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Biostratigraphy and chronostratigraphy of the Maltese Lower Globigerina Limestone Member (Globigerina Limestone Formation): new preliminary data based on calcareous plankton

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KEY WORDS - Calcareous plankton biostratigraphy, Chattian, Lower Globigerina Limestone, Maltese Islands.

ABSTRACT - The preliminary results of the study carried out on calcareous plankton (foraminifera and nannofossils) assemblages from the Maltese Lower Globigerina Limestone are presented here. The Lower Globigerina Limestone (LGL) is the lowermost member of the Globigerina Limestone Formation, widely outcropping in the Maltese Archipelago; this member has been generally referred to the Early Miocene (Aquitanian).

The investigation of 78 samples from 11 sections (encompassing the whole succession of the unit) on Gozo and Malta islands (one of them close to the type section of the formation) has allowed us to assign a Chattian age (Late Oligocene) to the Lower Globigerina Limestone Member (LGLM). Globigerinoides primordius, Paragloborotalia opima nana, P. pseudokugleri, Subbotina gortanii, Globoturborotalita angulisuturalis, G. anguliofficinalis, *and* Coccolithus miopelagicus, Cyclicargolithus abisectus, Dictyococcites bisectus, D. scrippsae, Helicosphaera recta, Sphenolithus *cf.* ciperoensis, S. dissimilis, Triquetrorhabdulus carinatus, Zygrhablithus bijugatus *are taxa particularly significant of the foraminiferal and nannofossil assemblages respectively. In all the investigated sections, these taxa assure the assignment of the member to the lower part of planktonic foraminiferal P.22 Zone and nannofossil NP25 Zone. Thus, it has also been possible to estimate in biostratigraphic terms the hiatus between the Lower and the Middle Globigerina Limestone members, the latter being referable to the upper half part of the planktonic foraminiferal N4 Zone (upper part of N5 Zone-basal part of N7 Zone interval in Gozo) and to the nannofossil CN1 Zone (CN2 Zone in Gozo). This hiatus is emphasized also by the occurrence at the top of the LGLM of a hardground with overlying phosphatized elements such as nodules or pebbles.*

