department. Localities on Malta are labelled with M, those on Gozo with G and on Comino with C.

The Maltese Islands form a small archipelago in the Mediterranean Sea between Sicily and North Africa, about 100 kilometres S of the southeastern tip of Sicily and 270 kilometres N of Africa. The states of Tunisia and Libya lie W and S of the islands respectively.

Malta is the main island of the group that consists furthermore of Gozo (Ghawdex), Comino (Kemmuna), Cominotto (Kemmunett), St. Pauls Island (Selmunett), Filfia and several more small islands and isolated rocks (see fig. 1). The names between parentheses are the Maltese names. The geographical names used in this paper are those from the topographic maps 1:31,680 (1958) and 1:25,000 (1962).

The island group is situated along an axis with a NW-SE trend, extending over a length of about 44 kilometres. The total area of land equals about 315 square kilometres. The islands are the subaerial elevations at the southern tip of a shallow marine ridge that extends in a southerly direction from the coast of southeastern Sicily. The maximum depth of this submarine connection between Sicily and Malta is about 180 metres.

The shape of the islands is strongly influenced by the different types of rocks of which they are built. Five rock-units are distinguished after our field work and following the earlier literature (SPRATT, 1843; MURRAY, 1890) (See fig. 2, 3).

They are from top to bottom

Upper Coralline Limestone,	algal and detrital limestone
Greensand,	calcareous and glauconitic sand and glauconitic clay
Blue Clay,	dark marine clay
Globigerina Limestone	marly limestone with chert, hardgrounds and pebble beds
Lower Coralline Limestone,	algal and detrital limestone.

At the highest point of the islands, near Dingli on Malta, these rock-units attain a combined thickness of about 240 metres from sea level upwards.

In addition to these marine formations Quaternary terrestrial deposits are present at some places.

The high regions and hills in the western part of Malta and on Gozo are capped by the rather hard Upper Coralline Limestone. Where erosion broke the limestone surface into isolated patches, table mountains and buttes developed. Especially on Gozo well developed buttes can be observed. The softer, marly, Globigerina Limestone forms undulating plains, mainly on Malta, whereas the Blue Clay and Greensand are encountered mostly in slopes protected by a cap of Upper Coralline Limestone. The Lower Coralline Limestone is especially found in the inaccessible escarpments along the seafront of the southwestern coast of Malta and Gozo.

The surface of Malta and Gozo shows a slight dip in a northeastern direction. Consequently most river systems drain to the north and northeast. Only along the eastern coast of Malta, and in a narrow strip along the southwestern and western coasts of Malta and Gozo, some minor drainage systems exist in eastern and western directions respectively.

The islands have a Mediterranean type of climate. Nearly all precipitation falls between September and May, the rest of the year is extremely dry.

At present the river courses on the islands carry no water during a considerable part of the year. To catch the run-off and for infiltration purposes dams, or a series of dams, have been constructed across suitable valleys. Fresh water for domestic and industrial purposes is extracted from two levels, the so-called Upper Water Table in the Upper Coralline Limestone of the higher regions and the Lower Water Table in several formations at or just above sea-level (see chapter 3).

1.2. LITERATURE

The literature about the geology of the Maltese Islands can be traced back to the middle of the seventeenth century. A compilation and bibliography of most of the earlier work has been given by HYDE (1955).

SPRATT (1843) is the first to give a subdivision of the Maltese strata in a more 'modern' way. From top to bottom this informal lithologic subdivision consists of a numbered series ranging from 1 to 4 (see fig. 2). FORBES (1843) gives a list of fossils found by SPRATT. The authors do not try to place the Maltese strata in a geological time-scale.

MAYER-EYMAR (1858) places the Maltese limestone with a question mark in his Mainzische Stufe. Several years later DUNCAN (1864) and JONES (1864) try to make correlations from Malta to the West Indies by means of larger foraminifera, i.c. *Lepidocyclina*. This is the first correlation attempt from Malta to a region outside Europe.

FUCHS (1874, 1876) is the next author to make correlations. His thorough knowledge of the Mediterranean area and his acquaintance with many European type localities make his correlations very reliable for that time. He divides the Maltese strata into two larger parts (see fig. 3), Leithakalkstufe and Bormidien (FUCHS, 1874), and gives a name to each smaller rock-unit (see fig. 2). These names are either purely lithological or identical with the name of a type of sediment known to him elsewhere. Bormidien is used as an equivalent of the Aquitanian in the sense of MAYER. It is not used in the sense of the Bormidian

Spratt, Forbes (1843)	Fuchs (1874)	Godwin (1880)	Murray (1890)	Gregory (1891)	Cooke (1896)	Felix (1973)
No.1 Coral limestone	1 Leithakalk = Upper limestone out.	A Upper or Coral limestone I	Upper 1 Coralline Limestone			Upper Coralline Limestone
No.2 Yellow sandstone and blue clay	2 Grünsand und Heterosteginakalk	B Yellow and black or green sand intermixed (Yellow sandstone)	2 Greensand	Greensand		Greensand
	3 Badner Tegel = Marl out.	C II Blue Clay or Marl	3 Blue Clay	Blue Clay		Blue Clay
No.3 Freestone	Pectenschichten von Schio 4 = Calcareous sandstone out.	D White sandstone E Reddish, yellow and grey sandstone F III Pale yellow sandstone G Chocolate coloured nodules, teeth, shells etc H Yellow sandstone	Globigerina 4 Limestone	Upper Globigerina Limestone	A A ferruginous argillaceous freestone B First seam of phosphatic nodules C A fine-grained, blueish freestone D Second seam of phosphatic nodules with smaller seams above and below E Fine-grained limestone with several bands of phosphatic nodules locally developed F A massive compact limestone with chert nodules	Globigerina Limestone
				Lower Globigerina Limestone	G Third nodule seam H A variously textured limestone with phosphatic nodules sparsely distributed I Fourth seam of phosphatic nodules	
No.4 Semi-crystalline limestone	5 Unterer Kalkstein = Inferior limestone out	I IV Lower or semi-crystalline limestone	Lower 5 Coralline Limestone			Lower Coralline Limestone

FIG. 2. Previously used lithostratigraphic names

of PARETO (1865) (= Tongriano and Stampiano of SACCO (1888)) and VERVLOET (1966, p. 35), or BLOW and SMOUT (1968). The deposits of Bazas and Mérignac, the 'Oligocaene Meeresmolasse' in Bavaria, and possibly the Sotzka Schichten as well, are all thought to be equivalents by FUCHS (1874).

Two years later FUCHS (1876) considers the name 'Badner Tegel' for his 'Marl' (see fig. 2) less well chosen. The 'Marl' is then thought to have greater affinities to the Schlier of the Vienna Basin (Ottnang, Laa), especially so because of the occurrence of '*Nautilus aturia* BASTEROT' that probably would be lacking in the real 'Badner Tegel' and in the layers of Tortona which he regards as being of the same age. His correlations have been based on many fossil pelycypods (especially pectinids), gastropods and brachiopods. Echinids and foraminifera are mentioned only in the context of the *Scutella* layer of his Inferior Limestone.

In his article about the so-called 'Badner Tegel' on Malta (FUCHS, 1876), he gives a list of 30 species of foraminifera identified by VON HANTKEN. FUCHS distinguishes the Upper from the Inferior Limestone by using pectinids and

De Stefani (1913)	Vaufrey (1929)	Trechmann (1938) & Bather	Roman & Roger (1939)	Felix (1937)
7 Calcari superiori a Nulliporae	V Calcaires supérieurs coralliens à Nullipores	Upper Coralline Limestone	Calcaires coralliens supérieurs	Upper Coralline Limestone
6 Sabbie verdi	IV Sables glauconieux à Globigérines	Greensand	Grès verts	Greensand
Argille turchine 5 superiori 2 inferiori	III Argile bleue à Ptéropodes	Blue Clay	Argiles bleues	Blue Clay
4 Marne a Globigerinae	II Calcaire à Globigérines	Globigerina Limestone	Calcaires à Globigérines: supérieurs moyens inférieurs	Globigerina Limestone
Calcari inferiori 3 a Nulliporae, 1 di Ras il Kala Amphisteginae e Orbitoides	I Calcaire coralliens inférieurs à Amphistegina et Orthophragmina	Lower Coralline Limestone	Calcaires Nullipores Inférieurs	Lower Coralline Limestone

FIG. 3. Previously used chronostratigraphic correlations

Formations	FUCHS (1874)	COOKE (1891)	GREGORY (1896)	DE STEFANI (1913)		TRECHMAN (1938) & BATHER	ROMAN & ROGER (1939)	EAMES et al. (1962)	FELIX (1973)
Upper Coralline Limestone			Tortonian 7			Tortonian Upper Miocene	Vindobonien ——		Tortonian
——			——	Elveziano		——			
Greensand	Leithakalk- stufe	Helvetian	Helvetian 6			Helvetian Middle Miocene	Helvétien		——
——		——	——	——		——	——	Burdigalian	
Blue Clay		Langhian	Langhian	5 Langhiano con passagio al Tortoniano	2 Tortoniano con passagio al Langhiano	Schlier	Burdigalien supérieur		Serravalian ——
——	——			——		——			Langhian
Globigerina Limestone	Bormidien	——	—— 4 Aquitanian	Langhiano ——		Burdigalian —— Aquitanian	Burdigalien inférieur ——		—— Burdigalian ——
——			——			——		——	Aquitanian ——
Lower Coralline Limestone	(= Aquita- nian)	Aquitanian	Tongrian	3 Elveziano	1 Aquitaniano ad Elveziano	Tongrian Oligocene	Aquitanien	Aquitanian	Chattian

points out that predecessors were unable to do so because they probably mixed up several species of *Pecten.*

In 1880 the Reverend GODWIN summarizes the knowledge of the natural history of the islands; he uses an emended SPRATT subdivision.

The geology and stratigraphy of the Maltese Islands become more widely known in the second half of the nineteenth century and so SUESS, in his famous textbook for geologists (1880, 1921), can give a picture of one of Malta's big faults, the Maghlaq Fault on the southwestern coast.

MURRAY (1890) presents the first more extensive list of foraminifera for the Maltese formations, to which he gives the names that are still in use today. His article is accompanied by a geological map, one of the few available, and an extensive bibliography. MURRAY does not give an opinion on the position of the formations in the geological time-scale; he only mentions the opinions of his predecessors.

During his visit to Malta, MURRAY stimulated COOKE, a local resident to continue his geological work on the Maltese Islands. And not in vain: from 1891 to 1896 COOKE publishes a dozen articles, mostly about the Blue Clay, Globigerina Limestone and the Pleistocene sediments. In 1896 he publishes a division of the Globigerina Limestone into nine beds and three parts (see fig. 2) with an accompanying list of fossils (COOKE, 1896–2).

In the meantime GREGORY (1891, p. 633) stipulates that, before any correlation can be attempted, the fauna has to be studied with greater care. He thinks only foraminifera and echinids useful, especially the latter, on grounds of the careful collecting of COOKE. On evidence from echinid faunas, GREGORY considers the Lower Coralline Limestone to be of Tongrian Age (see fig. 3), comparable with the Calcaire à Astéries in the Aquitaine basin and with the deposits of Castelgomberto in the Vicentin. He attributes a Tortonian Age to the Upper Coralline Limestone (see fig. 3) because of 'its superposition to the Helvetian and the agreement of its fossils with those of the Leithakalk as shown by Herr Fuchs' (GREGORY, 1891, p. 635).

LEMOINE and DOUVILLÉ (1904) in their monograph on the genus *Lepidocyclina* GÜMBEL, refer again to the work of JONES (1864). They consider the Lower Coralline Limestone to be of Aquitanian Age. R. DOUVILLÉ (1906) describes the *Lepidocyclina* of Marsaskala, while H. DOUVILLÉ (1926) mentions *Lepicocyclina elephantina* from Malta and Albania. Both authors have decided on an Aquitanian Age for the Lower Coralline Limestone.

DE STEFANI (1913) gives a different subdivision (see figs. 2, 3) on grounds of his disbelief in faults (1913, p. 5): 'è per ispiegare la presenza dei calcari nelle colline di Gargur, Nasciar e Musta, a destra del Uied il Ghasel, calcari che egli (MURRAY) crede sottostanti alle argille e marne ora indicate, suppone la cosi detta Grand Fault di Malta, per la quale il lato N-O dell'isola si sarebbe abbassato di fronte alla massima parte di S-E.'. He distinguishes two clayey formations and two lower limestone formations and remarks that this is not a theoretically expected result (1913, p.58): 'Questa successione, come già ho dimostrato altrove per tante altri regioni, no è quella teoretica, la quale supporebbe il passaggio, dal basso all'alto, del Langhiano, all'Elveziano, al Tortoniano'.

VAUFREY (1929) visits Malta mainly for its Quaternary fossils but also gives a subdivision of the strata, which is nearly identical to that of MURRAY (see fig. 2).

TRECHMANN (1938) describes the Quaternary conditions in Malta and gives a lithostratigraphical subdivision with a time correlation by BATHER (no bibliographical reference) (see figs. 2, 3).

An article on pectinids with a comprehensive description of the species occurring on Malta is published by ROMAN and ROGER (1939), as a completion of the work of COTTREAU (1913) on the echinids. Based on the pectinids they give a chronostratigraphic position to all the Maltese formations (see figs. 2, 3).

The lithology of the Maltese strata is described by MORRIS (1952) who considers the stratigraphy only so far as it applies to the water supply.

HYDE (1955) publishes his compilation work 'to make the geological phenomena of the Islands ... understandable to anyone who is interested in this science'.

A new transatlantic correlation, again Malta-West Indies, has been made by BLOW (1957) by means of planktonic and larger foraminifera. He does not attribute all the strata present to a time unit. His main interest lies in the Lower Coralline Limestone with its joint occurrence of *Miogypsinoides complanatus* and *Miogypsina irregularis*, followed 'without unconformity' by the Globigerina Limestone with *Orbulina*. The same relation of species is reported from southwestern Sicily. EAMES and CLARKE (1957), in a paper immediately following, state that *M. complanatus* occurs together with *Orbulina* in the Upper Aquitanian of 'two areas of the Mediterranean region' probably referring to Malta and Sicily. EAMES et al. (1962) refer to these publications when discussing the Mid-Tertiary stratigraphy. For Maltese stratigraphy their remark on 'indigenous' *Miogypsina* above the *Orbulina* datum in a well at Zabbar (p. 29) is of extreme importance. The same was found in a well at Vittoria in Sicily. Although not expressed explicitly, a contemporaneity is suggested of the *Miogypsina* bearing parts of the Lower Coralline Limestone and the Ragusa Limestone.

A general review of the geology of the islands is given by HOUSE, DUNHAM and WIGGLESWORTH (1961).

An excellent geological map has been published, based on the field work of BP geologists (Malta geological 1957, 1: 31, 680); except for some details ours cannot be but a repetition.

LAGAAIJ (1968, 1969) refers to Malta while dealing with the bryozoan species *Nellia oculata* BUSK.

On the basis of my sample collections details have been published on the *Planorbulinella larvata* lineage by FREUDENTHAL (1969) and on the *Uvigerina melitensis* lineage by MEULENKAMP (1969).

Besides more general stratigraphical work, a long series of articles has been published on the fossil vertebrate fauna of the Maltese Islands, especially about the Quaternary birds and mammals, among which the pigmy elephants and dormice belong to the best known. Reference to most of these articles can be found in the bibliographies of MURRAY (1890), VAUFREY (1929), HYDE (1955) and DE BRUIJN (1966).

After finishing the manuscript, I received the paper of GIANELLI and SALVATORINI (1972) on the biostratigraphy of the Globigerina Limestone, which is referred to the interval Aquitanian-Langhian.

1.3. ACKNOWLEDGEMENTS

The completion of this thesis involved the help of many persons to whom I am greatly indebted.

I owe a great deal to the encouragement, positive criticism and support of C. W. Drooger, which helped me to keep going the discontinuous process resulting in this text.

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The support of my parents and my wife enabled me to start and complete this study.

2. GEOLOGY

2.1. Introduction

Because of the great amount of geological work done in Malta before I started my investigation, it is considered appropriate to have a general geological chapter preceding the more detailed ones on stratigraphy and paleoecology. This general chapter will contain an intricate mixture of my observations and relevant data from the literature.

2.2. Regional situation

Bathymetric charts of the area between Sicily and Africa show the presence of a shallow platform between the island and the continent. This platform has an average depth of about 90 metres below sea-level. Depressions with a northwest-southeast strike and depths to over 1500 metres are found along the SW side of the Maltese Islands extending NW (Hyde, 1955, p. 28; Pannekoek, 1969, Pl. I). North and east of the islands, there is a shallow platform of less than 90 metres deep, that extends to the region south of the Sicilian coast, except for a transecting channel. The maximum depth of this channel is no more than about 185 metres. The shallow platform is striking NE-SW with spurs in a southeasterly direction on its eastern side.

The NW-SE and NE-SW directions are probably due to tectonics. Roughly the same directions are found in the strike of some of the faults on the islands. The axes of the islands and of the entire archipelago are oriented along a NW-SE line as well. The isobaths of 185 metres (100 fathoms) at the western and eastern sides of the archipelago run roughly from N to S, a trend that recurs in the orientation of the axis of an anticlinal structure crossing Malta (see below) and in the western slope of the Ionian basin along the east coast of Sicily and further southwards.

Structural interpretations of the Mediterranean basins generally bypass Malta and Gozo and concentrate on the larger topographical units in their vicinity, Sicily and North Africa. In recent literature (van Bemmelen, 1969; Ritsema, 1969) it is stated that the Calabrian arc shoves in ESE direction over the Ionian block. The line of overthrust would pass through Mount Etna, separating the major northern part of Sicily from the southern part, the Ragusa platform. In the interpretation of Pannekoek (1969), the Maltese Islands and southeastern Sicily belong to the same unit, the stable Mesozoic foreland. In which way the Sicilian fault that cuts off the Ragusa platform, would be related to NE-SW trending (transcurrent?) fault systems in Tunesia and eastern Algeria across the stable Malta platform, is open to speculation. Anyway, the predominant ENE-WSW oriented fault-and-joint systems of Malta and Gozo show roughly the same direction.

The Maltese Islands are situated in an area with positive anomalies of up to 25 mgal (HOFMAN, 1952). Both in the north and in the south the Maltese area is bordered by a region with negative anomalies down to 25 mgal. The latter regions are the only places with negative anomalies between Sicily and North Africa. The northern region, the smaller, is situated N and NW of the Maltese archipelago, the southern region S and mainly SE of the islands. Both are elongated areas along an E-W exis.

2.3. MALTESE STRUCTURES

2.3.1. *General remarks*

Structurally the area can be divided into three parts. Along the NW-SE striking axis of the archipelago the two outer parts, Gozo and eastern Malta, form elevated areas as compared with the lower lying central part, Comino and Malta N of the Grand Fault. The outer parts each form a hardly dissected block, whereas the central part consists of a series of narrow blocks, forming a horst and graben system with occasional synclinal drag-folding (see fig. 1).

Throughout the islands, but especially on Malta, the strata, in general, show a slight dip to the northeast. This causes the oldest strata to be exposed mainly along the southwestern coast in high and steep cliffs. In contrast the north-eastern coastal area is low with wide bays and deep inlets, particularly so in the area of horst and graben structures of northern Malta.

2.3.2. *Faults and joints*

Faults are the main tectonic phenomena in the islands. They have one property in common: as far as can be ascertained all of them are vertical or subvertical. According to their strike a differentiation into three groups can be made:

1. NE-SW striking faults
2. ENE-WSW striking faults
3. NW-SE striking faults.

2.3.2.1. NE-SW striking faults

This group is most important on Malta E of the Grand Fault (see MALTA Geological, 1957). The Grand Fault crosses Malta from Fomm ir Rih on the western coast to Maddalena Bay on the northeastern coast (see fig. 1). The faults of this group can best be observed in the field along the southwestern coast of Malta. The longitudinal axes of Grand Harbour and Marsamxett Harbour, bordering Valletta, also correspond to this direction. As far as can be deduced from the slickensides no horizontal movements occurred along the fault planes in the final phases of movement. The downthrow of the faults generally is rather small, varying between some centimetres and about 15 to 20 metres.

2.3.2.2. ENE-WSW striking faults

The predominant strike of the faults on Gozo and Malta north of the Grand Fault is ENE-WSW. The Grand Fault itself belongs to this group (see fig. 1).

The parallel faults of this group divide the northwestern part of Malta and the area between Malta and Gozo in a horst and graben system. The horsts are from N to S, Comino, Marfa Ridge, Mellieha and Bajda Ridge, and Wardija Ridge. The downthrow at the faults of this group varies between 65 and some 120 metres. The Grand Fault has a downthrow of about 90 to 150 metres. HYDE (1955) mentions a downthrow of 200 feet for the Grand Fault, while HOUSE et al. (1961) conclude a downthrow of 300 to 600 feet.

2.3.2.3. NW-SE striking faults

In number this is the least important group to be observed on the Maltese Islands. Faults belonging to this group occur both on Malta and Gozo.

Generally they have a small extension and run between two parallel faults of other groups (MALTA Geological, 1957).

The most conspicuous example of this group is the Maghlaq Fault (see fig. 1), S of Qrendi, along the southwestern coast of Malta. It has a downthrow of 180 to 200 metres. HYDE (1955) and HOUSE et al. (1961) give somewhat different figures, 200 feet and 800 feet respectively. Along this fault, a strong upward drag can be seen near Torri Hamrija (M286). It is very likely that the southwestern coast of Malta with its steep cliffs is due to the invisible continuation of the Maghlaq Fault, running off shore probably from Benghisa in the southeast to at least Fomm ir Rih. In addition to the narrow strip near Qrendi, the islet of Filfla (see outline map on fig. 1) is the only other part of the archipelago S of this fault. Other faults of this group have a maximum downthrow of 20 metres.

2.3.2.4. Joints

The directions of the strike of joints in the Maltese strata show the same directional categories as those of the faults. In the Upper Coralline Limestone of the Bingemma Hills, along the western part of the Grand Fault (see fig. 1), the pattern of joints can be seen in the field as low ridges of some centimetres in height. The limestone of these ridges is more dense and less apt to wear off than the bedded limestone in between. The cementing of calcium carbonate evidently was deposited from water, most probably moving upwards for most of the time. In the Maltese area, evaporation is greater than precipitation during the greater part of the year, so capillary rise and consequent evaporation is common for long periods.

2.3.2.5. Remarks

With the exception of Maghlaq Fault and the Grand Fault, including the system of parallel faults on northern Malta, faults in the Maltese Islands have a small downthrow. Their downthrow ranges from about 60 metres to some centimetres, merging into joints without obvious displacement. It seems likely that faults and joints are genetically related, possibly having originated under the same conditions of shearing stress. If so, this might explain the (sub)-vertical fault planes along which displacement is only of the normal type. As far as appears from the directions of observed slickensides, all movements have been in a vertical sense. Movements along the faults continued until in sub-recent times. This is demonstrated most clearly in the outcrops situated along the Maghlaq Fault (see fig. 1, southern coast of Malta). Here Quaternary conglomerates cling to the slickensided face of the fault. On the other hand, at least part of the joint and fault system may be of nearly synsedimentary origin as can be concluded in several exposures. In the bed of the Wied tal Qlejgha, north of Rabat on Malta, pebbles of the small pebble type of the Globigerina Limestone (see 3.3.2.2.) were found in a fracture at a distance of at least 1.50 metre below the nearest pebble-bed. On Gozo near Dwejra, on the western coast (G388, fig. 1) a similar outcrop was found (see also 3.3.2). These phenomena suggest non-depositional periods during which the Globigerina Limestone was consolidated up to the surface. Evidently the sediment of the pebble-beds was deposited over these surfaces and filled open fissures that had formed after consolidation and before the sedimentary cover was laid down. As far as could be ascertained these cracks follow the joint pattern, but in detail their course appeared to be rather irregular.

2.3.3. *Folds*

Folding of the Maltese strata is of a subordinate significance. Some drag-folding can be observed near fault planes and small local folds occur in slumped material.

2.3.3.1. Anticlinal structure

One larger anticlinal structure traverses Malta in a N-S direction from Ras il Ghallis, north of the Grand Fault, to Ghar Lapsi, south of the Maghlaq Fault along the southern coast (see fig. 1). The fold-axis dips in a northern direction, the anticlinal flanks show a slight dip. On the crest of the anticline three 'domes' are located, near Naxxar, just south of the Grand Fault, near Zebbug and near Ghar Lapsi, but north of the Maghlaq Fault. Again, a synsedimentary structure is suggested because west of this anticline all formations are represented, whereas on the east side Blue Clay and Greensand are lacking (see fig. 1). However, in the east erosion may have removed such formations, but near Zabbar (M457, eastern Malta, San Anard, fig. 1) we find the Upper Coralline Limestone immediately on top of the Globigerina Limestone.

2.3.3.2. Drag folds

The best example of drag folding can be observed along the southern coast of Malta at the Maghlaq Fault (see fig. 1). Near Torri Hamrija (M286), the layered Quaternary deposits on the sea side of the fault show a strong drag, increasing towards the fault from about 25 degrees up to the vertical with a local tendency to overturning.

A less pronounced example is to be seen at Fomm ir Rih (western Malta, see fig. 1) where the Grand Fault is exposed in the sea cliffs. In the cliffs north of the fault a well developed synclinal structure is exposed, showing upward drag of the southern flank.

2.3.3.3. Minor folds

In the deposits of the Upper Coralline Limestone small folds occur due to slumping. A good exposure is along the Rabat-Mtarfa road on central Malta (M391, fig. 1). Slumping structures do exist in the Lower Coralline Limestone as well, but they are difficult to observe because of the inaccessibility of the outcrops.

2.4. Structural history

As will be seen from the following chapters Oligo-Miocene sedimentation occurred intermittently on a stable near-horizontal platform.

It is unknown at which time the joint-and-fault system came into being. Its presence already seems well established during the deposition of the Globigerina Limestone (see 2.3.2.5 and 3.3.2.2).

During or after the deposition of the Lower Coralline and Globigerina Limestones, a north-south trending anticlinal warping developed with an axis crossing the area which is occupied by Malta today. The rise of this structure continued for some time after the deposition of the Globigerina Limestone causing a thinning from W to E of the Blue Clay and the Greensand towards the axis of the anticline. Yet, on the western side of the anticline all five formations are represented, but on the eastern side the Blue Clay and Greensand are lacking, while the Upper Coralline Limestone is restricted to a limited area around San Anard (M457, eastern Malta, near Zabbar, see fig. 1), northeast of Zabbar. In a post-depositional period the area was tilted to the northeast and the horst and graben system came into being. Relative vertical movements have been going on to historic times. It is reasonable to suppose that activity along the NW-SE directed faults is fairly recent, possibly as late as Quaternary time. This would be shown at Maghlaq Fault and it would explain the distinct expression of this direction in the submarine topography on the platform.

3. LITHOSTRATIGRAPHY

3.1. INTRODUCTION

The names of the successive lithostratigraphic units in Malta and Gozo, as used in this paper (see 1.1, 1.2, figs. 2, 3) have become well established in the literature since MURRAY (1890). Although these names are not in full accordance with the International code on stratigraphic terminology (1960, 21st Int. Geol. Congress Norden, Copenhagen, vol. 25, p. 11, 19) I prefer to leave them as they are. Renaming them on the basis of geography probably would add to the confusion. Hence the old names are retained as purely lithostratigraphic units of formation level. For each one an appropriate type locality and section will be given, which so far has not been done.

3.2. LOWER CORALLINE LIMESTONE (MURRAY, 1890)

3.2.1. *Field data*

Type locality: Migra Ilma, about 3 kilometres SE of Dingli at the cliffs along the southwestern coast of Malta. It can be reached from Fawwara, descending at the east side of Kullana (topographical maps, 1957, 1962).

Type section: M17 & M21 (see figs. 1, 4). A continuous section from sea level to the local top of the Lower Coralline Limestone. At the top of the section the formation is overlain by Globigerina Limestone. The exposed thickness of the formation at Migra Ilma is about 72 metres. The lower part of the formation extends to an unknown depth below sea level.

Name: The name Lower Coralline Limestone was used for the first time by MURRAY (1890). Previous names are 'Semi-crystalline limestone' or 'Unterer Kalkstein = inferior limestone', others are indicated in fig. 2. The Maltese name for the Lower Coralline Limestone is Zonkor, the same as used for the Upper Coralline Limestone.

Distribution: The Lower Coralline Limestone is the lowest rock-unit to be found in the Maltese archipelago. This limestone builds the extensive and steep cliffs, with a maximum height of about 100 metres, along the southwestern coasts of Malta and Gozo. Unfortunately the accessibility of the cliffs is poor. The type section has been chosen at one of the better accessible places. The location was chosen in the Dingli area because in this region the visible formational succession is thickest.

On Malta, the Lower Coralline Limestone is exposed along the southwestern coast, mainly south of the Grand Fault (see fig. 1), along the northeastern end of the Grand Fault, around Salina Bay, in Wied Incita (M456, SW of Attard, central Malta), north and west of Zabbar, at Marsaskala and in Wied has Saptan and Wied Dalam north of Birzebuga, all in eastern Malta. Furthermore

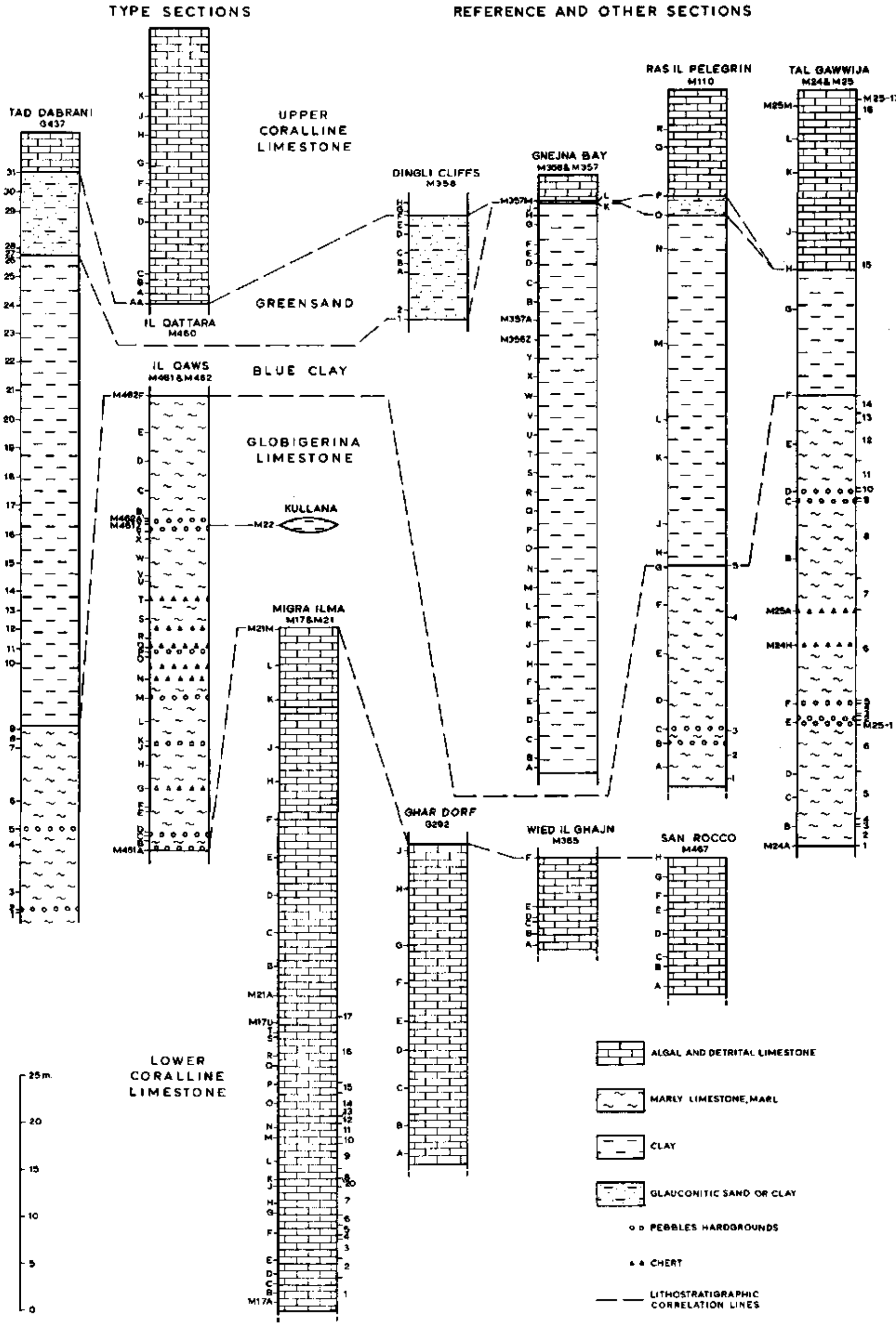

FIG. 4. Lithology of some sections on Malta and Gozo

there are several outcrops south and east of Zebbug (central Malta).

