Atti Soc. Tosc. Sci. Nat., Serie A, **92** (1985)
pagg. 165-197, figg. 3, tav. 3, tav. f.t. 1.

R. Mazzei (*)

THE MIOCENE SEQUENCE OF THE MALTESE ISLANDS: BIOSTRATIGRAPHIC AND CHRONOSTRATIGRAPHIC REFERENCES BASED ON NANNOFOSSILS

Riassunto — *La sequenza miocenica dell'Arcipelago Maltese: inquadramento biostratigrafico e cronostratigrafico sulla base dei nannofossili.* In questo studio è stato affrontato il problema dell'inquadramento biostratigrafico e cronostratigrafico, sulla base dei nannofossili calcarei, dei sedimenti terziari delle isole di Malta e di Gozo ad esclusione del Lower Coralline Limestone e del Lower Globigerina Limestone. Le sezioni considerate sono state scelte tra quelle precedentemente studiate da Giannelli e Salvatorini (1972, 1975) dal punto di vista dei Foraminiferi planctonici. Lo schema biostratigrafico adottato è quello di Bukry (1973, 1975), come riportato in Okada e Bukry (1980). I riferimenti zonali effettuati per ciascuna unità studiata con le conseguenti attribuzioni cronostratigrafiche sono riportati qui di seguito:

Middle Globigerina Limestone - La porzione di questa unità compresa tra i livelli a noduli fosfatici 1 e 2 (sezioni 4 e 6 di Malta) è stata riferita alla Zona CN1, Sottozona CN1a (Aquitaniano); quella compresa tra i livelli 2 e 3 (sezioni 4, 5, 6 di Malta; sezione 15 di Gozo) alla Zona CN2 (Burdigaliano).

Upper Globigerina Limestone - Tale unità è risultata appartenere interamente alla Zona CN4 (Langhiano).

Blue Clay - I primi metri della formazione sono riferibili ancora alla Zona CN4 (parte sommitale); in questo tratto è stato posto il limite Langhiano/Serravalliano. Nell'intervallo restante fino al livello di sabbia glauconitica (livello a *Flabellipecten*) sono state individuate le sottozone CN5a e CN5b (pars) del Serravalliano mentre nella parte più alta della formazione il riferimento biostratigrafico è risultato differenziato: la parte superiore della Sottozona CN7b (Tortoniano inferiore) è stata riconosciuta nelle sezioni 5 di Malta e 15 di Gozo; la parte superiore della Zona CN8 (Tortoniano medio) nella sezione 10 di Gozo.

Greensand e Upper Coralline Limestone - Queste due formazioni sono state attribuite ad una porzione già inoltrata della Sottozona CN9b (Messiniano).

(*) Dipartimento di Scienze della Terra, University of Siena, Siena (Italy).

Investigation carried out with the grant of the Consiglio Nazionale delle Ricerche (N. 83.00536.05).

Il riconoscimento delle unità biostratigrafiche di cui sopra ha permesso anche di individuare lacune di sedimentazione all'interno della Formazione del Globigerina Limestone (in corrispondenza dei livelli a noduli fosfatici), di quella delle Blue Clays (alla base del livello a *Flabellipecten*) e al limite Blue Clays/Greensand; delle lacune, oltre che l'estensione biostratigrafica, è stata stimata anche quella temporale.

Abstract — A study has been made of the calcareous nannofossils of the Miocene sequence of the Maltese Islands (with the exception of the Lower Globigerina Limestone unit).

Identification of the coccolith zones not only permitted the chronostratigraphic placing of the sediments studied (the sequence can be referred to the Aquitanian-Messinian interval), but also to detect hiatuses within the Globigerina Limestone Formation (coinciding with the phosphatic nodule beds), the Blue Clay Formation (at the base of the glauconitic sand level) and at the Blue Clay/Greensand boundary. An evaluation has also been made of the biostratigraphic and temporal extent of these hiatuses.

Key words — Biostratigraphy, chronostratigraphy, calcareous nannofossils, Miocene, Maltese Islands.

FOREWORD

The Miocenic sediments of the Maltese Islands have been the subject of several paleontological and paleontological-stratigraphic studies during these last few years (see, for example, MARTINI, 1971; BOSSIO, 1972; GIANNELLI and SALVATORINI, 1972, 1975; MENESINI, 1972, 1974, 1979; FELIX, 1973; RUSSO and BOSSIO, 1977; HOJJATZADEH, 1978; BENNETT, 1979; CHALLIS, 1979; DI GERONIMO *et Al.*, 1981). Based on different groups of fossils (Foraminifers, calcareous Nannoplankton, Ostracods, Ittiodontolites, Echinoids, Molluscs, etc.), these studies have combined in providing useful information for solving taxonomic, paleoenvironmental, biostratigraphic, chronostratigraphic and other problems.

The objective of this paper is to make a further contribution to this research: to be more precise it will attempt to define the calcareous nannofossil biostratigraphy of some remarkable sections and, hence, their chronostratigraphic position.

The samples used are those examined by GIANNELLI and SALVATORINI (1972, 1975) relative to the plankton Foraminifers. Consequently, the study became even more interesting as it gradually became clear that it was possible to make biostratigraphic deductions based on the direct correlation of the coccolith units and those studied by above Authors.

Of the sections previously considered by GIANNELLI and SALVATORINI, this study has selected sections 4 (Matahleb zone), 5 (zone north of Fomm ir Rih Bay), 6 (zone south of Fomm ir Rih Bay) all on Malta, and 10 (zone on the western margin of Ir-Ramla Bay) and 15 (zone slightly north of Victoria) on Gozo. These sections are the most representative, as a whole, of the Tertiary sequence of the islands and present the best exposure conditions. Their exact location can be found in GIANNELLI and SALVATORINI (1972, 1975), an approximation being given in Fig. 1 of this paper.

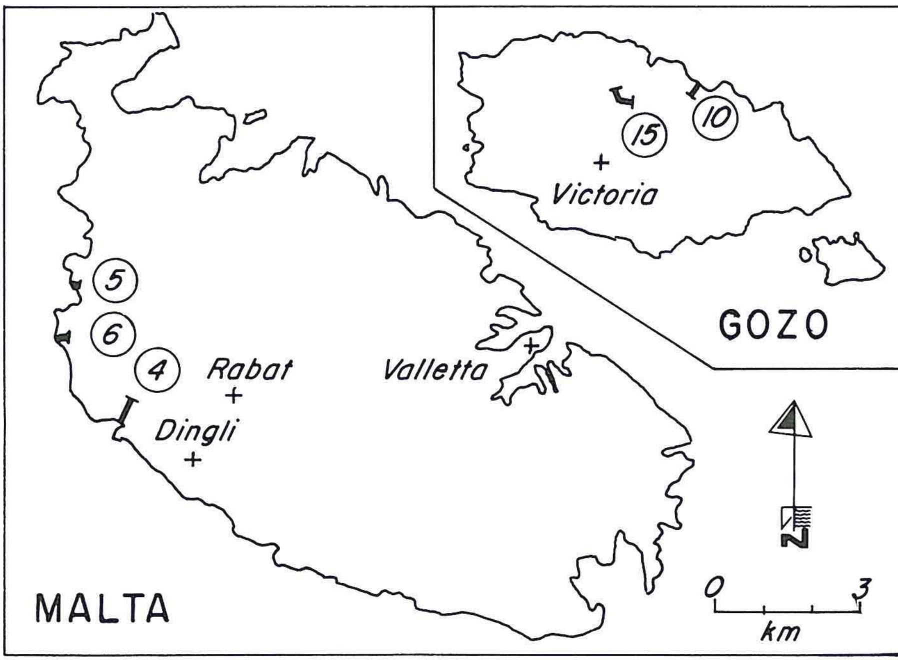


Fig. 1 - Approximate location of the sections.

PREVIOUS BIOSTRATIGRAPHIC STUDIES

The biostratigraphy and chronostratigraphy of the Miocene sequence of the Maltese Islands defined by the authors were based mainly on the plankton Foraminifers and the calcareous Nannoplankton, which are known to provide the most accurate solution to this problem in the time interval involved.

GIANNELLI and SALVATORINI (1972, 1975) identified 11 plankton Foraminifer biozones in the Middle Globigerina-Upper Coralline Limestone interval. By correlation with the zonal scheme of BLOW (1969), these Authors attributed the sediments studied to the Aquitanian, Burdigalian, Langhian, Serravallian, Tortonian and Messinian. They also detected hiatuses within the sequence and evaluated their extent on biostratigraphic scale.

A minor biostratigraphic detail was provided by FELIX (1973), who identified only 6 plankton Foraminifer biozones in a wider interval than GIANNELLI and SALVATORINI (its analysis also included the Lower Globigerina Limestone unit). FELIX attributed the entire sequence to the Aquitanian-Tortonian interval.

In a more generalized study conducted for proposing the well-known zonal scheme, MARTINI (1971) analyzed the calcareous nannofossil content of some samples from the Globigerina Limestone Formation and from the Blue Clay Formation. He identified, in the former unit, the *Sphenolithus heteromorphus* Zone (NN5), and, in the latter, the *Discoaster exilis* Zone (NN6).

A more detailed study was conducted by HOJJATZADEH (1978), but was based only on the Discoasterids and confined to the uppermost part of the Globigerina Limestone Formation and to the Blue Clay Formation. This Author recognized the *Sphenolithus heteromorphus* (NN5), *Discoaster exilis* (NN6) and *Discoaster kugleri* (NN7) zones of MARTINI's (1971) standard zonation, and concluded it belonged to the Langhian-Serravallian age.

LITHOSTRATIGRAPHICAL OUTLINES OF THE SECTIONS

The Maltese Islands are composed of Oligo-Miocene limestones and marls with very subsidiary Quaternary deposits. The sequence of the Tertiary sediments is usually divided into 5 lithostratigraphic units, comprising, from the bottom upwards:

— Lower Coralline Limestone Formation
— Globigerina Limestone Formation
— Blue Clay Formation
— Greensand Formation
— Upper Coralline Limestone Formation

Despite the presence of tectonic displacements these units have still retained their original horizontal bedding.

Many descriptions have already been given in the literature of the Maltese sequence (see, for example, HYDE, 1955; HOUSE *et Al.*, 1962; GIANNELLI and SALVATORINI, 1972, 1975; FELIX, 1973; PEDLEY *et Al.*, 1976; PEDLEY *et Al.*, 1978) and further details can be obtained from these publications. Considering that the present research was prevalently of a biostratigraphic nature, only a few lithostragraphic observations on the studied sections will now be presented.

LOWER CORALLINE LIMESTONE FORMATION (sections 4 and 6 of Malta). In the sections considered only the upper part of the formation outcrops. It consists of massive, coarse-grained limestone of a whitish colour, containing mainly coralline Algae (*Lithothamnion* and *Archaeolithotamnion*); in subordinate quantities are benthonic Foraminifers, Gastropods, Pectinids, Echinoids, etc..

The Lower Coralline Limestone Formation is separated from the overlying unit in sections 6 and 15 by a prominent calcarenite layer containing abundant *Scutella* and other Echinoids, of a yellow-reddish colour. This somewhat thin horizon is known in the geological literature as the «*Scutella* transition bed».