RIASSUNTO - [Biostratigrafia e cronostratigrafia del Membro Lower Globigerina Limestone (Formazione del Globigerina Limestone) dell'Arcipelago Maltese: risultati preliminari sulla base del plancton calcareo] - *L'età del Membro Lower Globigerina Limestone (Formazione del Globigerina Limestone) dell'Arcipelago Maltese è stata in genere considerata Miocene inferiore (Aquitaniano, raramente Burdigaliano) nonostante nel passato alcuni autori, compreso uno degli scriventi, ne avessero per primi sostenuto l'appartenenza all'Oligocene superiore (Cattiano). Per precisare definitivamente la posizione cronostratigrafica del membro maltese, che ha evidenti riflessi sulla cronologia delle tappe dell'evoluzione paleogeografica e strutturale dell'arcipelago e, quindi, su quelle dell'evoluzione geodinamica del Mediterraneo centrale, sono state studiate 11 sezioni dell'unità per un totale di 78 campioni. Tali sezioni, ubicate sia nell'Isola di Malta che in quella di Gozo, per la maggior parte comprendono l'intera successione locale del membro. Qui si riportano i risultati preliminari derivanti dall'esame micropaleontologico delle associazioni a plancton calcareo (foraminiferi planctonici e nannofossili). Le associazioni a foraminiferi planctonici hanno presentato, tra gli elementi più significativi,* Globigerina ciperoensis, "G." euapertura, "G." tripartita, Globigerinella obesa, Globigerinoides primordius *(raro),* Globoquadrina sellii, Globoturborotalita anguliofficinalis, G. angulisuturalis, G. woodi s.l., Paragloborotalia opima nana, P. pseudokugleri, P. siakensis *e* Tenuitellinata praestainforthi. *La distribuzione di questi taxa nelle sezioni ha consentito la loro attribuzione alla parte bassa della Zona P.22. Le associazioni a nannofossili calcarei ben si accordano all'attribuzione biostratigrafica operata con i foraminiferi, essendo risultate di pertinenza della Zona NP25 (MNP25a). Tra i taxa che maggiormente concorrono a questa attribuzione si ricordano* Cyclicargolithus abisectus, Dictyococcites bisectus, D. scrippsae, Helicosphaera recta, Sphenolithus *cf.* ciperoensis, S. dissimilis, Triquetrorhabdulus carinatus *e* Zygrhablithus bijugatus. *In riferimento alla recente ratifica del Global Stratotype Section and Point (GSSP) della base del Neogene (ovvero del limite Paleogene/Neogene, limite Oligocene/Miocene, limite Cattiano/Aquitaniano), i risultati biostratigrafici ottenuti hanno consentito di stabilire un'età oligocenica superiore (Cattiano) per il Membro Lower Globigerina Limestone. È stato altresì possibile valutare in termini biostratigrafici lo* hiatus *compreso tra i membri "Lower" e "Middle" della stessa formazione (per quest'ultimo membro sono stati utilizzati dati pubblicati in precedenza da alcuni degli scriventi). Questo hiatus, evidenziato sul terreno dalla costante presenza alla sommità del membro inferiore di un hardground (sormontato da un livello fosforitico alla base del membro intermedio), è risultato abbracciare: a) nelle sezioni dell'Isola di Malta, gran parte della Zona P.22 e la porzione inferiore della Zona N4 dei foraminiferi planctonici, nonché la porzione superiore della Zona NP25 (o porzione superiore della Zona MNP25a) ed il tratto inferiore della Zona CN1 (comprendente almeno la Zona MNP25b e la Sottozona MNN1a) dei nannofossili. L'entità della lacuna cambia nelle diverse aree e testimonianza ne è lo spessore molto variabile del membro inferiore (da 0 a 80 m, secondo la bibliografia); b) nelle sezioni dell'Isola di Gozo, oltre agli intervalli mancanti a Malta anche la parte superiore della Zona N4 e gran parte della Zona N5 (quindi la parte restante della Zona CN1 o, in altri termini, le sottozone MNN1b-d, le zone MNN2a-b) per la mancanza del tratto inferiore del Membro Middle Globigerina Limestone. La durata dello hiatus è da considerarsi variabile per lo stesso motivo di Malta (spessore dell'unità da 0 a 40 m, secondo la bibliografia), ma certamente in alcune aree esso si amplia fino a comprendere le zone N6 e N7 (quindi l'intero Burdigaliano) per la completa scomparsa del membro intermedio.*

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INTRODUCTION

The Globigerina Limestone Formation (Murray, 1890) crops out widely in the Maltese Islands; its type locality and section were designed by Felix (1973) at Il Qaws (NW of Dingli, along the southwestern coast of Malta Island; Fig. 1). Since the 19th century, many authors reported the age of this unit (e.g., Wright 1855; Fuchs 1874; Gregory 1891; Cooke 1893, 1896), but only from 1970's appropriate dating criteria were used. In fact, Giannelli & Salvatorini (1972) first constrained the age of the Globigerina Limestone Formation basing on planktonic foraminifera and correlated it to Blow's (1969) zonation as well as to the Standard Chronostratigraphic Scale. In particular, they referred the Middle-Upper Globigerina Limestone to the N4 p.p. (N6-N7 in Gozo) - N9 biostratigraphic interval and therefore to the Aquitanian (Burdigalian in Gozo) - Langhian stages. As regards the Lower Globigerina Limestone Member (Rizzo, 1932), Giannelli & Salvatorini (1972) supposed a Late Oligocene (Chattian) age (see also their "post-scriptum", p. 72) because: a) the top of the underlying Lower Coralline Limestone Formation (Murray, 1890) was referred to the Late Oligocene (Chattian) by means of the larger foraminifera; b) the earliest sediments of the overlying Middle Globigerina Limestone Member (Rizzo, 1932) were ascribed to the Early Miocene (Aquitanian) age; c) the characteristic phosphoritic bed separating the Lower and Middle Globigerina Limestone members suggested a sedimentary hiatus.

On the contrary, Felix (1973) ascribed the Lower Globigerina Limestone Member to the Aquitanian and afterwards this interpretation, although based on insufficient planktonic foraminiferal data, was followed or confirmed by many authors (for example Rose, 1974; Pedley et al., 1976, 1978; Challis, 1979; Menesini, 1979a, b; Theodoridis, 1984; Oil Exploration Directorate, 1993; Kienel et al., 1995; Rehfeld & Janssen, 1995).