On Gozo, the Lower Coralline Limestone is exposed along the whole coast, with the exception of the stretch between Reqqa Point and Dahlet Qorrot (see fig. 1). Along the southwestern coast of Gozo it forms high cliffs.

This rock-unit is neither exposed on Comino nor on Cominotto.

Lithology: The formation consists of prevalently indurated to strongly indurated, rarely soft detrital limestones. The Lower Coralline Limestone is of a stratified nature, the thickness of the individual beds varying between some centimetres and several metres. The majority of the beds has a thickness in the order of one to two metres.

Except for the cliff-faces, the limestone is generally covered with a strongly recrystallized crust, some millimetres to some centimetres in thickness. The texture of the limestone may be coarsely granular or microcrystalline with all intermediates, depending on the original depositional properties and the degree of weathering and recrystallization.

Due to the inaccessibility of most of the cliffs and the recrystallized character of inland outcrops, I have been unable to recognize single beds within the formation that might be useful for lithostratigraphic correlation all over the island.

The lower part of the visible Lower Coralline Limestone consists of a series of beds with thicknesses varying from 50 centimetres to 3 metres. This part of the formation is well bedded and originally built up of calcareous mud with foraminifera, echinids, gastropods, algae, occasional corals and their fragments. Because of fragmentation and/or recrystallization, the majority of the fossils is beyond recognition at more specific taxonomic levels. In the lower half of the type section (M17K, see fig. 4), there is a layer of some 50 centimetres thickness in which vertical borings occur with walls consisting of a one millimetre thick layer of lime, showing small rings and pustules on the outside. The borings are filled with a dense limestone and contain the same association of fossils as the immediately surrounding rocks. Similar layers, stratigraphically not the same one, are present in quarries at Wied Incita (M456, south of Attard, Central Malta) and near Naxxar (M178, along the Grand Fault, see fig. 1). In these two quarries, they may occur at the same level, situated as they are at 6 to 10 metres below the top of the Lower Coralline Limestone.

The upper half of the exposed Lower Coralline Limestone in M21 (figs. 1, 4) and other sections shows a slight change in lithology: the limestone becomes coarser in texture.

The outcrops near the top of this formation at Marsaskala and at San Rocco (M467, east of Valletta, see fig. 1) near Fort Ricasoli, are remarkable for the big specimens of *Lepidocyclina dilatata* (10 centimetres in diameter), described already as *Eulepidina elephantina* by R. Douvillé (1906, p. 631) (see 1.2, 4.3.2, 7.3). At other places several species of larger foraminifera become rather frequent near the top of the formation (see fig. 5).

In the Dingli cliffs some irregular bedding can be seen from a distance (M358, southwestern coast of Malta, fig. 1), appearing as minor unconformities. These

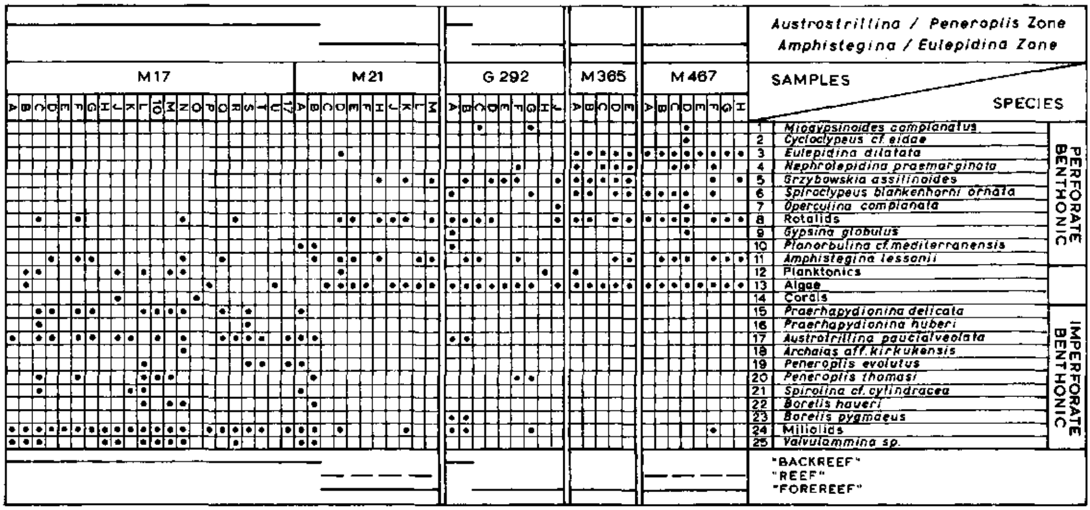

FIG. 5. Faunal elements in some sections of the Lower Coralline Limestone

unconformities have probably been caused by deposition of sediment on the slopes of reef structures. Coral reefs have nowhere been observed; 'reefs', so far as they are recognizable as such, were formed by rather pure layers of algae.

Lower limit: The lower limit of the Lower Coralline Limestone is always at sea level as far as this paper is concerned. Limestones similar to the Lower Coralline Limestone continue for at least another 600 metres downwards in wells (EAMES et al., 1962).

Upper limit: The top of the formation often consists of a bed in which *Scutella melitensis* (EAMES, et al. 1962), occurs, occasionally in such quantities that it forms a *Scutella*-breccia (G360, Dwejra Bay, Gozo, fig. 1). The echinids may occur just above the Lower Coralline Limestone as well: the *Scutella*-beds are therefore hard to place relative to the boundary. Where *Scutella* are absent, the top of the formation may be marked by a chocolate-brown hardground or by a pebble-bed (see 3.3.2.). The overlying Globigerina Limestone is less indurated, finer grained and more marly; as a result this upper limit of the Lower Coralline Limestone is nearly everywhere well discernible. Along the shore, induration may disguise the Globigerina Limestone; the texture of the rocks permits the differentiation in this instance.

3.2.2. *Sedimentary history*

The thick series of detrital and algal limestones is evidence of a shallow marine sedimentation area with negligible influence of terrigenous material. The well bedded character and the coarse texture in the higher parts suggest important wave action.

3.3. GLOBIGERINA LIMESTONE (MURRAY, 1890)

3.3.1. *Field data*

Type locality: Il Qaws, situated along the southwestern coast of Malta about 3 kilometres NW of Dingli. It can be reached from Dingli by following the road along the cliffs in a northwestern direction as far as possible. This road changes into a cart track, from which one can descend at several places to Ras id Dawwara, a small cape on which the base of the type section is located.

Type section: M461 & M462 (see figs. 1,4). These outcrops form a continuous section from the base of the formation to the local top. M461 constitutes the lower part, M462 the upper part (see fig. 4). In this section the Globigerina Limestone reaches a thickness of about 48 metres.

Name: MURRAY (1890) was the first to use the term Globigerina Limestone (see fig. 2). Previous authors referred to the formation in various ways, by giving it a number, or by calling it sandstone, calcareous sandstone, or Pectenschichten von Schio etc. (see fig. 2). The Maltese name for this rock-unit is Franka of Freestone.

Distribution: The formation forms numerous outcrops, but commonly it is covered with a thin layer of arable land. Because this formation weathers easily, it bears the greater part of the cultivated land of the islands. Moreover it underlies the major part of the urban development in this most densely populated country of Europe. For these reasons the best exposures are to be found along the coast and in steep-walled valleys. The thickness of the Globigerina Limestone varies between about 25 and 60 metres.

The Globigerina Limestone is the formation covering the greatest surface on the Maltese Islands. It is not found on the islands of Comino and Cominotto (see fig. 1). It is relatively unimportant in the western and northwestern hills of Malta and in the eastern part of Gozo. In these areas, the formation is only encountered in hillslopes, in exposures along the coast and in gullies.

Like the Lower Coralline Limestone, the Globigerina Limestone acts as a reservoir of potable water at those places where it reaches downwards to and below sea level. The fresh water of this Lower Water Table floats here on the salty water.

Lithology: The formation consists of more or less marly, fine-grained limestones, with intercalated hardgrounds, pebble-beds (nodule beds of the literature) and silicified levels with silex concretions. With the help of these intercalations the following generalized subdivision has been made from top to bottom (modified after COOKE (1896) on the basis of my own observations):

Upper {
10. Transitional layers to Blue Clay. A zone of about one metre thickness in which marly limestone gradually changes upwards into clay. Locally there are shell fragments in burrows (M110, see fig. 1).
9. White, yellow-white or bluish, marly limestone with occasional ferruginous concretions.
8. Fourth pebble seam which frequently is double.

Middle	7. Whitish or greyish, marly limestone with occasional clay lenses.
	6. White or whitish, finely laminated, marly limestone, locally silicified, or with seams of yellow, greenish or brown chert 'nodules', and occasional minor pebble seams.
Lower	5. Yellowish white, soft, marly limestone.
	4. Third pebble seam.
	3. Yellow, finely granular limestone or marly limestone.
	2. Second pebble seam.
	1. Yellow or whitish marly limestone.
	0. First pebble seam or hardground, locally with *Scutella*-breccia.

This sequence figures the standard case in which all major traceable beds would be represented on top of one another. In most outcrops however, only parts of the succession are present or one or more of the components is lacking. The 4th pebble seam may consist of two seams at a vertical distance of about one metre. The other pebble seams may show similar twinning. There may be additional minor seams in some exposures and occasional chert occurrences may be found in the lower part of the sequence (see fig. 4).

A more general subdivision into three parts is recommended for the field work instead of the sequence represented above. In this subdivision the lower unit of the formation (beds 0–5) is indurated, slightly granular and it has a yellow or reddish-yellow colour in the outcrops. The middle part (beds 6–7) is more marly, laminated, white or bluish coloured and it may strongly resemble parts of the transitional beds from the Globigerina Limestone to the overlying Blue Clay. The third and upper part of the formation (beds 8–10) again resembles the lower part: but for the exception mentioned above it has a yellow colour and it is more indurated than the middle part. Finally it should be remarked that both pebble-beds and chert are less prominent in eastern Malta.

Lower limit: The base of the Globigerina Limestone coincides with a *Scutella* breccia or with a dark brown or chocolate-brown indurated layer in which *Scutella melitensis* may be present (see 3.2.1). Occasional *S. melitensis* are present in the lowest part of the Globigerina Limestone just above the breccia or in and above the indurated layer. The *Scutella* breccia may reach a thickness of 60 centimetres (G360, Dwejra Bay, Gozo, fig. 1), it is best developed on western Gozo.

The indurated layer has a more widespread occurrence than the breccia. Except for parts of the northeastern coast of Gozo (G292, east of Nadur, Gozo, fig. 1), it was found throughout the islands at the base of the Globigerina Limestone. At places where erosion removed the overburden it appears to have a continuous, occasionally slightly undulating surface. The indurated layer itself does not form part of the Globigerina Limestone proper, but it has been developed at the top of the underlying Lower Coralline Limestone.

As a consequence, the lower limit of the Globigerina Limestone is supposed to correspond to a hardground and thus to correspond with a stratigraphical hiatus. This level strongly resembles the hardgrounds higher in the Globigerina Limestone, both in colour and in shape.

On Gozo (G394B, near Xlendi Bay, Gozo, see fig. 1), some three levels with hardground-like phenomena occur below the *Scutella*-bed, but in this exposure there is a more gradual lithological change from the Lower Coralline Limestone to the Globigerina Limestone. The limit between both formations is more arbitrarely placed here at the *Scutella*-bed. The upper part of the Lower Coralline Limestone is only slightly coarser than the sediments above the *Scutella*-bearing stratum.

In other exposures, the lower limit is generally distinct, as the Lower Coralline Limestone on the whole is coarser and more compact, the Globigerina Limestone marly and less crystalline. Only in outcrops situated at or close to sea-level, the distinction between the Lower Coralline Limestone and the Globigerina Limestone may be rather difficult owing to recrystallization.

Upper limit: The upper limit of the Globigerina Limestone can only be observed in a few exposures, which are mainly situated along the coast.

Towards the upper limit of this formation, clay lenses may occur (M22, southern flank Gebel Ciantar, southwestern coast of Malta, see fig. 4). The limit itself consists of a zone of about one metre thickness in which the marly limestone passes into marl and higher up into clay. In most exposures the overlying Blue Clay bulges over this transitional zone, thus hiding the contact. Morphologically the upper limit of the formation can be reconstructed from the upward decrease in angle of the slopes, the lower angle corresponding to the Blue Clay.

3.3.2. *Hardgrounds and pebble-beds*

In the previous literature hardgrounds and pebble-beds have never been differentiated, they have been lumped together under the name of nodule-beds. As nodules proper are commonly defined as concretionary bodies, this term is not well applicable to the Maltese phenomena. The designations hardgrounds and pebble-beds are considered preferable. Both groups are closely related.

3.3.2.1. Hardgrounds

Hardgrounds in the Maltese archipelago can be recognized by their sharply delimited upper surface that is coloured by some pigment in which calcium-phosphate compounds are predominant and aluminium and sulphur may occur as an additional constituent. The surface of the hardgrounds may be continuous or interrupted. The continuous surface is slightly undulating and shows depressions up to some 10 centimetres in depth. The interrupted surface consists of irregular rims of 5 to about 15 centimetres and more in width, which surround shallow depressions of about 5 tot 15 centimetres in depth. The top of an interrupted surface seems to be more level and flatter than the top of a closed surface, as far as can be seen in the exposures. Between the closed type and the interrupted variety with narrow rims all intermediates do occur.

The rims may be discontinuous in some places. In that case the hardgrounds cannot be distinguished from pebble-beds when seen from above. In vertical sections the difference is easily noticed because pebbles have a distinctly coloured surface all round, where discontinuity is indicated by an abrupt change in the colour of the rock, whereas interrupted rims are an inseparable part of the underlying limestone.

Below the more or less developed thin crust the thickness of the coloured layer is up to about 10 centimetres, as visible in vertical sections of the hardgrounds. The dark-brown, grey-brown or occasionally green colour fades downwards and the rock gradually obtains the light yellow or yellowish colour of the Globigerine Limestone underneath.

The depressions in the hardgrounds may be filled with a Globigerina Limestone matrix that contains organic debris, echinid remains, *Pecten* shells, shark teeth, fish remains and pebbles of the types discussed below. In the hardground exposure at Marsalforn beach in Gozo (northern coast see fig. 1), two teeth of *Mastodon angustidens* (CUVIER) were discovered (d'ERASMO, 1928). This hardground, in recent time washed clear at about today's sea level, is very beautifully developed. It consists of a hardground with overlying pebble-bed and a zone of grading.

Although one cannot exclude the possibility of a corpse of *Mastodon* floating a considerable time and distance in the sea, these elephant remains may support the hypothesis that some terrestrial traffic was possible and did occur occasionally.

3.3.2.2. Pebble-beds

Pebble-beds are more common than hardgrounds in the Globigerina Limestone.

The pebbles show two main types, flat irregularly shaped and well rounded more regular types. The flat types are the bigger, of extremely irregular shape, and about 10 to 15 centimetres in diameter with a thickness of several centimetres. The smaller pebbles vary in size between 1 to 2 millimetres and some 5 to 8 centimetres in diameter; they are mostly well rounded. The pebbles have a brown-grey outer layer and show a lighter hue of this colour inside. This coating and/or colouring of the pebbles is identical to those found in the hardgrounds. The pebbles consist of coloured Globigerina Limestone. The matrix between the pebbles consists of the normal Globigerina Limestone material which is not especially indurated, coloured or coated.

The thickness of the pebble-beds is strongly variable, any thickness between 2 to 5 centimetres and 100 centimetres may be encountered. When the top of a pebble-bed contains many pebbles they give the impression of a hardground if one looks from above, but in a vertical section it may be seen that we are dealing with pebbles that are not part of the substratum. Beds with many larger pebbles have a smooth upper limit that is well discernible in the field. Beds containing many small pebbles, with the most common pebble size between 2 and 3 centimetres, commonly have less sharp upper limits. They may show graded bedding, but absence of any regularity in pebble size distribution occurs as well.

In the pebble-beds, the pebbles may occur from closely packed to widely dispersed in a Globigerina Limestone matrix.

On top of the pebble-beds a zone occurs of up to about one metre thickness in which widely dispersed fine pebbles are present. Similar distribution patterns of fine pebbles may occur above the hardgrounds (see 3.3.2.1.). The underside of the pebble-beds is frequently sharp, it is hardly ever level or smooth, but shows small undulations and pits. Burrows of 1 to 3 centimetre diameter going downwards from the pebble-beds give the underside a very irregular appearance because they are filled with material identical to that of the pebble-beds. Some burrows can be traced downwards for some 2 metres under the pebble-bed.

If present, the grading within the pebble-beds is generally normal, i.e. coarse at the bottom and gradually becoming finer upwards. But in some Maltese outcrops (M110–2, Fomm ir Rih, western coast) an upward sequence could be observed, that goes from densely packed, to dispersed, to densely paked again, to end with a dispersed arrangement of small pebbles in the uppermost part. In vertical planes of large exposures the pebble-beds can be seen to split. In fissures, fine pebbles occur in a matrix of slightly granular Globigerina Limestone. On Gozo (G388, Dwejra Bay, western coast) a pebble-bed is exposed with floating fragments of detached Globigerina Limestone. The joints below and above this bed (there is another pebble seam about one metre higher up) are partly filled with fine pebbles. In the Wied tal Qleghja, N of Mtarfa on central Malta (see fig. 1), joints with fine pebbles were observed in the bed of the rivercourse (see 2.3.2.5.).

3.3.2.3. Chert

Especially in a rather restricted area, between the Grand Fault and Gebel Ciantar (southwestern coast of Malta, see fig. 1), the middle part of the Globigerina Limestone contains abundant chert (see figs. 4, 9).

The chert shows varieties of different colour. Most conspicuous is a dark brown chert in layers of about 25 centimetres thickness, which consist of large flattened slabs of chert lying in the plane of bedding. The irregularly shaped concretions have a diameter of about 15 to 25 centimetres. Less conspicuous is a yellow-greenish, greenish or greyish-green chert. This variety occurs as bodies of 50 to 100 centimetres in diameter in the Globigerina Limestone. The bodies commonly disintegrate into small parts. The bedding or laminations that occurs in the Globigerina Limestone may sometimes be followed across these chert bodies as they are indicated by thin black laminae. The outer part of such a body shows a gradual change from chert into marly limestone over about 5 centimetres. A third type encountered in outcrops, consists of a set of thin, partly silicified bands, occurring in a zone of about 3 metres thickness. The bands are some 10 to 20 centimetres apart.

In the sections in which most chert is present a certain type of succession could be observed. Going upwards in the rock unit, it was noticed that the lower cherts consist of yellowish-green or greyish-yellow patches of chert or of somewhat silicified parts in the marly limestone. Higher up follows a layer of dark brown chert and finally the upper cherts consist of two levels with greyish, yellow or greenish chert in laminae, in layers or in large lense-shaped bodies. It is to be noted that these chert occurrences go together with intervals of the Globigerina Limestone which are relatively distinctly laminated.

3.3.3. *Sedimentary history*

Considering the sedimentary features, described above, it may be concluded that the sequence of marly limestones that forms the Globigerina Limestone is evidently not the result of continuous quiet deposition of sediments. In the next chapters (4 and 5) this conclusion will be confirmed by biostratigraphic evidence.

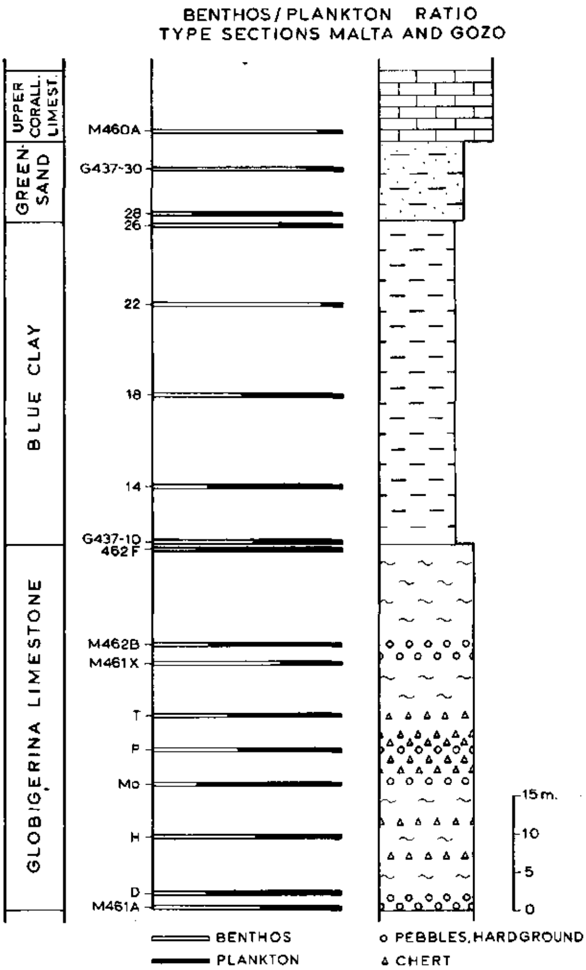

FIG. 6. Benthos/plankton ratio in the type sections

Previous authors (MURRAY & RENARD, 1884; MURRAY, 1890) suggested, or left the suggestion, that this formation was formed in a deep sea. They were lead to this theory by the presence of large quantities of tests belonging to species of planktonic foraminifera (actually not such a high percentage, see fig. 6) and by the presence of the 'nodule' beds, which were considered as typical for deep-sea sediments.

However the presence of hardgrounds and of pebble-beds containing detached hardground material, indicates that the surface of the sediments was at or close to sea-level during parts of the time that is represented by this rock unit. Evidently sedimentation was not continuous, but periods of sedimentation alternated with non-depositional intervals. It is generally supposed that hardgrounds were formed close to, at and even slightly above sea-level. In my opinion this does not necessarily imply that hardgrounds cannot develop in deep water, but in such instances one would not expect the enormous quantities of displaced pebbles.

For the Maltese sediments it is supposed that during non-depositional periods, the surface of the sediments, lying just below, at or just above sea-level, was attacked by organisms and chemical agents. The surface became indurated and of darker colour as a consequence of biochemical and chemical action which formed small pits and holes into the surface (REVELLE & EMERY, 1957).

These pits and holes gradually grew into small, flat-bottomed steep-rimmed depressions with diameters varying between 10 and 100 centimetres; the influence of wave and surf action cannot be excluded. Detached parts that remained in the environment for some time got the shape of the various types of pebbles described above (3.3.2.2.).

The originally smooth surface changed into a meshwork of hollows with narrow ridges of indurated limestone in between. Holes could develop through the ridges so that the small basins became interconnected. The ridges and rims of the basins are always coloured, but the bottom may be less coloured and even show the original colour of the parent-rock.

A similar process is still to be observed along the Maltese coasts and especially at the eastern coast at Xrop il Ghagin (M 371, east of Zejtun, see fig. 1). At this locality, the coast consists of steep cliffs in the Globigerina Limestone. At the base of the cliffs a bed is continuously exposed in a 5 degrees dipslope to sea-level. The surface of this bed shows different stages of the development of similar flat-bottomed basins. Close to the sea and sea-level the surface of this bed is very hard, recrystallized, brownishly coloured and rough, covered with flat-bottomed interconnected basins of about one square metre, bordered by steep rims. Going upwards to the base of the cliffs, the surface becomes less crystallized, the colour becomes lighter and the depressions have smaller dimensions. Finally, at about 3 metres above sea-level the pitted surface with its solution depressions changes into a slightly undulating surface. The depressions are no longer flat-bottomed nor do they have steep rims. The surface is only slightly indurated at this height. From here on, the surface of the bed changes rapidly into an ill defined parting in a normally coloured and stratified Globigerina Limestone. The change in appearance occurs between sea-level and about four metres above. This demonstrates the importance of the position of the bed relative to the sea-level: the closer to the sea, the more a hardground-like appearance. This recently formed rock surface is similar to those which were observed in vertical sections and from above on the synsedimentary hardgrounds at the base of the Globigerina Limestone along the northeastern coast of Malta, at Marsaskala, and at other places.

The pebbles of the pebble-beds were partly derived from the receding rims in between the growing depressions of the hardgrounds, partly from rocks and boulders on the Miocene shoals and/or coast of the Malta and Gozo area. The big flat pebbles were not transported far from the place of origin: they have undergone some local chemical attack which caused their irregular shape and surface. Other pebbles were broken up and consequently were developed into the well rounded more regularly shaped pebbles by rolling.

This may have happened at all places where wave and surf action did not remove them immediately to deeper environments The coating and colouring of the pebbles all around must have happened in or very close to the environment of hardground formation.

It is more difficult to reconstruct a good picture of the formation of the pebble-beds, especially because the calcareous matrix gives few possibilities for good preservation of sedimentological phenomena. Above all, the larger flat pebbles and the closely packed occurrences probably were not transported far from the place of origin, remaining at shallow depth at which wave action could wash the pebbles together and remove the finer material. However it is much more difficult to explain the beds with more widely dispersed pebbles, as some kind of lag deposit or as an insular talus deposit. Mass transport seems more plausible, although probably not going beyond an immature stage of proximal turbidites in the area involved. This might explain the frequently imperfect normal grading, the twinning, the occurrence of pebbles floating in a fine-grained matrix and the local presence of reversed grading. Likely these pebble-mud flows arrived on deeper non-depositional surfaces of Globigerina Limestone that were without well-developed hardgrounds, but which were sufficiently consolidated that the arriving pebble-mud filled hollows in the surface, open borings of organisms and even open cracks (see 3.3.2.2.). The next chapters (4. and 5.) will show that faunal breaks plead in favour of such an explanation.

As a whole, the Globigerina Limestone seems to have been formed on a relatively shallow marine platform at such a depth and/or under such conditions that reefs did not develop in the Malta area itself. Probably they did occur elsewhere on the platform at such a distance that only their fine detrital material could form an important constituent of the sediment together with the remains of the autochthonous benthonic and planktonic faunas. Shallower depth likely accounts for intermittent periods of non-deposition and formation of hardgrounds. It is not understood why reefal grow was not reinstalled during these periods.

The occurrence of gaps seems to be especially true for the lower part of the Globigerina Limestone, the first important one immediately overlying the Lower Coralline Limestone. For the higher parts the area seems to have been more open marine, with a better development of planktonic faunas. The middle part of the Globigerina Limestone shows evidence of rhythmic sedimentation, possibly of seasonal character. The chert in this part of the formation shows the increased importance of siliceous organisms, as it is commonly the case with laminated Neogene deposits in the Mediterranean.

3.4. BLUE CLAY (SPRATT, 1843)

3.4.1. *Field data*

Type locality: Tad Dabrani, a hill on Gozo, situated on the western side of the road from Victoria to Marsalforn, about one kilometre SW of Marsalforn (see fig. 1). The base of the type section is situated in the northern slope of the dry valley between the hills Ta Kuljat and Tad Dabrani starting above a small cliff some 500 metres from the main road.

Type section: G437 (see figs. 1, 4). This section forms part of a continuous exposure from the base of the Globigerina Limestone to the local top of the Upper Coralline Limestone. Before the building of a barrage in the Wied ta Marsalforn even the top of the Lower Coralline Limestone was exposed in the riverbed. After the building of the barrage the former riverbed silted up and the Lower Coralline Limestone outcrop was covered.

The type section has been chosen on Gozo because it forms part of a sequence in which all rock units were represented. A reference section with easier access is situated on Malta. This section M356 & M357 is situated at Gnejna Bay on the western coast of Malta (see fig. 1), about 2 kilometres N of the Grand Fault. It can be reached from the end of the road to Ghajn Tuffieha Bay by taking the footpath in southern direction from the hotel to Ras il Qarabba. The section is situated immediately S of the peninsula Ras il Qarabba. It is continuous from sea level to the local top of the Upper Coralline Limestone. The base of this section is not showing the lowermost beds of the Blue Clay but these are visible a hundred metres farther south. This section was not chosen as the type section of the formation because of repeated landsliding (one during the period of my observations).

Name: SPRATT (1843) was the first to use the name Blue Clay. SPRATT (1843), FORBES (1843) and FUCHS (1874) used terms like 'Marl', 'Badner Tegel' or 'Yellow sandstone and blue clay' (see fig. 2). The Maltese name of this rock unit is Tafal, which means clay.

Distribution: The Blue Clay is found on Malta and Gozo. It is easily erodable and all exposures are encountered in the vicinity of the overlying, protecting Upper Coralline Limestone except for one strip N of Mosta along the Grand Fault lying against Lower Coralline Limestone (see fig. 1). This exposure is a remnant of a former cover of Blue Clay N of the Grand Fault. Except at places where it is exposed in steep slopes or in cliffs, the Blue Clay is used everywhere for agricultural purposes.

In central and eastern Malta the Blue Clay was either not deposited or removed by later erosion. At the only place where younger formations are present, near Zabbar, the Blue Clay is lacking (see fig. 1).

This formation is important for the hydrology of the islands for it forms the impervious base of the overlying Greensand and/or the Upper Coralline Limestone, which act as the reservoir which retains part of the yearly precipitation. Its top forms the base of the so-called Upper Water Table in places where the clayey variety of the Greensand is lacking. The Blue Clay has been used also as the base for large artificial reservoirs of potable water.