Upper Oligocene (1).

GLOBIGERINA LIMESTONE FORMATION (sections 4, 5 and 6 of Malta; sections 10 and 15 of Gozo). Marly limestone, at times stratified, predominantly yellowish, containing very abundant calcareous micro- and nannoplankton. Other, locally abundant, fossils include Molluscs, Echinoids, shark teeth, etc.. The best and most complete outcrop can be noted in section 4, where it reaches a thickness of about 70 m.

Within the formation are prominent dark yellow beds, of variable thickness and frequency, containing phosphorite pubbles. There are 3 main horizons on the Island of Malta (sections 4 and 6) and only 2 on Gozo (section 15).

The unit is usually divided into 3 parts, on the basis of the

(1) The ages given for the various units were taken from GIANNELLI and SALVATORINI (1972, 1975).

freshness of these layers, as well as the paleontological characteristics: Lower, Middle and Upper Globigerina Limestone. To simplify matters the nodule-bearing horizons within the studied sections have been termed as follows:

— level 1 (separating the Lower and Middle Globigerina Limestone)
— level 2 (within the Middle Globigerina Limestone)
— level 3 (separating the Middle and Upper Globigerina Limestone).

The clay content gradually but rapidly increases with the passage into the overlying unit.

Because of the uncertainty of the biostratigraphic data relative to the studied sections, GIANNELLI and SALVATORINI (1972) were reluctant to attribute an age to the Lower Globigerina Limestone unit (2). These Authors, on the other hand, assign the Middle Globigerina Limestone unit to the Lower Miocene (Aquitanian and Burdigalian), and the Upper Globigerina Limestone unit to the Middle Miocene (Langhian).

BLUE CLAY FORMATION (sections 4 and 5 of Malta; sections 10 and 15 of Gozo). More or less clayey marls of a blue-grey colour, mainly rich in calcareous micro- and nannoplankton. They also include Corals, Molluscs, Echinoids, Pteropods, remains of marine vertebrates, etc.

The formation is well exposed in the sections under study. Its maximum thickness (about 50 m) can be observed in section 15.

A glauconitic sandy bed can also be noted in the upper part of the marls (sections 5, 10 and 15). Of a variable but limited thickness, it is characterized by frequent bivalves belonging to the genera *Amusium* and *Flabellipecten*.

Middle Miocene-Upper Miocene (Upper Langhian-Lower Tortonian or Upper Langhian-Middle Tortonian).

GREENSAND FORMATION (sections 4 and 5 of Malta; sections 10 and 15 of Gozo). Poorly cemented sands whose greenish colour can be related to presence of numerous glauconitic grains. The Greensand Formation is always of limited thickness, reaching a maximum of about 6 m in section 15.

---

(2) A biostratigraphic study (plankton Foraminifers, calcareous Nannoplankton and Ostracods) is now under way on the Lower Globigerina Limestone unit, utilizing more favourable sections.

The unit has strong concentrations of *Heterostegina,* and also contains common Molluscs and Echinoids.

In the sections the contact with the underlying marls is sharps, whereas the contact with the Upper Coralline Limestone Formation appears transitional, because of the glauconitic grains dispersed within the lowermost part of this unit.

Upper Miocene (Messinian).

UPPER CORALLINE LIMESTONE FORMATION (sections 4 and 5 of Malta; sections 10 and 15 of Gozo). This prevalently whitish formation can be divided into 2 parts: a lower, thinner part in which the limestone is detritic, with abundant rhodolites (*Lithophyllum*), Brachiopods, etc., and marly intercalations; and an upper part whose limestone is more compact and mainly contains coralline Algae, Molluscs and Corals.

The total thickness of this unit never exceeds 20 m in the sections under study.

Upper Miocene (Messinian).

BIOSTRATIGRAPHY AND CHRONOSTRATIGRAPHY

The micropaleontological analysis was conducted on several samples taken from the Miocene sequence of the Maltese Islands, with the exception of the Lower Globigerina Limestone unit.

From the point of view of abundance and preservation, there is a wide variation in the calcareous Nannoplankton. It is, in fact: a) generally abundant and well preserved in the Middle-Upper Globigerina Limestone units and Blue Clay Formation; and b) absent or rare and poorly preserved in the Greensand and Upper Coralline Limestone formations. With regard to the Middle-Upper Globigerina Limestone units and Blue Clay Formation, the number of species is also well represented (poorly diversified assemblages can be noted in the lowermost part of the Middle Globigerina Limestone unit only).

There is little evidence of reworking throughout the units; however, it is more conspicuous in the phosphatic nodule beds within the Globigerina Limestone Formation, in the glauconitic sand level within the Blue Clay Formation (upper part) and at the Blue Clay/Greensand boundary.

Figure 2 shows a range-chart of the most important autochthonous species, based on the results of the analysis of sections 4, 5, 6 (Malta) and 15 (Gozo), which represent the situation most common to the Maltese Islands.

The open ocean low-latitude zonation of BUKRY (1973, 1975), with subsequent modifications by OKADA and BUKRY (1980) was utilized for this study (Table 1).

The biostratigraphic intervals recognized in the Miocene sequence, from the Middle Globigerina Limestone unit on, are described below, limiting the report to the main features only.

MIDDLE GLOBIGERINA LIMESTONE UNIT

The lower part of the unit, between the phosphatic nodule levels 1 and 2 (sections 4 and 6 of Malta), has been referred to the *Triquetrorhabdulus carinatus* Zone (*Cyclicargolithus abisectus* Subzone), while the remainder (sections 4, 5 and 6 of Malta; section 15 of Gozo) has been assigned to the *Sphenolithus belemnos* Zone.

Cyclicargolithus abisectus Subzone (CN1a): interval from the disappearance of *Sphenolithus ciperoensis* to the end-acme of *C. abisectus*.

The best represented taxa are *Coccolithus miopelagicus, C. pelagicus, Cyclicargolithus abisectus, C. floridanus, Pontosphaera* sp. and *Sphenolithus moriformis* (all common). *Coronocyclus nitescens, Helicosphaera euphratis, H.* spp. and *Triquetrorhabdulus* sp. are also found in rare and scattered specimens.

Identification of the subzone is mainly based on the common occurrence of *C. abisectus,* lacking *S. ciperoensis.* We can exclude any possibility of it being the *S. ciperoensis* Zone (the nominal taxon could be missing because of environmental conditions) because of the absence of species such as *Dictyococcites dictyodus, D. bisectus, D. scrippsae, Helicosphaera recta* and *Zygrhablithus bijugatus,* whose last occurrence has often been utilized by many Authors (see, for example, MARTINI, 1971; BUKRY, 1973; MARTINI and MULLER, 1975; BIZON and MULLER, 1979a, b) to define the *S. ciperoensis* Zone/*T. carinatus* Zone boundary at various latitudes, as well as at different depths of deposition.

Observations. By attributing the sediments between the phosphatic nodule levels 1 and 2 to the *C. abisectus* Subzone (which

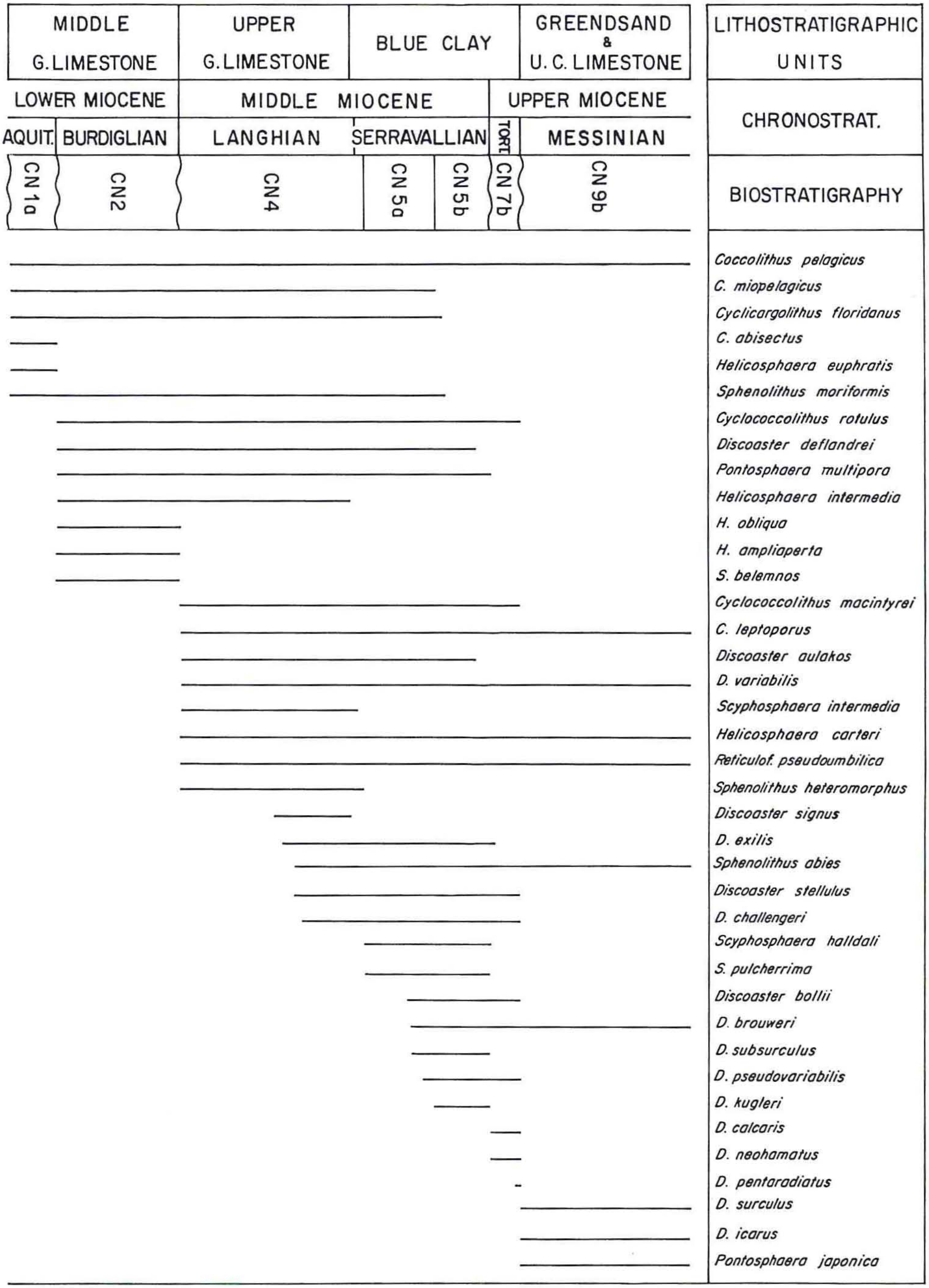


Fig. 2 - Range-chart of the most significant taxa.

corresponds to the lower part of the NN1 Zone of MARTINI, 1971), we directly imply that there is an immediate correlation between this biostratigraphic unit and Interval 2 (*Globigerinoides primordius* assemblage) of GIANNELLI and SALVATORINI (1972), and consequently, according to the conclusions drawn by these Authors, with the upper half of N4 Zone of BLOW (1969).

