



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

Luca Maria FORESI, Roberto MAZZEI, Gianfranco SALVATORINI & Francesca DONIA

L.M. Foresi, Dipartimento di Scienze della Terra, Università di Siena, Via Laterina 8, I-53100 Siena, Italy; foresi@unisi.it
R. Mazzei, Dipartimento di Scienze della Terra, Università di Siena, Via Laterina 8, I-53100 Siena, Italy; mazzeir@unisi.it
G. Salvatorini, Dipartimento di Scienze della Terra, Università di Siena, Via Laterina 8, I-53100 Siena, Italy.
F. Donia, Dipartimento di Scienze della Terra, Università di Siena, Via Laterina 8, I-53100 Siena, Italy; fnc-donia@libero.it

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 anguliusuturalis, G. anguliofficialis, 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 chronostratigrafia 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 (Aquitaniense, 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 chronostratigrafica 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, Globigerina obesa, Globigerinoides primordius (raro), Globoquadrina sellii, Globoturborotalita anguliofficialis, G. anguliusuturalis, 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/Aquitaniense), 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.*

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 qualitative 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 biotrital 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 ciproensis ciproensis* 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. anguliofficialis* (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

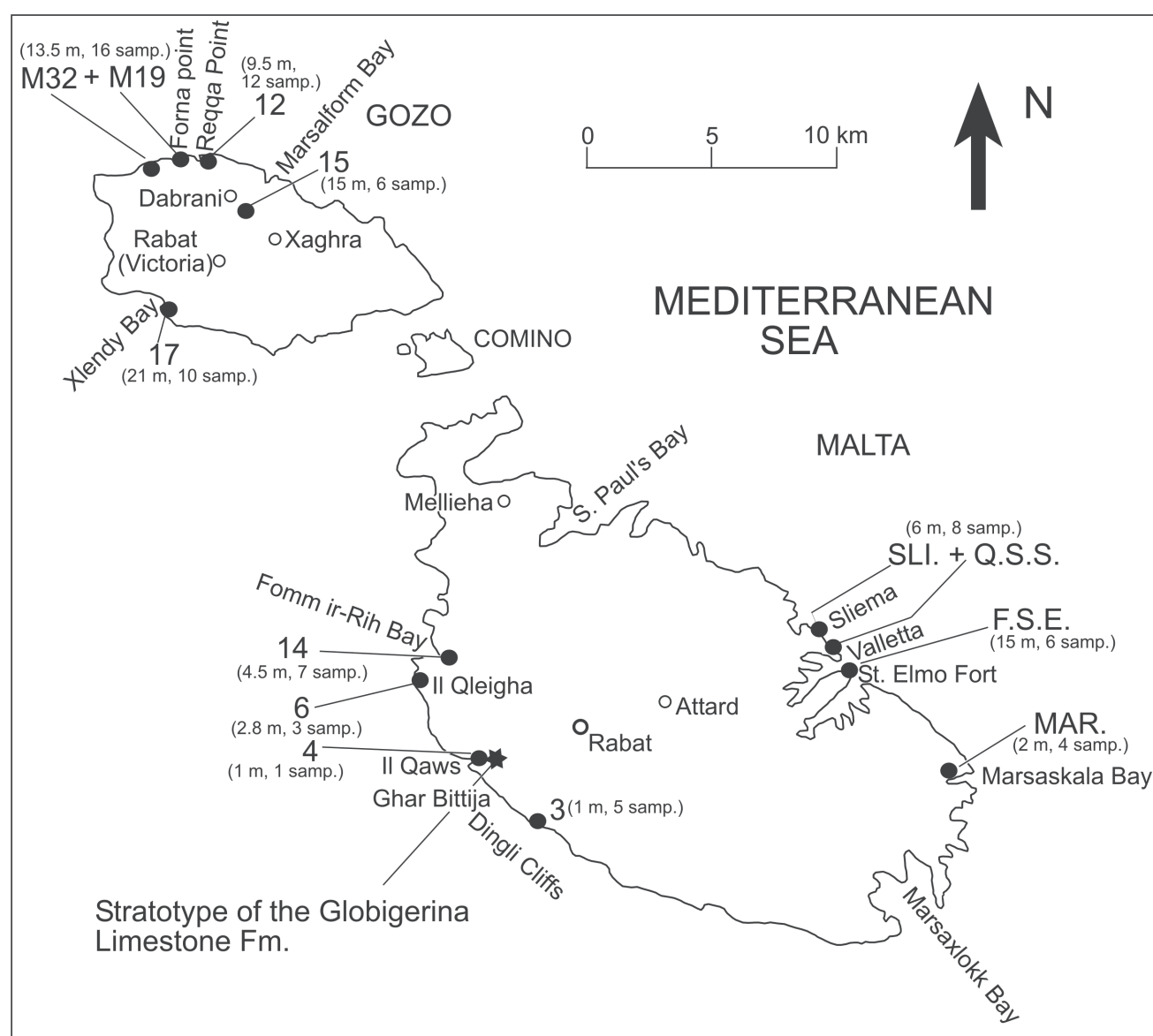


Fig. 1 - Location map of studied sections (sampled by Giannelli & Salvatorini, 1972 and newly by the present authors). SLI. + Q.S.S. = Sliema Section; F.S.E. = Fort St. Elmo Section; MAR. = Marsaskala Section; M32 + M19 = Forna Point Section. Collected samples and thickness of the section are indicated 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 ciproensis* (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. kampneri*, *H. recta* (rare), *H. spp.*, *Pontosphaera* cf. *enormis*, *P. multipora*, *Sphenolithus* cf. *ciproensis* (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. ciproensis*. 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. ciproensis*" (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 P22 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.

REFERENCES

- Aubry M. P. & Villa G. (1996). Calcareous nannofossil stratigraphy of the Lemme-Carrosio Paleogene/Neogene Global Stratotype Section and Point. In Steininger F.F., Iaccarino S. & Cati F. (eds.), *In Search of the Paleogene/Neogene Boundary*. Pt. 3. The Global Stratotype Section and Point. The GSSP for the base of the Neogene (the Paleogene/Neogene Boundary). *Giornale di Geologia*, Ser. 3^a, 58 (1/2): 51-69.
- Bennett S.M. (1980). Palaeoenvironmental studies in Maltese Mid-Tertiary carbonates. PhD Thesis, University of London, London.