Lithology: The Blue Clay consists of a sequence of rather similarly weathering layers of bluish clay. In well exposed outcrops stratification is clearly visible because of slight differences in colour of the layers. This stratification can be followed for some distance, but due to cultivation or covering by debris from overlying formations it is impossible to correlate the individual layers from one exposure to another. The Blue Clay contains a small quantity of gypsum which may occur in large crystals up to 10 centimetres length. Mostly, however, it is present as small dispersed needles of some millimetres length. The thickness of this rock unit varies between some decimetres and about 60 metres.

Lower limit: The Lower limit of the Blue Clay is not sharp. Within a vertical distance of about one metre the marly Globigerina Limestone passes into the Blue Clay. In this transitional zone burrowing may be frequent (M110, western coast, Fomm ir Rih, see fig. 1). In these burrows coarser, more granular material, resembling that of the upper part of the Globigerina Limestone, is present.

Upper limit: The upper limit of the Blue Clay is not sharp either. There is a rather gradual transition either to the Greensand or to the Upper Coralline Limestone.

The transition to the Greensand is characterized by an upward increasing quantity of glauconite in the clay. The clay becomes darker until so much glauconite is present that the colour has changed from bluish-grey or brownish to greyish-green or dark green. This transition occurs over a vertical distance of about one metre.

In the transition to the Upper Coralline Limestone, the beginning of the change is characterized by the occurrence of occasional small flakes of algal limestone in the clay. Going upwards in the lithological column, the flakes grow in diameter and they become thin patches of algal limestone. Still higher the algal limestone forms thin continuous layers alternating with thin layers of clay. At the top of this transitional zone only small isolated patches of clay are left. The thickness of this zone varies between 0.5 and 2.5 metres.

3.4.2. *Sedimentary history*

The Blue Clay is the first stratigraphical unit that bears witness to ample supply of terrigenous material to the sedimentation area, arriving in suspension. Without faunal evidence it is hard to give the reason why carbonate deposition became suppressed.

3.5. GREENSAND (MURRAY, 1890)

3.5.1. *Field data*

Type locality: Tad Dabrani on Gozo, immediately above the type section of the Blue Clay.

Type section: G437 in between the Blue Clay and the Upper Coralline Limestone (see figs. 1, 4).

On Malta, M358 in the Dingli Cliffs (see fig. 1) on the southwestern coast forms a reference section. The exposure can be reached by descending the cliffs at Maddalena Chapel, going along the path in a western direction. The section extends from the top of the Blue Clay to the base of the Upper Coralline Limestone. A narrow tunnel for irrigation purposes has been driven into the face of the cliff on top of the Blue Clay. Through a vertical shaft the top of the section can be reached. This reference section is easy to reach and is one of the biggest outcrops in the islands.

Name: SPRATT (1843) speaks about 'yellow sandstone'. FUCHS (1874) names the formation 'Grünsand und Heterosteginenkalk'. GODWIN (1880) uses the description 'Yellow and black or green sand intermixed'. MURRAY (1890) used the name Greensand which is constantly applied afterwards in English-written texts. The Maltese name for this rock unit is Ramel, which means sand.

In this paper the term Greensand is applied to rocks on top of the Blue Clay that contain visible quantities of glauconite. These rocks may be yellow-red, greyish-green, and dark green to nearly black. They can be clayey or granular calcareous.

Distribution: The Greensand is found on Malta and Gozo. It is always associated with either the Blue Clay or the Upper Coralline Limestone or both. The Greensand is well developed on Gozo and in the Dingli cliffs. If present, its thickness varies from some decimetres to about 12 metres.

This formation is not represented on the Geological sketchmap of Malta and Gozo (fig. 1) because of its extremely restricted horizontal extension from the overlying Upper Coralline Limestone.

Lithology: There are two varieties of the Greensand. If both are present in the same section there is a lower clayey sediment and a calcareous type above.

The calcareous variety of the Greensand consists of coarse, agglutinated calcareous sand with a reddish-yellow weathering colour. In this variety large echinids are present and *Heterostegina* is occasionally abundant. Burrowing structures are clearly present. In the literature the presence of rolls of *Heterostegina* has been mentioned (FUCHS, 1874). Such rolls can be observed in the reference section M358 (southwestern coast, near Dingli). Close observation shows that this peculiar phenomenon is related to the presence of burrows. The rolls of foraminifera happen to be fillings of these borings in which they were deposited in vertical or subvertical columns. The diameter of the borings is only slightly larger than or as large as the diameter of the Heterosteginids (0.5–2.0 cm) causing the specimens to lie against each other with their lateral sides, forming roll-like structures.

This granular type of Greensand shows a remarkable weathering surface in some exposures. Thin curtains of indurated Greensand hang down from the top of the exposures some centimetres to some decimetres in front of the fresh rock. Wind erosion removed the softer fresh rock from behind the indurated surface layer.

The calcareous variety is not always present. It is lacking for instance under the type section of the Upper Coralline Limestone (M460, southwestern coast of Malta, W of Rabat, see fig. 1).

If the calcareous type is present, the clayey or sandy variants are always in the lower part of the unit. The clayey variety is mostly present but it may be very thin (some centimetres) or lacking. Together with the top of the Blue Clay this variety forms the base of the Upper Water Table (see 3.4.1. Distribution).

Lower limit: There is no distinct lower limit but a gradual change from Blue Clay into Greensand (see 3.4.1.). Usually the lower limit of the Greensand is obscured by scree or by debris from its higher part or from the Upper Coralline Limestone.

Upper limit: The Greensand does not change abruptly into the Upper Coralline Limestone. A transitional zone occurs in between with a thickness of some centimetres to 50 centimetres. The top of the Greensand may change into a greenish marl or clay in which occasional thin algal layers occur. In the lower part of the transitional zone the algal flakes are not interconnected. Going upward the algal flakes become algal layers. Then small layers become thicker and closer together. The intercalating clay occurs in gradually thinning layers until only small patches remain. In the Upper Coralline Limestone the rock consists of algal or detrital limestone without any glauconitic or clayey parts. In general the transition shows a gradual increase of algal limestone and a diminishing of the glauconite and clay.

3.5.2. *Sedimentary history*

The Greensand unit gives evidence of the slowing down of the rate of deposition and reinstallment of calcareous organic sedimentation.

3.6. Upper Coralline Limestone (Murray, 1890)

3.6.1. *Field data*

Type locality: Il Qattara. The type locality is situated above the type locality of the Globigerina Limestone, at Il Qaws (see fig. 1). It can be reached along the same road (see 3.3.1.). Branching off from the cart track, a path partly hewn into the rock traverses the whole type section.

Type section: M460, southwestern coast of Malta, NW of Dingli (see figs. 1, 4). This section extends from an impervious horizon of grey clay with occasional algal layers (Blue Clay) to the top of the local topography. The total thickness of the section is about 27 metres.

Name: This rock unit is called Upper Coralline Limestone in English-written texts since MURRAY (1890). SPRATT (1843) called it 'Coral limestone', a misleading name because it consists mainly of coralline algae. FUCHS (1874) described it as 'Leithakalk = Upper limestone aut'. (see fig. 2) and GODWIN (1880) referred to it as 'Upper of Coral limestone'. For the other names the reader is referred to fig. 2. The Maltese name for the Upper Coralline Limestone is Zonkor, the same as that used for the Lower Coralline Limestone.

Distribution: The Upper Coralline Limestone is exposed on Malta, Gozo and Comino. The thickness of this rock unit varies considerably from about 1 metre on isolated hilltops to over 60 metres on Comino.

With the exception of a single exposure NE of Zabbar (eastern Malta) and two others in downfaulted blocks, along the Grand Fault at Fort Mosta (see fig. 1) and along the Maghlaq Fault SW of Qrendi respectively, all outcrops are situated west of the NS line that runs from San Pawl il Bahar to Gebel Ciantar (see fig. 1).

Lithology: The lower part of the Upper Coralline Limestone consists for the greater part of pure algal limestone, with thin intercalated layers and lenses of algal debris with echinids and *Pecten*. Going upwards in the stratigraphical column it becomes a nearly pure algal limestone, in longer sections changing upwards into detrital limestone. The highest parts are covered with a subrecent calcareous crust of several centimetres thickness. Fossils are difficult to extract from the Upper Coralline Limestone. In the higher parts they often occur as casts in a matrix of algal or skeletal limestone.

3.6.2. *Sedimentary history*

The predominant algal character of the formation indicates a return to a shallow, platform environment. Notable influence of sediment transport from a hinterland is lacking.

4. BIOSTRATIGRAPHY

4.1. Introduction

In the Maltese rocks six biozones were distinguished based on planktonics, and seven units based on benthonic foraminifera.

In the Lower Coralline Limestone, the lowest formation (see 3.2.), only a zonation by means of benthonic foraminifera could be made. The planktonic specimens encountered in the samples of the Lower Coralline Limestone were partly well preserved, partly badly so. The well preserved specimens permit reliable species determination but it is quite well possible that they were washed in from higher units. The badly preserved specimens cannot be determined reliably. In addition to indeterminable *Globigerina* specimens, *Globigerinoides* could be recognized, at least in the upper part of the Lower Coralline Limestone.

It is considered beyond the purpose of this paper to give a full account of all investigated samples and specifically determined microfossils. To give an insight in the major changes of the vertical succession of faunal associations the reader is referred to the composite range charts (figs. 5, 7, 8), based on the type sections of the lithostratigraphic units (see fig. 4). All samples are placed at equal distances. Their exact spacing can be seen in the schematic lithostratigraphic columns (see fig. 4). Additional evidence on some of the zones will be given in the text, for instance for the upper part of the Lower Coralline Limestone (see figs. 4, 5).

4.2. Zonation by means of planktonic foraminifera

In the formations younger than the Lower Coralline Limestone six biozones were distinguished by means of planktonic foraminifera. These biozones were primarily based on the forms occurring in the type sections and they were checked in the other sections on the islands. As this zonation is a local one, established with local data, it can be compared with other zonations only with care. For this reason it is thought preferable to present the successive intervals as informal zones, based on associations, so that adding to the existing confusion of formal zonal names is possibly avoided. Anyway the reader has to be careful in speculating on details of this succession. Another drawback of our zonation will be advanced in the discussion of the lowermost association.

From bottom to top I distinguish the *Globigerinoides trilobus/Globoquadrina dehiscens* association, followed by the *Praeorbulina* association, the *Orbulina suturalis* association, the *Orbulina universa* association, the *Globigerina continuosa* and the *Globigerina acostaensis* associations.

4.2.1. *Globigerinoides trilobus/Globoquadrina dehiscens association*

The lower part of the interval characterized by this assemblage shows the appearance of recognizable *Globigerinoides trilobus* and *Globoquadrina dehiscens* (see fig. 7).

The upper limit is placed just below the appearance of *Praeorbulina*. If the latter is absent the top is marked by the beginning of *Orbulina*.

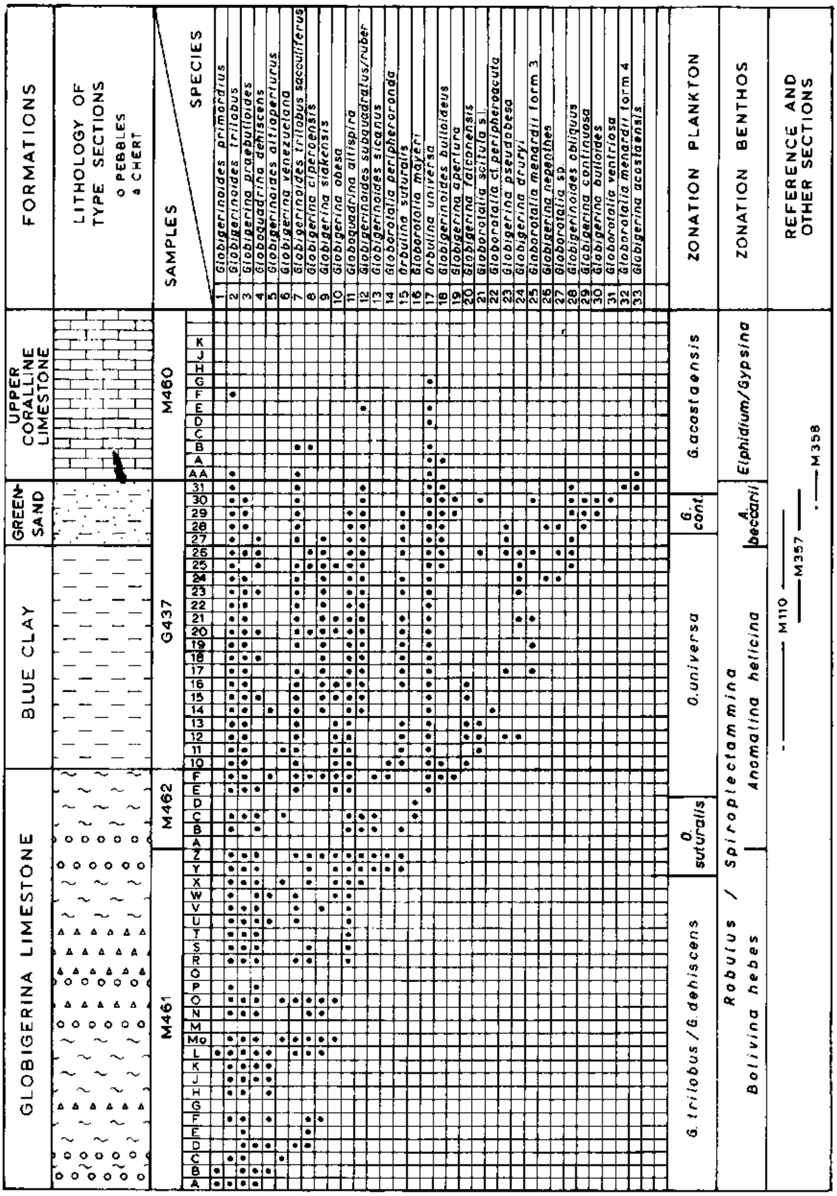

FIG. 7. Distribution chart of the main planktonic foraminiferal species in Malta and Gozo (type sections)

The assemblage as a whole contains few characteristic species among which *Globigerinoides altiaperturus* and *Globigerina ciperoensis* are noteworthy. Transitional forms between *G. altiaperturus* and *Globigerinoides subquadratus* were found in section G437 (see figs. 1, 4, 7), in the upper part of this interval below the type section of the Blue Clay (see 3.4.). The continuous occurrence of *G. ciperoensis* throughout the zone may indicate either an extended range or reworking. *Globigerinita dissimilis* did not occur in samples of this zone.

The lower limit of this interval coincides with the hardground at the boundary between the Lower Coralline Limestone and the Globigerina Limestone. The upper limit can be placed at the penultimate (third) pebble-bed in the Globigerina Limestone of the type section (see figs. 4, 7).

Subdivision within this interval might be possible but is considered to be of dubious value. If one considers the type section (see figs. 4, 7), *Globigerinoides trilobus sacculiferus* and *G. ciperoensis* seem to start their range together in M461D, the first sample above another pebble-bed. The same is true for the continuous range of *G.altispira* which starts in the middle part of the Globigerina Limestone and again above a local pebble seam.

As the vertical ranges of this association and its subunits are clearly related to the lithological features of the sediments, this confirms the opinion that the hardgrounds and the pebble-beds are indications of longer periods of non-deposition. They represent hiatuses in an otherwise continuous deposition. Zonation of this type seems to be of restricted value, the more so as it seems even not to be applicable to the entire Maltese realm.

4.2.2. *Praeorbulina association*

This association does not occur in one of the type sections and therefore it is not indicated in the distribution chart of planktonic foraminifera (fig. 7). It was only found on the island of Gozo in that part of the section G437 that underlies the type section of the Blue Clay (see fig. 4).

The lower limit is characterized by the first occurrence of members of the genus *Praeorbulina*. The upper limit is placed just below the appearance of *Orbulina suturalis*. Other species occurring in this interval are *Globigerinoides sicanus*, *Globorotalia peripheroronda* and *Globorotalia scitula*.

4.2.3. *Orbulina suturalis association*

The lower limit of the interval of this association is marked by the first occurrence of the zonal marker. The upper limit is placed just below the appearance of *Orbulina universa* (see fig. 7).

A clear depositional gap at the penultimate pebble-bed in the type section of the Globigerina Limestone (see figs. 4, 7) can be concluded from the joint first occurrence of *G. sicanus*, *G. peripheroronda* and *O. suturalis*, the former two of which are present already in the underlying *Praeorbulina* association in section G437 (see above). An irregular first appearance was observed for *Globigerina druryi*. This species appears right at the base of the association in section G437, while it is absent in the corresponding interval in section M462 on Malta (see figs. 4, 7).

The upper limit of this interval does not coincide with the lithostratigraphical boundary between Globigerina Limestone and Blue Clay, but it is situated, in the type section, in the upper part of the Globigerina Limestone, some metres below the transition (see figs. 4, 7).

4.2.4. *Orbulina universa association*

The lower part of this interval is characterized by the appearance of *Orbulina universa*. The upper limit is placed just below the first occurrence of *Globigerina continuosa*.

In the lower part of the zone forms close to *Globorotalia peripheroacuta* are present in one sample. No more highly evolved representatives of the *fohsi*-lineage were found. The monotonous fauna prevents further subdivision of this large interval.

Few characteristic species appear in this interval, among them there are some rare representatives of the *Globorotalia menardii* group. These specimens resemble members of the *menardii* succession found in southern Spain by TJALSMA (1971). They may be attributed to his *Globorotalia menardii* form 3.

The few other species appearing for the first time in this interval are *Globigerina pseudobesa*, *Globigerina falconensis* and *Globigerinoides bulloideus*. *Globigerina siakensis* meets its upper limit in the top part of the *Orbulina universa* interval.

This interval covers the entire Blue Clay. In the type section the limits of the zone do not coincide with the limits of the formation (see figs. 4, 7, 9).

4.2.5. *Globigerina continuosa association*

This interval would range from the beginning of *Globigerina continuosa* to the first occurrence of *Globigerina acostaensis*. It coincides with an ill-delimited part of the Greensand (see figs. 4, 7). In the type section of the latter unit the nominate species was found in only three samples.

Globigerinoides obliquus, *Globigerina bulloides* and *Globorotalia ventriosa* made their appearance in this interval, while representatives of the genus *Globoquadrina* disappear.

4.2.6. *Globigerina acostaensis association*

This association, the lower limit of which has been defined by the first occurrence of *Globigerina acostaensis*, has been recognized in the uppermost sample of the Greensand type section (G437–31, see figs. 4, 7) and the basal part of the Upper Coralline Limestone. The samples contained representatives of the *Globorotalia menardii* group, referable to *G. menardii* form 4, described by TJALSMA (1971) from southern Spain. A transitional form between *G. continuosa* and *G. acostaensis*, as reported by BLOW (1959, 1967), has not been observed in my samples.

Higher samples in the Upper Coralline Limestone yielded a poor fauna without *G. acostaensis*. *Orbulina universa* is the species most frequently found.

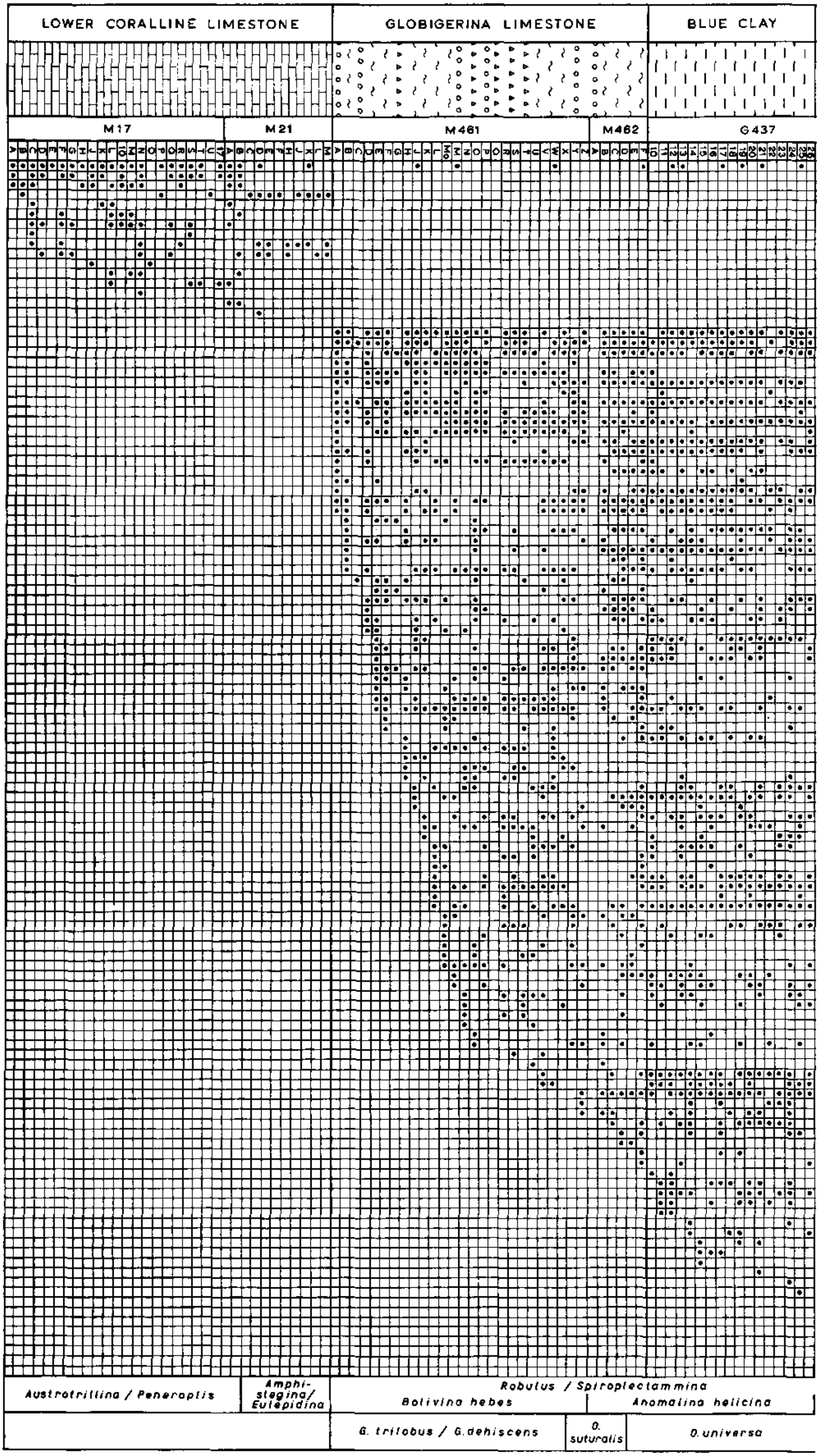

FIG. 8. Distribution chart of the main benthonic foraminiferal species in Malta and Gozo

(type sections)

4.3. Zonation by means of benthonic foraminifera

The successive thanatocoenoses of benthonic foraminifera in the investigated Maltese strata can be grouped into four zones. From bottom to top these zones are named:
Austrotrillina-Peneroplis Assemblage-zone, *Amphistegina-Eulepidina* Assemblage-zone, *Robulus-Spiroplectammina* Assemblage-zone, and *Elphidium-Gypsina* Assemblage-zone.

The *Robulus-Spiroplectammina* Assemblage-zone is divided into three subzones, from bottom to top the *Bolivina hebes* Subzone, the *Anomalina helicina* Subzone and the *Ammonia beccarii* Subzone.

The lower two zones occur in the Lower Coralline Limestone, the *Robulus-Spiroplectammina* Zone comprises the Globigerina Limestone and the Blue Clay. The topmost zone is found in the Greensand and in the Upper Coralline Limestone. This zonation is based on the type sections and other local exposures. It is not pretended to be applicable outside the Maltese Islands.

4.3.1. *Austrotrillina - Peneroplis Assemblage-zone*

This zone is characterized by the regular presence of *Austrotrillina paucialveolata*, and numerous other Miliolids, associated with *Praerhapydionina delicata*, *Peneroplis evolutus*, *P. thomasi*, *Spirolina* cf. *cylindracea* and *Borelis haueri*. Occasionally *Borelis pygmaeus* and *Gypsina globulus* are found in this zone (see fig. 5). The majority of the species of foraminifera occurring in this zone is imperforate.

The lower limit is at sea-level in the longest sections, the upper limit coincides with the disappearance of *Austrotrillina paucialveolata* from the sequence of the type section (between sample M21B and M21C; see figs. 4, 5, 8).

4.3.2. *Amphistegina - Eulepidina Assemblage-zone*

This zone appears in the type section of the Lower Coralline Limestone after an abrupt faunal change. Rotaliid species and *Amphistegina lessonii*, of subordinate importance in the previous zone, suddenly become conspicuous elements of the fauna. Also algal remains start to become numerous. Variable amounts of perforate larger foraminifera were found. Rather frequent in several outcrops (Marsaskala, eastern coast of Malta, M467, see figs. 1, 5) is *Eulepidina dilatata*, which species is often associated with *Miogypsinoides complanatus*, *Cycloclypeus* cf. *eidae*, *Nephrolepidina praemarginata*, *Grzybowskia assilinoides*, *Spiroclypeus blanckenhorni ornata* and *Pararotalia viennoti*.

The majority of recognizable species of foraminifera in this zone is perforate, in contrast with those of the underlying *Austrotrillina - Peneroplis* Zone. Recognizable algal fragments form an important part of the rock in the *Amphistegina - Eulepidina* Zone.

The lower limit of this zone is placed at the appearance of *Eulepidina dilatata* and/or the disappearance of *Austrotrillina paucialveolata*, the upper limit at the disappearance of the former species. This upper limit coincides with the top of the Lower Coralline Limestone, which is formed by a hardground in most cases (see 3.2.1.).

Between the *Austrotrillina - Peneroplis* Zone, which is thought to represent some kind of backreef facies (see chapter 6), and the *Amphistegina - Eulepidina* Zone, that mainly represents a forereef environment, a zone corresponding to a reefal facies might be expected. In fact indications of a reefal facies are found in section M467, San Rocco, east of Valletta, (see figs. 1, 4, 5). In sample M467E from this section algae are forming the main constituent of the thanatocoenoses; there are some questionable *Eulepidina dilatata*. In section M56, Tal Merhla, western coast of Malta, northwest of Dingli, sample M56AA consists of nearly pure algal limestone. But as these samples do not contain foraminifera, or do not differ in foraminiferal contents from samples of the *Amphistegina - Eulepidina* Zone they were included in this zone.

4.3.3. *Robulus - Spiroplectammina Assemblage-zone*

The regular presence of *Robulus rotulatus* and *Spiroplectammina carinata* characterizes this assemblage zone. Among the usual associated species may be mentioned *Cibicices dutemplei, C. tenellus, Bolivina antiqua, B. arta, B. reticulata, Gyroidina soldanii altiformis, Hanzawaia boueana, Eponides antillarum, Cancris auriculus, C. indicus, Nodosaria raphanistrum, N. ovicula* and *Siphonina reticulata.*

The lower limit of this zone is placed at the appearance of *Spiroplectammina carinata* and *Robulus rotulatus.* This limit coincides with the lower limit of the Globigerina Limestone. The upper limit is placed at the disappearance of *Spiroplectammina carinata* and at the first appearance of *Heterostegina costata* and *Elphidium crispum.* This upper limit is situated in the clayey facies of the Greensand near the transition into the calcareous facies (see figs. 4, 8, 9).

Three subzones are distinguished, from bottom to top, the *Bolivina hebes* Subzone, the *Anomalina helicina* Subzone and the *Ammonia beccarii* Subzone. These subzones cannot be sharply delimited. They relate to subordinate environmental changes and not to a more general evolutionary development of the associations.

4.3.3.1. Bolivina hebes Subzone

Bolivina hebes acts as the marker for this subzone to which it is restricted (see fig. 8). Characteristic for the assemblage of this subzone, or relatively frequent are furthermore *Spirillina vivipara, Asterigerina planorbis, Spiroplectammina* cf. *wrighti, Robulus inornatus, Angulogerina angulosa, Cassidulina laevigata, C. subglobosa, Nonion boueanum* and *Virgulina schreibersiana.*

The *Bolivina hebes* Subzone has its lower limit at the appearance of *Bolivina hebes* which coincides with the lower limit of the Globigerina Limestone. The upper limit of this subzone is placed at the disappearance of *Bolivina hebes.* The uppermost pebble-bed in the type section of the Globigerina Limestone indicated this limit in the field (see figs. 4, 8).

4.3.3.2. Anomalina helicina Subzone

The species *Anomalina helicina* is frequent in this subzone but it ranges higher up (see fig. 8). The assemblages generally contain *Martinottiella communis, Sphaeroidina bulloides, Nonion pompilioides, Vaginulina legumen, Robulus serpens, R. calcar, Stilostomella hispida, Ehrenbergina alicantina* and *Ephistomina elegans*. Some of these species continue their range into the next higher subzone (see fig. 8).

The *Anomalina helicina* Subzone is found in the upper part of the Globigerina Limestone, from the uppermost pebble-bed onwards, and it extends to the top of the Blue Clay (see figs. 4, 8, 9).

The change in lithology between Globigerina Limestone and Blue Clay is clearly reflected in the distribution of some elements in the fauna, but these changes were considered of dubious value for the distinction of yet another subzone. Amongst the forms more or less vanishing at or close to this lithological boundary (base Blue Clay) are *Cibicides rhodiensis* and a group of indefinite arenaceous species. More conspicuous is the explosion of Buliminidae with *Bulimina inflata, B. ovata, B. elongata, Rectobolivina marentinensis, Uvigerina rustica, U. pygmaea* and *U. proboscidea*, together with some others such as *Sphaeroidina bulloides* and *Epistomina elegans*.

4.3.3.3. Ammonia beccarii Subzone

This subzone is distinguished from the previous one by the frequent presence of *Ammonia beccarii* (see fig. 8). The assemblage resembles those of the *Anomalina helicina* Subzone. Especially the buliminid forms listed as rather typical for the Blue Clay diminish in numbers. The *Ammonia beccarii* Subzone is limited to the clayey part of the Greensand (see figs. 4, 8, 9).

4.3.4. *Elphidium - Gypsina Assemblage-zone*

This zone is distinguished by the presence of *Elphidium crispum, E. macellum, Gypsina globulus* and several *Triloculina* species. *Heterostegina costata* is frequently found at the base. Other characteristic species are *Astrononion perfossum, Spirillina vivipara* (see 4.3.3.1.), *Nonion boueanum* (already frequent in the *A. beccarii* Subzone), *Asterigerina planorbis, Cancris auriculus, Eponides schreibersi, E. repandus,Textularia conica, Reusella spinulosa, Discorbis globularis* and *Cibicides lobatulus*. *Planorbulinella rokae* was not found in the type section of the Upper Coralline Limestone but it occurred in sample M25 (see fig. 1, western coast of Malta, NW of Dingli) taken from the base of the Upper Coralline Limestone.

The rather sudden presence of larger perforate foraminifera indicates a faunal break. The *Elphidium - Gypsina* Assemblage-zone starts at the appearance of *Heterostegina costata* associated with *Elphidium crispum* and *Gypsina globulus*. The upper limit is placed at the top of the Upper Coralline Limestone. The zone is present in the calcareous facies of the Greensand and in the Upper Coralline Limestone.

4.3.5. *Remarks*

The biozonation of the Maltese Islands, based on benthonic foraminifera, is strongly related to the lithology.