This correlation permits us to define more precisely the correlation proposed in the literature, in the latest calibrations between calcareous Nannoplankton and plankton Foraminifer zonations (see, for example, RYAN *et Al.*, 1974; VAN COUVERING and BERGGREN, 1977; BERGGREN, 1978; BIZON and MULLER, 1979a).

Chronostratigraphic reference. Calcareous Nannoplankton biostratigraphy of the Aquitanian stratotype is not known, but MULLER and PUJOL (1979) have recently recognized the NN1 Zone of MARTINI (1971) in several sections located near the section type. Bearing this in mind, it seems reasonable to assign the lowest part of the Middle Globigerina Limestone unit to this stage. Confirmation can also be obtained from the results of GIANNELLI and SALVATORINI, who attribute the interval in question to the Aquitanian, basing their reference on the result of ANGLADA (1971a, b) for the stratotype.

Sphenolithus belemnos Zone (CN2): interval from the appearance of the nominal taxon to the appearance of *Sphenolithus heteromorphus*.

The association found in the interval of the Middle Globigerina Limestone unit included between the phosphatic nodule levels 2 and 3 are more diversified than those described above. Common *Coccolithus miopelagicus, C. pelagicus, Cyclococcolithus rotula, Cyclicargolithus floridanus, Pontosphaera* sp., *Sphenolithus belemnos* and *S. moriformis* are generally associated with rare *Discoaster deflandrei, Pontosphaera multipora, Helicosphaera ampliaperta, H. intermedia, H. obliqua* and *Reticulofenestra* sp..

The occurrence of *S. belemnos* lacking *S. heteromorphus* dispels any doubts as to recognition of the CN2 Zone.

Observations. Correlation of the *S. belemnos* Zone, as it appears here, with Interval 3 (*Globigerinoides altiaperturus* assemblage) of GIANNELLI and SALVATORINI (1972) and, as suggested by these Authors, with the interval between the basal part of N6 Zone and the basal part of N7 zone of BLOW (1969), is consistent with that reported by many Authors (see, for example, BERGGREN, 1978; MEULENKAMP *et Al.*, 1975; VAN COUVERING and BERGGREN, 1977; BIZON and MULLER, 1979b).

Chronostratigraphic reference. According to recent bibliographic data (see, for example, RYAN *et Al.*, 1974; MEULENKAMP *et Al.*, 1975; VAN COUVERING and BERGGREN, 1977; BIZON and MULLER, 1979b), recognition of the *S. belemnos* Zone (practically identical to NN3 Zone of MARTINI, 1971) in the sediments included between the phosphatic nodule levels 2 and 3, clearly indicates that these sediments belong to the Burdigalian, in accordance with the results of GIANNELLI and SALVATORINI. It should be noted that MULLER and PUJOL (1979) identified only the NN2 Zone of MARTINI in the Burdigalian stratotype; these same Authors, however, suggest that the Burdigalian extends biostratigraphically from the base of the NN2 Zone to the upper part of NN4 Zone.

UPPER GLOBIGERINA LIMESTONE UNIT

This unit belongs entirely to the *Sphenolithus heteromorphus* Zone (sections 4 and 5 of Malta; sections 10 and 15 of Gozo).

Sphenolithus heteromorphus Zone (CN4): interval from the appearance of *Cyclococcolithus macintyrei* to the disappearance of the nominal taxon.

The nannofossil assemblages are mainly characterized by the occurrence of *Sphenolithus heteromorphus* (common), *Cyclococcolithus leptoporus, C. macintyrei, Reticulofenestra pseudoumbilica* and *Helicosphaera carteri* (all from rare to common). *Coccolithus miopelagicus, C. pelagicus, Cyclicargolithus floridanus, Sphenolithus moriformis* are always common throughout the interval whereas *Cyclococcolithus rotula, Discoaster aulakos, D. deflandrei, D. variabilis, Pontosphaera multipora, Lithostromation perdurum, Helicosphaera intermedia, H.* sp., *Scyphosphaera intermedia, Rhabdosphaera procera, Thoracosphaera* sp. are found only in rare and scattered specimens. In the upper part of the unit rare *Discoaster exilis, D. challengeri, D. signus, D. stellulus* and *Sphenolithus abies* occur.

We can assume that the Upper Globigerina Limestone unit belongs to this zone, because of the occurrence of *C. macintyrei* and *S. heteromorphus,* starting from the base of said unit. The upper boundary of the CN4 Zone lies some metres above the Globigerina Limestone/Blue Clay boundary.

Observations. GIANNELLI and SALVATORINI (1975) distinguished within the Upper Globigerina Limestone unit Interval 4 (*Praeorbulina* assemblage) and Interval 5 (*Orbulina* assemblage), which they correlated with the N8 Zone (pars)-N9 Zone (pars) interval of BLOW (1969). From the point of view of the calcareous nannofossils, the unit proved to belong entirely to the CN4 Zone.

It is well-known that, when calibrating zonations based on the two groups of organisms, the upper boundary of the CN4 Zones is generally placed within the N11 Zone (see, for example, RYAN *et Al.*, 1974; MEULENKAMP *et Al.*, 1975; VAN COUVERING and BERGGREN, 1977; BERGGREN, 1978) whereas the lower boundary has no fixed placing: some Authors assign it to the upper portion of the N8 Zone (RYAN *et Al.*, 1974; BIZON and MULLER, 1979), others lower it until it coincides with the lower limit of the N8 Zone (VAN COUVERING and BERGGREN, 1977; BERGGREN, 1978), and still others place it in the uppermost part of the N7 Zone (MEULENKAMP *et Al.*, 1975). In view of these calibrations, the results obtained by GIANNELLI and SALVATORINI and those given in this paper are quite compatible; one cannot exclude that a more or less early portion of the CN4 Zone is not represented in the Upper Globigerina Limestone unit.

Chronostratigraphic reference. From the stratigraphic distribution of the calcareous nannofossils given by MARTINI (1968) for the Bricco della Croce section (type Langhian), we can deduce the position of the section in the most recent zonations. Thus the section belongs to the NN5 Zone-NN7 Zone (basal part) interval of MARTINI (1971), and, correspondingly, to the CN4 Zone-CN5b Subzone (basal part) interval of OKADA and BUKRY (1980). CITA and BLOW (1969) refer this same section to the N8 Zone (pars)-N10 Zone (lower part) interval of BLOW's standard zonation.

Considering the calibrations obtained, in favourable series, between calcareous nannofossil zonations and plankton Foraminifer zonations, the duration of the Langhian clearly differs depending on whether we adopt MARTINI's or CITA and BLOW's results. This has also been shown by MEULENKAMP *et Al.* (1975) (3). Obviously, a revision should be made of the Langhian stratotype from the biostratigraphic point of view.

At present, the identification made here of the CN4 Zone per-

(3) According to these Authors the Langhian stratotype belongs to the following biostratigraphic intervals: N8 Zone (upper part)-N10 Zone (lower part) interval of the planktonic Foraminifers, NN4 Zone (upper part)-NN7 Zone (basal part) interval of the nannofossils.

mits the Upper Globigerina Limestone unit to be referred to this stage.

Blue Clay Formation

The basal metres of the formation belong to the uppermost part of the *Sphenolithus heteromorphus* Zone. Moving upwards to the glauconitic sandy bed, the unit has been referred to the *Discoaster exilis* Zone (*Coccolithus miopelagicus* and *Discoaster kugleri* subzones). With regard to remaining part of the marls, different biostratigraphic references exist in the various sections: *Discoaster hamatus* Zone (*Catinaster calyculus* Subzone) has been recognized in sections 5 and 15, and *Discoaster neohamatus* Zone in section 10.

Coccolithus miopelagicus Subzone (CN5a): interval from the disappearance of *Sphenolithus heteromorphus* to the appearance of *Discoaster kugleri.*

Discoaster kugleri first occurs in the middle part of the marls; consequently, the underlying marly interval, except for a short basal way (see above), can be placed in this subzone.

Discoasterids occur consistently in the assemblages: *Discoaster exilis* is particularly frequent; *Discoaster aulakos, D. challengeri, D. deflandrei, D. stellulus* and *D. variabilis* are fairly common; on the contrary *Discoaster bollii, D. brouweri, D.* aff. *kugleri, D. intercalaris, D. pseudovariabilis, D. subsurculus* are less frequent and limited to the upper part of the subzone. Among the best represented species throught the interval are also to be mentioned *Coccolithus miopelagicus, C. pelagicus, Cyclococcolithus macintyrei, C. rotula, Cyclicargolithus floridanus, Reticulofenestra pseudoumbilica, Rhabdosphaera procera, Helicosphaera carteri, Sphenolithus abies, S. moriformis* (all from common to abundant). Finally rare and sporadic occurrences of *Cyclococcolithus leptoporus, Pontosphaera multipora, Scyphosphaera halldali, S. pulcherrima, Holodiscolithus macroporus* and *Lithostromation perdurun* are to be mentioned.

Observations. Placed within the Maltese sequence, the upper limit of the CN4 Zone lies within Interval 6, slightly above the N9 Zone/N10 Zone boundary, which is, with some reservations, as indicated by Giannelli and Salvatorini. This result is in disagreement with that reported by several authors which fix this limit within the N11 Zone (see above).

Note that HOJJATZADEH (1978) has attributed the lower part of the Blue Clay Formation to the NN6 Zone of MARTINI (equivalent to the CN5a Subzone of OKADA and BUKRY); in this way the upper limit of the CN4 Zone would coincide with the Interval 5/Interval 6 boundary of GIANNELLI and SALVATORINI, and thus fall within the N9 Zone of Blow, further increasing the discrepancy observed.

The *Coccolithus miopelagicus* Subzones includes the upper part of Interval 6 (*Globorotalia peripheroronda* assemblage) and most of Interval 7 (*Globoquadrina* gr. *altispira* assemblage) of GIANNELLI and SALVATORINI (1975). The lower limit of this subzone has already been dealt with; the upper limit, according to recent literature (see, for example, BERGGREN and AMDURER, 1973, BERGGREN and POORE, 1974; RYAN *et Al.*, 1974; BERGGREN and VAN COUVERING, 1974; VAN COUVERING and BERGGREN, 1977; BERGGREN, 1978; BIZON and MULLER 1979b) should be placed within the N12 Zone of BLOW. Thus this zone can be recognized in the mid-upper part of the marls, in confirmation of that indicated by GIANNELLI and SALVATORINI.

It should also be emphasized that the position given here for the upper limit of the CN5a Subzone is almost identical to that proposed by HOJJATZADEH (1978).

Discoaster kugleri Subzone (CN5b): interval from the appearance of the nominal taxon to the appearance of *Catinaster coalitus*.

As mentioned above, *Discoaster kugleri* first occurs in the middle part of the Blue Clay Formation; it appears in rare specimens up to the glauconitic sand level. *Catinaster coalitus* was not found.