Only Jacobs et al. (1996) and Rose et al. (1992) did not agree with the last inferred age. The former referred the member to the Chattian based on calcareous nannofossils (without any species list) and supported this interpretation with Sr-isotope data; the latter accepted the results of Giannelli & Salvatorini (1972) on the age of the Globigerina Limestone Formation (including the dating of its lowermost member), because these results allowed to correlate the sedimentary history of this unit with global sea level changes as indicated by Haq et al. (1987).

In the present study, the calcareous plankton (foraminifera and nannofossils) assemblages from some sections (sampled by Giannelli & Salvatorini, 1972 and newly by us) covering the whole Lower Globigerina Limestone interval and including that of the type area, have been examined in order to better define the age of this member. The preliminary bio-chronostratigraphic results are reported here; an exhaustive paper also based on new sections and integrated with detailed micropaleontological and stratigraphical documentation (logs, samplings, range charts with quali-quantitative analysis, etc.) is in progress.

LITHOSTRATIGRAPHIC OUTLINE

The Lower Globigerina Limestone Member (LGLM) is laterally and vertically variable in its lithological and paleontological features; it is often represented by biodetrital limestones (biomicrosparites and biomicrites) rich in benthonic and planktonic foraminifera. In the lower part of the unit, the limestones are coarse-grained, yellow-brown and characterized by abundant bioturbation; in the upper part, they are often fine-grained, marly and light yellow. Macrofossils are frequent, represented especially by bryozoans (mainly in the lower part of the member), pectinids (particularly *Flabellipecten*) and echinoids (e.g., *Schizaster*).

According to the Oil Exploration Directorate (1993), the thickness of the member ranges from 0 to 80 m.

For many authors, the so-called "*Scutella* Bed" (or "transitional Bed") at the top of the Lower Coralline Limestone Formation marks the boundary with the overlying Globigerina Limestone Formation. Instead, other authors (Felix, 1973; Bennett, 1980; Carbone et al., 1987; Rose et al. 1992) locate this boundary on the upper surface of a ubiquitous hardground below the "*Scutella* Bed". In this work, we follow the latter interpretation.

The Lower/Middle Globigerina Limestone boundary is marked by a ubiquitous bed rich in phosphatic nodules (or pebbles according to the different interpretations). This bed, which was defined "Lower Main Phosphorite Conglomerate Bed" by Pedley & Bennett (1985), lies over an often phosphatized hardground at the top of the lower member and represents the base of the overlying unit for many authors, the top of the underlying member for others. An accurate description of these two levels is provided by Pedley & Bennett (1985) and Rehfeld & Janssen (1995).

MATERIAL

The biostratigraphic analysis on calcareous plankton (foraminifera and nannofossils) of the LGLM has been carried out on 11 sections from both Malta and Gozo islands. Their location, with respect to the well-known localities, their thickness and the number of collected samples are reported in Fig. 1.

CALCAREOUS PLANKTON BIOSTRATIGRAPHY

Foraminifera

Some of the 78 samples which have been analysed (particularly those from the lower intervals of the sections) were poorly suitable for this study. Many specimens showed calcareous incrustations and thus were difficult to classify. Generally, assemblages appear poorly diversified and there is no appreciable change in their biostratigraphic meanings both horizontally and vertically. The generic terminology follows Iaccarino et al. (2005), with some exceptions. Among the most interesting taxa, we point out:

- *Globigerinoides primordius* (Blow & Banner), which occurs in the lowermost part of many sections; it is relatively common only in few samples. Its first occurrence is recorded close to the base of Blow's (1969) P.22 Zone by many authors (e.g., Bolli & Saunders, 1985; Spezzaferri, 1994; Iaccarino et al., 1996) or in the uppermost part of P.21 Zone by Biolzi (1985) and Boersma & Premoli Silva (1991). P.22 is here used as emended by Berggren & Miller (1988; see also Berggren et al., 1995), i.e. defined by the *Paragloborotalia opima opima* (Bolli) LO (last occurrence) at the lower boundary and the *Paragloborotalia kugleri* (Bolli) FO (first occurrence) at the top. It corresponds to the *Globigerina ciperoensis ciperoensis* Zone of Bolli & Saunders (1985; see also Iaccarino et al., 1996);