The *Austrotrillina - Peneroplis* Assemblage-zone, the *Amphistegina - Eulepidina* Assemblage-zone and the *Elphidium - Gypsina* Assemblage-zone are confined to lithologically rather similar limestones. The *Robulus - Spiroplectammina* Assemblage-zone extends over marly limestones, clays and glauconitic clays. In this zone the assemblages of the lower subzone show some resemblance to those from the lower part of the *Elphidium - Gypsina* Assemblage-zone (see fig. 8). This corresponds to a similarity in lithology, a slighty marly limestone for the lower part of the *Robulus - Spiroplectammina* Assemblage-zone and a limestone with clayey admixtures for the lower part of the *Elphidium - Gypsina* Assemblage-zone.

This interrelation between zonation and lithology and the fairly constant character of the lithostratigraphic subdivisions allowed my biostratigraphic units to be recognizable throughout the Maltese archipelago.

4.4. Correlation of biozones

In order to establish a correlation with deposits and zones outside the Maltese archipelago my subdivisions will now be compared with other biozonations based on planktonic and benthonic foraminifera within the Mediterranean area (see fig. 9). Furthermore a comparison will be made with the worldwide tropical zonation based on planktonic foraminifera as proposed by Blow (1969). This zonation is to a certain extent applicable to subtropical regions too because many accompanying species are mentioned in addition to the typical tropical species. For this reason the zonation proposed by Bolli (1966) will not be dealt with.

4.4.1. *Correlation by means of planktonic foraminifera*

4.4.1.1. Globigerinoides trilobus - Globoquadrina dehiscens association

Most of the species generally used for subdivision of the Lower Miocene are lacking in our samples, thus hampering a precise correlation with Blow's zonal scheme. The presence of *Globigerinoides altiaperturus* from the basal part onwards may indicate that already the basal part of this interval is attributable to the *Globoquadrina dehiscens praedehiscens - G. dehiscens dehiscens* Partial range zone (N5) of Blow (1969). In the upper part of the type section of the Globigerina Limestone (M461, see figs. 4, 7, 9) no clear indication could be found for the presence of any younger biozone of the Blow zonation.

On Gozo, well below the type section of the Blue Clay (G437, see figs. 4, 9), the upper part of the *G. trilobus - G. dehiscens* interval contains frequent *Globigerinoides subquadratus*, which according to Cordey (1967) would indicate at least the level of Bolli's *Globigerinita stainforthi* Zone, which is the equivalent

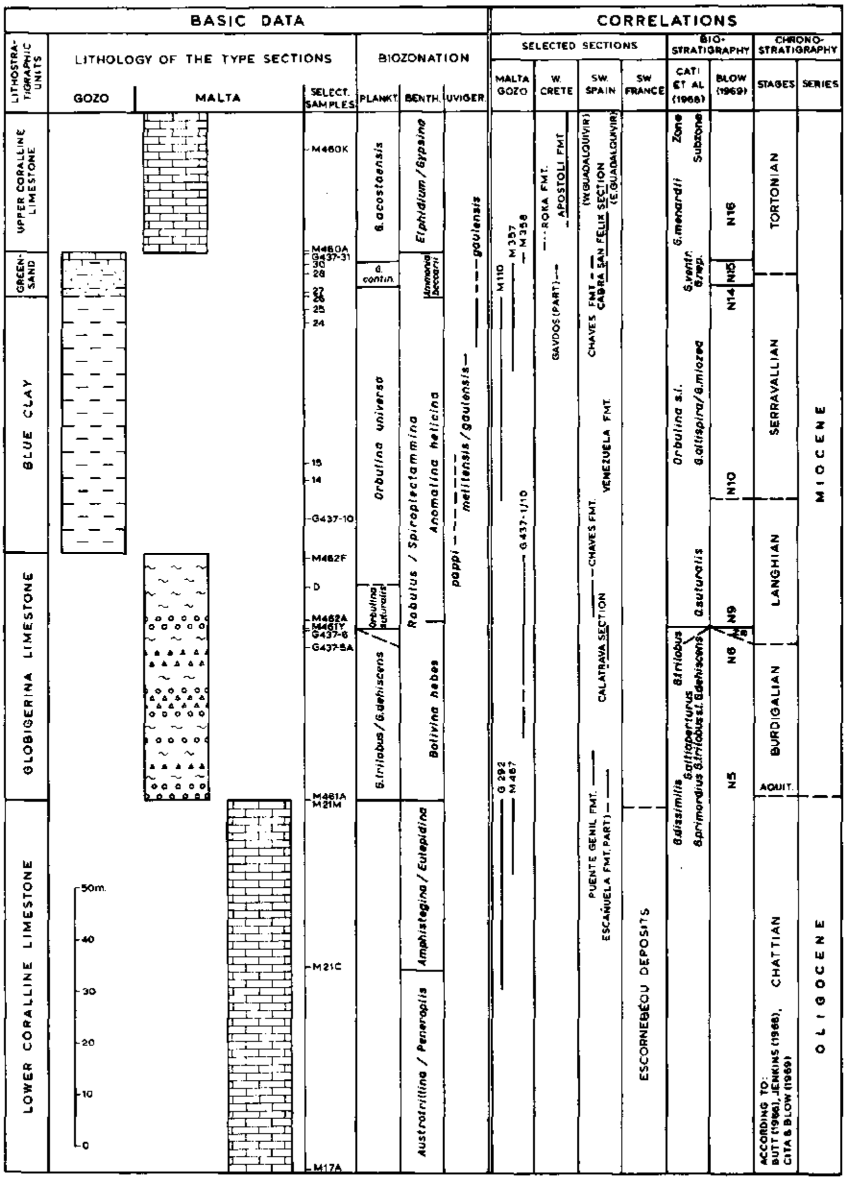

FIG. 9. Correlation chart

of the *Globigerinita insueta* - *Globigerinita dissimilis* Concurrent range zone (N6) of BLOW (1969) (see figs. 4, 7, 9).

The presence of *G. altiaperturus* and *G. trilobus* in the lower part of our interval enables correlation of this part with the *G. altiaperturus* - *G. trilobus* s.l. Subzone of CATI et al. (1968). The few individuals of *Globigerinoides primordius* in my samples suggest that the *G. primordius* Subzone of CATI et al. is present in the Maltese interval as well. The major, upper part of the Maltese interval is comparable to the *Globoquadrina dehiscens* Subzone of CATI et al. (see figs. 7, 9).

4.4.1.2. Praeorbulina association

The fauna of this interval is clearly younger than that of the preceding one, which suggests a break in the sedimentation just below its base. In section G437 on Gozo, the only section where this interval was studied, this break occurs just below sample G437-5A (see 4.2.2. and figs. 4, 7, 9).

The combined presence of *Globigerinoides sicanus*, members of the genus *Praeorbulina* and *Globorotalia peripheroronda* suggests a correlation with *the Globigerinoides sicanus - Globigerinatella insueta* Partial range zone (N8) of BLOW (1969).

The Maltese association can also be correlated with the *Praeorbulina glomerosa* s.l. Subzone of CATI et al. (1968), which subzone is defined as extending from the appearance of its marker to the first occurrence of *Orbulina suturalis* (see figs. 7, 9).

4.4.1.3. Orbulina suturalis association

The joint first occurrence of *Globigerinoides sicanus* and *Orbulina suturalis* in the type section of the Globigerina Limestone indicates a still greater break in the stratigraphical succession. It places the lower limit of my *Orbulina suturalis* interval in the *Orbulina suturalis - Globorotalia peripheroronda* Partial range zone (N9) of BLOW (1969) (see figs. 7, 9).

The *Orbulina suturalis* Subzone of CATI et al. (1968) is defined as the interval between the first occurrence of the zonal marker and the appearance of *Globorotalia miozea*. As far as recognizable the interval of my *Orbulina suturalis* association would only cover the lower part of CATI's *Orbulina suturalis* Subzone (see figs. 7, 9).

4.4.1.4. Orbulina universa association

This long interval is characterized by the absence of clear markers (see figs. 7, 9). Specimens close to *Globorotalia peripheroacuta*, in the basal part of the Blue Clay, give a clue that this part of the interval may be attributable to part of the N10 zone of BLOW (*Globorotalia peripheroacuta* Consecutive range zone; see figs 7, 9).

The major part of this interval in the Blue Clay contains a fauna which is not typical for any of the biozones of BLOW (1969). The only event which may be of importance is the disappearance of *Globigerina siakensis* near the top of the interval (see fig. 7), below the first occurrence of *Globigerina continuosa*. Because my next higher association will be referred to BLOW's N15 Zone, it seems likely that my *O. universa* interval covers the range from N10 up to N14 (see fig. 9).

The present interval can be correlated with the larger part of the *Orbulina* s.l. Zone of CATI et al. (1968). That is with the upper part of their *Orbulina* *suturalis* Subzone and with the greater part of their *Globoquadrina altispira / Globororalia miozea* Subzone (see fig. 9).

4.4.1.5. Globigerina continuosa association

In the biozonation of BLOW (1969) the first occurrence of *Globigerina continuosa* marks his *Globorotalia continuosa* Consecutive range zone (N15). The extinction of *Globigerina siakensis* he placed just below this level. A similar succession of events occurs in Malta and Gozo. So the upper part of the *Orbulina universa* interval of my zonation may be equated to the topmost part of BLOW's *Globigerina nepenthes - Globorotalia siakensis* Concurrent range zone (N14), and my *G. continuosa* interval corresponds with N15 (see figs. 7, 9).

The upper limit of BLOW's *G. continuosa* Zone has been defined by the evolutionary appearance of *Globigerina acostaensis.*

Since *Globigerina continuosa* was not recognized by CATI et al. (1968) accompanying species from this interval have been applied to insert the *G. continuosa* association in their zonal scheme. The joint occurrence of *Globorotalia menardii* s.l., *Globigerinoides obliquus* and *Globorotalia ventriosa* suggests that my interval may correspond to part of their *Globorotalia ventriosa / Globigerina nepenthes* Subzone (see figs. 7, 9).

According to their data *Globorotalia menardii* s.l. would be restricted to their *Globorotalia menardii* Zone. As may be concluded from my data, representatives of the *Globorotalia menardii* group appear already at a distinctly lower level, i.e. in the lower part of the *O. universa* interval (see fig. 7).

Although the first definite occurrence of *Globigerinoides obliquus* in Malta is situated in the *Globigerina continuosa* interval, this species occurs already in the upper part of the *Orbulina* s.l. Zone of CATI et al., prior to the onset of *Globorotalia ventriosa* and *Globorotalia menardii.*

4.4.1.6. Globigerina acostaensis association

Since the lower limit of the *Globorotalia acostaensis acostaensis - Globorotalia merotumida* Zone (N16) of BLOW (1969) is defined by the appearance of *Globigerina acostaensis* the Maltese *Globigerina acostaensis* association is equated with the assemblage of the lowermost part of Zone N16 of BLOW (see figs. 7, 9).

It is difficult to correlate the Maltese *G. acostaensis* interval with the zonal scheme of CATI et al. (1968). Only the occurrence of representatives of the *G. menardii* group (*G. menardii* form 4) indicates that my interval is to be included in their *Globorotalia menardii* Zone. Probably it corresponds to the middle part of that zone (see fig. 9).

4.4.2. *Correlation by means of benthonic foraminifera*

My zonation by means of benthonic foraminifera results in a scheme which is of local usefulness only. The assemblages as such cannot be used for detailed chronostratigraphic correlations with other zonations outside the Maltese area. They may give clues for a fair guess about larger chronostratigraphic units, such as Oligocene and Miocene, but even this is not necessarily true for all of them.

The lowermost *Austrotrillina* - *Peneroplis* assemblage of predominantly imperforate species (see 4.3.1.) contains several elements known from Oligocene faunas elsewhere, especially in the Middle East (GRIMSDALE, 1952; VAN BELLEN, 1956). Since the work of ADAMS (1968) *Austrotrillina paucialveolata* may be considered an Oligocene species.

Also the *Eulepidina* - *Amphistegina* Zone with its *Spiroclypeus, Cyclocypeus, Miogypsinoides, Nephrolepidina* and *Pararotalia viennoti* has a Late Oligocene character (see 4.3.2.), but on the basis of the generic composition alone, an Early Miocene age is defensible as well (EAMES et al., 1962).

The topmost association with larger foraminifera (see figs. 8, 9), containing *Heterostegina, Gypsina* and *Planorbulinella* (see 4. 3. 4.), seems to be Middle Miocene or younger, merely because of the absence of Lepidocyclinids and Miogypsinids.

The assemblages of smaller foraminifera of the *Robulus* - *Spiroplectammina* Zone (see 4.3.3.) are much more difficult to place, especially because of the admittedly subjective character of the specific determinations. A roughly Miocene age seems plausible, but it cannot be denied that circumstantial evidence drawn from the other assemblages above and below, plays a role in this age determination.

Lineages of benthonic species with measurable changes of properties in geologic time, may give a better chance for correlation with deposits outside the restricted Maltese area. These correlations are commonly confined to similar types of sediments as different species of benthonic foraminifera prefer different environments, but they may give opportunities to compare with the chronostratigraphic scale at stage level.

In the deposits of the Maltese Islands five genera occur, lineages of which are known outside the Maltese area. The genera *Miogypsinoides, Nephrolepidina, Uvigerina* and *Planorbulinella* display measurable changes in the morphology of the test, on which exists a fair knowledge in the Mediterranean area, and for some of them outside as well. The genus *Cycloclypeus* is the fifth in the series mentioned above, but I have as yet too few measurements on Mediterranean forms to draw definite conclusions for the purpose of correlation at the stage level.

4.4.2.1. Correlation by means of Miogypsinoides

Miogypsinoides is occasionally found in the upper part of the Lower Coralline Limestone, in the *Eulepidina* - *Amphistegina* Assemblage-zone (see 4.3.2.; fig. 6). Unfortunately no assemblages of free specimens could be analysed, but the large amount of rock thin sections from several places, indicates, especially on the basis of M_γ, that one is invariably dealing with long-spiralled Miogypsinids that can be placed without hesitation in the species *Miogypsinoides complanatus*.

On the basis of the principle of nepionic acceleration *M. complanatus* ($M_x > 17$) is considered to be the oldest Miogypsinid species in the European-Mediterranean area. Comparable *M. complanatus* assemblages are known, amongst others, from Escornebéou in the Aquitaine basin (BUTT, 1966), which deposits are considered to be older than the type Aquitanian. The Miogypsinids in the type Aquitanian have much lower M_x values (between 12 and 7). For this reason *M. complanatus* might be considered to be of Late Oligocene (Chattian or older) age, which assumption would be corroborated by the occurrence of *Miogypsina septentrionalis*, thought to be more advanced than *M. complanatus* in the neotype section of the Chattian in Germany.

It has been argued by EAMES et al. (1962) that *M. complanatus* has a much longer range into the Early Miocene, amongst others on the basis of its co-occurrence with *Miogypsina irregularis* in Malta and Sicily, reported by BLOW (1957). No such combination of species was found in the Lower Coralline Limestone. There is only evidence of the presence of *M. complanatus*. No Miogypsinids have been found in any Maltese sample above this level.

In Sicily in the Ragusa Limestone *Miogypsinoides* and *Miogypsina* do occur together. On the basis of ample material from the Ragusa Limestone, present in the Utrecht collections, it appears that we are dealing with a combination of species different from that reported by BLOW (1957). Actually the Ragusa Limestone appears to contain *Miogypsinoides bantamensis* together with *Miogypsina globulina* (DROOGER, personal communication), a combination of species much younger than that of the *M. complanatus* bearing top of the Lower Coralline Limestone of Malta. The age of this association, figured by EAMES et al. (1962, pl. 3), is a matter of discussion. EAMES et al. considered these mixtures to be of Aquitanian age. In earlier publications DROOGER (1954) thought them to be due to reworking, but later on (1963) after frequent observations of co-occurrences of *Miogypsinoides bantamensis*, *Miogypsina globulina* and *Miolepidocyclina burdigalensis*, he considered the former species a retarded immigrant from elsewhere. The combinations he dated as Burdigalian because of the latter two species.

As a result the Miogypsinids give a (Late) Oligocene age to the top of the Lower Coralline Limestone in Malta and an Early Miocene age to at least part of the Ragusa Limestone on Sicily.

LAGAAY (1968, 1969) gives a similar age for this unit in his discussion on the distribution of the bryozoan species *Nellia oculata* BUSK.

4.4.2.2. Correlation by means of Lepidocyclina

Changes in the configuration and size of the embryonic apparatus of the subgenus *Nephrolepidina* have been used for the establishment of lineages (VAN DER VLERK, 1963). Following the data of FREUDENTHAL (1964) and VERVLOET (1966), the Mediterranean *Nephrolepidina* lineage would consist of the species series *Lepidocyclina praemarginata*, *L. morgani* and *L. tournoueri*.

The Maltese specimens of *Nephrolepidina* are considered to belong to *L. praemarginata* (see 7.3.). This species of R. DOUVILLÉ is re-described and measured by VERVLOET (1966) from its type locality Costa Lupara, and from the nearby locality Mollere, which deposits are undoubtedly of Oligocene age.

This age determination is repeated by MEULENKAMP and AMATO (1972) for the deposits of Mollere. In the Mediterranean the occurence of *L. praemarginata* was furthermore established from the Greek island of Ithaca (LANGE, 1968). In these localities *L. praemarginata* was not found together with *Miogypsinoides complanatus*. In contrast the latter species was found to be accompanied at Escornebéou (DROOGER & FREUDENTHAL, 1964) by *Lepidocyclina morgani*.

The stage of development of the Maltese *Nephrolepidina* again points to an Oligocene age.

Unlike the results of measurements on *Miogypsinoides*, the *Nephrolepidina* species points to an age of the top of the Lower Coralline Limestone that is slightly older than the age of the Escornebéou deposits.

4.4.2.3. Correlation by means of Cycloclypeus

Cycloclypeus lineages are useful for age determinations in the Indo-Pacific area since the work of TAN SIN HOK (1932). The *C. eidae* group would be of Early Miocene age in this area, but it is considered doubtful whether the Maltese forms are closely related. Since European *Cycloclypeus* assemblages and their phylogenetic relations are still insufficiently known (MACGILLAVRY, 1962; MEULENKAMP & AMATO, 1972) biostratigraphic correlations have to remain speculative.

The Spanish ornate and inornate forms can hardly be used for chronostratigraphic conclusions, because their sediments are suspected to be of turbiditic origin. The Maltese forms are closest to the assemblage described from Mollere in Northern Italy by MEULENKAMP and AMATO (1972), and which was considered to be of Oligocene (Rupelian) age by the latter authors.

As a conclusion it may be stated that Maltese *Cycloclypeus* gives some induction for an Oligocene age for the upper part of the Lower Coralline Limestone.

4.4.2.4. Correlation by means of Uvigerina

In the Neogene of the Mediterranean area two successive lineages of *Uvigerina* show distinct changes towards uniserial arrangement of the chambers with geologic time (MEULENKAMP, 1969): the *Uvigerina melitensis* group and the *Uvigerina cretensis* group.

The older *U. melitensis* lineage, that was mainly based on Maltese material, probably descends from *Uvigerina (Hopkinsina) bononiensis compressa* CUSHMAN (MEULENKAMP, 1969, p. 135), which subspecies is represented in the upper part of the Globigerina Limestone (G437-4, see fig. 4) close to the *Orbulina* datum (G437-6, see figs. 7, 8, 9). The more advanced forms of the *U. melitensis* group are present in the Blue Clay and in the Greensand (see figs. 8, 9).

The most primitive species is *U. pappi*, found in the lower part of the Blue Clay in the *Anomalina helicina* Subzone. *U. pappi* is succeeded by *U. melitensis* which occurs in the middle part of the Blue Clay in the same subzone as *U. pappi*, (see figs. 8, 9). The most progressive form found in the Maltese formations is *U. gaulensis*, occurring in the upper part of the Blue Clay and in the Greensand. It is represented in the *Anomalina helicina* Subzone and in the *Ammonia beccarii* Subzone (see figs. 8, 9; 4.3.3.).

The highest developed species of this lineage, *U. felixi*, is not represented in my Maltese and Gozitan samples. It is found in the lower part of the Apostoli Formation in the Rethymnon province of Crete (see fig. 9). In the Apostoli Formation *U. felixi* is concurrent with *U. selliana*, the most primitive species of the *U. cretensis* lineage.

Of both lineages only the *U. melitensis* group occurred in Malta and Gozo. Outside the Maltese archipelago it is sofar restricted to Crete. This prevents direct correlations with other areas and with the Neogene stratotypes.

By second order correlation MEULENKAMP (1969) correlates the *U. melitensis* - *U. gaulensis* interval, i.e. the Blue Clay and the Greensand with the Serravallian Stage. Overlap with the topmost Langhian below and the basal Tortonian at the top cannot be excluded.

4.4.2.5. Correlation by means of Planorbulinella

In his biometrical study of the family Planorbulinidae, FREUDENTHAL (1969) divides the genus *Planorbulinella* into several species by means of statistical treatment of measurements on its internal features.

A Maltese population of the *Planorbulinella larvata* lineage was described by FREUDENTHAL from sample M25 (southwestern coast of Malta, NW of Dingli) in the basal part of the Upper Coralline Limestone near Dingli (see fig. 1). The Maltese population belongs to *P. rokae*, which species was originally described from the Roka Formation of Crete (see fig. 9).

Planorbulinella rokae was not encountered in any of the stratotypes of the Neogene (FREUDENTHAL, 1969), but its successor in the lineage *P. astriki* is present in the middle part of the type section of the Tortonian in Italy (FREUDENTHAL, 1969, p. 80). This suggests that the basal part of the Upper Coralline Limestone was deposited before the Middle Tortonian. An Early Tortonian Age seems the most plausible age assignment, but the final part of the Serravallian cannot be excluded (see fig. 9).

5. CHRONOSTRATIGRAPHIC CORRELATION OF THE MALTESE SEDIMENTARY SUITE

After the review in the previous chapters of the various lines of evidence that are drawn from the foraminifera it may now be tried to give a total picture of the position of the lithostratigraphic units in terms of the chronostratigraphic scale (see fig. 9).

The major part of the Lower Coralline Limestone is of unspecified Oligocene age because of the association of imperforate species such as *Austrotrillina paucialveolata*, *Praerhapydionina delicata* and *Peneroplis evolutus* (see 4.4.2.). Such faunas do not allow correlation with European stages, but comparison is only possible towards the Middle East and beyond eastwards.

In the topmost part of the Lower Coralline Limestone the assemblage of perforate larger foraminifera enables better correlations in the European - Mediterranean realm. With different emphasis *Miogypsinoides*, *Nephrolepidina* and *Cycloclypeus* species again point to an Oligocene age, somewhere in the Rupelian - Chattian interval. The additional species such as *Spiroclypeus blanckenhorni ornata*, *Grzybowskia assilinoides*, *Eulepidina dilatata* and *Pararotalia viennoti*, though each by itself has a wider and less definite time range, as an association equally fit in best with a (Middle-) Late Oligocene age assignment. The assumed level of development of *Miogypsinoides (M. complanatus)* would be slightly out of step with that of *Nephrolepidina* and *Cycloclypeus* in Northern Italy, being somewhat higher. Various explanations are possible. One is that my species determinations are not that accurate being based on rock sections mainly. Another is of course that evolution in these groups is not so strictly synchronous as it is hoped. And finally the mixture of data from various places in the Lower Coralline Limestone may give an incorrect impression of a contemporaneous association of species. It is quite well possible that the topmost part of this limestone is not of exactly the same age throughout the islands, especially so as clear evidence of gaps in the record starts in this part of the column. Hardgrounds are present in this upper part and immediately on top (see 3.2.1., 3.3.1., 3.3.2.).

Whatever the variation in age that might be concluded, the total evidence clearly points to a pre-Aquitanian age, if I base my evidence of Aquitanian on its type locality in France. For instance the Miogypsinids of the type Aquitanian *(M. gunteri* and *M. tani)* are more highly evolved than those found in Malta.

Some authors wish to extend the Aquitanian below the range of the type deposits for instance by taking the *Globigerinoides* datum level as the Chattian - Aquitanian boundary. *Globigerinoides* individuals were found in the Lower Coralline Limestone, but it is not sure whether they are autochthonous in this interval (see 4.1.). If so, their co-occurrence with *Miogypsinoides complanatus* is not new: it is known from other places such as Escornebéou (BUTT, 1966).

This implies that placing of the Oligo - Miocene boundary at the level of appearance of *Globigerinoides* transfers the entire Miogypsinid history into the Miocene, which would cause the neotype Chattian with its rather evolved *M. septentrionalis* to be placed in the Miocene.

The latter contradiction with the original contents of the Oligocene, is an important reason to place the entire interval of the Lower Coralline Limestone in the Oligocene.

There are no positive data in the assemblages of benthonic foraminifera to compare the next higher lithostratigraphic unit, the Globigerina Limestone, with the types of the stages of the chronostratigraphic scale (see 4.3.3.; fig. 8).

Planktonic foraminifera give better possibilities, though results are not of great accuracy (see 4.4.1.). The major part of the Globigerina Limestone in the type section, i.e. up to the 4th pebble-bed (see figs. 4, 7), would be comparable with BLOW's N5 Zone, possibly with some equivalent of N4 in the basal part (see 4.2.1.; 4.4.1.; fig. 9). According to JENKINS (1966) and TJALSMA (1971, p. 108) we would be dealing with equivalents of the Burdigalian and Aquitanian.

The *Praeorbulina* interval that is locally present below the fourth (see 4.2.2.; 4.4.1.2.; figs. 4, 9) pebble-bed would correspond to BLOW's N8 Zone, and thus to the basal Langhian according to CITA and BLOW (1969).

The upper part of the Globigerina Limestone that contains my *Orbulina suturalis* association (see 4.2.3.; 4.4.1.3.; figs. 7, 9) would correspond via BLOW's N9 Zone to the major part of the type Langhian, again according to CITA and BLOW (1969) and TJALSMA (1971).

As a whole the Globigerina Limestone seems to range in age from some time level during the Aquitanian at the bottom to far into the Langhian (see 4.4.; fig. 9). It is clear that several parts of this time interval are not represented by sediments, but correspond to non-depositional gaps in the stratigraphic record. Probably no sediments were formed during a considerable lapse of time that straddles the Chattian - Aquitanian boundary, and part of the Lower Langhian is conspicuously lacking in part of the islands (see 4.2.2.; 4.4.1.2.; fig. 9). Considering the distribution chart of the planktonics in the various sections there are suggestions of several other parts of the Lower Miocene being absent, especially at the levels of hardgrounds and pebble-beds (see fig. 7). It is furthermore suggested that these missing intervals are not the same throughout the islands, but of rather local importance only.

Planktonic foraminifera suggest that the Blue Clay started to be deposited towards the end of the Langhian (see 4.2.4.; 4.4.1.4.; figs. 7, 9). My next higher planktonic association that is entirely restricted to the Blue Clay, contains evidence of BLOW's zonal sequence N10 to N14. The Blue Clay thus comprises the entire Serravallian and possibly the lower part of the Tortonian.

Indications for the presence of the N15 and N16 Zones of BLOW (1969) in the Greensand point to an Early to Middle Tortonian age for the Greensand (see 4.2.5.; 4.4.1.5.; 4.4.1.6.; fig. 9).

The Greensand being absent in several sections there is a suggestion that this unit may be roughly contemporaneous with the top of the Blue Clay at places where the latter unit is immediately overlain by the Upper Coralline Limestone. The large number of planktonic zones that would be correlative with the Blue Clay - Greensand interval (see fig. 9) suggests that we are dealing with a condensed series in which unverified gaps and reworking might be present.

The presence of the major part of the *Uvigerina melitensis* lineage (*U. pappi* to *U. gaulensis*) in the Blue Clay and Greensand series would indicate that these units are mainly of Serravallian age with indefinite overlaps on Langhian and Tortonian (see 4.4.2.4.; fig. 9). This age assignment seems to be in good accordance with that arrived at by means of the planktonics (see 4.4.1.).

Finally there is evidence from *Planorbulinella rokae* that the basal part of the highest lithostratigraphic unit, the Upper Coralline Limestone, would be of Tortonian age, either Early or Middle (see 4.4.2.5.). How far this limestone ranges up into the time scale cannot be verified, but the constant lithological character suggests that it does not reach above the Miocene and possibly even not beyond the Tortonian. There is no indication of considerable change of environment that might be expected if the Messinian, the final stage of the Miocene, was still represented in the sedimentary columns of the Maltese Islands.

6. PALEOECOLOGY AND SEDIMENTARY HISTORY

The interpretation of the successive foraminiferal assemblages and of the sediments containing them should lead to environmental conclusions on the basis of their own merits. Yet, we are severely hampered by our ignorance of the general Oligo-Miocene paleogeographic configuration of the central Mediterranean area, in which Malta is such a small visible remnant. Neither sediments nor faunas give any clue about the land-sea distribution in the area.

As shown by the nature of the Maltese sediments, the supply of terrigenous material during deposition must have been negligible (see chapter 3). Two lines of reasoning may be followed to explain the main characteristics of the stratigraphic succession, but my data do not permit a definite choice:

1. The Malta area was situated in the open sea, far away from any source of terrigenous material. The occurrence of sediments of an obvious shallow water origin, such as the Lower Coralline Limestone, would then imply the presence of an isolated, shallow, but probably largely submarine platform of unknown dimensions. Warm climatic conditions, at least of a subtropical nature, would have allowed the accumulation of the thick series of organoclastic deposits.
2. The region of study was bordered by a distant hinterland, which did not supply substantial amounts of detrital material as a consequence of a low relief and/or climatic conditions of an extreme character (semi-arid to arid).

These conflicting concepts immediately lead to considerable problems in connection with the paleoecological interpretation of the lowermost assemblage zone in the Lower Coralline Limestone (see 4.3.1.). The major part of this lower unit contains an assemblage in which Miliolidae and Peneroplidae are the highly predominant elements (see figs. 5, 8). Very similar associations of the same time interval have been described from the Middle East, where they were explained as back reef communities (HENSON, 1950; VAN BELLEN, 1956).

As stated above, I know so few details of the Oligocene in surrounding countries, that I do not know where to look for the position of hinterland and/or reefal barriers. Moreover a thickness of back reef sediments greater than some 50–60 metres cannot be expected under stable sea-level conditions. This would mean that such a 'shallow water, back reef' environment remained in the same position over the entire, fairly large Malta-area, during a long lasting period of subsidence, which allowed the deposition of a hundred or more metres (see 3.2.1.) of the same type of sediment. The concept of a back reef strip in between a fringing reefal barrier and an emerging hinterland is thus hard to apply (VAN BELLEN, 1956).

The often somewhat muddy character of the Lower Coralline Limestone, as well as the composition of its foraminiferal assemblages (see fig. 5), show some similarity to the recent, nearshore shelf deposits of the Persian Gulf (MURRAY, 1965). In the prevalence of Miliolidae and Peneroplidae, the fauna of these sediments appears to be closely related to the associations found in the adjacent lagoonal and back reef environments. A difference with the probably Oligocene equivalents of Malta is the greater diversity of the modern assemblages, which might point to a more effective separation of the ancient Maltese depositional realm from the surrounding waters than in today's Persian Gulf or Red Sea.