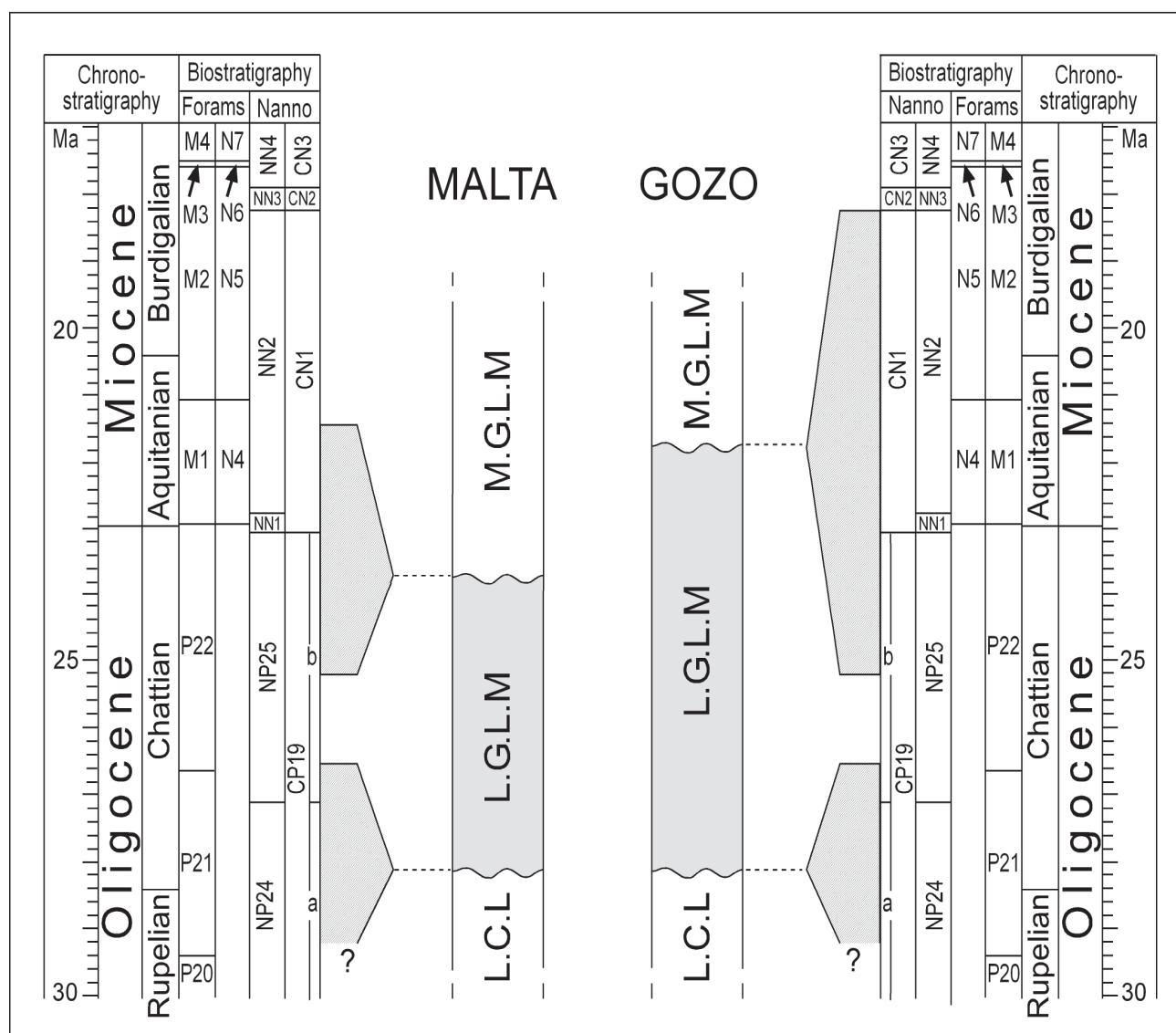


Fig. 2 - Bio-chronostratigraphic frame of the L.G.L.M. (following Gradstein et al., 2004) and evaluation of the hiatus between this member and the following M.G.L.M. The maximum thickness of the L.G.L.M. reported in the considered sections (15 m at Malta Island and 21 m at Gozo Island) is shown. L.C.L.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