- *Paragloborotalia pseudokugleri* (Blow), which occurs in the lowermost part of many sections and is generally common to abundant. According to Blow (1969) the taxon represents the immediate ancestor of *P. kugleri* (in the Maltese succession this latter appears at the base of the overlying Middle Globigerina Limestone Member - MGLM; Giannelli & Salvatorini, 1972) and occurs from P.22 (lowermost part in Spezzaferri, 1994) to N4 zones of Blow (1969);

- *Subbotina gortanii* (Borsetti), which in some sections occurs up to the Lower/Middle Globigerina Limestone boundary; it is generally present with rare specimens. The taxon disappears about at the P.21/P.22 zonal boundary (Blow, 1969; Stainforth et al., 1975; Molina, 1979; Bolli & Saunders, 1985; Spezzaferri, 1994, among others);

- *Globoturborotalita angulisuturalis* (Bolli) and the immediate ancestor *G. anguliofficinalis* (Blow). The former is generally rare in the LGLM and characterizes the P.21-N4 interval (e.g., Blow, 1969; Stainforth et al., 1975; Kennett & Srinivasan, 1983). The latter is

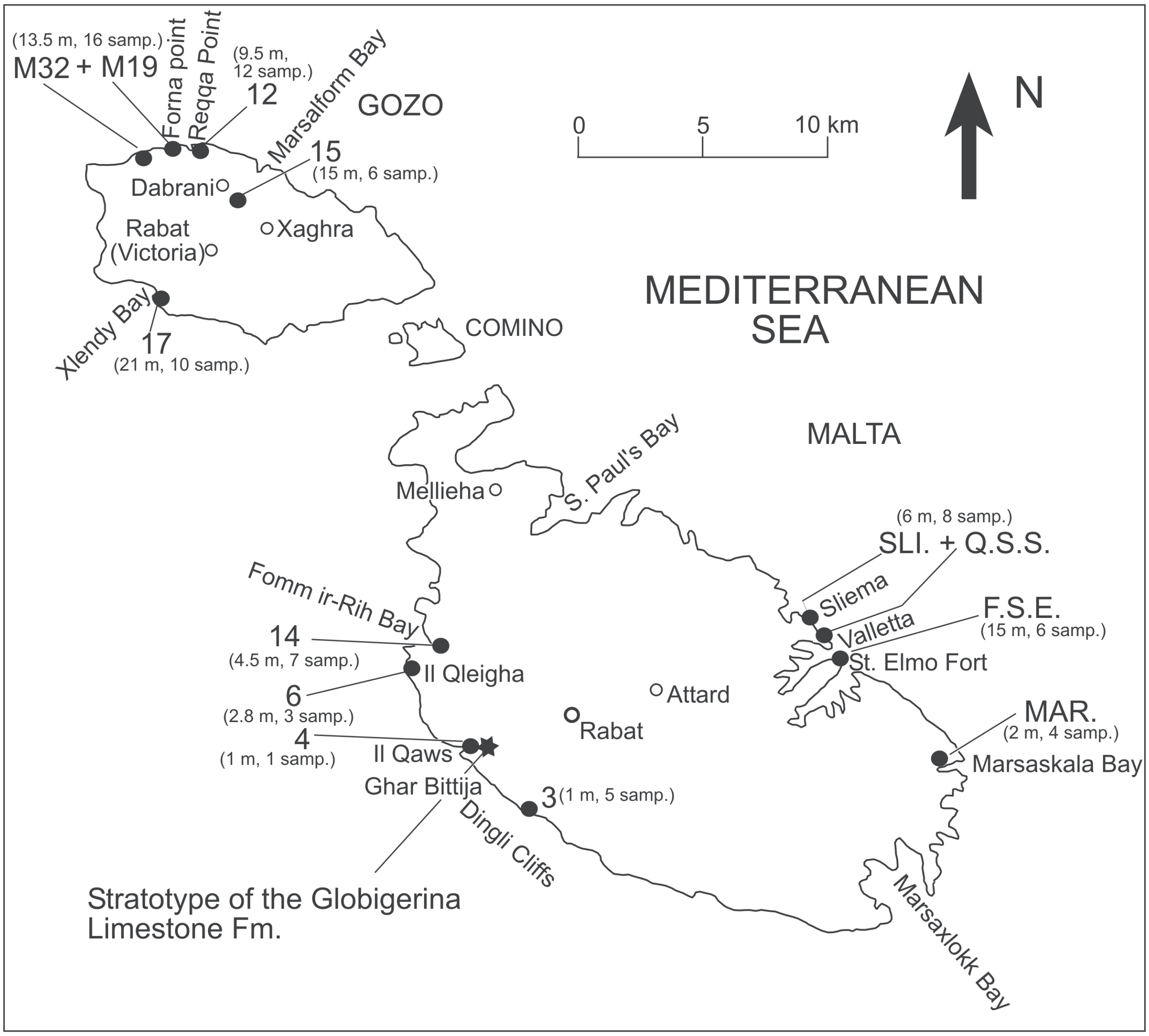

Fig. 1 - Location map of studied sections (sampled by Giannelli & Salvatorini, 1972 and newly by the present authors). SLI. + Q.S.S. = Sliema Section; F.S.E. = Fort St. Elmo Section; MAR. = Marsaskala Section; M32 + M19 = Forna Point Section. Collected samples and thickness of the section are indicated within parentheses.

ubiquitous and common; in some sections it occurs up to the Lower/Middle Globigerina Limestone boundary. The taxon disappears near to the P.21/P.22 zonal boundary.

The occurrence of the mentioned taxa allows us to refer the LGLM to the lower part of P.22 Zone. Additional taxa of the assemblages are consistent with this biostratigraphic assignment: *Globigerina ciperoensis* (Bolli), *"Globigerina" euapertura* Jenkins, *"G." tripartita* (Koch), *Globigerinella obesa* (Bolli), *Globoquadrina sellii* (Borsetti), *Globoturborotalita woodi* s.l., *Paragloborotalia opima nana* (Bolli), *P. siakensis* (LeRoy), *Tenuitellinata praestainforthi* (Blow), among others.

Nannofossils

Nearly all the considered 78 samples provided a calcareous nannofossil content. However, the nannofossil assemblages show a wide variation in abundance: from very rare to common or abundant. Furthermore, they are variably preserved, but this does not hinder the identification of the taxa.