Yet, these data do not permit to think now only in terms of a relatively wide, shallow marine 'gulf', nearly cut off from the open sea by some kind of reefal zone and bordered by a hinterland of low relief. Turning our attention to the distribution of recent foraminiferal faunas on the Bahama Banks (TODD & LOW, 1971), another depositional model is presented. In the protected, shallow parts of the recent platform associations with *Peneroplis* and various Miliolidae among the prevalent forms are found. On the other hand, *Amphistegina lessonii*, abundant in the upper part of the Lower Coralline Limestone (see 4.3.2.; fig. 5), is largely restricted to the outer edges of the modern Banks. The difficult point in this alternative explanation is the very great thickness of the *Austrotrillina* - *Peneroplis* Zone (see figs. 4, 5, 9), which would mean that a large intra-reefal platform remained unchanged in character and position during a large period of subsidence (see also above).

According to the 'classical concept', the rather sudden change in microfaunal composition in the higher beds of the Lower Coralline Limestone must be explained by a shift from back reef to fore reef conditions, considering the diversified assemblage of perforate larger foraminifera and the increase of algal debris (see 4.3.2.; fig. 5). Actually, algal growth *in situ* is observed at some places between the two associations.

Having rejected the idea of a rather narrow strip of reef environments in front of some coastline, we now have to assume either an increasing open marine influence in a previously restricted gulf, or a migration of a marginal zone, situated along the outer edges of an isolated submarine platform over sediments, which were formed in its original central parts. There are no data to make a choice between both alternatives to explain the change to more open marine conditions. Even the question whether relative movements of sea-level played an essential part in the nature of sedimentation and the composition of the microfaunas cannot be answered.

The hardgrounds, which locally occur in the upper part of the Lower Coralline Limestone (see 3.3.1.), may have been formed by submarine cementation under non-depositional conditions in shallow basins of limited size, surrounded by algal reefs and shoals of organoclastic material. At the top of the Lower Coralline Limestone, we are faced however, with a widespread hardground and a considerable stratigraphic gap in the record, straddling the Oligo - Miocene boundary (see 4.4.2.; fig. 9). Emergence of the area over such a long period would have left other traces than just an calcium-phosphatic hardground. The sediments and fossils (*Scutella*, solitary corals; see 3.3.1.) on top of the boundary are not in favour of a sudden deepening of the depositional realm to explain the absence of supply and the consequent cementation of the deposit at the interface. Thus, the conclusions of SHINN (1969) and PURSER (1969) regarding the origin of lithified surfaces in Holocene sediments of the Persian Gulf under the influence of marine transgressions can not directly be applied to the present Oligo - Miocene examples. Particularly the long lasting absence of sediment supply cannot merely be attributed to a retreat of some coastline. It seems necessary to assume the establishment of restricted conditions.

The major part of the Globigerina Limestone up to the topmost pebble-bed (see figs. 4, 9) corresponds to a single biozone, the *Bolivina hebes* Subzone, the association of which is distinctly environmentally controlled (see 4.3.3.). Planktonics are fairly common (see figs. 6, 7), which points to a free access of waters from the open sea. The benthonic assemblages show fully marine, offshore character (see 4.3.3.; fig. 8). One of the species that is fairly common is *Nonion boueanum* (see fig. 8), which seems to thrive in muddy to finely clastic sediments between some 30 and 75 metres, if one dares to compare this form with *Nonionella atlantica*, described by KRUIT (1955) and by DROOGER and KAASSCHIETER (1958) from the gulf and shelf area near Trinidad. *N. boueanum* occurs together with several other indicators of recent relatively deep substrates in Mediterranean offshore regions: *Gyroidina soldanii*, *Nonion pompilioides*, *Pullenia bulloides*, *Cassidulina laevigata*, *Bolivina and Uvigerina* species (see fig. 8 and BLANC-VERNET, 1969). Other elements, more characteristic for this subzone than for the next higher one, probably lived attached to algae: *Asterigerina planorbis*, *Spirillina vivipara* and various species of *Cibicides*, such as *C. rhodiensis* (see figs. 8, 9). Since they are not predominant they may have been introduced to the sedimentation area by transport. Actual growth of calcareous algae being absent, we may conclude that sea depth was generally somewhere between 40 and 100 metres, which means a relative rise of sea level with respect to the lower stratigraphic units.

The sediment of the Globigerina Limestone, ranging from finely calcarenitic to calcareous mud, was most probably deposited off an area with prevailing shallow water conditions with reefal growth.

Although data of surrounding areas again are poor it is known now that during the deposition of this roughly Aquitanian - Burdigalian part of the Globigerina Limestone coarser calcarenitic and open marine limestones were formed on the Ragusa platform (see 4.4.2.1.). Fine-grained, washed out material thus may have arrived in the Maltese area from a northern direction.

Yet one cannot escape from the earlier picture of a somehow, or occasional, restriction of the area during the deposition of the Globigerina Limestone. Breaks in the planktonic succession and pebble-beds seem to indicate periods of non-deposition with hardground formation, and their breaking up in shallower areas (see 3.3.2.; 3.3.3.).

Actual hardgrounds in the succession are relatively rare, commonly associated with the lowermost and uppermost pebble-beds only. If the hardgrounds were formed in shallower water only, because wave action has to account for the considerable amount of pebbles, much of the Maltese area evidently remained submerged to depths of 50 metres and more for most of the time. The pebble material probably derived from shallower points of the platform, outside the area of today's archipelago. During periods of hardground formation the Malta area was not necessarily devoid of sedimentation, very slight deposition is quite feasible. Since the pebble-beds show features of proximal turbidites, such thin sediments may have been easily mixed up in the pebble-beds, if they had been formed at all.

Although the pebble-beds witness of breaking up of hardgrounds and transport along submarine slopes, it remains difficult to understand that there are no other witnesses of temporary shallow water conditions such as larger fragments of reefal and algal growth.

In the upper part of the Globigerina Limestone the benthonic fauna shows a change due to more muddy sea bottoms which trend is continued during deposition of the Blue Clay (see 3.3.; 3.4.; 4.3.; fig. 8). The increasing importance in the assemblages of many buliminid species and of *Epistomina elegans* and *Sphaeroidina bulloides* points to open marine muddy platforms. Depth may have increased further, but not necessarily beyond 150 metres. The change from calcareous mud to blue clay probably was primarily due to the disappearance of the reefal and organic source areas in the central Mediterranean. The age of the Blue Clay being Serravallian, this change cannot be brought in connection with the Tortonian spreading of a clayey facies throughout the Mediterranean. This phenomenon, though not understood, shows that the Mediterranean area had become an area with widespread uniform sedimentational conditions. Sedimentation from suspension evidently was slow regarding the rapid faunal changes in the Blue Clay interval. This slow deposition culminated in the formation of the Greensand, in which the fauna shows the reappearance of for instance *Nonion boueanum*. The presence of scarce *Ammonia beccarii* is ill understood, but this species does not necessarily indicate the near-presence of a coastal area.

The renewed shallowing tendency drawn from the fauna of the Greensand evidently continued and it brought back the possibility of calcareous algal growth (see 3.5.). The sediment and fauna of the Upper Coralline Limestone (see 3.6.; figs. 4, 7, 8) finally announces a fully open marine shallow platform of depths of less than 50 metres, on which calcareous algae, epiphytal benthonic foraminifera (*Cibicides lobatulus* etc.) and inhabitants of shallow organo-detrital material (*Elphidium crispum* etc.) were living side by side.

As summary, the Maltese archipelago was part of a marine area throughout the Oligo - Miocene, in which sea depth increased until Langhian - Serravallian time to no more than 150–200 metres to decrease again in the later part of the Miocene history. Superposed on these relative sea-level changes the area was gradually transformed from a sheltered gulfal realm or intra-reefal basin of unknown shape in the beginning, to a shallow platform in the open sea. The area may have belonged to an emerged land mass at the end of the Miocene and troughout the Pliocene. Its more recent mammal faunas show that Malta was an island during at least part of the Pleistocene, as it is today.

7. FAUNAL REFERENCE LIST

7.1. INTRODUCTION

The faunal reference list is arranged alphabetically according to generic names.

Reference to illustrations in this paper is given between parentheses. All planktonic species have been entered in this chapter. The list of benthonic species is not complete. Most of these species are well known from the literature, and can be found in BARKER (1960), DIECI (1959), FORAMINIFERI PADANI (1957), MACFADYEN (1930), MARKS (1950). As a consequence the number of benthonic species dealt with is restricted to those which are of some importance for stratigraphy or paleoecology or on which some remarks were considered necessary.

7.2. PLANKTONIC FORAMINIFERA

Globigerina acostaensis (BLOW) = *Globorotalia acostaensis* BLOW, 1959 Bull. Amer. Pal., vol. 39, no. 178, p. 208, pl. 17, figs. 106a-c, 107. Upper part of the Greensand and lower part of the Upper Coralline Limestone.

Specimens of *G. acostaensis* are relatively tightly coiled, the final whorl consists of 4–6 chambers; the outline of the chambers in spiral view is nearly semi-circular in contrast to the elongate shape in *G. continuosa*. In morphology my specimens of *G. acostaensis* are close to juveniles of *G. siakensis*. The higher arched aperture and the more loosely coiling of the latter precludes a mis-identification (plate 7; fig. 15a, b) (fig. 7, no. 34).

Globigerina apertura CUSHMAN, 1918. U.S. Geol. Surv., Bull., vol. 676, p. 57, pl. 12, figs. 8a-c. Top Globigerina Limestone to Greensand.

An extremely discontinuous vertical distribution of *G. apertura* has been observed in the Maltese deposits. The species is present in the topmost sample of the Globigerina Limestone, it is absent in the Blue Clay type section and reappears in the Greensand type section. The aperture of my specimens is relatively small in comparison to that of the figured holotype. It is close to that of *G. decoraperta*, but lacks the protruding rim of the latter (fig. 7, no. 19).

Globigerina bulloides D'ORBIGNY, 1826. Ann. Sci. Nat., sér. 1, tome 7, p. 277; Modèle no. 17, 76 = *Globigerina bulloides* D'ORBIGNY, LOEBLICH & TAPPAN 1957, U.S. Nat. Mus., Bull., vol. 215, p. 31, pl. 4, figs. 1a-c. Greensand (fig. 7, no. 30).

Globigerina ciperoensis BOLLI = *Globigerina ciperoensis ciperoensis* BOLLI, 1957. U.S. Nat. Mus., Bull., vol. 215, p. 109, pl. 22, figs. 10a-b. Globigerina Limestone to Upper Coralline Limestone (fig. 7, no. 8).

Globigerina continuosa (BLOW) = *Globorotalia opima continuosa* BLOW, 1959.

Bull. Amer. Pal., vol. 39, no. 178, p. 218, pl. 19, figs. 125a-c; BLOW, 1969, Proc. 1st Int. Conf. Plankt. Microf., Geneva 1967, vol. 1, p. 347, pl. 3, figs. 4–6. Greensand.

The greater part of my specimens has four fairly inflated chambers, a slightly lobulate equatorial outline and a broadly rounded outline in axial view. The chamber outline in spiral view is elongated. The aperture is relatively high arched, bordered in most cases by a lip. Variation has been observed in the number of chambers in the last whorl, varying from 4.5 to 3.5 as well in the position of the aperture which shifts in extreme cases towards a nearly umbilical position. *G. siakensis* differs mainly in having a more loose coiling and a semicircular chamber outline in spiral view (plate 7, fig. 9a, b, c) (fig. 7, no. 29).

Globigerina druryi AKERS, 1955. Jour. Pal., vol. 29, no. 4, p. 654, figs. 1a-c, TJALSMA, 1971. Utrecht Micropal. Bull., vol. 4, p. 77, pl. 11, figs. 4–7c. Blue Clay.

On Gozo (section G437, see figs. 4, 6, 7, 9) *G. druryi* appears already at the base of the *O. suturalis* interval. On Malta, however, the species is not found below the lower part of the *O. universa* interval. The variation is similar to that described from S. Spain. At the top of the Blue Clay *G. druryi* grades into *G. nepenthes* (plate 7, fig. 8a, b) (fig. 7, no. 24).

Globigerina falconensis BLOW, 1959. Bull. Amer. Pal., vol. 39, no. 178, p. 177, figs. 40a-c. Blue Clay (fig. 7, no. 20).

Globigerina nepenthes TODD, 1957. U.S. Geol. Surv., Prof. Paper, vol. 280-H, p. 301, pl. 78, figs. 7a-b. Upper part of the Blue Clay to the lower part of the Greensand. (fig. 7, no. 26).

Globigerina obesa (BOLLI) = *Globorotalia obesa* BOLLI, 1957. U.S. Nat. Mus., Bull., vol. 215, p. 119, pl. 29, figs. 2a-3. Globigerina Limestone and Blue Clay (fig. 7, no. 10).

Globigerina praebulloides BLOW, 1959. Bull. Amer. Pal., vol. 39, no. 178, p. 180, pl. 8, figs. 47a-c; pl. 9, fig. 48. Globigerina Limestone, Blue Clay and Greensand (fig. 7, no. 3).

Globigerina pseudobesa (SALVATORINI) = *Turborotalia pseudobesa* SALVATORINI, 1966. Atti Soc. Tosc. Sc. Nat., vol. 73(A), p. 10, pl. 2, figs. 6a–15; *Globigerina pseudobesa* (SALVATORINI), TJALSMA, 1971, Utrecht Micropal. Bull., vol. 4, p. 72, pl. 10, figs. 1a–2b, textfig. 16. Blue Clay and lower part of the Greensand (fig. 7, no. 23).

Globigerina siakensis LEROY, 1939. Natuurk. Tijdschr. Ned. Indië, vol. 99, no. 6, p. 262, pl. 4, figs. 20–22; TJALSMA, 1971. Utrecht Micropal. Bull., vol. 4, p. 67, pl. 8, figs. 6a–7, textfig. 13. Globigerina Limestone, Blue Clay and lowermost part of the Greensand (plate 7, fig. 4a, b) (fig. 7, no. 9).

Globigerina venezuelana HEDBERG, 1937. Jour. Pal., vol. 11, no. 8, p. 681, pl. 92, figs. 7a-b. Globigerina Limestone and lowermost part of the Blue Clay (fig. 7, no. 6).

Globigerinita dissimilis (CUSHMAN & BERMUDEZ) = *Globigerina dissimilis* CUSHMAN & BERMUDEZ, 1937. Cushman Lab. Foram. Res., Contr., vol. 13, no. 1, p. 25, pl. 3, figs. 4–6; *Catapsydrax dissimilis* (CUSHMAN & BERMUDEZ), BOLLI, LOEBLICH & TAPPAN, 1957. U.S. Nat. Mus., Bull., vol. 215, p. 36, pl. 7, figs. 6a–8c. Lower Coralline Limestone.

Only two specimens were found in sample M17–18 (see fig. 4) which was taken from loose material on the bottom of a small grotto in the type section of the Lower Coralline Limestone. Its provenance was not clear so *G. dissimilis* was not used in the biozonation (see 4.2.1.).

Globigerinoides altiapertura BOLLI = *Globigerinoides triloba altiapertura* BOLLI, 1957. U.S. Nat. Mus., Bull., vol. 215, p. 113, pl. 25, figs. 7a–8. Globigerina Limestone, lower part of the Blue Clay.

A transition into *G. subquadratus* was found in the *G. trilobus* - *G. dehiscens* interval in section G437 on the island of Gozo (plate 7, fig. a, b) (fig. 7, no. 5).

Globigerinoides bulloideus CRESCENTI, 1966. Geol. Rom., vol. 5, p. 43, textfigs. 8–3–3a, 9; TJALSMA, 1971. Utrecht Micropal. Bull., vol. 4, p. 81, pl. 10, figs. 6a-b; pl. 11, figs. 12a-b; pl. 12, fig. 1a–3b; textfig. 20. Top of the Globigerina Limestone, the Blue Clay, the Greensand and the lowest part of the Upper Coralline Limestone (plate 7, fig. 13a, b) (fig. 7, no. 18).

Globigerinoides obliquus BOLLI, 1957. U.S. Nat. Mus., Bull., vol. 215, p. 113, pl. 25, figs. 10a-c; TJALSMA, 1971. Utrecht Micropal. Bull., vol. 4, p. 84, pl. 12, figs. 4a–5c, textfig. 21. Top of the Blue Clay and Greensand (plate 7, fig. 14a, b) (fig. 7, no. 28).

Globigerinoides primordius BLOW & BANNER = *Globigerinoides quadrilobatus primordius* BLOW & BANNER, 1962. Fund. Mid. Tert. Strat. Corr., p. 115, pl. 9, figs. Dd-Ff; fig. 14 (3–8); *Globigerinoides primordius* BLOW & BANNER, BUTT, 1966. Late Olig. Foram. Escornebéou, p. 87, pl. 7, figs. 6, 9–10. Lowermost part of the Globigerina Limestone (fig. 7, no. 1).

Globigerinoides ruber (D'ORBIGNY) = *Globigerina rubra* d'ORBIGNY, 1839. In: de la Sagra, Hist. Phys. Nat. Cuba, p. 82; ibid. vol. 8, pl. 4, figs. 12–14; *Globigerinoides ruber* (d'ORBIGNY), BANNER & BLOW, 1960. Cushman Found. Foram. Res., Contr., vol. 11, p. 19, pl. 3, figs. 8a-b. Upper part of the Globigerina Limestone, Blue Clay, Greensand and Upper Coralline Limestone.

See for remarks under *Globigerinoides subquadratus.* According to CORDEY (1967) *G. subquadratus* possesses 4 chambers in the penultimate whorl whereas *G. ruber* has 3–3.5. In part of the samples the material was in such a bad state of preservation that separation between the two species could not be made. In the range chart both species are therefore given together (fig. 7, no. 12).

Globigerinoides sicanus DE STEFANI, 1950. Plinia, Palermo (Italy), vol. 3 no. 4, p. 9 = *Globigerinoides bisphericus* TODD, 1954. Amer. Jour. Sci., vol. 252, no. 11, p. 681, pl. 1, figs. 1a-c, 4. Upper part of the Globigerina Limestone (fig. 7, no. 13).

Globigerinoides subquadratus BRONNIMANN, 1954, In: TODD, CLOUD, LOW & SCHMIDT, Amer. Jour. Sci., vol. 252, no. 11, p. 680, pl. 1, figs. 5, 8a-c; CORDEY, 1967. Paleontology, vol. 10, no. 4, p. 650, pl. 103, figs. 2–4. Upper part of the Globigerina Limestone, Blue Clay, Greensand and Upper Coralline Limestone.

See also the remarks under *G. ruber*. According to CORDEY (1967) the Lower - Middle Miocene forms, called *G. subquadratus*, differ in phylogeny and morphology from the Upper Miocene - Recent *G. ruber*. A time gap should exist between the ranges of the two species. At Malta such a gap has not been observed. *G. subquadratus* individuals were found up to the Greensand. The most plausible explanation is that reworking of *G. subquadratus* specimens and breaks in the record at the level of the Greensand, are responsible for the overlap of the ranges of *G. subquadratus* and *G. ruber* (fig. 7, no. 12).

Globigerinoides trilobus (REUSS) = *Globigerina triloba* REUSS, 1850 Kön. Akad. Wiss. Wien, Math. Nat. Cl., Denkschr., vol. 1, p. 374, pl. 47, figs. 11a-d; *Globigerina sacculifera* BRADY, 1884. Rep. Voy. Challenger, Zool., vol. 9, p. 604, pl. 80, figs. 11–17; pl. 82, fig. 4; *Globigerinoides sacculiferus* var. *immatura* LEROY, 1939. Natuurk. Tijdschr. Ned. Indië, vol. 99, no. 6, p. 263, pl. 3, figs. 19–21. Globigerina Limestone, Blue Clay, Greensand and Upper Coralline Limestone.

The *sacculiferus* variants are easily distinguishable; they have been entered separately in fig. 7 (fig. 7, nos. 2, 7).

Globoquadrina altispira (CUSHMAN & JARVIS) = *Globigerina altispira* CUSHMAN & JARVIS, 1936. Cushman Lab. Foram. Res., Contr., vol. 12, no. 1, p. 5, pl. 1, figs. 13a–14; *Globoquadrina altispira altispira* (CUSHMAN & JARVIS), BOLLI, 1957. U.S. Nat. Mus., Bull., vol. 215, p. 111, pl. 24, figs. 7a–8b; *Globoquadrina altispira* (CUSHMAN & JARVIS) *globosa* BOLLI, 1957. U.S. Nat. Mus., Bull., vol. 215, p. 111, pl. 24, figs. 9a–10c. Upper half of the Globigerina Limestone, Blue Clay and Greensand.

High-spired forms with laterally compressed chambers (*altispira altispira* type) are only found in the upper part of the *O. universa* interval (see figs. 7, 9) (fig. 7, no. 11).

Globoquadrina dehiscens (CHAPMAN, PARR & COLLINS) = *Globorotalia dehiscens* CHAPMAN, PARR & COLLINS, 1934. Linn. Soc. London, Jour. Zool., vol. 38, no. 262, p. 569, pl. 11, figs. 36a-c; *Globoquadrina langhiana* CITA & GELATI, 1960. Riv. Ital. Paleont., vol. 66, p. 242, textfigs. 1a-c; pl. 29, figs. 1–20. Globigerina Limestone, Blue Clay, basal part of the Greensand.

The specimens in the *G. trilobus* - *G. dehiscens* association are mostly of the *langhiana*-type, with a smaller and less angular apertural face than in typical *G. dehiscens* (fig. 7, no. 4).

Globorotalia mayeri CUSHMAN & ELLISOR, 1939. Cushman Lab. Foram. Res., Contr., vol. 15, no. 1, p. 11, pl. 2, figs. 4a-c; *Globorotalia (Turborotalia) mayeri* CUSHMAN & ELLISOR, BLOW, 1969. Proc. 1st Int. Conf. Plank. Microf., Geneva 1967, vol. 1, p. 351, pl. 3, figs. 7–9. Top of the Globigerina Limestone (fig. 7, no. 16).

Globorotalia menardii form 3 TJALSMA, 1971. Utrecht Micropal. Bull., vol. 4, p. 59, pl. 5, figs. 1a–3c. Rare in the upper half of the Blue Clay and in the Greensand (plate 7, fig. 10a, b, c) (fig. 4, no. 25).

Globorotalia menardii form 4 TJALSMA, 1971. Utrecht Micropal. Bull., vol. 4, p. 59, pl. 5, figs. 4a–6c. Topmost sample of the Greensand type section and in the lowermost sample of the Upper Coralline Limestone type section (plate 7, fig. 16a, b, c) (fig. 7, no. 33).

Globorotalia peripheroronda BLOW & BANNER, 1966. Micropaleontology, vol. 12, p. 294, pl. 1, figs. 1a-c; pl. 2, figs. 1–3. Upper part of the Globigerina Limestone, base of the Blue Clay (plate 7, fig. 7a, b, c) (fig. 7, no. 14).

Globorotalia cf. *peripheroacuta* BLOW & BANNER, 1966. Micropaleontology, vol. 12, p. 294, pl. 1, figs. 2a-c; pl. 2, figs. 4–5, 13. Basal part of the Blue Clay.

The few specimens found differ from *G. peripheroacuta* by having an acute peripheral margin on the final chamber only, when seen in axial view, instead of on the last three chambers as in *G. peripheroacuta* (fig. 7, no. 14).

Globorotalia scitula (BRADY) = *Pulvinulina scitula* BRADY, 1882. Roy. Soc. Edinburgh, Proc., vol. 11 (1880–1882), no. 111, p. 716; *Pulvinulina patagonica* (d'ORBIGNY), BRADY, 1884. Rep. Voy. Challenger, Zool., vol. 9, p. 693, pl. 103, figs. 7a-c. Basal part of the Blue Clay, top of the Blue Clay and Greensand (plate 7, fig. 12a, b, c) (fig. 7, no. 21).

Globorotalia ventriosa OGNIBEN = *Globorotalia scitula ventriosa* OGNIBEN, 1958. Riv. Ital. Paleont., vol. 64, p. 246, pl. 15, figs. 4a-d, 5. A single sample in the top of the Greensand type section (fig. 7, no. 32).

Globorotalia sp. = *Globorotalia sp.* TJALSMA, 1971. Utrecht Micropal. Bull., vol. 4, p. 64, pl. 8, figs. 2a–3c. Top of the Blue Clay, lower half of the Greensand.

My specimens agree well with those from the Guadalquivir basin, southern Spain, from where they were described (plate 7, fig. 11) (fig. 7, no. 27).

Orbulina suturalis BRONNIMANN, 1951. Cushman Found. Foram. Res., Contr., vol. 2, no. 4, p. 135, textfig. 2, fig. 1–15; *Orbulina suturalis* BRONNIMANN emend. BLOW, 1956. Micropaleontology, vol. 2, p. 66, textfig. 2, no. 5–7; textfig. 3, stage 6; *Biorbulina bilobata* (d'ORBIGNY), BLOW, 1956 Micropaleontology, vol. 2, p. 69, textfig. 2, no. 16; textfig. 3, stage C (lower fig.). Upper part of the Globigerina Limestone, Blue Clay, Greensand (plate 7, fig. 5) (fig. 7, no. 15).

Orbulina universa d'ORBIGNY, 1839. In: de la Sagra, Hist. Phys. Nat. Cuba, p. 2; ibid., vol. 8, pl. 1; *Globigerina bilobata* d'ORBIGNY, 1846. For. Foss. Vienne, p. 164, pl. 9, figs. 11–14. Top of the Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone.

The *O. universa* datum level is situated about seven metres below the top of the Globigerina Limestone in the type section (plate 7, fig. 6) (fig. 7, no. 17).

Praeorbulina glomerosa (BLOW) = *Globigerinoides glomerosa* BLOW, 1956. Micropaleontology, vol. 2, p. 64, textfig. 1, no. 9–19; textfig. 2, no. 1–4; textfig. 3, stages 3–5; *Globigerinoides transitoria* BLOW, 1956. Micropaleontology, vol. 2, p. 65, textfig. 2, no. 12–15; textfig. 3, stage B. Top of the Globigerina Limestone.

This species occurs in the uppermost part of the Globigerina Limestone from the last pebble-bed onward. It was not frequently found in the samples of the type section, so it was lumped with *O. suturalis* in fig. 7.

Alabamina perlata (ANDREAE) = *Pulvinulina perlata* ANDREAE, 1884, Geol. Spezialk. Elsass-Loth., Abh., vol. 2, no. 3, p. 124, pl. 8, fig. 12a-c. Globigerina Limestone, Greensand, Upper Coralline Limestone. The Maltese specimens have no pustules on the test, in contrast to the type specimen.

Ammonia beccarii (LINNÉ) = *Nautilus beccarii* LINNÉ, 1758. Syst. Nat., Ed. 10, vol. 1, p. 710, pl. 1, fig. 1a-c; *Rotalia beccarii* (LINNÉ), BATJES, 1958. Kon. Belg. Inst. Nat. Wet., Verh., vol. 143, p. 167, pl. 12, fig. 10a-c. Blue Clay upper part, Greensand, Upper Coralline Limestone lower part (fig. 8, no. 116).

Ammonia beccarii (LINNÉ) var. *globula* (COLOM) = *Rotalia beccarii* (LINNÉ) var. *globula* COLOM, 1936. 1ª Nota Soc. Española Hist. Nat., Bol., vol. 36, p. 216, pl. 27, fig. 6; p. 217, textfig. 5, no. 1–4. Greensand.

Inflated form with some 25 chambers, 11 of which are in the last whorl. According to the type description the maximum numbers are 33 and 13 respectively. In fig. 8 this species was lumped with *A. beccarii* (fig. 8, no. 115).

Amphistegina lessonii d'ORBIGNY, 1826. Ann. Sci. Nat., sér. 1, vol. 7, p. 304, pl. 17, fig. 1–4; Modèle no. 98; *Amphistegina radiata* (FICHTEL & MOLL), HANZAWA, 1957. Geol. Soc. Amer., Mem., vol. 66, p. 60, pl. 6, fig. 11; pl. 31, fig. 4–8; pl. 32, fig. 1; *Amphistegina lessonii* d'ORBIGNY, BUTT, 1966. Late Olig. Foram. Escournebéou, p. 75, pl. 4, fig. 4a-c. Lower Coralline Limestone, Upper Coralline Limestone.

Test small, involute with a smooth periphery, more or less equally biconvex. Diameter 0.5–1.6 mm, thickness 0.3–0.7 mm.

A. lessonii occurs throughout the investigated part of the Lower Coralline Limestone. In the lower zone (see figs. 5, 8) it is less frequent than in the upper zone. The smaller specimens occur in the lower miliolid limestones; they are relatively thicker than the bigger ones. The bigger specimens are found mainly in the upper part of the Lower Coralline Limestone in association with algae and other perforate larger foraminifera. The species is very rare in the Upper Coralline Limestone.

Recent *Amphistegina* occurs in warm, shallow, water, usually at less than 50 metres depth, often associated with *Heterostegina* and algal rocks. The upper part of the Lower Coralline Limestone and the Upper Coralline Limestone evidently represent a similar depositional environment (plate 3, fig. 6) (fig. 5; fig. 8, no. 10).

Anomalina helicina (COSTA) = *Nonionina helicina* COSTA, 1855. Mem. R. Acc. Sci. Napoli, vol. 2, (1855–1857), p. 123, pl. 1, fig. 18a-c; *Anomalina helicina* (COSTA), WEZEL, 1964, Riv. Ital. Pal. Strat., vol. 70, p. 350, pl. 24, fig. 10a-b. Globigerina Limestone, Blue Clay (plate 6, fig. 1a, b) (fig. 8, no. 95).

Archaias aff. *A. kirkukensis* HENSON = aff. *Archaias kirkukensis* HENSON, 1950. Middle East Tert. Peneropl., p. 43, pl. 7, fig. 3, 4, 9; pl. 8, fig. 1–5; *Archaias kirkukensis* HENSON, VAN BELLEN, 1956. Jour. Inst. Petrol., vol. 42, no. 393, p. 250, pl. I A. Lower Coralline Limestone.

The Maltese *Archaias* aff. *A. kirkukensis* is very rare. Only two specimens were found, one in sample M17N and one in sample M364C. One of these specimens is very indistinct (M17N), the other might be an A-form of *A. kirkukensis*. The difference with the specimens figured by HENSON is that the pilars in my specimens are rather thick and regularly placed. They remind of the subepidermal partitions of *Meandropsina anahensis* HENSON.

My best specimen comes from the local top of the Lower Coralline Limestone (see fig. 4) from an association with *Grzybowskia assilinoides*, *Austrotrillina paucialveolata*, *Borelis haueri*, *Borelis pygmaeus* and *Rotalia* spp., which association belongs in the *Austrotrillina* - *Peneroplis* Assemblage Zone (see 4.3.1.). The other specimen comes from a similar association with *Borelis haueri*, *Praerhapydionina delicata* and *Austrotrillina paucialveolata* from a topographically lower part of the Lower Coralline Limestone. Neither of the specimens is sectioned well enough to be reproduced in a photograph (fig. 5; fig. 8, no. 14).