- Berggren W.A., Kent D.V., Swisher C.C. III & Aubry M.P. (1995). A revised Cenozoic Geochronology and Chronostratigraphy. In Berggren W.A., Kent D.V., Aubry M.P. & Hardenbol J. (eds.), *Geochronology Time Scales and Global Stratigraphic Correlation: An Unified Temporal Framework for an historical Geology. SEPM, Special Publication*, 54: 129-212.
- Berggren W.A. & Miller K.G. (1988). Paleogene tropical planktonic foraminiferal biostratigraphy and magnetobiochronology. *Micropaleontology*, 34 (4): 362-380.
- Billups K., Pälike H., Channell J.E.T., Zachos J.C. & Shackleton N.J. (2004). Astronomic calibration of the late Oligocene through early Miocene geomagnetic polarity time scale. *Earth and Planetary Science Letters*, 224 (1-2): 33-44.
- Biolzi M. (1985). The Oligocene/Miocene boundary in selected Atlantic, Mediterranean and Paratethyan sections based on biostratigraphic and stable isotope evidence. *Memorie di Scienze Geologiche*, 37: 303-378.
- Bizon G. & Müller C. (1979). Remarks on the Oligocene/Miocene boundary based on the results obtained from the Pacific and the Indian Oceans. *Annales Géologiques des Pays Helléniques*. Tome Hors Série, 1: 101-111.
- Blow W.H. (1969). Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. In Brönnimann P. & Renz H.H. (eds.), *Proceedings First International Conference on Planktonic Microfossils*, Geneva 1967, 1: 199-421.
- Boersma A. & Premoli Silva I. (1991). Distribution of Paleogene planktonic foraminifera - Analogies with the Recent? *Palaeogeography, Palaeoclimatology, Palaeoecology*, 83 (1-3): 29-48.
- Bolli H.M. & Saunders J.B. (1985). Oligocene to Holocene low latitude planktic foraminifera. In Bolli H.M., Saunders J.B. & Perch-Nielsen K. (eds.), *Plankton Stratigraphy*, 1: 155-262. University Press, Cambridge.
- 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.
- 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 Deep Sea Drilling Project*, 32: 677-701.
- Bukry D. (1978). Biostratigraphy of Cenozoic marine sediment by calcareous nannofossils. *Micropaleontology*, 24 (1): 44-60.
- Carbone S., Grasso M., Lentini F. & Pedley H.M. (1987). The distribution and paleoenvironment of early Miocene phosphorites of southeast Sicily and their relationship with the Maltese phosphorites. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 58: 35-53.
- Catalano S. & Di Stefano A. (1996) - Nuovi dati geologici e stratigrafici sul Flysch di Capo d'Orlando nei Peloritani Orientali (Sicilia Nord-Orientale), *Memorie della Società Geologica Italiana*, 51: 149-164.
- Challis G.R. (1979). Miocene Echinoid biofacies of the Maltese Islands. *Annales Géologiques Des Pays Helléniques*. Tome Hors Série, 1: 253-262.
- Cooke J.H. (1893). On the occurrence of Concretionary Masses of Flint and Chert in the Maltese limestone. *Geological Magazine*, 20: 157-160.
- Cooke J.H. (1896). Notes on the Globigerina Limestones of the Maltese Islands. *Geological Magazine*, 33: 502-511.
- Felix R. (1973). Oligo-Miocene stratigraphy of Malta and Gozo. Weenman H. & Zonen B.V. (eds.), 104 pp. Wageningen.
- Fornaciari E., Raffi I., Rio D., Villa G., Backman J. & Olafsson G. (1990). Quantitative distribution patterns of Oligocene and Miocene calcareous nannofossils from the western equatorial Indian Ocean. In Duncan R.A., Backman J. & Peterson L.C., *Proceedings of the Ocean Drilling Program, Scientific Results*, 115: 237-254.
- Fornaciari E. & Rio D. (1996). Latest Oligocene to early middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. *Micropaleontology*, 42 (1): 1-36.
- Fuchs Th. (1874). Das Alter der Tertiärschichten von Malta. Sitzber. Kais. Akad. Wiss. Wien Math. Nat. Cl., 70 (1), 92-105. Translated by Appellius F.L.: L'età degli strati terziari di Malta. *Bollettino Regio Comitato Geologico d'Italia*, 5: 377-386.