The diverse assemblages include *Clausicoccus fenestratus*, *Coccolithus eopelagicus*, *C. miopelagicus*, *C. pelagicus*, *Cyclicargolithus abisectus* (generally common), *C. floridanus*, *Dictyococcites bisectus* (rare to common), *D. scrippsae, Discoaster deflandrei*, *Helicosphaera euphratis*, *H. intermedia*, *H. kamptneri, H. recta* (rare), *H.* spp., *Pontosphaera* cf. *enormis, P. multipora*, *Sphenolithus* cf. *ciperoensis* (rare and sporadic), *S. compactus*, *S. dissimilis*, *S. moriformis*, *S.* spp., *Triquetrorhabdulus carinatus* (rare) and *Zygrhablithus bijugatus* (rare to common).

According to Martini (1971), Bukry (1973, 1975, 1978), Martini & Müller (1975, 1986), Müller (1976), Bizon & Müller (1979), Perch-Nielsen (1985) and Fornaciari et al. (1990) the co-occurrence of *C. abisectus, D. bisectus, D. scrippsae, H. recta* and *Z. bijugatus* is essentially indicative of the NP24-NP25 interval of Martini (1971), which corresponds to CP19 Zone of Okada & Bukry (1980). Similar conclusions could be provided also by the presence in some sections of *S.* cf. *ciperoensis*. In fact, typical specimens of this taxon, which occurs notably in the same Martini's biostratigraphic interval, have been fully documented in the Mediterranean area by many authors (Catalano & Di Stefano, 1996; Fornaciari & Rio, 1996, among others).

NP24 (CP19a Subzone) mainly differs from NP25 (CP19b Subzone) by the occurrence of *Sphenolithus distentus* in NP 24. As *S. distentus* is absent in the LGLM, this member could be only referred to the NP25 Zone (MNP25a of Fornaciari & Rio, 1996). This assumption is supported by the generally common occurrence of *S. dissimilis*. In fact, this taxon seems to develop from *S. moriformis* in the upper part of the NP24 Zone and occurs up to the middle-upper part of the NN2 Zone (Perch-Nielsen, 1985).

If one takes into account the biostratigraphic results based on planktonic foraminifera, the correlation between foraminiferal and nannofossil zonal schemes (see Berggren et al., 1995 and Gradstein et al., 2004) assures the assignment of the sediments under discussion to the lower part of the NP25 Zone.