The assemblages differ mainly from those of the CN5a Subzone in the presence of the nominal taxon and absence of *Coccolithus miopelagicus*, *Cyclicargolithus floridanus* and *Sphenolithus moriformis* (really rare specimens of these taxa have been found with *D. kugleri* for a short way). Note also that *Discoaster bollii* increase in frequency until it become common, starting near the horizon on which *Discoaster aulakos* and *D. deflandrei* disappear, a few metres below the glauconitic sand level.

Observations. The CN5b Subzone (equivalent to the NN7 Zone of MARTINI) includes, as shown here, the upper part of Interval 7 (*Globoquadrina* gr. *altispira* assemblage) and Interval 8 (*Globorotalia melitensis* assemblage) of GIANNELLI and SALVATORINI (1975), or, in terms of BLOW's zonation, part of the N12 Zone. Bearing in mind that the upper boundary of the subzone corresponds to the N13 Zone/N14 Zone boundary, or slightly precedes it (see, for example, BERGGREN and AMDURER, 1973; BERGGREN and POORE, 1974; RYAN *et Al.*, 1974; BERGGREN and VAN COUVERING, 1974; VAN COUVERING and BERGGREN, 1977; BERGREEN, 1978; BIZON and MULLER, 1979b), it becomes obvious that the CN5b Subzone is not totaly represented in the Blue Clay Formation.

Chronostratigraphic reference. MULLER's study (1975) of the Serravallian type has shown that the Serravallian belongs to the NN7 Zone and, probably, to zones NN8 and NN9 (lower part) of MARTINI's standard zonation. According to this study, only the uppermost part of the marls underlying the glauconitic sandy bed can be referred to the Serravallian. Assuming that the lower boundary of the CN5b Subzone lies within the N12 Zone Of BLOW (see above) and that, according to CITA and BLOW (1969), the Serravallian stratotype comprises the interval N10 Zone (upper part)-N14 Zone, it become clear that the lower boundary of the Serravallian must be placed much further down in the Miocene sequence of the Maltese Islands.

At this point it is worth recalling that the most recent bibliography (see, for example, BERGGREN and AMDURER, 1973; BERGGREN and VAN COUVERING, 1974; RYAN *et Al.*, 1974; MEULENKAMP *et Al.*, 1975; HSÜ *et Al.*, 1978; BIZON and MULLER, 1979b) assigns a CN4 Zone (uppermost part)-CN7 Zone (pars) biostratigraphic extension to the Serravallian for the calcareous nannofossils and N10 Zone-N15 Zone (pars) for the plankton Foraminifers. Thus the following observations can be made for the marls underlying the glauconitic sand level:

— the bibliography states that the upper limit of the CN4 Zone falls within the N11 Zone (see above); in this study, however, it has been placed some metres above the base of the marls, in an interval that, according to GIANNELLI and SALVATORINI, can be referred to the low part of the N10 Zone. This discrepancy is undoubtedly of some importance for an accurate placement of the Langhian/Serravallian boundary; however, considering that a Langhian age can certainly be proved for the upper part of the Globigerina Limestone Formation, the Langhian/Serravallian boundary can thus be confined only to a horizon of the lower part of the Blue Clay Formation.

— Serravallian sediments can be found up to the glauconitic sand level, as shown by the presence of the CN5b Subzone in horizons directly underlying the latter.

Catinaster calyculus Subzone (CN7b): interval from the appearance of the nominal taxon to the disappearance of *Discoaster hamatus*.

Coccolithus pelagicus, Cyclococcolithus macintyrei, C. rotula, Discoaster bollii, D. calcaris, D. pseudovariabilis, Helicosphaera carteri, Reticulofenestra pseudoumbilica and *Sphenolithus abies* are the most frequent taxa throughout the upper part of the Blue Clay Formation (marls included between the glauconitic sand level and the Greensand Formation) in sections 5 and 15. In the lowermost and uppermost part of the marly interval in question there are rare specimens of *Discoaster exilis* and *D. pentaradiatus* respectively. Present throughout the interval, albeit in rare occurrences, are *Cyclococcolithus leptoporus, Discoaster brouweri, D. challengeri, D. neohamatus, D.* aff. *kugleri, D. stellulus, D. variabilis* and *Rhabdosphaera procera.*

Discoaster hamatus and *Catinaster calyculus,* whose co-occurrence could undoubtedly mark the CN7b Subzone, are not present, possibly as a result of cooler water. In these circumstances, the occurrence of *Discoaster exilis* confined to slightly above the glauconitic sandy bed, of *Discoaster calcaris* throughout the entire interval, and, in particular, the occurrence of *Discoaster pentaradiatus* at the top of the marls provide the main backing to the biostratigraphic reference presented here. Although the first two species disappear and appear respectively within the CN7 Zone, on which point all the authors are in agreement, the third species first appears in the upper part of the unit, as discovered recently in Mediterranean (COLALONGO *et Al.*, 1979) and extra-Mediterranean (MAZZEI *et Al.*, 1979) areas.

Observations. The occurrence of the *Catinaster calyculus* Subzone (upper part) in the Blue Clay Formation is in good agreement with that of the Interval 9 (*Globorotalia continuosa* assemblage) of GIANNELLI and SALVATORINI (1975). These Authors, in fact, noted the evolutionary appearance of *Globorotalia acostaensis* slightly above the glauconitic sand level and it is well known to appear in horizons just preceding those marked by the disappearance of *Discoaster hamatus* (MARTINI, 1975; MEULENKAMP *et Al.*, 1975; MAZZEI, 1977; COLALONGO *et Al.*, 1979a; MAZZEI *et Al.*, 1979), which defines the upper limit of the CN7b Subzone.

It should be remembered that HOJJTZADEH (1978) refers the upper part of the marls in the Fort Chambray section (Gozo and Comino) and the Form ir-Rih Bay section (located near section 5, along the western coast of Malta) to the NN7 Zone of MARTINI (equal to the CN5b Subzone), in clear contradiction to what has just been described.

Chronostratigraphic reference. The uppermost part of the *Discoaster hamatus* Zone characterizes the basal levels of the Tortonian stratotype (MARTINI, 1975; MAZZEI, 1977). Its identification in the marls of section 5 of Malta and section 15 of Gozo thus enables us to assign them to a rather low part of this stage.

Discoaster neohamatus Zone (CN8): interval from the disappearance of *Discoaster hamatus* to the appearance of *Discoaster berggrenii.*

The higher part of the marls in section 10 of Gozo Island is characterized by poor nannofossil assemblages. Only rare specimens of *Coccolithus pelagicus, Cyclococcolithus macintyrei, Discoaster brouweri, D. calcaris, D. loeblichii, D. pentaradiatus, Lithostromation perdurum, Reticulofenestra pseudoumbilica, Helicosphaera carteri* and *Sphenolithus abies* occur.

With regard to the portions of sections 5 and 15 whose lithology and stratigraphic position are similar and can be referred to *Catinaster calyculus* Subzone (see above), we may point out the occurrence of *Discoaster pentaradiatus* in this portion, starting at the base, as well as the absence of *Discoaster bollii* and *D. pseudovariabilis.* This situation is indicative of a higher biostratigraphic interval. It is particularly worth noting that as the last occurrence of *D. bollii* and *D. pseudovariabilis* takes place within the *Discoaster bellus* Subzone (BUKRY, 1973), a large part of this unit can be excluded from the reference. Moreover, we will probably not go beyond the top of the CN8 Zone, because of the absence of taxa that are exclusive to (e.g. *Discoaster berggrenii, D. quinqueramus*), or particularly frequent in (e.g. *Cyclococcolithus leptoporus, Discoaster icarus, D. surculus, Pontosphaera japonica*) the overlying unit.

Observations. GIANNELLI and SALVATORINI (1975) refer the uppermost marls of section 10 of Gozo Island to Interval 10 (*Globorotalia cultrata limbata* assemblage). They also retain that this interval corresponds to the *Globigerinoides obliquus extremus* Subzone (*Globorotalia acostaensis* Zone) of D'ONOFRIO *et Al.* (1975), excluding an initial portion.

Considering the recent calibrations between calcareous nannofossil and plankton Foraminifer biozones found in Tortonian-Messinian series in other Mediterranean (COLALONGO *et Al.,* 1979a) and extra-Mediterranean (MAZZEI *et Al.*, 1979; SALVATORINI and CITA, 1979) areas, the lower boundary of the *G. obliquus extremus* Subzone can be seen to fall within the middle part of the CN8 Zone and upper boundary in the upper part of the CN9b Subzone. Consequently, the CN8 Zone defined here (excluding an initial portion) would appear to be at least partly verified.

Chronostratigraphic reference. According to the studies on the Tortonian stratotype by MARTINI (1975) and MAZZEI (1977), the biostratigraphic reference conducted here places the marly interval in question in the middle part of this stage.

GREENSAND AND UPPER CORALLINE LIMESTONE FORMATIONS

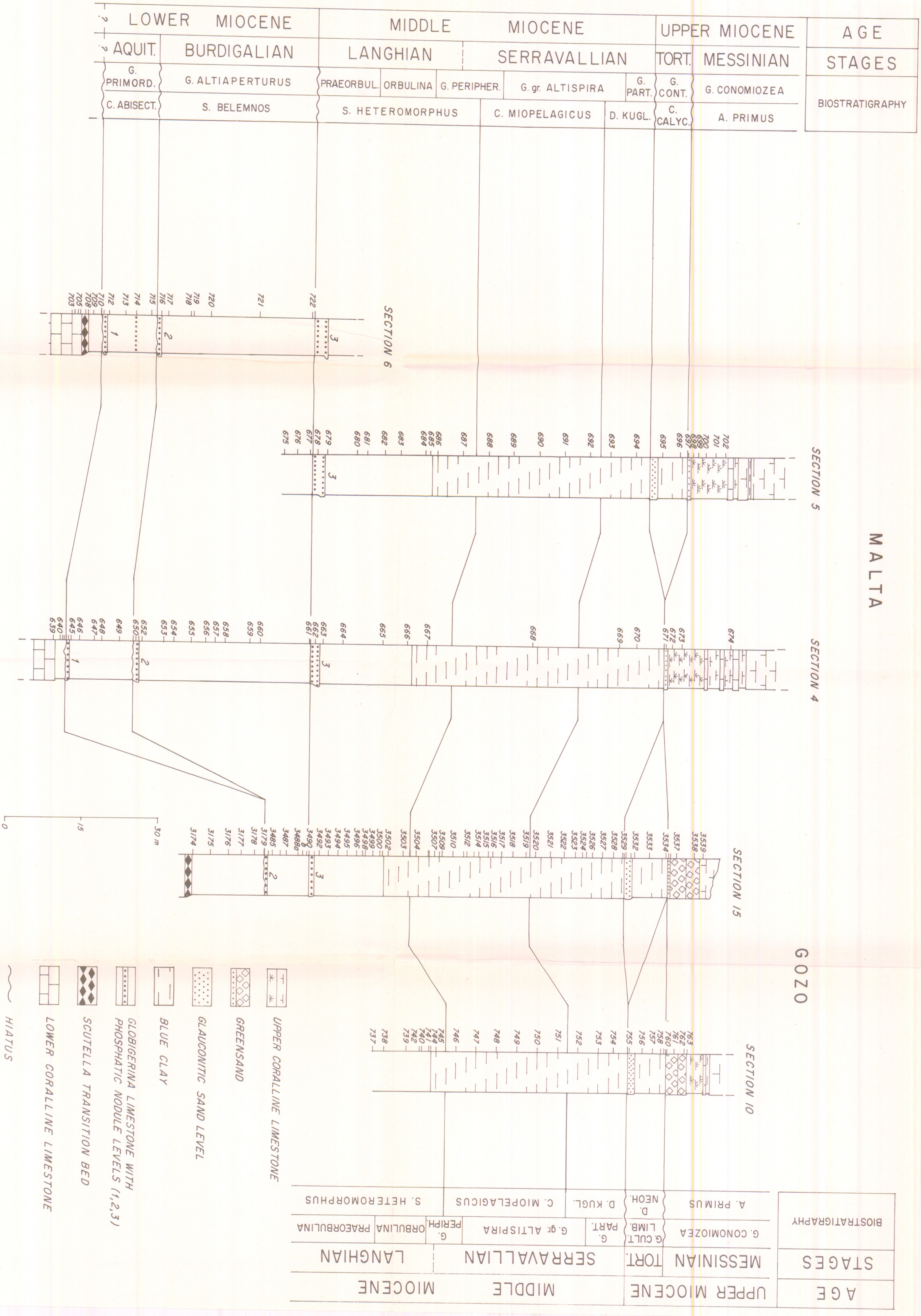
These two formations have been referred to the *Discoaster quinqueramus* Zone (*Amaurolithus primus* Subzone) (sections 4, 5 of Malta; sections 10, 15 of Gozo).