Astrononion perfossum (CLODIUS) = *Nonionina perfossa* CLODIUS, 1922. Ver. Freunde Nat. Mecklenburg, Archiv., p. 144, pl. 1, fig. 19; *Nonion perfossum* (CLODIUS), BATJES, 1958. Kon. Belg. Inst. Nat. Wet., Verh., vol. 143, p. 141, pl. 6, fig. 16. Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone.

This species is most frequent in the Upper Coralline Limestone (fig. 8, no. 86).

Austrotrillina paucialveolata GRIMSDALE, 1952. Bull. Brit. Mus. (Nat. Hist.), Geol., vol. 1, no. 8, p. 229, pl. 20, fig. 7–10; ADAMS, 1968. Bull. Brit. Mus. (Nat. Hist.), Geol., vol. 16, p. 89, pl. 3, fig. 1–6. Lower Coralline Limestone, rather frequent in the lower part.

Test ovate, rounded at the base, subtriangular to triangular in transverse section. The chambers are distinct and rounded with depressed sutures, arrangement quinqueloculine. Outer walls are thick with coarse alveolae. The inner wall of a chamber, lying against a previous chamber is thin, without alveolae. Thickened inner walls (platform, GRIMSDALE, 1952) are occasionally visible. The alveolae are rounded or ovate and sparse in relation to the total thickness of the wall. They are arranged in a fairly regular pattern. Neither in the thin-sections, nor in free specimens are traces of ornamentation visible. In the free specimens the surface appears to be smooth. The aperture is loop-shaped with a single tooth (M17–19). Maximum length 1.42 mm, maximum width 1.05 mm.

The Maltese specimens differ from the type specimen because of the greater regularity of the alveolae and the slightly more depressed sutures. They differ from *Austrotrillina striata* TODD & POST by having no striae and by their distinct sutures. The shape of the test of *A. striata* is more rounded and its maximum dimensions are less. Most of the Maltese specimens differ from *Austrotrillina howchini* (SCHLUMBERGER) by being less triangular in transverse section and by having coarser and more rounded alveolae. Some specimens, however, resemble *A. howchini* as figured by HANZAWA (1957, pl. 22, fig. 12–13; pl. 34, fig. 1–2) by the shape of the test rather than by the alveolae. The alveolae of my specimens are coarser.

EAMES et al. (1962, p. 13) mention *Austrotrillina paucialveolata* from the upper part of the Lower Asmari of the Middle East, together with *Archaias operculiniformis*, *Palaeonummulites incrassatus*, *Eulepidina*, *Peneroplis thomasi*, and *Praerhapydionina delicata*. They also mention the concurrence of *A. paucialveolata* with *Miogypsinoides* in the 'Chattian' of Israel. In Iran *A. paucialveolata* ends its range at the top of the Lower Asmari, being replaced by *A. howchini* in the Middle Asmari Limestone. According to the review of the genus given by ADAMS (1968) *A. paucialveolata* occurs in 'undoubted Lower Oligocene beds' (p. 93), but he refers specimens seen by him from the Lower Coralline Limestone to *A.* cf. *striata* provisionally (plate 2, fig. 1–2; plate 5, fig. 9–11) (fig. 5; fig. 8, no. 2).

Bolivina antiqua d'ORBIGNY, 1846. Foram. foss. bass. Vienne, p. 240, pl. 14, fig. 11–13; *Bolivina antiqua* d'ORBIGNY, MARKS, Cushman Found. Foram. Res., Contr., vol. 2, no. 2, p. 59. Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone.

Less frequent in the middle part of the Globigerina Limestone and in the lower part of the Upper Coralline Limestone (plate 4, fig. 18).

Bolivina arta MACFADYEN, 1930. Miocene foram. Clysmic area, p. 58, pl. 4, fig. 21; CUSHMAN, 1937. Cushman Lab. Foram Res., Spec. Publ., vol. 9, p. 79, pl. 9, fig. 23–26. Globigerina Limestone, Blue Clay.

Some specimens seem transitional to *Bolivina antiqua* (fig. 8, no. 23).

Bolivina dilatata REUSS, 1950. K. Akad. Wiss. Wien, Math. Nat. Cl., Denkschr., vol. 1, p. 381, pl. 48, fig. 15; *Bolivina dilatata dilatata* REUSS, CICHA & ZAPLETALOVA, 1963. Sborn. Ustred. Ust. Geol., odd. pal., vol. 28, p. 131, fig. 11. Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone.

This species is but occasionally present in the Globigerina Limestone and scarce in the Blue Clay and Greensand. It is more frequently found in the Upper Coralline Limestone (plate 4, fig. 19a-b).

Bolivina hebes MACFADYEN, 1930. Miocene foram. Clysmic area, p. 59, pl. 2, fig. 5a-c; CUSHMAN, 1937. Cushman Lab. Foram. Res., Spec. Publ., vol. 9, p. 83, pl. 9, fig. 27–29. Globigerina Limestone.

This zonal marker is commonly, although not frequently found in the greater part of the Globigerina Limestone (plate 4, fig. 22) (fig. 8, no. 21).

Bolivina reticulata HANTKEN, 1875. K. Ungar. Geol. Anst., Mitt. Jahrb., vol. 4, no. 1, p. 65, pl. 15, fig. 6; CUSHMAN, 1937. Cushman Lab. Foram. Res., Spec. Publ., vol. 9, p. 50, pl. 6, fig. 24–27. Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone.

Bolivina reticulata occurs throughout the whole sequence of rocks from the Globigerina Limestone onwards. In the chert-bearing middle part of the Globigerina Limestone it is scarce or lacking (plate 4, fig. 20a-b) (fig. 5, no. 39).

Bolivina scalprata SCHWAGER *miocenica* MACFADYEN, 1930. Miocene foram. Clysmic area, p. 61, pl. 4, fig. 22; *Bolivina scalprata* SCHWAGER var. *miocenica* MACFADYEN, CICHA & ZAPLETALOVA, 1963. Sborn. Ustred. Ust. Geol., odd. pal., vol. 28, p. 125, fig. 6. Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone.

The species is rare to extremely rare (Blue Clay) (plate 4, fig. 21a, b) (fig. 8, no. 22).

Borelis haueri (d'ORBIGNY) = *Alveolina haueri* d'ORBIGNY, 1846. Foram. foss. bass. Vienne, p. 148, pl. 17, figs. 17–18; *Nautilus melo* FICHTEL & MOLL, var. α, 1798. Test. microsc. Arg. Naut., p. 118, pl. 24, fig. a-f; *Neoalveolina melo* (FICHTEL & MOLL) *haueri* (d'ORBIGNY) REICHEL, Etude sur les Alvéolines, p. 107; *Neoalveolina melo* (FICHTEL & MOLL), SOUAYA, Jour. Pal., vol. 37, p. 446. Lower Coralline Limestone (frequent), Upper Coralline Limestone (rare).

Test small, ovate. In macrospheric specimens chambers in about 6 whorls. The septula are frequently not in alignment. The sutures are slightly depressed (as far as can be seen in the thin-sections). The walls are thin. Length 0.5–1.2 mm, diameter 0.4–0.8 mm, diameter proloculus 0.05–0.07 mm.

My specimens differ from *Borelis pygmaeus* (HANZAWA) in having shorter tests. They differ from *Borelis primitivus* COLE by a more elongate test and smaller chamberlets. The difference from *Borelis melo melo* and *B. melo curdica* is in the absence of alternating big and small chamberlets in my specimens.

REICHEL (1937, p. 107) placed *Borelis haueri* in the group of *Borelis melo* as *Borelis melo haueri*, together with *Borelis melo melo* (FICHTEL & MOLL) and *Borelis melo curdica* REICHEL. EAMES et al. (1962, p. 20) consider *Borelis haueri* a typical Neogene species, but HANZAWA (1957, p. 67) quoting BURSCH (1947) mentions an association of *B. haueri* with *Nummulites intermedius-fichteli*. Consequently a Paleogene age seems to be possible as well (plate 2, fig. 4–5) (fig. 5; fig. 8, no. 12).

Borelis pygmaeus HANZAWA = *Borelis* (*Fasciolites*) *pygmaea* HANZAWA, 1930. Tôhoku Imp. Univ. Sci. Repts., ser. 2 (Geol.), vol. 14, no. 1, p. 94–95, pl. 26, fig. 14–15; *Borelis pygmaeus* HANZAWA. HANZAWA (1957) Geol. Soc. Amer., Mem., vol. 66, p. 55–56, pl. 34, fig. 8–9. Lower Coralline Limestone.

Test small and elongate, chambers in 5–6 closely coiled whorls. In consecutive chambers the walls of the chamberlets are partly alternating partly not. The chambers may be irregularly curved. Maximum length 1.8 mm, maximum diameter 0.75 mm, diameter of the proloculus 0.05–0.07 mm (visible in very few thin-sections).

Borelis pygmaeus HANZAWA occurs in the upper part of the lower zone of the Lower Coralline Limestone (see figs. 5, 8), especially in foraminiferal skeletal limestones. Morphologically the species is not clearly separable from *Borelis haueri*, which seems to be more frequent in the Maltese material.

HANZAWA (1957) described this species from the Tagpochau Limestone of Saipan. In the Tagpochau Limestone *Borelis pygmaeus* is associated with *Austrotrillina howchini*, *Nephrolepidina*, *Eulepidina*, several Peneroplidae and algae (HANZAWA, 1957, table 3 & 4). EAMES et al. (1962, p. 13) mention *B. pygmaeus* from the Lower Asmari of Iran (Rupelian fide EAMES et al.) in which it is present with *Archaias operculiniformis*, *Austrotrillina paucialveolata*, *Eulepidina* and *Praerhapydionina delicata*. *B. pygmaeus* occurs in New Guinea and Melanesia in stage e (EAMES et al., 1962, p. 20) in *Spiroclypeus*-rich beds with *Miogypsina*, *Miogypsinella*, *Miogypsinoides*, *Austrotrillina howchini* and

Eulepidina, but without *Nummulites*. In the Lindi area (Tanzania) *B. pygmaeus* is associated with *Eulepidina*, *Nephrolepidina*, *Miogypsina*, *Miogypsinella*, *Miogypsinoides* and *Spiroclypeus*. The age of this association is given as Aquitanian.

If all these determinations and mine are correct, *B. pygmaeus* seems to have an Oligo-Miocene range (plate 2, fig. 3) (fig. 5).

Bulimina affinis d'ORBIGNY, 1839. In: de la Sagra, Hist. Phys. Nat. Cuba, p. 105; ibid., vol. 8, pl. 2, fig. 25–26; DIECI, 1959 Pal. Ital., vol. 54, p. 58, pl. 5, fig. 5. Blue Clay (plate 4, fig. 15)

Bulimina costata d'ORBIGNY, 1852. Prodr. pal. strat. moll. ray., vol. 3, p. 194; FORNASINI, 1901. Boll. Soc. Geol. Ital., vol. 20, p. 174, textfig. 1. Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone (plate 4, fig. 11) (fig. 8, no. 90).

Bulimina elongata d'ORBIGNY, 1846. Foram. foss. bass. Vienne, p. 187, pl. 11, fig. 19–20. Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone.

The variety *Bulimina elongata* d'ORBIGNY var. *lappa* CUSHMAN & PARKER, 1937 (Cushman Lab. Foram. Res., Contr., vol. 13, no. 2, pl. 7, fig. 8) is frequently found in the Maltese samples, in the range chart it is lumped with *B. elongata* (fig. 8, no. 74).

Bulimina inflata SEGUENZA, 1862. Accad. Gioenia Sci. Nat., Atti, ser. 2, vol. 18, p. 109, pl. 1, fig. 10; DIECI, 1959. Pal. Ital., vol. 54, p. 60, pl. 5, fig. 10. Blue Clay, Greensand, Upper Coraline Limestone (plate 4, fig. 13) (fig. 8, no. 105).

Bulimina ovata d'ORBIGNY, 1846. Foram. foss. bass. Vienne, p. 185, pl. 11, fig. 13–14; CUSHMAN & PARKER, 1939. Cushman Lab. Foram. Res., Contr., vol. 13, no. 2, p. 47, pl. 6, fig. 4–5. Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone (plate 4, fig. 10, 14) (fig. 8, no. 94).

Cancris auriculus (FICHTEL & MOLL) = *Nautilus auricula* FICHTEL & MOLL, var. β FICHTEL & MOLL, 1798. Test. microsc. Arg. Naut., p. 110, pl. 20, fig. d-f; *Cancris auriculus* (FICHTEL & MOLL), MARKS, 1951. Cushman Found. Foram. Res., Contr., vol. 2, no. 2, p. 66. Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone.

Cancris auriculus is found in the lowest part of the Globigerina Limestone. Small specimens have no keel (fig. 8, no. 67).

Caucasina schischkinskaya SAMOILOVA, 1947. Soc. Nat. Moscou, Bull., n.s. vol. 52, (sect. geol. vol. 22), no. 4, p. 82, 100, textfig. 10; *Caucasina oligocaenica* KHALILOV, ESPITALIÉ & SIGAL, 1961. Rev. Micropal., vol. 3, no. 4, p. 204, pl. 1, fig. 1a-d, 3–8. Globigerina Limestone (from about the third pebble-seam onwards), Blue Clay, Greensand, Upper Coralline Limestone.

The Maltese specimens differ from the figured type specimen because they are shorter and narrower, have more elongated and less inflated chambers in the buliminid part, which gives the test a smoother appearance. The Maltese specimens fall in the range of *C. oligocaenica* as figured by ESPITALIÉ and SIGAL. They resemble the variants figured as 4 and 8 best (plate 4, fig. 12).

Chrysalogonium obliquatum (BATSCH) = *Nodosaria obliquata* (BATSCH) CUSHMAN, 1931. Cushman Lab. Foram. Res., Contr., vol. 7, p. 65, pl. 8, fig. 15–19. Rare in Globigerina Limestone and Greensand.

The Maltese specimens have no slitlike aperture but a cribrate one.

Cibicides dutemplei (d'ORBIGNY) = *Rotalina dutemplei* d'ORBIGNY, 1846. Foram. foss. bass. Vienne, p. 157, pl. 8, fig. 19–21; *Cibicides dutemplei* (d'ORBIGNY), BATJES, 1958. Kon. Belg. Inst. Nat. Wet., Verh., vol. 143, p. 150, pl. 9, fig. 9.

Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone. In the *C. dutemplei* group flattened forms are the more common type in my samples from the lower part of the Globigerina Limestone. The types with a higher test are more common from the last pebble-bed in the Globigerina Limestone upwards (see fig. 4). Neither type is represented in the cherty parts of the Globigerina Limestone. A number of aberrant specimens does occur with two apertures, or in which the last chamber has doubled into twin chambers with apertures in opposite directions. The variety *Cibicides dutemplei* (d'ORBIGNY) var. *praecinctus* (KARRER) is commonly found. In the distribution chart (fig. 8) it has been lumped with *C. dutemplei* (plate 6, fig. 2a, b, c, 4a, b, c) (fig. 8. no. 18).

Cibicides lobatulus (WALKER & JACOB) = *Nautilus lobatulus* WALKER & JACOB 1798. Adams Essays, Kanm. Ed., p. 642, pl. 14, fig. 36; *Cibicides lobatulus* (WALKER & JACOB), BATJES, 1958. Kon. Belg. Inst. Nat. Wet., Verh., vol. 143, p. 153, pl. 9, fig. 7–8. Blue Clay (scarce), Greensand (occasionally), Upper Coralline Limestone.

In this paper all planoconvex *Cibicides* specimens with a lobulate periphery that could not be specified as *C. dutemplei* or one of the other species of *Cibicides* mentioned, were counted as *C. lobatulus* (see also BATJES, 1958, p. 153). The species is extremely variable. Some specimens resemble *Falsocibicides* POIGNANT 1958 but lack the supplementary apertures. *C. lobatulus* in its initial stages shows a strong resemblance to *C. dutemplei*. Some specimens have a hollow, curved base, the imprint of the substratum onto which they were attached (plate 6, fig. 3a, b, 5a, b) (fig. 8, no. 108).

Cibicides tenellus (REUSS) = *Truncatulina tenella* REUSS, 1865. Sitz. ber. K. Akad. Wiss. Wien, vol. 50, p. 477, pl. 5, fig. 6; *Cibicides tenellus* (REUSS) BATJES, 1958. Kon. Belg. Inst. Nat. Wet., Verh., vol. 143, p. 151, pl. 9, fig. 3a-c, 4a-c. Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone.

Some planoconvex specimens may show resemblance to *Hanzawaia boueana* (fig. 8, no. 55) but differ in having no flaps on the chambers at the flattened, evolute side (plate 6, fig. 6a, b) (fig. 8, no. 19).

Cycloclypeus cf. *C. eidae* TAN SIN HOK = cf. *Cycloclypeus eidae* TAN SIN HOK, 1932. Wet. Med. Dienst Mijnb. Ned. Indië, vol. 19, p. 50, fig. 6; pl. 12, fig. 3; pl. 13, fig. 1–4. Lower Coralline Limestone.

Specimens of *Cycloclypeus* are very rare in some of the samples from the uppermost part of the Lower Coralline Limestone. They occur in thin sections (sample M467D) and in washed residues (samples from Ghar Hassan, including M372, SE Malta). The latter specimens allow some conclusions about the external and internal characteristics. All specimens are ornate, displaying regularly distributed small knobs and an elevated, central part of the test. Counts and measurements could be performed on 6 specimens only. The number of spirally arranged chambers (including the first two chambers) varies from 20 to 23, possibly 24. The diameter of the protoconch is very small, between 0.04 and 0.07 mm (mean approximately 0.057 mm).

Comparison of these scanty data with those presented by TAN SIN HOK and MACGILLAVRY (1962) suggests our specimens to be more closely related to *C. eidae* than to any other of the Indonesian or European groups described. On the basis of the number of pre-cyclic chambers, my specimens are very close to those described from Mollere by MEULENKAMP and AMATO (1972). In Mollere, inornate representatives of *Cycloclypeus* are found, with an average number of pre-cyclic chambers (including I and II) of 21. The Maltese individuals differ from those from Mollere by their ornamented surface and by the distinctly smaller size of the protoconch: 0.04–0.07 mm instead of 0.09–0.15 mm. A comparable large difference in the average size of the protoconch may be observed with respect to the Spanish ornate specimens (MACGILLAVRY, 1962), which are also fairly close to those from Malta in their number of pre-cyclic chambers (plate 2, fig. 9; plate 5, fig. 7) (fig. 5).

Grzybowskia assilinoides (BLANCKENHORN) = *Heterostegina assilinoides*, BLANCKENHORN, 1890. Zeitschr. Deutsch. Geol. Ges., vol. 42, p. 342, pl. 17; *Heterostegina assilinoides* BLANCKENHORN, emend. HENSON, 1937. Eclog. Geol. Helv., vol. 30, no. 1, p. 48, pl. 4, fig. 1–5; *Grzybowskia assilinoides* (BLANCKENHORN), HOTTINGER, 1966. C.M.N.S., Proc. Third Session, Berne 1964, p. 65, pl. 15, fig. 1–2; *Grzybowskia* cf. *involutiformis* (PAPP & KUEPPER), HOTTINGER 1966, C.M.N.S., Proc. Third Session, Berne 1964, p. 65, pl. 15, fig. 3; *Grzybowskia* aff. *involutiformis* (PAPP & KUEPPER), HOTTINGER 1966, C.M.N.S. Proc. Third Session, Berne 1964, p. 65, pl. 15, fig. 4–9; *Grzybowskia assilinoides* (BLANCKENHORN), BUTT, 1966. Late Olig. Foram. Escornebéou, p. 93, pl. 8, fig. 24–26. Lower Coralline Limestone.

It appeared very difficult to impossible to distinguish *Grzybowskia assilinoides* from *Spiroclypeus blanckenhorni ornata* in equatorial sections. The third chamber of this *Grzybowskia* species may have a secondary septum, but this is not necessarily so. The same goes for *Spiroclypeus blanckenhorni ornata*. *Grzybowskia involutiformis* also shows the same features so I am unable to distinguish *G. involutiformis* as a separate species (plate 2, fig. 6–7) (fig. 5; fig. 8, no. 17).

Gypsina globulus (REUSS) = *Ceriopora globulus* REUSS, 1848. Naturw. Abh. Wien, vol. 2, no. 1, p. 33, pl. 5, fig. 7; *Gypsina globulus* (REUSS), BURSCH 1947. Schweiz. Pal. Abh., vol. 65, p. 43, pl. 3, fig. 9. Lower Coralline Limestone (rare), Upper Coralline Limestone (common) (plate 3, fig. 5) (fig. 5; fig. 8, no. 119).

Heterostegina costata d'ORBIGNY, 1846. Foram. foss. bass. Vienne, p. 212, pl. 12, fig. 15–17; *Heterostegina costata costata* d'ORBIGNY, PAPP, 1963. In:

Evol. trends foram., p. 352, fig. 2e. Greensand (upper part), Lower Coralline Limestone (lower part) (fig. 8, no. 120).

Lepicocyclina (*Eulepidina*) *dilatata* (MICHELOTTI) = *Orbitoides dilatata* MICHELOTTI, 1861. Holl. Maatsch. Wet. Haarlem, Nat. Verh., verz. 2, vol. 15, p. 17, pl. 1, fig. 1–2; *Lepicocyclina dilatata* (MICHELOTTI), LEMOINE & DOUVILLÉ, 1904. Soc. Géol. France, Mém., vol. 32, p. 12, pl. 1, fig. 2; pl. 2, fig. 8, 21; pl. 3, fig. 10, 15; *Lepidocyclina elephantina* MUNIER-CHALMAS, LEMOINE & DOUVILLÉ, 1904. Soc. Géol. France, Mém., vol. 32, p. 13, pl. 2, fig. 13, 19; *Lepidocyclina* (*Eulepidina*) *dilatata* (MICHELOTTI), BUTT, 1966 Late Olig. Foram. Escornebéou, p. 98, pl. 8, fig. 17–18. Lower Coralline Limestone, rather frequent in the upper zone (see fig. 5, 8).

Test large to extremely large, circular, thin, undulating. Surface commonly smooth with minute pustules. The embryonic apparatus of the megalospheric specimens is very large and eulepidine. The chambers of the equatorial layer are rounded to hexagonal, ogival, or spatulate depending on the section. The lateral chambers are commonly arranged in tiers with pillarlike structures in between. Diameter up to about 10 cm, thickness up to 3 mm, thickness of the equatorial layer 0.125–0.350 mm, maximum diameter of the embryonic apparatus 3.2 mm.

The Maltese specimens come from the top part of the Lower Coralline Limestone. The best exposures are in the vicinity of Marsaskala (M365, M374) and of San Rocco near Zabbar on Malta (M467). The extremely large specimens (8 to over 10 cm) occur close to the very top of the Lower Coralline Limestone. In about 2 metres vertical distance the maximum size of the specimens grows from about 1.5 cm to about 10 cm and diminishes again to 4–8 cm in the next higher two metres (Marsaskala). At San Rocco the largest specimens are visible in the road along the coast immediately under the Globigerina Limestone.

R. DOUVILLÉ and LEMOINE (1904, p. 13) remarked that *Lepidocyclina elephantina* has the aspect of a giant *Lepidocyclina dilatata*, indistinguishable but for their size. R. DOUVILLÉ (1906, p. 631) mentions *Lepidocyclina* from Marsaskala '*Lepidocyclina dilatata* Micht., mutation *elephantina* M. Ch.' He considers them to belong to the same stratigraphic level as Peyrère and Mollere, i.e. 'Stampien terminal' or 'Aquitanian inférieur'.

The difference between *Lepidocyclina dilatata* and *L. ephippioides* would be that the latter has no pillars (GRIMSDALE, 1952, p. 244). It is considered doubtful whether *Lepidocyclina ephippioides* (JONES & CHAPMAN) in the sense of GRIMSDALE is a different species.

EAMES et al. (1962, p. 11) mention that *Eulepidina* occurs in association with *Miogypsina* in the Lower Coralline Limestone. I found no such association (plate 1, fig. 4–6) (fig. 5; fig. 8, no. 16).

Lepidocyclina (*Nephrolepidina*) *praemarginata* R. DOUVILLÉ, 1908. Bull. Soc. Géol. France, 4e sér., vol. 8, p. 91, fig. 1–2, 4; *Nephrolepidina praemarginata* (R.DOUVILLÉ), H. DOUVILLÉ, 1924. Soc. Géol. France, Mém., n.s. vol. 1, no. 2, pt. 2, p. 77, pl. 6, fig. 5–7; *Lepidocyclina* (*Nephrolepidina*) *praemarginata* R. DOUVILLÉ, VERVLOET, 1966. Strat. Pal. Data Tert. Southern Piemont, p. 59, fig. 5, pl. 12, photo 1–4. Lower Coralline Limestone, upper part in a considerable number of samples.

Test small, circular, thick in vertical section. Nephrolepidine embryonic apparatus. Pillars occur, occasionally forming small knobs on the outer surface. Diameter 1.3–2.9 mm, height 0.5–1.5 mm, thickness of the equatorial layer 0.05–0.08 mm, diameter of the protoconch 0.10–0.22 mm.

The Maltese specimens are rather small as compared with the dimensions given by DOUVILLÉ (1908) for this species. In the type diagnosis the dimensions are given as varying between 3 and 6 mm. The diameter of my specimens is smaller partly because in many specimens the outer margin is broken off. In that case the maximum diameter measurable was taken as the diameter of the individual. The size of the Maltese specimens is more like the general size of *Lepidocyclina tournoueri* LEMOINE & DOUVILLÉ as described in its type description (LEMOINE & DOUVILLÉ, 1904), about 2 mm. The Maltese specimens differ externally from *L. tournoueri* by their ornamentation. According to this ornamentation the Maltese *Nephrolepidina* would belong to the species *Lepidocyclina* (*Nephrolepidina*) *morgani* LEMOINE & DOUVILLÉ, being small representatives of this species. The only reliable method for specific determination is to measure properties of the embryonic apparatus. This method was developed by VAN DER VLERK (1963). In my paper the method used, is that modified by FREUDENTHAL (1964).

In the thin-sections of the Lower Coralline Limestone all cuts through *Nephrolepidina* were skew but for one specimen. Sample M372, Ghar Hassan (see fig. 1) provided a number of separate individuals that could be measured following the methods mentioned above.

The results of the measurements are as follows:

N = 16	range	mean ± σ_M
A	26– 47	35.9 ± 1.5
B	31– 49	41.3 ± 0.67
A + B	64– 94	77.0 ± 2.1
C	2– 3	2.46 ± 0.12
d′	134–281	218.0 ± 9.5
d″	179–409	303.0 ± 14.3
h′	108–217	151.0 ± 7.2
h″	230–435	288.0 ± 13.5

Comparing these data with the results of the measurements of *Lepidocyclina morgani* from Escornebéou (DROOGER & FREUDENTHAL, 1964, p. 515) one sees that the average embryonic apparatus of the Maltese specimens is smaller and contains less adauxiliary chambers.

VERVLOET (1966, p. 59, fig. 5) measured *Lepidocyclina* (*Nephrolepidina*) *praemarginata* from its type locality, Costa Lupara, using the same method. The mean values he obtained for *L.* (*Nephrolepidina*) *praemarginata* are very close to the mean values of the Maltese specimens. This caused me to place the Maltese specimens of *Nephrolepidina* in the species *Lepidocyclina* (*Nephrolepi-*

dina) praemarginata. The results of my measurements exclude *Lepidocyclina tournoueri* (see DROOGER & FREUDENTHAL, 1964, p. 522).

R. DOUVILLÉ (1908) describes *L. (N.) praemarginata* from an association with *Lepidocyclina dilatata*, *L.* cf. *raulini* and *Nummulites* in its type locality. VERVLOET (1966, p. 60) remarks that *L. praemarginata* seems to have been living before the rise of the Miogypsinids.

This supposition seems to be incorrect for Malta as both groups are found at the same stratigraphic level, the top of the Lower Coralline Limestone. However, *N. praemarginata* seems to appear before *Miogypsinoides* in the Maltese sections.

VERVLOET places the Costa Lupara deposits in the Mollere Member of his Ceva Formation. The age would be Oligocene, which conclusion is affirmed by MEULENKAMP and AMATO (1972) (plate 1, fig. 1–3) (fig. 5).

Marginulina behmi (REUSS) = *Cristellaria behmi* REUSS, 1866. Foram. deutsch. Sept., p. 138, pl. 2, fig. 37; *Marginulina behmi* (REUSS) 1957, Foram. Pad., pl. 11, fig. 10. Globigerina Limestone, Blue Clay, Greensand (plate 5, fig. 1–2) (fig. 8, no. 40).

Marginulina subbullata HANTKEN, 1875. K. Ungar. Geol. Anst., Mitt., Jahrb., vol. 4, no. 1, p. 46, pl. 4, fig. 9–10; pl. 5, fig. 9. Blue Clay, Greensand (rare), Upper Coralline Limestone (plate 5, fig. 3) (fig. 8, no. 113).

Miogypsinoides complanatus (SCHLUMBERGER) = *Miogypsina complanata* SCHLUMBERGER, 1900. Bull. Soc. Géol. France, sér. 3, vol. 28, p. 330, pl. 2, fig. 13–16; pl. 3, fig. 18–21; *Miogypsina (Miogypsinoides) complanata* (SCHLUMBERGER), DROOGER & MAGNÉ, 1959. Micropal., vol. 5, no. 3, p. 273, pl. 2, fig. 1–3; *Miogypsinoides complanata* (SCHLUMBERGER), DROOGER, 1963. In: Evol. trends foram., p. 315–349, fig. 1–2, 4–10. Lower Coralline Limestone, in several samples.

The Maltese specimens occur exclusively in the upper part of the Lower Coralline Limestone. No free specimens were available, but a fair number of observations could be made on rock thin sections. All individuals show thick side walls with predominant vertical structures and without lateral chambers which proves that they all belong to *Miogypsinoides*. As to the internal features good and reliable observations are scarce because of the random character of the sections. A fairly large number of microspheric specimens was observed. The exact value of their X could not be obtained in most of the specimens. However, in a few specimens the number of nepionic chambers is more than 30. In seven macrospheric specimens originating from five different samples, the number of spiral chambers (the X value of DROOGER) was counted ($11 < X < 19$ or more). The protoconch diameter was measured and found to range between 0.075 mm and 0.095 mm, which gives the impression of relatively small initial chambers. Better observations could be made on γ, which in the seven observations was found to range from $-350°$ to $-250°$. The average of these observations is $-309°$. In the $M_x - M\gamma$ scatter diagram of the Miogypsinidae, given by DROOGER (1963, fig. 10) an $M\gamma$ value of $-309°$ would correspond with an M_x value between 18.5 and 19.0.

Considering the definition of its lower M_x limit at 17, the species name *M. complanatus* is appropriate for the total of my observations. According to most authors *M. complanatus* indicates an Oligocene age (plate 2, fig. 8, 10) (fig. 5).

Operculina complanata (DEFRANCE) = *Lenticulites complanata* DEFRANCE, 1822. Dict. Sci. Nat., Min. Géol., vol. 25, p. 453; *Operculina complanata* (DEFRANCE), PAPP, 1963. In: Evol. trends foram., p. 352, fig. 2a; *Operculina carpenteri* SILVESTRI, SOUAYA, 1963. Jour. Pal., vol. 37, p. 444, pl. 53, fig. 3, 5–6, 8–9; pl. 54, fig. 2–3, 5. Lower Coralline Limestone.