CHRONOSTRATIGRAPHY AND CONCLUSIONS

The assignment of the LGLM to the lowermost part of the planktonic foraminiferal P.22 Zone and to the lower part of the nannofossil NP25 Zone firmly attributes the unit to the Upper Oligocene (Chattian). This agrees with the final results of a working group on the Oligocene/Miocene boundary (Steininger et al., 1997a). On this subject, we emphasize what follows:

- Steininger et al. (1997a) placed the Global Stratotype Section and Point (GSSP) of the Paleogene/Neogene Period-System boundary at meter 35 of the Lemme-Carrosio Section in the Piedmont Basin (Northern Italy);
- this level nearly approximates the base of the Subchron C6Cn.2n polarity record, dated at 23.80 Ma (a revised age of 23.03 Ma has been proposed by Billups et al., 2004 and is reported also in Gradstein et al., 2004);
- in biostratigraphic terms (see also: Steininger, 1996; Iaccarino et al., 1996; Aubry & Villa, 1996; Steininger et al., 1997b) the Oligocene/Miocene boundary was located a) in the uppermost part of the P.22 Zone (as defined by Berggren & Miller, 1988; see also Iaccarino et al., 1996), 2 m below the FO of *P. kugleri*, b) in the NN1 Zone (exactly in the MNN1b Subzone of Fornaciari & Rio, 1996), near the *Sphenolithus capricornutus* FO (about 1 m below the *S. capricornutus* LO) and 4 m below the *S. delphix* LO.

The assignment of the LGLM to the Upper Oligocene (Chattian) confirms the hypothesis of Giannelli & Salvatorini (1972) about the age of the member and their consequent assumption of a hiatus between the Lower and Middle Globigerina Limestone members. A biostratigraphic evaluation of this hiatus is also possible. In fact, the basal part of the MGLM of the Malta Island sections was referred to the upper half of Blow's (1969) N4 (read now: Zone N4 b of Kennett & Srinivasan, 1983 and M1b of Berggren & Miller, 1988) and to the CN1a Subzone of Okada & Bukry (1980) by Giannelli & Salvatorini (1972) and Mazzei (1980, 1985) respectively. On this subject, it can be noticed that the identification of the CN1a Subzone was "... mainly based on the common occurrence of *C. abisectus*, lacking *S. ciperoensis*" (Mazzei, 1985, p. 172). This evidence is not sufficient to distinguish the CN1a Subzone, characterized by an acme in frequency of *C. abisectus*; consequently, a generic attribution of the Middle Globigerina Limestone Member included between the "phosphatic nodule levels 1 and 2" (Mazzei, 1980, 1985) to the lower part of the CN1 Zone seems more appropriate. Regarding to the Gozo Island sections, the above-cited authors referred the MGLM to the N6 (*pars*)-N7 (*pars*) interval and to the CN2 Zone (corresponding to the MNN3 a-b zones of Fornaciari & Rio, 1996). With reference to the scheme of Gradstein et al. (2004), shown in Fig. 2, the foraminiferal biostratigraphic interval of Giannelli & Salvatorini (1972) is interpreted as N5 Zone (upper part)-N7 Zone (*pars*) interval. Awaiting a clarification on this subject (a plankton calcareous biostratigraphic analysis of several MGL sequences is in progress), we conclude as follows (Fig. 2): the biostratigraphic gap between the Lower and Middle Globigerina Limestone members in Malta Island spans at least from the upper-middle part of the P.22 Zone to the lower part of the N4 Zone (at least the N4a Zone of Kennett & Srinivasan, 1983, and the M1a Zone of Berggren & Miller, 1988), as well as at least from the upper part of the NP25 Zone to the lower part of the CN1 Zone (about 4 Ma); in Gozo, the gap is larger also comprising the upper part of the N4 Zone and the lower-middle part of the N5 Zone, as well as the remaining part of the CN1 Zone (about 7 Ma).

According to the geologic literature (Oil Exploration Directorate, 1993; Pedley et al., 1976, 1978), in the Maltese Archipelago the thickness of the LGLM ranges from 0 (e.g. at Rdum Dikkiena, near the Dingli Section) up to 80 m or more (in the Valletta Basin). This fact may indicate variable duration of the hiatus. In the southern part of the Gozo Island, the MGLM is completely lacking, suggesting therefore an even longer duration of the hiatus. To carry out an adequate contribution on this subject, a bio-chronostratigraphic study of several other sections is in progress.