Amaurolithus primus Subzone (CN9b): interval from the appearance of the nominal taxon to the disappearance of *Discoaster quinqueramus*.

In the samples coming from the Greensand Formation the calcareous nannofossils are very rare and insignificant biostratigraphically. Therefore the setting of the unit in the CN9b Subzone does not derive from direct data but from the occurrence of *Globorotalia conomiozea*, starting from the base of the formation (GIANNELLI and SALVATORINI, 1975). In fact, according to recent works on Tortonian-Messinian sediments in Mediterranean (MAZZEI, 1977; COLALONGO *et Al.*, 1979a) and extra-Mediterranean (BOSSIO *et Al.*, 1976) areas, the first appearance of *Amaurolithus primus* slightly pre-dates the first appearance of *G. conomiozea*.

As far as the Upper Coralline Limestone Formation is concerned, it should be pointed out that the samples with nannofossil content are limited to basal marly intercalations. These samples have provided assemblages represented by rare specimens of *Coccolithus pelagicus, Cyclococcolithus leptoporus, Discoaster brouweri, D. icarus, D.* cf. *intercalaris, D. surculus, D. variabilis, D.* sp., *Pontosphaera japonica, Helicosphaera carteri, Reticulofenestra pseudoumbilica* and *Sphenolithus abies*.

There being no zonal markers available the presence of *Discoaster icarus* was used, to keep the biostratigraphic reference within the



LOWER MIOCENE
MIDDLE MIOCENE
UPPER MIOCENE
AGE
AQUIT.
BURDIGALIAN
LANGHIAN
SERRAVALLIAN
TORT.
MESSINIAN
STAGES
G. PRIMORD.
G. ALTIAPERTURUS
PRAEORBUL.
ORBULINA
G. PERIPHER.
G. gr. ALTISPIRA
G. PART.
G. CONT.
G. CONOMIOZEA
C. ABISECT.
S. BELEMNOS
S. HETEROMORPHUS
C. MIOPELAGICUS
D. KUGL.
C. CALYC.
A. PRIMUS
BIOSTRATIGRAPHY
SECTION 6
SECTION 5
SECTION 4
SECTION 15
SECTION 10
MALTA
GOZO
0
15
30 m
UPPER CORALLINE LIMESTONE
GREENSAND
GLAUCONITIC SAND LEVEL
BLUE CLAY
GLOBIGERINA LIMESTONE WITH PHOSPHATIC NODULE LEVELS (1,2,3)
SCUTELLA TRANSITION BED
LOWER CORALLINE LIMESTONE
HIATUS
S. HETEROMORPHUS
C. MIOPELAGICUS
D. KUGL.
D. NEOH.
A. PRIMUS
PRAEORBULINA
ORBULINA
G. PERIPH.
G. gr. ALTISPIRA
G. PART.
G. CULT. LIMB.
G. CONOMIOZEA
LANGHIAN
SERRAVALLIAN
TORT.
MESSINIAN
MIDDLE MIOCENE
UPPER MIOCENE

Amaurolithus primus Subzone; this taxon has, in fact, been noted to spread stratigraphically no further than the upper limit of this subzone (CITA *et Al.*, 1973; BOSSIO *et Al.*, 1976; RAFFI and RIO, 1979).

Chronostratigraphic reference. The Greensand and Upper Coralline Limestone formations can be attributed to the Messinian, because of the occurrence of *Globorotalia conomiozea* from the base of the first unit, and the identification of the *Amaurolithus primus* Subzone in the second unit. In fact, it is well-known that the level in which *G. conomiozea* makes its appearance marks the lower boundary of the Messinian (COLALONGO *et Al.*, 1979b) and that, in the Mediterranea Basin, the upper limit of the CN9b Subzone can be placed in a horizon that, albeit poorly defined, certainly belongs to the interval characterized by the socalled Messinian «salinity crisis».

EVALUATION OF THE HIATUSES

The Miocene sequence of the Maltese Islands does not contain all the coccolith units recognizable in the more complete sequences. We were thus able to individuate hiatuses within the Globigerina Limestone Formation (in coincidence with the phosphatic nodule beds), the Blue Clay Formation (at the base of the glauconitic sand level) and at the Blue Clay/Greensand boundary (see Table 1).

By correlating the nannofossil units with a numerical time-scale, we can define the temporal duration of the hiatuses, as well as their biostratigraphic dimensions. The scale reported by BUKRY (1975) was chosen for this sequence (see Fig. 3).

Let us now examine these hiatuses, from the bottom upwards. Level 2 (within the Middle Globigerina Limestone unit) separated the sediments belonging to the *Cyclicargolithus abisectus* Subzone and those belonging to the *Sphenolithus belemnos* Zone. Level 3 separates the Middle Globigerina Limestone unit from the Upper one, referred to *S. belemnos* Zone and *Sphenolithus heteromorphus* Zone respectively. Thus, the biostratigraphic extent of the lower hiatus is at least CN1b plus CN1c subzones, that of the upper hiatus is at least CN3 Zone. Even if the data at our disposal are not sufficient to establish esactly how much of the three biostratigraphic intervals occurs in the Middle and Upper Globigerina Limestone units, it seems justified to consider that part of them are also missing. This assumption is also supported by the simultaneous appearance and disappearance of taxa characterizing each interval with their range, at levels 2 and 3 (see Fig. 2). Consequently, the hiatus located at the base of level 2 has a duration of more than 5.0 m.y., and that at the base of the level 3, more than 2.0 m.y. (see Fig. 3).

As can be seen from Table 1 and Fig. 3, the CN1a Subzone, as recognized in sections 4 and 6 of Malta, is missing in section 15 of Gozo. This leads us to conclude that the lower hiatus has a variable duration in the Maltese Islands, and is wider in Gozo. Further checks are now being made of this assumption.

The CN2 Zone seems to reach its maximum extent in sections 4 and 6, on the basis of the thickness of the sediments (see Table 1). Unfortunately precise micropaleontological data are not available for deciding whether a minor thickness referred to this zone in section 15 really corresponds to a minor biostratigraphic extent.

The *Discoaster kugleri* Subzone has been recognized in the marls immediately underlying the glauconitic sand bed (4). The smaller thickness of sediments referred to this subzone in sections 5 and 10, with respect to the same interval in section 15, does not necessarly imply a different evaluation of the hiatus at the base of the glauconitic sand level, but may be the result of a more scattered sampling (together with the low frequency of *D. kugleri*), which has resulted in a slightly inaccurate placement of the CN5a Subzone/CN5b Subzone boundary in sections 5 and 10.

Considering that the marls overlying the glauconitic sand level have been referred to the *Catinaster calyculus* Subzone (upper part) in sections 5 and 15, and to the *Discoaster neohamatus* Zone (upper part) in section 10, and that the *Amaurolithus primus* Subzone (with the exclusion of the basal part) occurs from the base of the Greensand Formation on, the following evaluations of the hiatuses can be proposed:

— the hiatus at the base of the glauconitic sand level has a variable duration, at least 1.7 m.y. in sections 5 and 15 (corresponding to the CN5b Subzone (upper part)-CN7b Subzone (lower part) interval), at least 5.7 m.y. in section 10 (corresponding to the CN5b Subzone (upper part)-CN8a Subzone interval);

(4) The *Discoaster kugleri* Subzone has been recognized up to the top of the marls in section 4. The lack of sediments correlable to the *Catinaster calyculus* Subzone is probably due to a slight local displacement.