Diameter 1.10–2.60 mm. EAMES et al. (1962, p. 67) record *Operculina complanata* in East Africa in the Middle Oligocene, associated with *Eulepidina, Nephrolepidina, Nummulites,* and *Palaeonummulites.* They do not record the presence of *Operculina* in Malta. The species was originally described from the Lower Miocene. It seems to have a long range in the Tertiary.

Some of the Maltese specimens resemble *Operculina carpenteri* as figured by SOUAYA from the Miocene of Egypt (plate 1, fig. 9) (fig. 5).

Pararotalia audouini (d'ORBIGNY) = *Rotalia audouini* d'ORBIGNY, 1850. Prodr. pal. strat. moll. ray., vol. 2, p. 407; *Rotalia audouini* d'ORBIGNY, FORNASINI, 1906. M. R. Accad. Ist. Bologna, ser. 6, vol. 3, p. 65, pl. 2, fig. 9–10; *Rotalia audouini* d'ORBIGNY, KAASSCHIETER, 1955. Kon. Ned. Akad. Wet., Verh., afd. Nat., ser. 1, vol. 21, p. 84, pl. 9, fig. 3a-c; *Pararotalia audouini* (d'ORBIGNY), BUTT, 1966. Late Olig. Foram. Escornebéou, p. 79, pl. 6, fig. 4. Lower Coralline Limestone.

Test small, trochoid, periphery rounded, slightly lobulate. Chambers in a spiral, about 10 chambers in the last whorl. Wall calcareous, perforate. Ventral plug; deep fissures radiating from a circular fissure around the ventral plug. Intercameral opening comma shaped. Diameter about 0.80 mm, thickness about 0.67 mm.

The figured type specimen (FORNASINI, 1906) shows a distinct keel, which is lacking wholly or partly in the last two chambers. The Maltese specimens show no keel. The test of the latter specimens is less compressed than the test of the figured type specimen.

Part of the Maltese specimens exactly resemble *Pararotalis audouini* as figured by BUTT (1966) from Escornebéou, SW France (plate 5, fig. 4a, b, c) (fig. 5; fig. 8, no. 9).

Pararotalia canui (CUSHMAN) = *Rotalia canui* CUSHMAN, 1928. Bull. Soc. Sci. Seine-et-Oise, sér. 2, vol. 8, p. 55, pl. 3, fig. 2; *Pararotalia canui* (CUSHMAN), BUTT, 1966. Late Olig. Foram. Escornebéou, p. 78, pl. 6, fig. 3. Lower Coralline Limestone.

Diameter about 0.35 mm, height about 0.25 mm. *P. canui* is very rarely encountered as separate specimens (plate 5, fig. 5) (fig. 5; fig. 8, no. 9).

Pararotalia viennoti (GREIG) = *Rotalia viennoti* GREIG, 1935. Jour. Pal., vol. 9, p. 524–526, pl. 58, fig. 1–14; *Rotalia viennoti* GREIG, SACAL & DEBOURLE, 1957. Soc. Géol. France, Mém., vol. 78, p. 40, pl. 16, fig. 1, 3; *Rotalia trochus* ROEMER, KÜMMERLE, 1963. Abh. hess. Landesamt Bodenf., no. 45, p. 62, pl. 11, fig. 4. Lower Coralline Limestone.

Occurs mainly in the upper part of the Lower Coralline Limestone associated with *Eulepidina*, *Nephrolepidina*, *Miogypsinoides*, *Grzybowskia*, and *Spiroclypeus*. Separate specimens could be sampled from a grotto in the miliolid facies of the type section of the Lower Coralline Limestone (M17–18). Some Maltese specimens resemble *R. trochus* as figured by KÜMMERLE (1963). BATJES (1958, pl. 12, fig. 9) figures a more biconvex specimen but mentions a planoconvex individual in his description of *R. trochus* (1958, p. 168). The Maltese specimens are two to three times larger as those of KÜMMERLE and BATJES (plate 5, fig. 6a, b, c) (fig. 5; fig. 8, no. 9).

Peneroplis evolutus HENSON, 1950. Middle East Tert. Peneropl., p. 37, pl. 5, fig. 12–14; pl. 6, fig. 1; pl. 10, fig. 2; VAN BELLEN, 1956. Jour. Inst. Petrol., vol. 42, no. 393, p. 250, pl. Ib. Lower Coralline Limestone.

Test small, compressed. Early chambers arranged in a very rapidly opening spiral of about one whorl or less, later chambers flabelliform with strongly recurved thin septa. Diameter up to 1.2 mm, thickness 0.12 mm, diameter protoconch 0.06–0.13 mm.

Peneroplis evolutus occurs regularly throughout the Lower Coralline Limestone. It is most frequent in the lower, miliolid facies, rare in the upper part. It is often accompanied by *Peneroplis thomasi* from which it is distinguished by a more rapidly opening spiral and by being more evolute.

HENSON (1950, p. 38) mentions *P. evolutus* from the Miliola Limestone in Iraq, associated with *Miogypsinoides complanatus*, *Nephrolepidina tournoueri*, *Rotalia viennoti* and *Meandropsina anahensis*. In the Miliola Limestone of the Kirkuk oilfield it is accompanied by *Archaias kirkukensis*, *Peneroplis thomasi* and *Austrotrillina howchini*. These assemblages resemble the association in the Lower Coralline Limestone very closely (fig. 5; fig. 8, no. 13).

Peneroplis thomasi HENSON, 1950. Middle East Tert. Peneropl., p. 36, pl. 5, fig. 7–11; VAN BELLEN, 1956. Jour. Inst. Petrol. vol. 42, no. 393, pl. Ic. Lower Coralline Limestone.

Test small, compressed. Chambers initially arranged in a spiral of about 2 whorls; later chambers narrow, strongly recurving with thin septa. No cyclical chambers were observed in the Maltese specimens. Diameter up to 1.75 mm, diameter protoconch 0.04–0.07 mm.

Peneroplis thomasi occurs throughout the Lower Coralline Limestone, although most frequent in the lower part. It occurs often together with *P. evolutus* to which it bears strong resemblance in the later part of the test. The spiral of *P. thomasi* may contain some 2 whorls as compared with one or less than one in *P. evolutus*.

HENSON (1950, p. 37) describes *Peneroplis thomasi* from the Upper Oligocene Miliola limestone in the Middle East. At its type locality in the Kirkuk oilfield, it occurs together with *Archaias kirkukensis* and *Austrotrillina howchini* (?) above a horizon with *Nummulites intermedius-fichteli* (fig. 5; fig. 8, no. 6)

Planorbulina cf. P. mediterranensis d'ORBIGNY = cf. *Planorbulina mediterranensis* d'ORBIGNY, 1826. Ann. Sci. Nat., sér. 1, vol. 7, p. 280, pl. 14, fig. 4–6, 6bis; Modèle no. 79; cf. *Planorbulina mediterranensis* d'ORBIGNY, SACAL &

DEBOURLE, 1957. Soc. Géol. France, Mém., vol. 78, p. 72, pl. 35, fig. 2. Lower and Upper Coralline Limestones.

Some transverse to oblique sections from the Lower Coralline Limestone show single layered orbitoidal forms with few irregular chambers. These individuals seem to be closest to *Planorbulina mediterranensis.* Diameter 0.8–1.1 mm, thickness about 0.25 mm.

These specimens appear in the upper part of the Lower Coralline Limestone in the transitional beds between the lower miliolid sediments and the skeletal limestone higher up. They range to the top of the Lower Coralline Limestone. Individuals from the Upper Coralline Limestone are better recognizable and might be assigned to this species with less doubt (plate 1, fig. 10) (fig. 5; fig. 8, no. 15).

Praerhapydionina delicata HENSON, 1950. Middle East Tert. Peneropl., p. 52 pl. 2, fig. 4, 6, 9. Lower Coralline Limestone in numerous samples of the lower zone.

Small, tapering test. Initial part with indistinct chamber arrangement (whorl?). Later chambers in a rectilinear, uniserial series. One curved specimen was observed in sample M17–10. The uniserial part of the test contains up to 16 chambers. The chambers are circular in transverse section. Internally the chambers have subepidermal partitions, mostly an even number between 10 and 14, 16 being the maximum. The subepidermal partitions do not alternate from one chamber to another, except when more partitions occur in the next younger chamber. In this case some partitions do alternate with those of the previous chamber. Only chambers with rectilinear arrangement possess subepidermal partitions. Sutures are scarcely visible or they are slightly depressed. In my thin-sections no ornamentation can be noticed on the outer wall.

Maximum length 2.20 mm, maximum diameter 0.55 mm, whorl diameter 0.12–0.20 mm.

The type specimen of the species comes from Iraq out of Oligocene limestones with *Archaias* cf. *aduncus*, *Grzybowskia assilinoides* and *Rotalia viennoti.* In Malta it is present in the lower, miliolid sediments of the Lower Coralline Limestone and as fragments in the upper part of the same. EAMES et al. (1962, p. 11, 28) mention *P. delicata* from the Upper Ragusa Limestone of Sicily.

The Maltese specimens differ from *Praerhapydionina cubana* VAN WESSEM by having a less conical test, a smaller initial whorl and no visible ornamentation in transverse section (compared with Utrecht coll. D25256–D25258). They differ from *Praerhapydionina huberi* HENSON by having less uniserial chambers and having better developed subepidermal partitions (plate 3, fig. 1, 2, 4) (fig. 5; fig. 8, no. 7).

Praerhapydionina huberi HENSON, 1950. Middle East Tert. Peneropl. p. 53, pl. 2, fig. 5, 7–8. Lower Coralline Limestone, rare (samples M17C, M17S).

Small tapering test. Initial part thought to form a whorl, later part uncoiling into uniserial arrangement. Rectilinear or slightly curved. The uniserial part of the test contains up to 14 chambers. The diameter of the chambers is one to three times the height. The chambers in the rectilinear part have slightly developed subepidermal partitions. Sutures are distinctly depressed or slightly so. Aperture terminal. The aperture has the shape of a small funnel with a recurved lip. The recurved part passes into the test, thus forming a closed circular channel in the apertural face. Maximum length 1.5 mm, maximum diameter 0.42 mm, diameter protoconch 0.1 mm.

The Maltese specimens of *Praerhapydionina huberi* differ from *P. delicata* by poor development of subepidermal partitions. They differ from *Spirolina* cf. *cylindracea* by a more tapering test, slightly more bulbous chambers, a thinner wall of constant thickness and possibly a smaller initial whorl. The dimensions of the few specimens encountered are within the range of typical specimens given by HENSON, the holotype is described from Upper Eocene limestones in Iraq (plate 3, fig. 3) (figs. 5; fig. 8, no. 8).

Rectobolivina marentinensis RUSCELLI, 1952. Riv. Ital. Pal. Strat., vol. 58, no. 2, p. 46, pl. 2, fig. 8. Globigerina Limestone (scarce), Blue Clay (plate 4, fig. 24) (fig. 8, no. 104).

Robulus ariminensis (d'ORBIGNY) = *Robulina ariminensis* d'ORBIGNY, 1846. Foram foss. bass. Vienne, p. 95, pl. 4, fig. 8–9; *Robulus ariminensis* (d'ORBIGNY), 1957. Foram. Pad., pl. 9, fig. 1. Blue Clay, scarce (plate 6, fig. 13).

Robulus calcar (LINNÉ) = *Nautilus calcar* LINNÉ, 1758. Syst. Nat., 10 Ed., p. 709, pl. conch. 12, t.1, fig. 3–4; t.19, fig. C, B; *Robulus calcar* (LINNÉ) DIECI 1959, Pal. Ital., vol. 54, p. 28, pl. 3, fig. 8–10. Globerigerina Limestone (rare), Blue Clay (plate 6, fig. 7) (fig. 8, no. 83).

Robulus cassis (FICHTEL & MOLL) = *Nautilus cassis* var. α FICHTEL & MOLL, 1798. Test. microsc. arg. naut., p. 95–98, pl. 17–18; *Planularia cassis* (FICHTEL & MOLL), DIECI, 1959. Pal. Ital., vol. 54, p. 37, pl. 3, fig. 11 a–b. Globigerina Limestone (upper part), Blue Clay, Greensand.

R. cassis is the biggest species of *Robulus* occurring in the Maltese samples (plate 6, fig. 12) (fig. 8, no. 64).

Robulus cultratus MONTFORT, 1808. Conch. syst., p. 215, fig. in text; DIECI, 1959. Pal. Ital., vol. 54, p. 30, pl. 2, fig. 15–16. Globigerina Limestone, Blue Clay, Greensand.

Typical *R. cultratus* has a wide keel. In the Maltese samples specimens intermediate between *R. rotulatus* and *R. cultratus* were placed under *R. cultratus* (plate 6, fig. 15) (fig. 8, no. 47).

Robulus inornatus (d'ORBIGNY) = *Robulina inornata* d'ORBIGNY, 1846. Foram. foss. bass. Vienne, p. 102, pl. 4, fig. 25–26; *Robulus inornatus* (d'ORBIGNY), DIECI, 1959. Pal. Ital., vol. 54, p. 32, pl. 2, fig. 19. Globigerina Limestone, Blue Clay, Greensand.

The lack of a keel distinguishes *R. inornatus* from *R. rotulatus* (plate 6, fig. 11) (fig. 8, no. 43).

Robulus rotulatus (LAMARCK) = *Lenticulites rotulatus* LAMARCK, 1804. Ann. Mus. Nat. Hist., vol. 5, p. 188; vol. 8, pl. 62, fig. 11; *Robulus rotulatus* (LAMARCK), 1957. Foram. Pad., pl. 10, fig. 6. Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone (scarce) (plate 6, fig. 8) (fig. 8, no. 20).

Robulus serpens (SEGUENZA) = *Robulina serpens* SEGUENZA, 1880. R. Accad.

Lincei, Cl. Sci. Fis. Mat., Nat. Mem., ser. 3, vol. 6, p. 143, pl. 13, fig. 25. Globigerina Limestone, Blue Clay, Greensand, Upper Coralline Limestone.

The Maltese specimens have a cribrate aperture. A keeled variety occurs (plate 6, fig. 9, 10) (fig. 8, no. 51).

Robulus vortex (FICHTEL & MOLL) = *Nautilus vortex* FICHTEL & MOLL, 1798. Test. microsc. arg. naut., p. 33, pl. 2, fig. d–i; *Lenticulina* (*Lenticulina*) *vortex* (FICHTEL & MOLL), BUTT, 1966. Late Olig. Foram. Escornebéou, p. 41, pl. 2, fig. 1. Globigerina Limestone, Blue Clay, Greensand (base) (plate 6, fig. 14) (fig. 8, no. 79).

Sphaeroidina bulloides d'ORBIGNY, 1826. Ann. Sci. Nat., sér. 1, vol. 1, p. 264, 267; Modèle no. 65, 3me éd.; *Sphaeroidina bulloides* d'ORBIGNY, BATJES 1958. Kon. Belg. Inst. Nat. Wet., Verh., vol. 143, p. 140, pl. 6, fig. 11. Globigerina Limestone (upper part), Blue Clay, Greensand (plate 5, fig. 8) (fig. 8, no. 93).

Spiroclypeus blanckenhorni ornata HENSON = *Spiroclypeus blanckenhorni* HENSON var. ornata HENSON, 1937. Eclog. Geol. Helv., vol. 30, no. 1, p. 51, pl. 5, fig. 4–7, textfig. 3–4; *Spiroclypeus* cf. *blanckenhorni ornata* HENSON, HOTTINGER, 1964. Colloque Paléogène Bordeaux 1962, p. 1024, pl. 7, fig. 2; *Spiroclypeus blanckenhorni* HENSON var. *ornata* HENSON, BUTT, 1966. Late Olig. Foram. Escornébéou, p. 92, pl. 8, fig. 22–23. Lower Coralline Limestone, in numerous samples of the upper zone.

Test up to 5 mm in diameter, circular in outline, flattened and relatively thin. The rim of large specimens may have a thickened marginal cord (plate 1, fig. 7, 8). The chambers are divided into chamberlets by secondary septa from the fourth chamber onwards. The chamberlets are rectangular, quadrate or hexagonal and have walls perpendicular to the chamber walls. The chamber walls are smoothly curved or have small undulations corresponding with the chamberlets. In the latter case the walls are thin to very thin. The chambers form an equatorial layer which is covered by 2–5 layers of lateral chambers on each side. In transverse section the lateral chambers are flat and elongate, arranged in tiers. Their height is about half or one third of the wall thickness. Diameter 1–5 mm, thickness 0.30–0.70 mm, diameter protoconch 0.15–0.20 mm.

It is not possible to make a distinction between the equatorial layers of *Grzybowskia assilinoides* and *Spiroclypeus blanckenhorni ornata*. The presence of secondary septa in the third chamber is without value for generic or specific distinction. The figured type specimen of *S. blanckenhorni ornata* has a secondary septum in the third chamber, a specimen figured by HOTTINGER (1962, pl. 7, fig. 2) lacks this feature. HOTTINGER (1962, p. 1026, table) places the form *blanckenhorni ornata* in the genus *Grzybowskia* but because of its lateral chambers it has to be placed in the genus *Spiroclypeus*.

Spiroclypeus blanckenhorni ornata differs from *S. anghiarensis* (SILVESTRI) in being thinner and having small pillars in between the lateral chambers. It differs from *S. blanckenhorni* HENSON by the presence of pillars (plate 1, fig. 7–8) (fig. 5).

Spirolina cf. *S. cylindracea* (LAMARCK) = cf. *Spirolinites cylindracea* LAMARCK, 1804. Ann. Mus. Nat., Hist. Nat., vol. 5, p. 245, fig. 15 (vol. 8, p. 62(14));

Spirolina cf. *cylindracea* (LAMARCK), HENSON, 1950. Middle East Tert. Peneropl., p. 31, pl. 8, fig. 11. Lower Coralline Limestone (M17C, -K, -L; M364A).

Test small, the initial part consisting of one or one and a half whorl, the later part uncoiling. The coiled part contains a protoconch and about 12 chambers in a flat spiral. The uncoiled part is uniserial and rectilinear, with 7 chambers as a maximum in the Maltese specimens. The aperture probably is terminal. Length 0.90–1.40 mm, diameter of the whorl 0.40–0.75 mm., diameter of the rectilinear part 0.40–0.90 mm, diameter of the protoconch 0.07–0.11 mm.

As only some 6 distinct specimens were encountered in my thin-sections the dimensions given are an indication only. The Maltese specimens show minor differences in shape but they are considered to belong to one species. Most (5) of my specimens were found in the miliolid facies of the Lower Coralline Limestone. One (M364A) was found in an association of algae, *Borelis haueri* and *Borelis pygmaeus*. This specimen is coarser than the specimens from the miliolid facies.

HENSON (1950, p. 24) mentions *Spirolina* cf. *cylindracea* from the basal Lower Fars (Middle Miocene) of NE Iraq. The Maltese specimens show less uniserial chambers (plate 3, fig. 9) (fig. 5; fig. 8, no. 5).

Spiroplectammina carinata (d'ORBIGNY) = *Textularia carinata* d'ORBIGNY, 1846. Foram. foss. bass. Vienne, p. 247, pl. 14, fig. 32–34; *Spiroplectammina carinata* (d'ORBIGNY), BUTT, 1966. Late Olig. Foram. Escornebéou, p. 38, pl. 1, fig. 1. Globigerina Limestone, Blue Clay, Greensand.

In the chert containing part of the Globigerina Limestone *S. carinata* is scarce or lacking (plate 4, fig. 16–17) (fig. 8, no. 25).

Uvigerina acuminata HOSIUS = *Uvigerina aculeata* HOSIUS (not d'ORBIGNY), 1893. Naturh. Ver. Preuss., Rheinl. Westfal., Verh., vol. 50 (ser. 5, vol. 10), p. 108, pl. 2, fig. 9 = *Uvigerina acuminata* HOSIUS, new name, 1895. Naturw. Ver. Osnabrück, Jahresber., no. 10 (1893–1894), p. 167, footnote; *Uvigerina acuminata* HOSIUS, PAPP, 1966. C.M.N.S., Proc. Third Session, Berne 1964, pl. 19, fig. 11–15. Globigerina Limestone, Blue Clay, Greensand.

U. acuminata is lacking in the chert containing part of the Globigerina Limestone (plate 4, fig. 5) (fig. 8, no. 30).

Uvigerina bononiensis FORNASINI, 1888, Soc. Geol. Ital., Boll. vol. 7, no. 1 p. 48, pl. 3, fig. 12–12a. Globigerina Limestone, Blue Clay.

Specimens of the *U. bononiensis* group occur from the higher part of the Globigerina Limestone onwards associated with representatives of the *U. melitensis lineage* (see 4.4.2.4.) (plate 4, fig. 9) (fig. 8. no. 31).

Uvigerina gaulensis MEULENKAMP, 1969. Utrecht Micropal. Bull., vol. 2, p. 137, pl. 2, fig. 16–22. Blue Clay (top), Greensand.

This species from the *U. melitensis* lineage is the highest developed form of this group in the Maltese Islands (plate 4, fig. 8) (fig. 8, no. 115).

Uvigerina melitensis MEULENKAMP, 1969. Utrecht Micropal. Bull., vol. 2, p. 136, pl. 2, figs. 12–15. Blue Clay (middle part) (fig. 8, no. 114).

Uvigerina pappi MEULENKAMP, 1969. Utrecht Micropal. Bull., vol. 2, p. 135, pl. 1, A; pl. 2, figs. 3–11. Blue Clay (lower part) (fig. 8, no. 112).

Uvigerina proboscidea SCHWAGER, 1866. Novara Exp. 1857–1859, Geol. Theil, vol. 2, no. 2, p. 250, pl. 7, fig. 96; *Uvigerina proboscidea* SCHWAGER, CUSHMAN & MACCULLOCH, 1948. Allan Hancock Pac. Exp., vol. 6, no. 5, p. 267, pl. 34, fig. 4. Globigerina Limestone, Blue Clay, Greensand.

U. proboscidea is lacking in the chert containing part of the Globigerina Limestone (plate 4, fig. 2) (fig. 8, no. 49).

Uvigerina pygmaea d'ORBIGNY = *Uvigerina pigmaea* d'ORBIGNY, 1826. Ann Sci. Nat., sér. 1, vol. 7, p. 269, pl. 12. fig. 8–9. Globigerina Limestone (top), Blue Clay, Greensand (base) (plate 4, fig. 1) (fig. 8, no. 96).

Uvigerina rustica CUSHMAN & EDWARDS, 1938. Cushman Lab. Foram. Res., Contr., vol. 14, no. 4, p. 83, pl. 14, fig. 6. Blue Clay (plate 4, fig. 3) (fig. 8, no. 109).

Valvulammina sp.

Lower Coralline Limestone, in samples M17-10, -A, -B, -C, -H, -J, -L, -M, N, -R; M21A, -B.

Test sphaeroidal, trochospiral, chambers arranged in two or more whorls. Initially about four chambers per whorl, later over four chambers in each convolution. Chambers distinct, slightly inflated. Sutures depressed. Wall thin, granular. Traces of ornamentation (M17-10''). No aperture visible in my thin sections. Diameter 0.7–1.3 mm, thickness about 0.3 mm.

As no separate specimens were present, specific determination was impossible. No appropriate specific name could be found in the literature on the basis of the thin-sections.

The Maltese specimens differ from the genus *Valvulina* d'ORBIGNY because they have more than three chambers per whorl in the initial part. The specimens occur all in the lower part of the Lower Coralline Limestone in the miliolid facies (plate 3, fig. 7–8).

Virgulina schreibersiana CZJZEK, 1848. Naturw. Abh., vol. 2, no. 1, p. 147, pl. 13, fig. 18–21; MARKS, 1951, Cushman Found. Foram. Res., vol. 2, no. 2, p. 59. Globigerina Limestone, scarce in the other formations (plate 4, no. 23 a, b) (fig. 8, no. 62).

8. SUMMARY

The marine Tertiary sediments of the Maltese Islands and their foraminiferal faunas form the subject of this paper. They were studied to obtain some refinement of the Oligo-Miocene stratigraphy in the Mediterranean region. Additional problems were the environmental history of the sedimentary sequence, the remarkable order of occurrence of *Orbulina* and *Miogypsina* reported by BLOW (1957) and the supposed synchronism of the Lower Coralline Limestone of Malta and the Ragusa Limestone of Sicily (EAMES et al., 1962).

Since 1843 the Maltese strata regularly aroused interest among geologists, resulting in a long series of papers on the geology and paleontology of the Tertiary and Quaternary deposits.

The Maltese Islands form an elevation on a submarine ridge that extends southward from Sicily. On Malta and Gozo, the bedding is generally subhorizontal (maximum dip about 5°). Three groups of faults, striking NE-SW, ENE-WSW and NW-SE, were distinguished. In general these faults, all vertical or subvertical, are part of a horst and graben system of relatively small vertical displacement. There are exposed only two major faults (downthrow over 100 metres) on the islands, the Grand Fault (ENE-WSW) and the Maghlaq Fault (NW-SE) (see fig. 1). Folding is restricted to slump, drag folding and one larger anticlinal structure.

In the marine Tertiary strata five formations are distinguished. For each a type section was designated. The lowermost is the Lower Coralline Limestone, an indurated algal or detrital limestone, best exposed in coastal sections and attaining a visible thickness of about 100 metres. The superposed Globigerina Limestone is a marly sediment with occasional hardgrounds and several pebble-beds in the lower two thirds of the formation and layers of chert in the middle part. The Globigerina Limestone varies in thickness between 25 and 60 metres and is the formation with the greatest areal extension on the islands. The next higher formation, the Blue Clay, is prone to erosion and is mostly found under or in the vicinity of a protective cap of younger calcareous formations. The Blue Clay is a bedded sediment, up to 50 metres in thickness, with occasional gypsum crystals and abundant foraminifera. Upon the Blue Clay lies the Greensand, a glauconitic clay or limestone, varying from some decimetres to some 15 metres in thickness. The uppermost marine formation, the Upper Coralline Limestone, strongly resembles the Lower Coralline Limestone. It has a lesser extension on the islands. It may be up to 60 metres in thickness and forms the cap that protects the Blue Clay.

In these sediments six biozones based on the planktonic foraminifera are established. Four biozones based on benthonic foraminifera are recognized, including one with three subzones.

From bottom to top the planktonic biozones are as follows:

1. *Globigerinoides trilobus – Globoquadrina dehiscens* association, occurring in the Globigerina Limestone up to the penultimate pebble-bed and corresponding roughly with zones N5-N6 of BLOW (1969).
2. *Praeorbulina* association, restricted to the Globigerina Limestone, but not found in the type section of this unit. It is comparable to zone N8 of BLOW (1969).
3. *Orbulina suturalis* association, on top of either of the previous zones, reaching up into the upper part of the Globigerina Limestone. It is equivalent to part of the zone N9 of BLOW (1969).
4. *Orbulina universa* association, extending from the top of the Globigerina Limestone, through the Blue Clay and to the basal part of the Greensand. It can be equated with parts of the zones N10–N14 of BLOW (1969).
5. *Globigerina continuosa* association, in the middle part of the Greensand of the type section, comparable to zone N15 of BLOW (1969).
6. *Globigerina acostaensis* association, from the upper part of the Greensand upwards into the Upper Coralline Limestone, corresponding to part of zone N16 of BLOW (1969).

The benthonic biozones are:

1. *Austrotrillina – Peneroplis* Assemblage-zone, representing a 'backreef' assemblage in the lower part of the Lower Coralline Limestone. It has affinities with the Oligocene of the Middle East.
2. *Amphistegina – Eulepidina* Assemblage-zone, containing species of the reef and fore-reef environment, in the upper part of the Lower Coralline Limestone. *Miogypsinoides complanatus* and *Lepidocyclina praemarginata* enable correlations with deposits of Middle to Late Oligocene Age (Chattian).
3. *Robulus – Spiroplectammina* Assemblage-zone, extending from the base of the Globigerina Limestone to the top of the Greensand. It contains three subzones:

3.1. *Bolivina hebes* Subzone, ranging from the base to the uppermost pebble-bed of the Globigerina Limestone. It represents an offshore environment with depositional breaks. This subzone contains no benthonic foraminifera that can be used for chronostratigraphic correlation.

3.2. *Anomalina helicina* Subzone, extending from the uppermost pebble-bed of the Globigerina Limestone to the top of the Blue Clay. Offshore environment. The representatives of the *Uvigerina melitensis* lineage point to a Serravallian Age.

3.3. *Ammonia beccarii* Subzone limited to the Greensand. Open marine but otherwise unknown environment. Uniserial *Uvigerina* in this subzone point to a Late Serravallian to Early Tortonian Age.

4. *Elphidium – Gypsina* Assemblage-zone, restricted to the Upper Coralline Limestone. It contains associations from reef and 'backreef' environments. *Planorbulinella rokae* at the very base of the Upper Coralline Limestone points to a Late Serravallian to Early Tortonian Age. The age of the zone is probably Tortonian.

The faunal succession shows several breaks. Some of the associations are difficult to explain ecologically because of the lack of data on the general paleogeographic configuration of the central Mediterranean area in the Oligo-Miocene.

The succession gives the impression that the depositional area first subsided and then there was a gradual shallowing.

The sequence starts with the Lower Coralline Limestone first deposited in a shallow gulf-type area, followed by a sea with shoals. The Globigerina Limestone and Blue Clay show a deepening in an open-marine environment to a maximum depth of 150–200 metres, as suggested by the foraminiferal faunas. The upper two formations (the Greensand and the Upper Coralline Limestone) and their foraminiferal associations indicate a gradual shallowing to an area with shoals, but still in an open-marine environment. The final stage, the emergence of the area, probably continued until now.

The remarkable co-occurrence of *Orbulina* and *Miogypsina*, reported by BLOW (1957), was not confirmed by my field data, nor the supposed synchronism of the Lower Coralline Limestone of Malta and the Ragusa Limestone of Sicily (EAMES et al., 1962). The top of the Lower Coralline Limestone is older (Late Oligocene) than the Ragusa Limestone of Sicily (Early Miocene).

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PLATE 1

Lower Coralline Limestone

1. *Lepidocyclina (Nephrolepidina) praemarginata* R. DOUVILLÉ, G360A, 30×.
2. *Lepidocyclina (Nephrolepidina) praemarginata* R. DOUVILLÉ, M372, 30×.
3. *Lepidocyclina (Nephrolepidina) praemarginata* R. DOUVILLÉ, M372, 30×.
4. *Lepidocyclina (Eulepidina) dilatata* (MICHELOTTI), M365A, 30×.
5. *Lepidocyclina (Eulepidina) dilatata* (MICHELOTTI), M1–2A, 30×.
6. *Lepidocyclina (Eulepidina) dilatata* (MICHELOTTI), G360C, 40×.
7. *Spiroclypeus blanckenhorni ornata* HENSON, M374–1, 35×.
8. *Spiroclypeus blanckenhorni ornata* HENSON, M71–1, 35×.
9. *Operculina complanata* (DEFRANCE), M372, 30×.
10. *Planorbulina* cf. *P. mediterranensis* d'ORBIGNY, M465C, 200×.