- Giannelli L. & Salvatorini G. (1972). I foraminiferi planctonici dei sedimenti terziari dell' Arcipelago maltese. I. Biostratigrafia del "Globigerina Limestone". *Atti Società Toscana di Scienze Naturali, Memorie*, Ser. A, 79: 49-74.
- Gradstein F.M., Ogg J.G. & Smith A.G., eds. (2004). *A Geological Time Scale 2004*. 585 pp. University Press, Cambridge.
- Gregory J.W. (1891). The Maltese fossil Echinoidea and their evidence on the correlation of the Maltese rocks. *Transactions of the Royal Society of Edinburgh*, 36, 3 (22): 585-639.
- Haq B.U., Hardenbol J. & Vail P.R. (1987). Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. *SEPM, Special Publication*, 42: 72-108.
- Iaccarino S., Borsetti A.M. & Rögl F. (1996). Planktonic foraminifera of the Neogene Lemme-Carrosio GSSP Section (Piedmont, Northern Italy). In Steininger F.F., Iaccarino S. & Cati F. (eds.), *In Search of the Paleogene/Neogene Boundary. Pt. 3. The Global Stratotype Section and Point. The GSSP for the base of the Neogene (the Paleogene/Neogene Boundary)*. *Giornale di Geologia*, Ser. 3ª, 58 (1/2): 35-49.
- Iaccarino S.M., Premoli Silva I., Biolzi M., Foresi L.M., Lirer F. & Petrizzo M.R. (2005). Practical manual Oligocene to Middle Miocene Planktonic foraminifera. 124 pp. In Biolzi M., Iaccarino S.M. & Rettori R. (eds.), *International school on planktonic Foraminifera*, 4º course, Perugia.
- Jacobs E., Weissert H., Shield G. & Stille P. (1996). The Monterey event in the Mediterranean: A record from shelf sediments of Malta. *Paleoceanography*, 11 (6): 717-728.
- Kennett J.P. & Srinivasan M.S., eds. (1983). *Neogene Planktonic Foraminifera. A phylogenetic atlas*. 265 pp. Hutchinson Ross Publishing Company, New York.
- Kienel U., Rehfeld U., Bellas S. & Kohring R. (1995). The Miocene Blue Clay Formation of the Maltese Islands; sequence-stratigraphic and paleoceanographic implications based on calcareous nannofossil stratigraphy and calcareous dinoflagellate cysts. *Berliner geowissenschaftliche Abhandlungen, Gündolf-Ernst-Festschrift E16*: 533-557.
- Martini E. (1971). Standard Tertiary and Quaternary calcareous nannoplankton zonation. In Farinacci A. (ed.), *Proceedings of 2nd Planktonic Conference (Rome, 1970)*, 2: 739-785.
- Martini E. & Müller C. (1975). Calcareous nannoplankton from the Type Chattian (Upper Oligocene). *6th Congress Regional Committee on Mediterranean Neogene Stratigraphy, Bratislava*, 1: 37-41.
- Martini E. & Müller C. (1986). Current Tertiary and Quaternary calcareous nannoplankton stratigraphy and correlation. *Newsletter Stratigraphy*, 16: 99-112.
- Mazzei R. (1980). Studio biostratigrafico di alcune sezioni mioceniche dell' Arcipelago Maltese sulla base del Nannoplankton calcareo. *Paleontologia Stratigrafica ed Evoluzione*, 1: 149-152.
- Mazzei R. (1985). The Miocene sequence of the Maltese Islands: biostratigraphic and chronostratigraphic references based on nannofossils. *Atti Società Toscana di Scienze Naturali, Memorie*, 92: 165-197.
- Menesini E. (1979a). Echinidi fossili dell' Arcipelago Maltese - I. *Atti Società Toscana di Scienze Naturali, Memorie*, 86: 51-64.
- Menesini E. (1979b). Maltese fossil Echinoids. *Annales Géologiques des Pays Helléniques*. Tome Hors Série, 2: 799-806.
- Molina E. (1979). Oligoceno-Mioceno inferior por medio de foraminiferos planctonicos en el sector central de las Cordilleras Béticas (España). Tesis Doctoral, Departamento de Paleontología Universidad de Granada: 342 pp., Granada.
- Müller C. (1976). Tertiary and Quaternary calcareous nannoplankton in the Norwegian-Greenland Sea, DSDP, Leg 38. In Talwani M., Udintsev C. et al. *Initial Reports of the Deep Sea Drilling Project*, 38: 823-841.
- Murray J. (1890). The Maltese islands, with special reference to their geological structure. *The Scottish Geographical Magazine*, 6: 449-488.
- Oil Exploration Directorate (Malta) (1993). *Geological Map of the Maltese Islands. Sheet 1-Malta. Scale 1:25.000*. Keyworth, British Geological Survey.