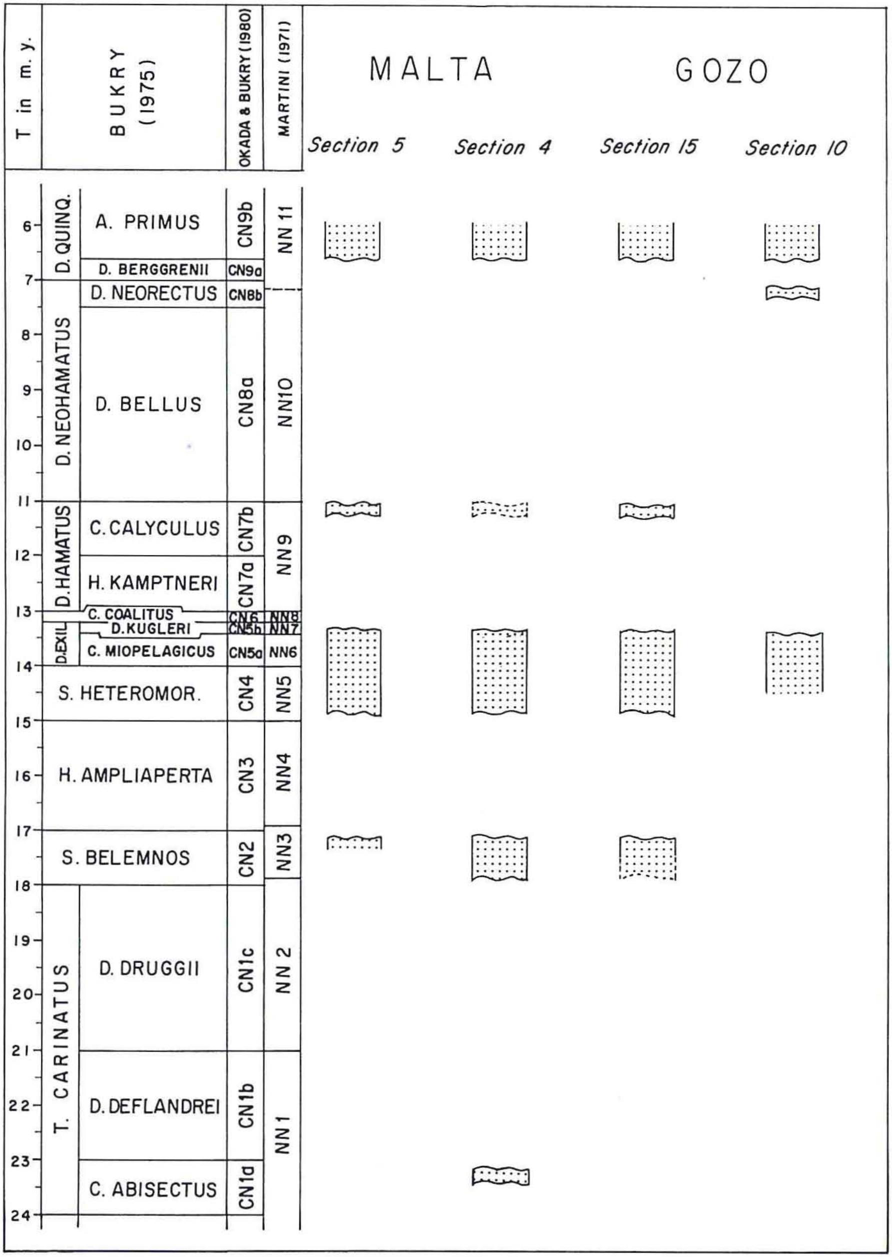


Fig. 3 - Biostratigraphic and temporal evaluation of the hiatuses recognized in the Miocene sequence of the Maltese Islands.

— the hiatus at the Blue Clay/Greensand boundary has a variable duration, at least 4.5 m.y. in sections 5 and 15 (corresponding to the CN8 Zone-CN9b Subzone (lowermost part) interval), at least 0.5 m.y. in section 10 (corresponding to the CN9a Subzone-CN9b Subzone (lowermost part) interval).

CONCLUSIONS

The main conclusions can be summarized as follows:

1) The Miocene sequence of the Maltese Islands, from the Middle Globigerina Limestone unit on, has been placed in the low-latitude zonal scheme of Okada and Bukry (1980). This biostratigraphic setting has created no special problems, as nannofossil assemblages characterized by open ocean tropical-subtropical species have usually been found. Some difficulties (absence or rarity of age-diagnostic species, taxonomical problems, etc.) arose for the lower and upper parts only of the interval studied, tied to cooler and/or shallow water conditions.

2) As is evident from Table 1, the calcareous nannofossil units have been directly correlated with the planktonic foraminiferal units of Giannelli and Salvatorini (1972, 1975). This correlation is consistent with those reported in literature for oceanic and Mediterranean areas and may sometimes lead to more precise definitions. The only difference is that of the position assigned to the upper boundary of the *Sphenolithus heteromorphus* Zone: the present study places it in horizons belonging to the middle-upper part of Interval 6 (*Globorotalia peripheroronda* assemblage) of Giannelli and Salvatorini, and thus, according to these Authors, within the N10 Zone, whereas the current literature place it higher, within the N11 Zone.

3) The coccolith units have permitted the chronostratigraphic placing of the Miocene sediments of the Maltese Archipelago. In particular, from the bottom upwards:

— the portion of the Middle Globigerina Limestone unit between layers 1 and 2 was shown to belong to the Aquitanian, and the portion between layers 2 and 3 to the Burdigalian; a Langhian age was reported for the Upper Globigerina Limestone unit

— the Langhian/Serravallian boundary was placed in the lowermost part of the Blue Clay Formation

— the marls (except for a short basal way) up to the glauconitic sand level were referred to the Serravallian; the remainder as far as the Greensand Formation was shown to be of Lower Tortonian age in sections 5 and 15, and Mid Tortonian in section 10

— the Greensand and Upper Coralline Limestone formations were referred to the Messinian. It should be noted that the biostratigraphic and chronostratigraphic placings given to these two formations derived from an integration with data of GIANNELLI and SALVATORINI.

4) The Miocene sequence was shown to be effected by hiatuses in correspondence to the phosphatic nodule beds (within the Globigerina Limestone Formation), at the base of the glauconitic sandy bed (in the upper part of the Blue Clay Formation) and at the Blue Clay/Greensand boundary, in close agreement with the results of GIANNELLI and SALVATORINI.

The biostratigraphic and temporal extent of these hiatuses were evaluated. The missing intervals are, from bottom to top:

— at least the CN1b-CN1c interval, corresponding to about 5.0 m.y., in coincidence with level 2 in sections 4 and 6 of Malta; the interval is certainly wider in section 15 of Gozo

— at least the CN3 Zone, corresponding to about 2.0 m.y., in coincidence with level 3

— at least the CN5b (upper part)-CN7b (lower part) interval, corresponding to about 1.7 m.y., at the base of the glauconitic sandy bed in sections 5 and 15; at least the CN5b (upper part)-CN8a interval, corresponding to about 5.7 m.y., at the base of the same bed in section 10

— at least the CN8-CN9b (lowermost part) interval, corresponding to about 4.5 m.y., at the Blue Clay/Greensand boundary in sections 5 and 15; at least CN9a-CN9b (lowermost part) interval, corresponding to about 0.5 m.y., at the Blue Clay/Greensand boundary in section 10.

REFERENCES

ANGLADA M.R. (1971a) - Sur la position du datum à *Globigerinoides* (Foraminiferida), la zone N4 (Blow 1967) et la limite Oligo-Miocene en Méditerranée. *C.R. Acad. Sc. Paris,* **272,** 1067-1070, Paris.

ANGLADA M.R. (1971b) - Sur la limite Aquitanien-Burdigalien, sa place dans l'échelle des Foraminifères planctoniques et sa signification dans le Sud-Est de la France. *C.R. Acad. Sc. Paris,* **272,** 1948-1951, Paris.

BERGGREN W.A. (1978) - Recent advances in Cenozoic planktonic foraminiferal biostratigraphy, biochronology and biogeography: Atlantic Ocean. *Micropaleontology,* **24** (4), 337-370, New York.

BERGGREN W.A., AMDURER M. (1973) - Late Paleogene (Oligocene) and Neogene planktonic foraminiferal biostratigraphy of the Atlantic Ocean (Lat. 30° N to Lat. 30° S). *Riv. Ital. Paleont.,* **79** (3), 337-392, Milano.

BERGGREN W.A., POORE R.Z. (1974) - Late Miocene-Early Pliocene planktonic foraminiferal biochronology: *Globorotalia tumida* and *Sphaeroidinella dehiscens* lineages. *Riv. Ital. Paleont.,* **80** (4), 689-698, Milano.

BERGGREN W.A., VAN COUVERING J.A. (1974) - The Late Neogene: biostratigraphy, geochronology and paleoclimatology of the last 15 million years in marine and continental sequences. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **16,** 1-216, Amsterdam.

BENNETT S.M. (1979) - A transgressive carbonate sequence spanning the Paleogene-Neogene boundary on the Maltese Islands. *Ann. Géol. Pays Hellén., Tome hors série,* fasc. 1, 71-80, Atene.

BIZON G., MÜLLER C. (1979a) - Remarks on the Oligocene/Miocene boundary based on results obtained from the Pacific and the Indian Ocean. *Ann. Géol. Hellén., Tome hors série,* fasc. 1, 101-111, Atene.

BIZON G., MÜLLER C. (1979b) - Report of the working group on Micropaleontology. *Ann. Géol. Pays Hellén, Tome hors série,* fasc. 3, 1335-1364, Atene.

BLOW W.H. (1969) - Late Middle Eocene to Recent Planktonic Foraminiferal Biostratigraphy. In: BRÖNNIMAN P., RENZ H.H., *Proc. First Intern. Conf. Plank. Microf., Geneva, 1967,* **1,** 199-422, Leiden.

BOSSIO A. (1972) - Alcune specie di *Aturia* (Nautiloidea) della Puglia e dell'Arcipelago di Malta. *Atti Soc. Tosc. Sc. Nat., Mem.,* Ser. A, **79,** 87-94, Pisa.

BOSSIO A., EL-BIED BAKICH K., GIANNELLI L., MAZZEI R., RUSSO A., SALVATORINI G. (1976) - Corrélation de quelques sections stratigraphiques du Mio-Pliocène de la zone atlantique du Maroc avec les stratotypes du Bassin Mediterranéen sur la base des Foraminifères planctoniques, Nannoplancton calcaire et Ostracodes. *Atti Soc. Tosc. Sc. Nat., Mem.,* Ser. A, **83,** 121-137, Pisa.

BUKRY D. (1973) - Low-Latitude Coccolith biostratigraphic zonation. In: EDGAR N.T., SAUNDERS J.B. *et Al., Initial Reports of Deep Sea Drilling Project,* **15,** 685-703, Washington.

BUKRY D. (1975) - Coccolith and Silicoflagellate Stratigraphy, Northwestern Pacific Ocean, Deep Sea Drilling Project, Leg. 32. In: LARSON R.L., MOBERLY R. *et Al., Initial Reports of the Deep Sea Drilling Project,* **32,** 677-701, Washington.

CHALLIS G.R. (1979) - Miocene Echinoid biofacies of the Maltese Islands. *Ann. Géol. Pays Héllen., Tome hors série,* fasc. 1, 253-262, Atene.

CITA M.B., BLOW W.H. (1969) - The biostratigraphy of the Langhian, Serravallian and Tortonian stages in the type-sections in Italy. *Riv. Ital. Paleont.,* **75** (3), 549-603, Milano.

CITA M.B., STRADNER H., CIARANFI N. (1973) - Biostratigraphical investigations on the Messinian stratotype and on the overlying «Trubi formation». *Riv. Ital. Paleont.,* **79** (3), 393-446, Milano.

COLALONGO M.L., DI GRANDE A., D'ONOFRIO S., GIANNELLI L., IACCARINO S., MAZZEI R., ROMEO M., SALVATORINI G. (1979) - Stratigraphy of Late Miocene Italian sections straddling the Tortonian/Messinian boundary. *Boll. Soc. Paleont. It.,* **18** (2), 258-302, Modena.

DI GERONIMO I., GRASSO M., PEDLEY H.M. (1981) - Palaeoenvironment and palaeogeography of Miocene marls from southeast Sicily and the Maltese Islands. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **34** (3/4), 173-189, Amsterdam.

D'ONOFRIO S., GIANNELLI L., IACCARINO S., MORLOTTI E., ROMEO M., SALVATORINI G., SAMPÒ M., SPROVIERI R. (1975) - Planktonic Foraminifera of the Upper Miocene from some Italian sections and the problem of the lower boundary of the Messinian. *Boll. Soc. Paleont. It.,* **14** (2), 177-196, Modena.

FELIX R. (1973) - Oligo-Miocene Stratigraphy of Malta and Gozo. VEENMAN H. and ZONEN B.V., 104 p., Wageningen.