PLATE 1

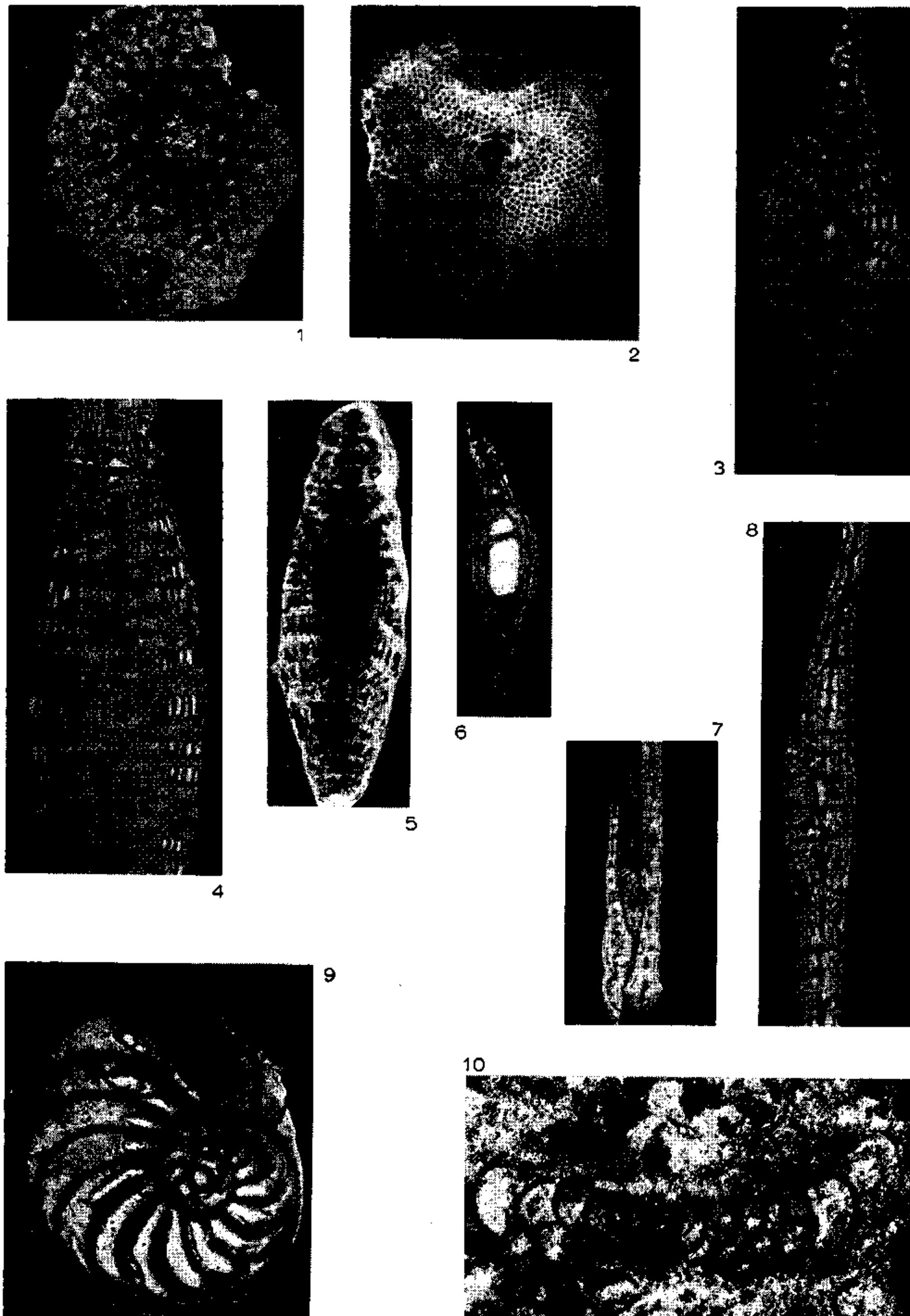

PLATE 2

Lower Coralline Limestone

1. *Austrotrillina paucialveolata* GRIMSDALE, M17–10, 30 ×.
2. *Austrotrillina paucialveolata* GRIMSDALE, M21B, 35 ×.
3. *Borelis pygmaeus* HANZAWA, M364A, 50 ×.
4. *Borelis haueri* (d'ORBIGNY), M21B, 125 ×.
5. *Borelis haueri* (d'ORBIGNY), M364B, 60 ×.
6. *Grzybowskia assilinoides* (BLANCKENHORN), M1–2C, 25 ×.
7. *Grzybowskia assilinoides* (BLANCKENHORN), G292J, 20 ×.
8. *Miogypsinoides complanatus* (SCHLUMBERGER), M377A, 30 ×.
9. *Cycloclypeus* cf. *C. eidae* TAN SIN HOK, M372, 40 ×.
10. *Miogypsinoides complanatus* (SCHLUMBERGER), M396A, 60 ×.

PLATE 2

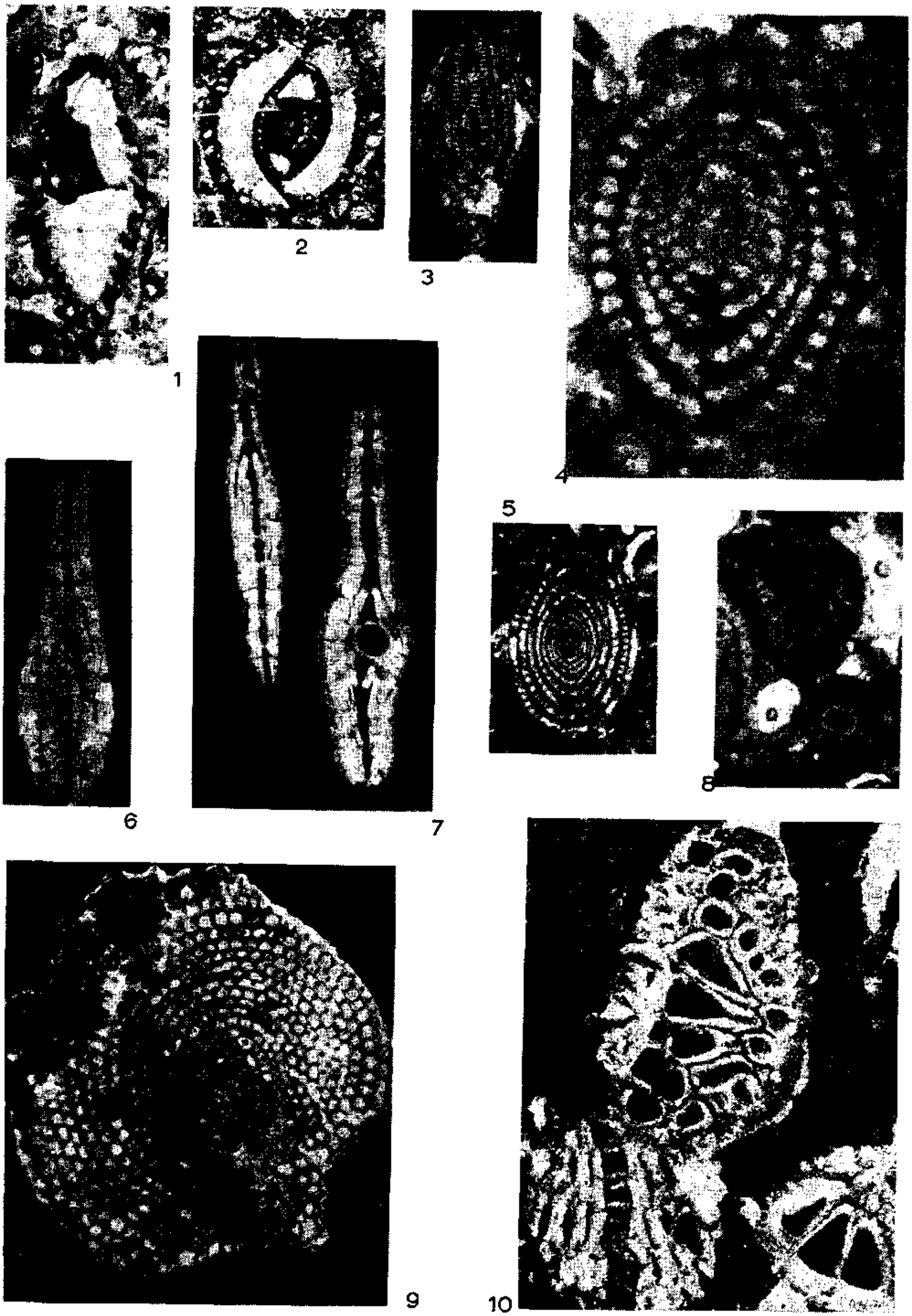

PLATE 3

Lower Coralline Limestone

1. *Praerhapydionina delicata* HENSON, M17–10, 30 ×.
2. *Praerhapydionina delicata* HENSON, M17C, 30 ×.
3. *Praerhapydionina huberi* HENSON, M17C, 30 ×.
4. *Praerhapydionina delicata* HENSON, M17C, 60 ×.
5. *Gypsina globulus* (REUSS), M467D, 30 ×.
6. *Amphistegina lessonii* d'ORBIGNY, M17–2, 30 ×.
7. *Valvulammina* sp., M17B, 30 ×.
8. *Valvulammina* sp., M17B, 30 ×.
9. *Spirolina* cf. *S. cylindracea* (LAMARCK), M17C, 30 ×.

PLATE 3

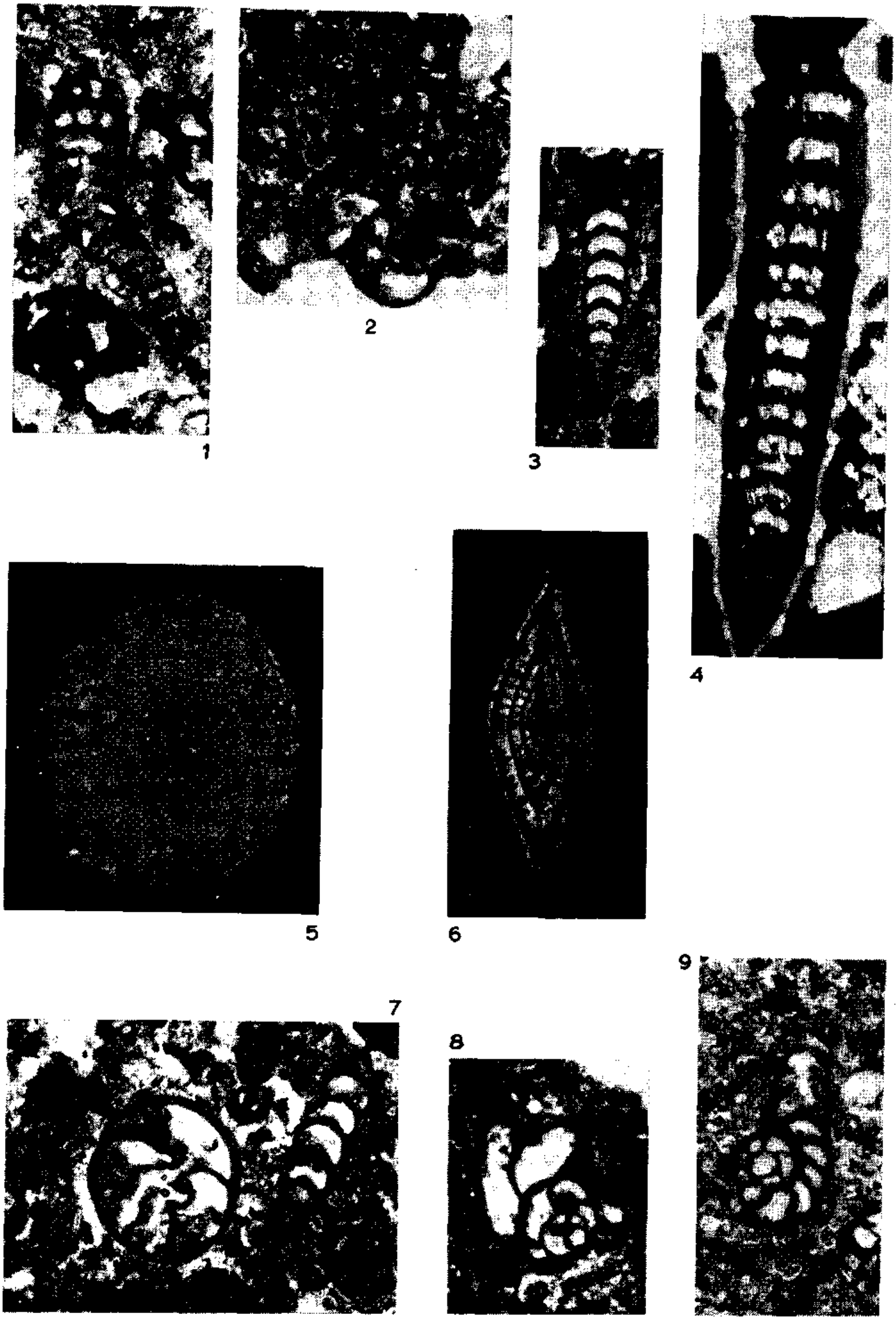

PLATE 4

1. *Uvigerina pygmaea* d'ORBIGNY, Blue, Clay, M357F, 80×.
2. *Uvigerina proboscidea* SCHWAGER, Blue Clay, M356G, 80×.
3. *Uvigerina rustica* CUSHMAN & EDWARDS, Blue Clay, M356J, 60×.
4. *Uvigerina* sp., Blue Clay, M357F, 115×.
5. *Uvigerina acuminata* HOSIUS, Blue Clay, M356B, 80×.
6. *Bulimina* cf. *costata* d'ORBIGNY, Blue Clay, M356B, 80×.
7. *Bulimina elongata* d'ORBIGNY, Blue Clay. M356B, 80×.
8. *Uvigerina gaulensis* MEULENKAMP, Blue Clay, M357F, 80×.
9. *Uvigerina bononiensis* FORNASINI, Blue Clay, M357F, 80×.
10. *Bulimina* cf. *ovata* d'ORBIGNY, Blue Clay, G437–21, 60×.
11. *Bulimina costata* d'ORBIGNY, Blue Clay, M357F, 80×.
12. *Caucasina schischkinskaya* SAMOILOVA, Globigerina Limestone, G437–3, 80×.
13. *Bulimina inflata* SEGUENZA, Blue Clay, M356V, 80×.
14. *Bulimina ovata* d'ORBIGNY, Blue Clay, M356J, 60×.
15. *Bulimina affinis* d'ORBIGNY, Blue Clay, M356D, 80×.
16. *Spiroplectammina carinata* (d'ORBIGNY), Globigerina Limestone, G437–6, 25×.
17. *Spiroplectammina carinata* (d'ORBIGNY), Globigerina Limestone, G437–6, 25×.
18. *Bolivina antiqua* d'ORBIGNY, Blue Clay, M356B, 80×.
19. *Bolivina dilatata* REUSS, Blue Clay, M357G, 80×.
20. *Bolivina reticulata* HANTKEN, Blue Clay, M356D, 80×.
21. *Bolivina scalprata* SCHWAGER *miocenica* MACFADYEN, Blue Clay, M356G, 80×.
22. *Bolivina hebes* MACFADYEN, Globigerina Limestone, G437–2, 80×.
23. *Virgulina schreibersiana* CZJZEK, Globigerina Limestone, M461W, 25×.
24. *Rectobolivina marentinensis* RUSCELLI, Blue Clay, M356R, 80×.

PLATE 4


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PLATE 5

1. *Marginulina behmi* (REUSS), Blue Clay, M356A, 25 ×.
2. *Marginulina* cf. *behmi* (REUSS), Blue Clay, M356E, 25 ×.
3. *Marginulina subbullata* HANTKEN, Blue Clay, M356D, 40 ×.
4. *Pararotalia audouini* (d'ORBIGNY), Lower Coralline Limestone, M17–20, 40 ×.
5. *Pararotalia canui* (CUSHMAN), Lower Coralline Limestone, M17–20, 115 ×.
6. *Pararotalia viennoti* (GREIG), Lower Coralline Limestone, M17–20, 40 ×.
7. *Cycloclypeus* cf. *C. eidae* TAN SIN HOK, Lower Coralline Limestone, M372, 12 ×.
8. *Sphaeroidina bulloides* d'ORBIGNY, Blue Clay, M356A, 80 ×.
9. *Austrotrillina paucialveolata* GRIMSDALE, Lower Coralline Limestone, M17–10, 30 ×.
10. *Austrotrillina paucialveolata* GRIMSDALE, Lower Coralline Limestone, M17–10, 60 ×.
11. *Austrotrillina paucialveolata* GRIMSDALE, Lower Coralline Limestone, M17–10, 60 ×.

PLATE 5

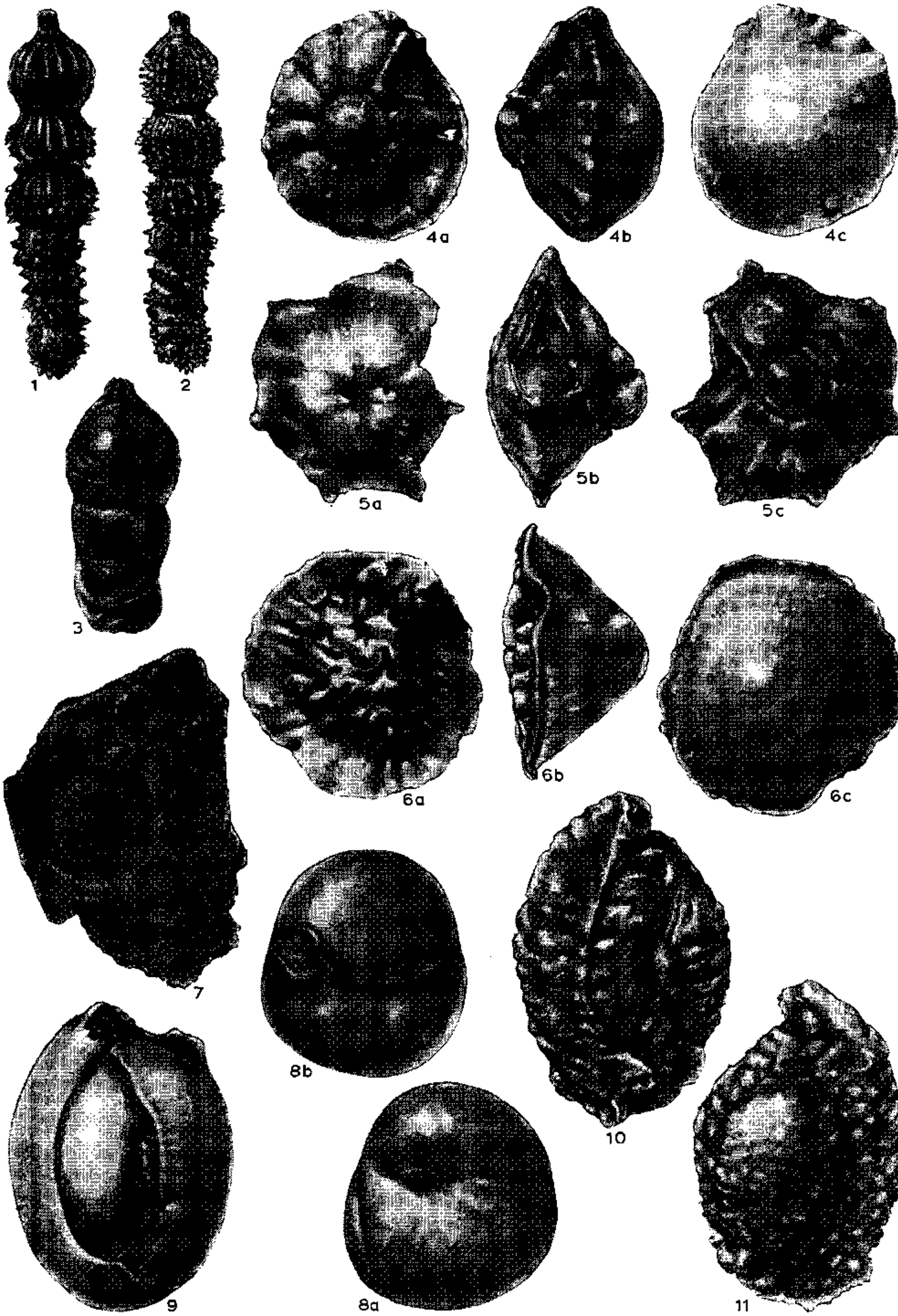


PLATE 6

1. *Anomalina helicina* (COSTA), Blue Clay, M252–0, 40 ×.
2. *Cibicides dutemplei* (d'ORBIGNY), Blue Clay, M356A, 40 ×.
3. *Cibicides lobatulus* (WALKER & JACOB), Upper Coralline Limestone, M460A, 40 ×.
4. *Cibicides dutemplei* (d'ORBIGNY), *praecinctus* (KARRER), Blue Clay, M356A, 40 ×.
5. *Cibicides lobatulus* (WALKER & JACOB), Blue Clay, M2TA, 40 ×.
6. *Cibicides tenellus* (REUSS), Blue Clay, M356A, 40 ×.
7. *Robulus calcar* (LINNÉ), Blue Clay, M356S, 40 ×.
8. *Robulus rotulatus* (LAMARCK), Blue Clay, M356A, 25 ×.
9. *Robulus serpens* (SEGUENZA), Blue Clay, M356M, 25 ×.
10. *Robulus serpens subcarenata* SELLI, Blue Clay, M252–0, 40 ×.
11. *Robulus inornatus* (d'ORBIGNY), Blue Clay, M356H, 25 ×.
12. *Robulus cassis* (FICHTEL & MOLL), Blue Clay, M252–0, 12 ×.
13. *Robulus ariminensis* (d'ORBIGNY), Blue Clay, M356F, 25 ×.
14. *Robulus vortex* (FICHTEL & MOLL), Blue Clay, M356H, 25 ×.
15. *Robulus cultratus* MONTFORT, Blue Clay, M252–0, 25 ×.

PLATE 6

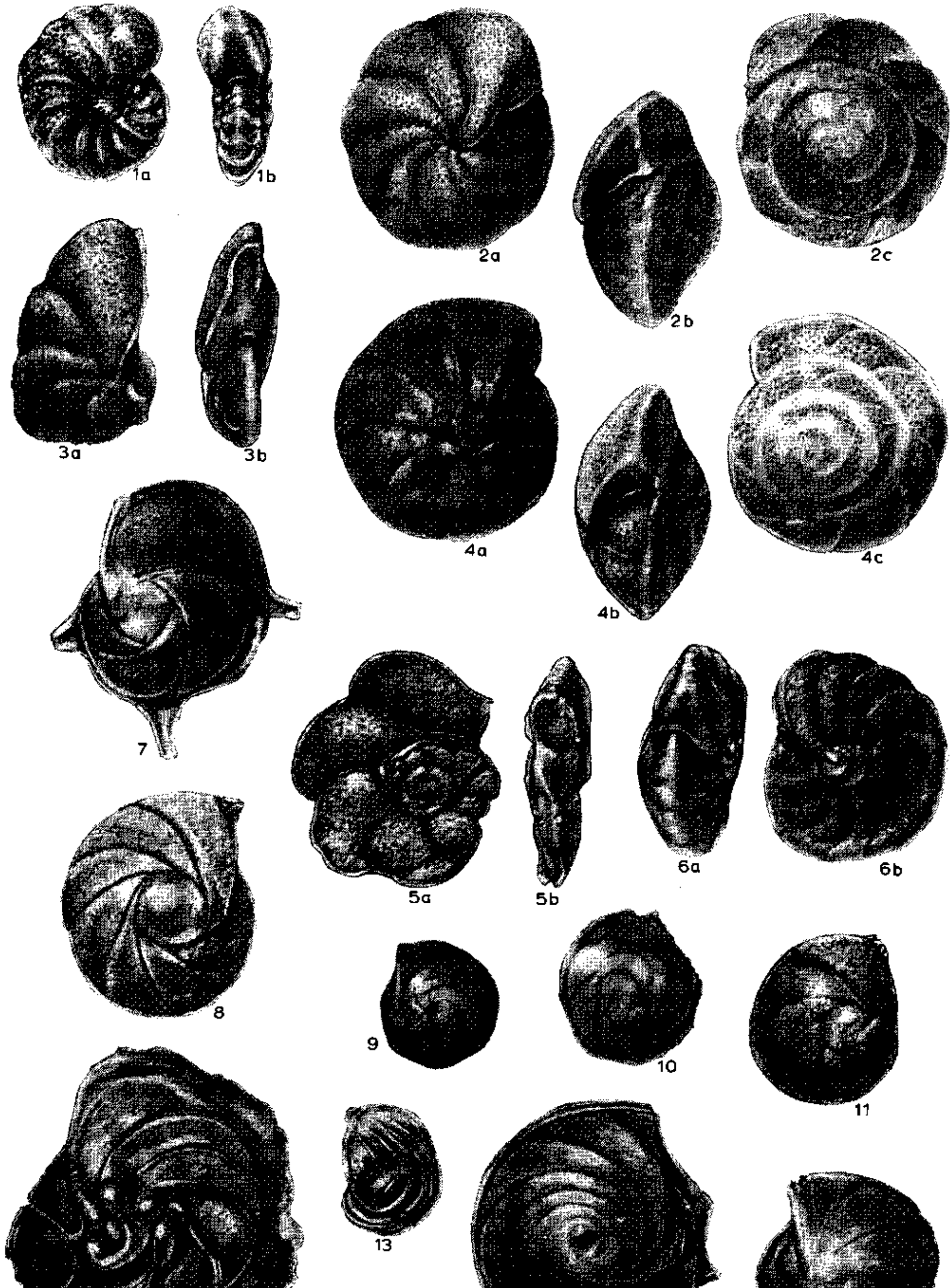
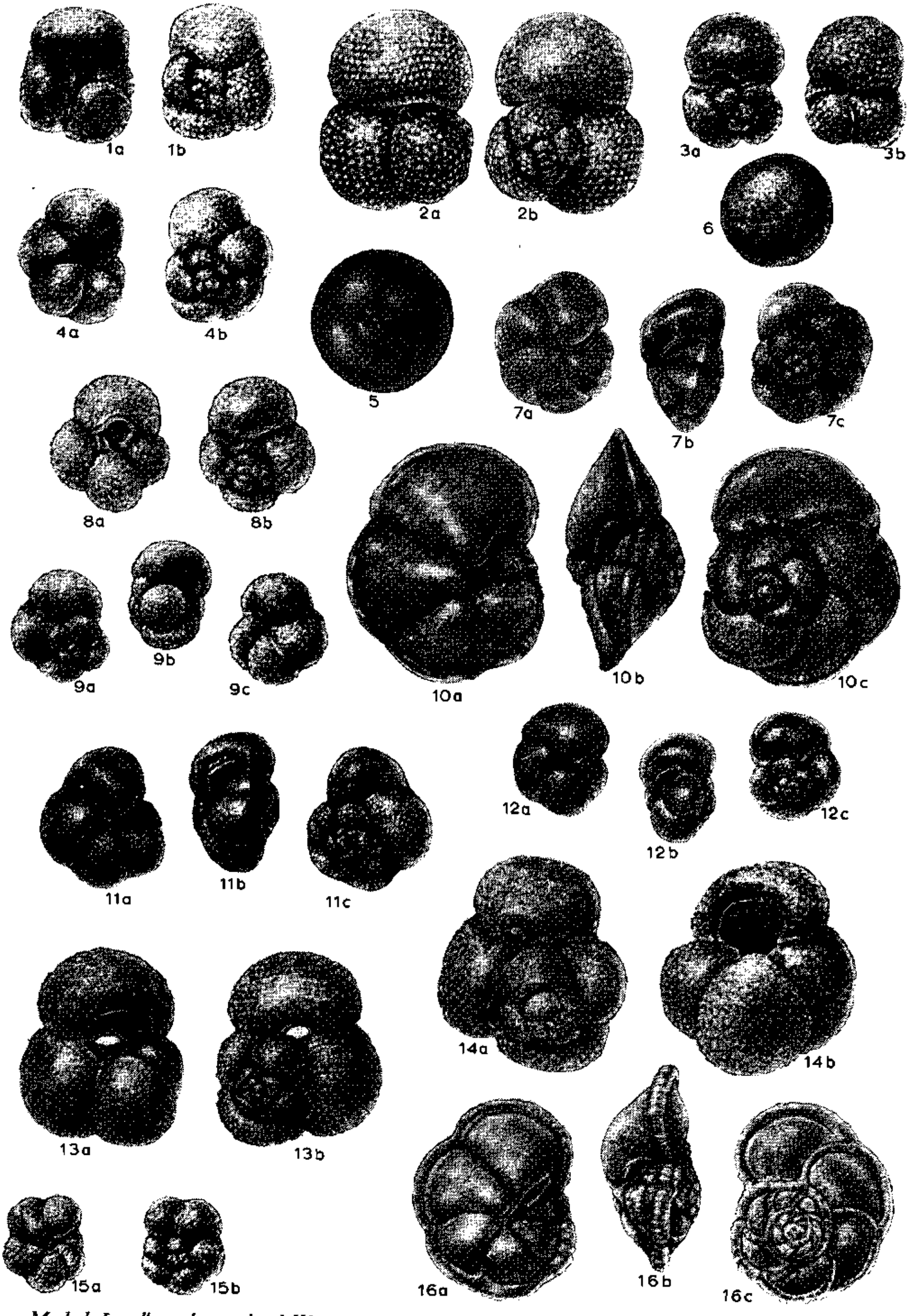


PLATE 7

1. *Globoquadrina dehiscens* (CHAPMAN, PARR & COLLINS), Globigerina Limestone, M461X, 50×.
2. *Globigerinoides trilobus* (REUSS), *immaturus* LEROY, Blue Clay, M356A, 50×.
3. *Globigerinoides altiaperturus* BOLLI, Globigerina Limestone, M461B/C, 50×.
4. *Globigerina siakensis* LEROY, Blue Clay, G437–20, 50×.
5. *Orbulina suturalis* BRONNIMANN, Blue Clay, M356X, 40×.
6. *Orbulina universa* d'ORBIGNY, Blue Clay, M356X, 25×.
7. *Globorotalia peripheroronda* BLOW & BANNER, Blue Clay, M110J, 180×.
8. *Globigerina druryi* AKERS, Blue Clay, G437–24, 80×.
9. *Globigerina continuosa* (BLOW), Greensand, G437–29, 50×.
10. *Globorotalia menardii* form 3 TJALSMA, Blue Clay, G437–19, 180×.
11. *Globorotalia* sp. TJALSMA, Greensand, G437–28, 80×.
12. *Globorotalia scitula* (BRADY), Greensand, G437–28, 80×.
13. *Globigerinoides bulloideus* CRESCENTI, Greensand, G437–30, 80×.
14. *Globigerinoides obliquus* BOLLI, Greensand, G437–30, 80×.
15. *Globigerina acostaensis* (BLOW), Greensand, G437–31, 50×.
16. *Globorotalia menardii* form 4 TJALSMA, Greensand, G437–31, 80×.

PLATE 7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