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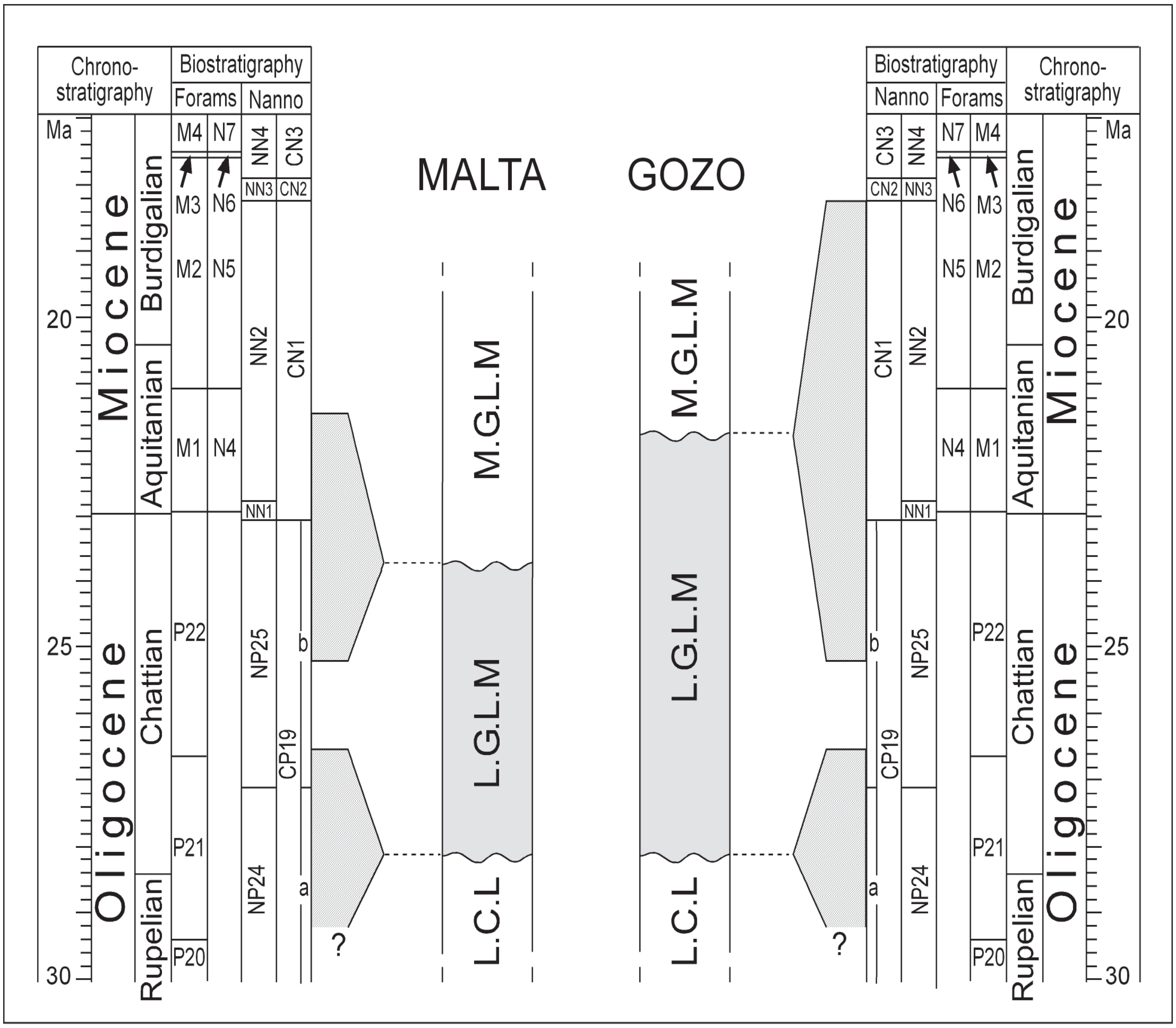

Fig. 2 - Bio-chronostratigraphic frame of the L.G.L.M. (following Gradstein et al., 2004) and evaluation of the hiatus between this member and the following M.G.L.M. The maximum thickness of the L.G.L.M. reported in the considered sections (15 m at Malta Island and 21 m at Gozo Island) is shown. L.C.L. = Lower Coralline Limestone; L.G.L.M. = Lower Globigerina Limestone Member; M.G.L.M. = Middle Globigerina Limestone Member.

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