GIANNELLI L., SALVATORINI G. (1972) - I Foraminiferi planctonici dei sedimenti terziari dell'Arcipelago maltese. I. Biostratigrafia del «Globigerina Limestone». *Atti Soc. Tosc. Sc. Nat., Mem.,* Ser. A, **79,** 49-74, Pisa.

GIANNELLI L., SALVATORINI G. (1975) - I Foraminiferi planctonici dei sedimenti terziari dell'Arcipelago maltese. II. Biostratigrafia di «Blue Clay», «Greensand» e «Upper Coralline Limestone». *Atti Soc. Tosc. Sc. Nat., Mem.,* Ser. A, **82,** 1-24, Pisa.

HOJJATZADEH M. (1978) - Discoasters of the Blue Clay (Middle Miocene) of Malta and Gozo. *Geol. Magaz.,* **115** (1), 1-17, Cambridge.

HOUSE M.R., DUNHAM K.C., WIGGLESWORTH J.C. (1962) - Geology and Structure of the Maltese Islands. In: BOWEN-JONES H., DEWDNEY J.C., FISHER W.B. - Malta, 25-33, Newcastle upon Tyne.

HYDE H.P.T. (1955) - Geology of the Maltese Islands. 135 p., Lux Press, Malta.

MARTINI E. (1968) - Calcareous Nannoplankton fron the type Langhian. *Giorn. Geol.,* **35,** 163-172, Bologna.

MARTINI E. (1971) - Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: FARINACCI A., *Proc. IInd Plankt. Conf., Roma, 1970,* **1,** 739-785, Roma.

MARTINI E. (1975) - Calcareous Nannoplankton from the type Tortonian. In: SENĚS J., *Proc. VIth Congr. R.C.M.N.S., Bratislava, 1975,* **1,** 53-56, Bratislava.

MARTINI E., MÜLLER C. (1975) - Calcareous Nannoplankton from the type Chattian (Upper Oligocene). In: SENĚS J., *Proc. VIth Congr. R.C.M.N.S., Bratislava, 1975,* **1,** 37-41, Bratislava.

MAZZEI R. (1977) - Biostratigraphy of the Rio Mazzapiedi-Castellania Section (type-section of the Tortonian) based on calcareous nannoplankton. *Atti Soc. Tosc. Sc. Nat., Mem.,* Ser. A, **84,** 15-24, Pisa.

MAZZEI R., RAFFI I., RIO D., HAMILTON N., CITA M.B. (1979) - Calibration of Late Neogene plankton Datum planes with the Paleomagnetic Record of Site 397 and correlation with Moroccan and Mediterranean sections. In: RAD U., RYAN W.B.F. *et Al., Initial Reports of the Deep Sea Drilling Project,* **47** (1), 375-389, Washington.

MENESINI E. (1972) - Resti di vertebrati raccolti in sedimenti miocenici dell'Arcipelago maltese. *Atti Soc. Tosc. Sc. Nat., Mem.,* Ser. A, **79**, 77-86, Pisa.

MENESINI E. (1974) - Ittiodontoliti delle formazioni terziarie dell'Arcipelago maltese. *Palaeont. Italica,* **67**, 121-162, Pisa.

MENESINI E. (1979) - Maltese fossil Echinoida. *Ann. Géol. Pays Hellén, Tome hors série,* fasc. 2, 799-806, Atene.

MEULENKAMP J.E., CARBONELL G., CICHA I., MARTINI E., PREMOLI SILVA I., RIEDEL W., RÖGL F., SCHRADER H.J. (1975) - Report of the Working Group on Micropaleontology. In: SENĚS J., *Report on activity of the R.C.M.N.S. Working Groups (1971-1975),* 10-30, Bratislava.

MÜLLER C. (1975) - Calcareous nannoplankton from the type Serravallian. In: SENĚS J., *Proc. VIth Congr. R.C.M.N.S., Bratislava, 1975,* **1**, 49-52, Bratislava.

MÜLLER C., PUJOL C. (1979) - Étude du nannoplancton calcaire et des Foraminifères planctoniques dans l'Oligocène et le Miocène en Aquitaine (France). *Géologie Méditerranéenne,* **6** (2), 357-368.

OKADA H., BUKRY D. (1980) - Supplementary modification and introduction of Code numbers to the low-latitude Coccolith biostratigraphic zonation (Bukry, 1973, 1975). *Marine Micropaleontology,* **5**, 321-325, Amsterdam.

PEDLEY H.M. (1978) - A new fish horizon from the Maltese Middle Miocene and its paleoecological significance. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **24**, 73-83, Amsterdam.

PEDLEY H.M., HOUSE M.R., WAUGH B. (1976) - The geology of Malta and Gozo. *Proc. Geol. Ass.,* **87** (3), 325-341.

PEDLEY H.M., HOUSE M.R., WAUGH B. (1978) - The geology of the pelagian block: the Maltese Islands. The ocean basins and margins. Edit. NAIRN A.E.M., KANES W.H., STEHLI F.G., **4B**, The western Mediterranean. Plenum press, New Yok and London, 417-433, New York.

RAFFI I., RIO D. (1979) - Calcareous nannofossil biostratigraphy of DSDP Site 132 - Leg 13 (Tyrrhenian Sea - Western Mediterranean). *Riv. Ital. Paleont.,* **85** (1), 127-172, Milano.

RYAN W.B.F., CITA M.B., DREYFUS RAWSON M., BURCKLE L.H., SAITO T. (1974) - A paleomagnetic assignment of Neogene Stage Boundaries and the development of isochronous datum planes between the Mediterranean, the Pacific and Indian Oceans in order to investigate the response of the world Ocean to the Mediterranean «salinity crisis». *Riv. Ital. Paleont.,* **80** (4), 631-688, Milano.

RUSSO A., BOSSIO A. (1977) - Prima utilizzazione degli Ostracodi per la biostratigrafia e la paleoecologia del Miocene dell'Arcipelago maltese. *Boll. Soc. Paleont. It.,* **15** (2), 215-227, Modena.

SALVATORINI G., CITA M.B. (1979) - Miocene foraminiferal stratigraphy, DSDP Site 397 (Cape Bojador, North Atlantic). In: RAD U., RYAN W.B.F. *et Al., Initial Reports of the Deep Sea Drilling Project,* **47** (1), 317-373, Washington.

Seněs J. (Edit.) (1976) - The events and resolutions of the VIth R.C.M.N.S. Congress. *Proc. VIth Congr. R.C.M.N.S., Bratislava, 1975,* **2,** 69 p., Bratislava.

Van Couvering J.A., Berggren W.A. (1977) - Biostratigraphical Basis of the Neogene time scale. In: Hazel J.E., Kauffmann E., *Concepts and methods of biostratigraphy.* Dowden, Hutchinson and Ross, Inc., 283-306, Stroudsburg.

(ms. pres. il 1 giugno 1985; ult. bozze il 15 gennaio 1986)

PLATE 1

The Miocene sequence of the Maltese Islands: biostratigraphic and chronostratigraphic references based on nannofossils.

Fig. 1 - *Cyclicargolithus abisectus* (Müller) Bukry
(× 1600). Sample 713; CN1a Subzone; Section 6 of Malta.

Fig. 2 - *Helicosphaera intermedia* Martini
(× 1600). Sample 654; CN2 Zone; Section 4 of Malta.

Fig. 3 - *Pontosphaera* sp.
(× 2000). Sample 721; CN2 Zone; Section 6 of Malta.

Fig. 4 - *Pontosphaera* sp.
(× 2000). Sample 721; CN2 Zone; Section 6 of Malta. Cross-polarized light.

Fig. 5 - *Pontosphaera multipora* (Kamptner) Roth
(× 1600). Sample 660; CN2 Zone; Section 4 of Malta. Cross-polarized light.

Fig. 6 - *Pontosphaera multipora* (Kamptner) Roth
(× 1600). Sample 660; CN2 Zone; Section 4 of Malta.

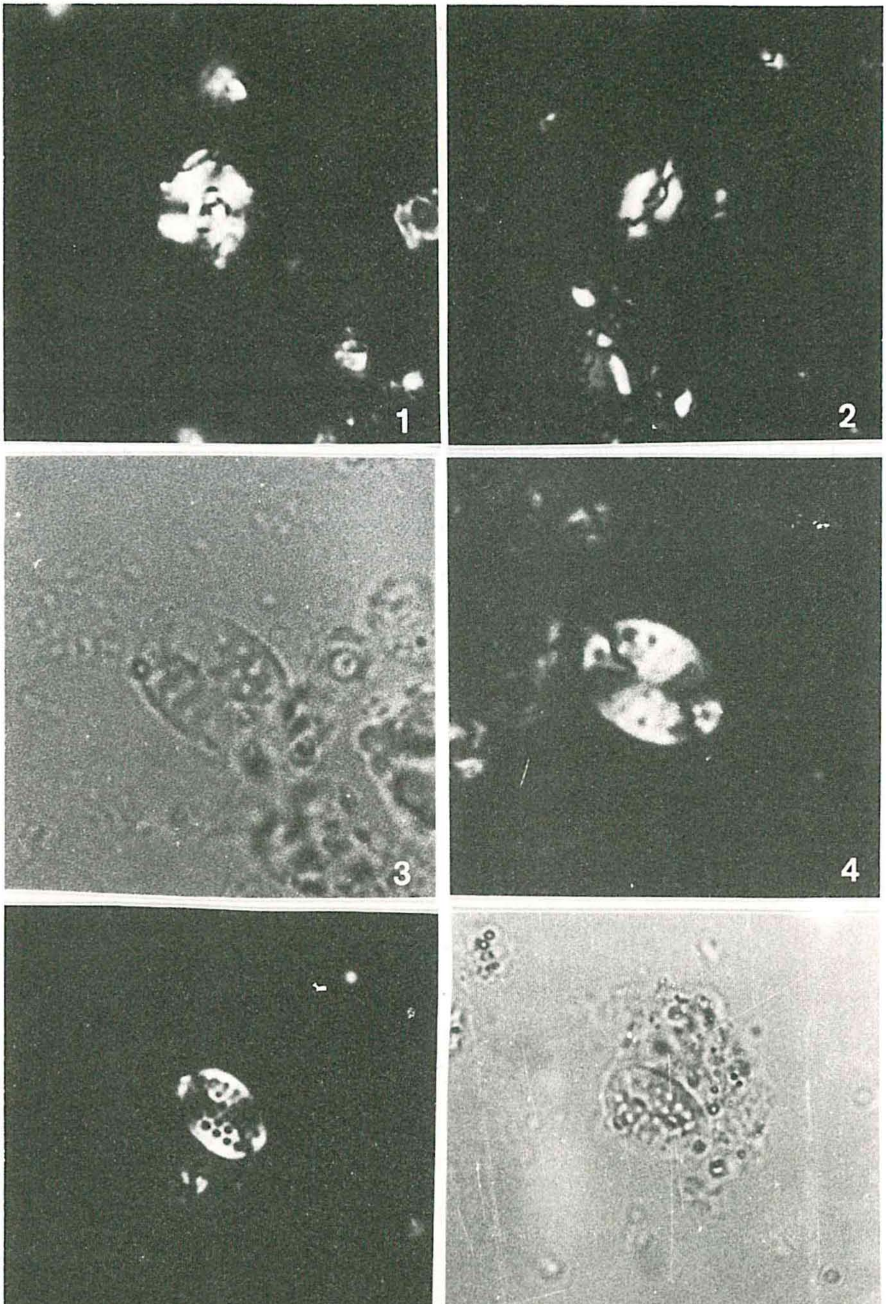


Plate 1

PLATE 2

The Miocene sequence of the Maltese Islands: biostratigraphic and chronostratigraphic references based on nannofossils.

Fig. 1 - *Cyclococcolithus macintyrei* Bukry and Bramlette
(× 2000). Sample 680; CN4 Zone; Section 5 of Malta.

Fig. 2 - *Sphenolithus* sp.
(× 2400). Sample 680; CN4 Zone; Section 5 of Malta. Cross-polarized light.

Fig. 3 - *Sphenolithus belemnos* Bramlette and Wilcoxon
(× 2400). Sample 3485; CN2 Zone; Section 15 of Gozo. Cross-polarized light.

Fig. 4 - *Sphenolithus* cf. *heteromorphus* Deflandre
(× 2000). Sample 3494; CN4 Zone; Section 15 of Gozo. Cross-polarized light.

Fig. 5 - *Discoaster variabilis* Martini and Bramlette
(× 1600). Sample 694; CN5b Subzone; Section 5 of Malta.

Fig. 6 - *Discoaster surculus* Martini and Bramlette
(× 1600). Sample 672; CN9b Subzone; Section 4 of Malta.

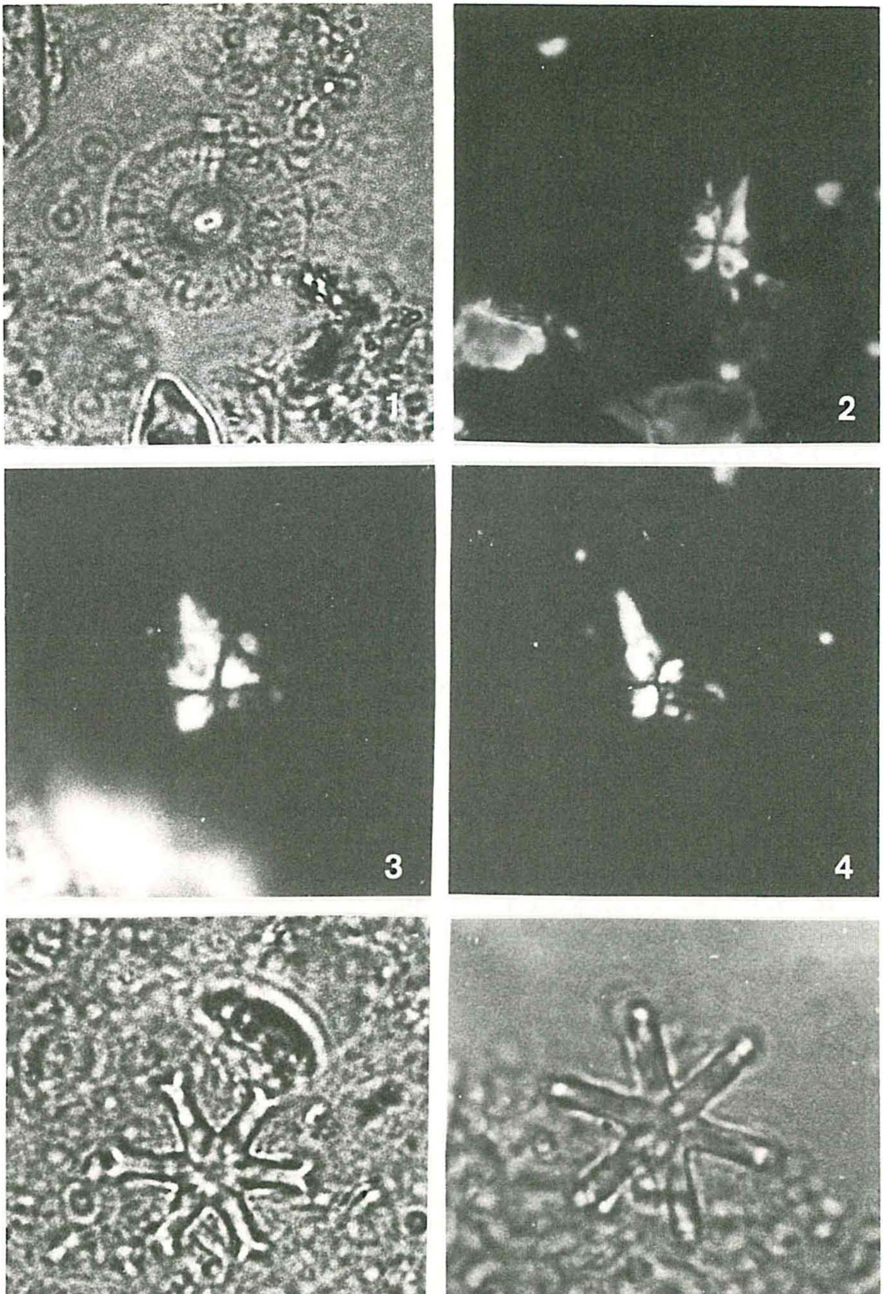


Plate 2

PLATE 3

The Miocene sequence of the Maltese Islands: biostratigraphic and chronostratigraphic references based on nannofossils.

Fig. 1 - *Discoaster signus* BUKRY
(× 2000). Sample 684; CN4 Zone; Section 5 of Malta.

Fig. 2 - *Discoaster calcaris* GARTNER
(× 2000). Sample 695; CN7b Subzone; Section 5 of Malta.

Fig. 3 - *Discoaster bollii* MARTINI and BRAMLETTE
(× 2000). Sample 668; CN5a Subzone; Section 4 of Malta.

Fig. 4 - *Discoaster* sp.
(× 2000). Sample 3528; CN5b Subzone; Section 15 of Gozo.

Fig. 5 - *Discoaster exilis* MARTINI and BRAMLETTE
(× 2000). Sample 3541; CN5a Subzone; Section 15 of Gozo.

Fig. 6 - *Discoaster stellulus* GARTNER
(× 1600). Sample 748; CN5a Subzone; Section 10 of Gozo.

Fig. 7 - *Discoaster* cf. *intercalaris* BUKRY
(× 2000). Sample 763; CN9b Subzone; Section 10 of Gozo.

Fig. 8 - *Discoaster variabilis* MARTINI and BRAMLETTE
(× 1600). Sample 756; CN8b Subzone; Section 10 of Gozo.

Fig. 9 - *Discoaster icarus* STRADNER
(× 1600). Sample 672; CN9b Subzone; Section 4 of Malta.

Fig. 10 - *Discoaster loeblichii* BUKRY
(× 1600). Sample 758; CN8b Subzone; Section 10 of Gozo.

Fig. 11 - *Discoaster surculus* MARTINI and BRAMLETTE
(× 1600). Sample 672; CN9b Subzone; Section 4 of Malta.

Fig. 12 - *Discoaster pentaradiatus* TAN SIN HOK
(× 1600). Sample 3534; CN7b Subzone; Section 15 of Gozo.

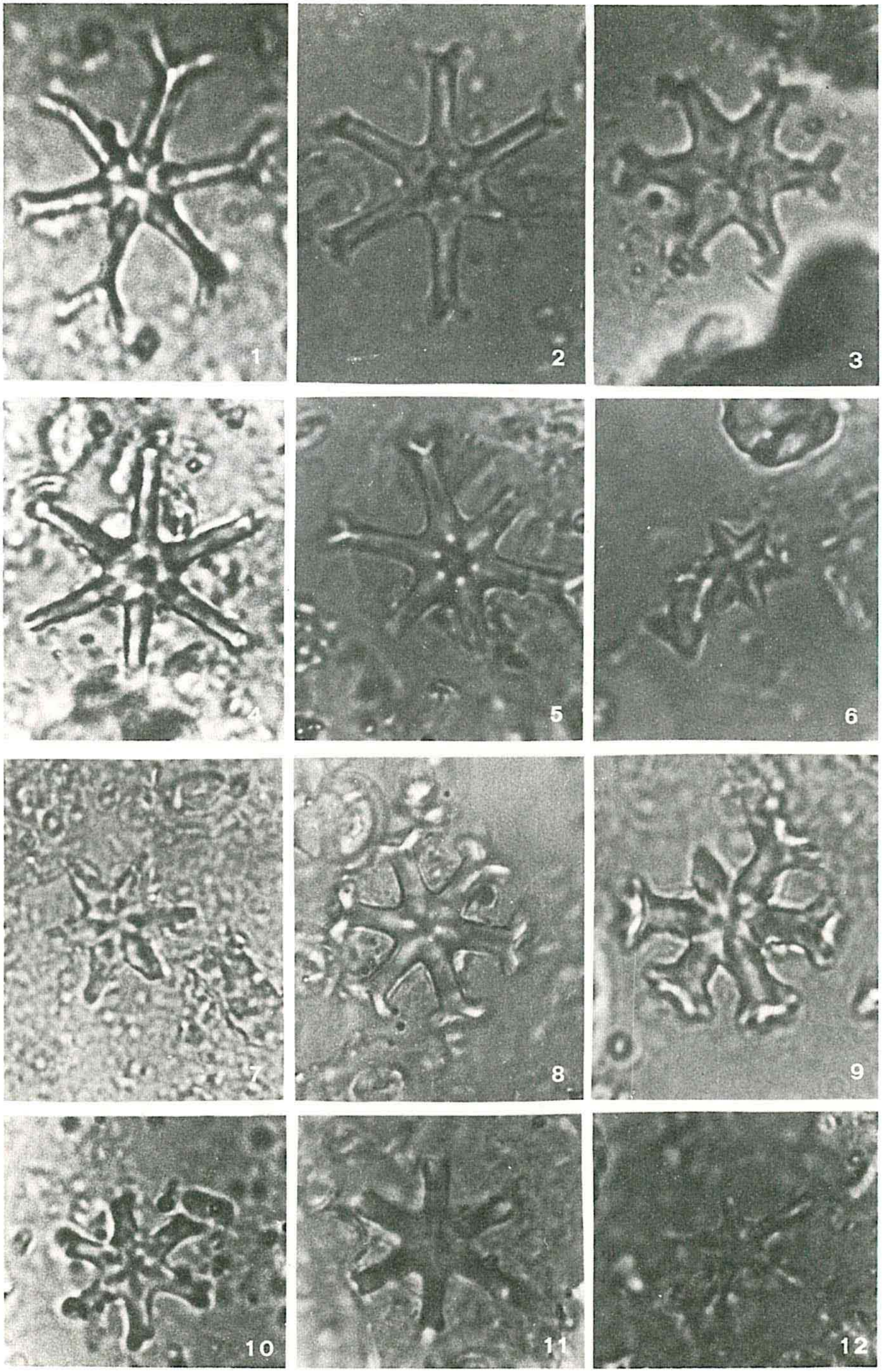


Plate 3