- 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.
- Pedley H.M. & Bennett S.M. (1985). Phosphorites, hardgrounds and syndepositional solution subsidence: a palaeoenvironmental model from the Miocene of the Maltese Islands. *Sedimentary Geology*, 45 (1-2): 1-34.
- Pedley H.M., House M.R. & Waugh B. (1976). The geology of Malta and Gozo. *Proceedings Geological Association*, 87 (3): 325-342.
- Pedley H.M., House M.R. & Waugh B. (1978). The geology of the Pelagian block: the Maltese Islands. In Nairn A.E.M., Kanes W.H. & Stehli F.G. (eds.), *The ocean basins and margins - 4B, the Western Mediterranean*. Plenum Press, New York: 417-433.
- Perch-Nielsen K. (1985). Cenozoic calcareous nannofossils. In Bolli H.M., Saunders J.B. & Perch-Nielsen K. (eds.), *Plankton Stratigraphy*, 1: 427-554. University Press, Cambridge.
- Rehfeld U. & Janssen A.W. (1995). Development of phosphatized hardgrounds in the Miocene Globigerina Limestone of the Maltese Archipelago, including a description of *Gamopleura melitensis* sp. nov. (Gastropoda, Euthecosomata). *Facies*, 33: 91-106.
- Rizzo C. (1932). Report on the Geology of the Maltese islands. 37 pp. Government Printing Office, Malta.
- Rose E.P.F. (1974). Stratigraphical and facies distribution of irregular Echinoids in Miocene limestone of Gozo, Malta and Cyrenaica, Libya. *Mémoires du Bureau de Recherches Géologique et Minières*, 78, 349-355.
- Rose E.P.F., Pratt S.K. & Bennett S.M. (1992). Evidence for Sea-Level Changes in the Globigerina Limestone Formation (Miocene) of the Maltese Islands. *Paleontologia i Evolució*, 24-25: 265-276.
- Spezzaferri S. (1994). Planktonic foraminiferal biostratigraphy and taxonomy of the Oligocene and Lower Miocene in the oceanic record. An overview. *Palaeontographia Italica*, 81: 1-187.
- Stainforth R.M., Lamb J.L., Luterbacher H., Beard J.H. & Jeffords R.M. (1975). Cenozoic planktonic foraminiferal zonation and characteristics of index forms. *The University of Kansas Paleontological Contributions*, 62: 1-425 [in two parts].
- Steininger F.F. (1996). Historical Background and Concepts. In Steininger F.F., Iaccarino S. & Cati F. (eds.), *In search of the Paleogene/Neogene Boundary*. Pt. 3. The Global Stratotype Section and Point. The GSSP for the base of the Neogene (the Paleogene/Neogene Boundary). *Giornale di Geologia, Ser. 3ª*, 58 (1/2): 5-7.
- Steininger F.F., Aubry M.P., Berggren W.A., Biolzi M., Borsetti A.M., Cartlidge J.E., Cati F., Corfield R., Gelati R., Iaccarino S., Napoleone C., Ottner F., Rögl F., Roetzel R., Spezzaferri S., Tateo F., Villa G. & Zevenboon D. (1997a). The Global Stratotype Section and Point (G.S.S.P.) for the base of the Neogene. *Episodes*, 20 (1): 23-28.
- Steininger F.F., Aubry M.P., Biolzi M., Borsetti A.M., Cati F., Corfield R., Gelati R., Iaccarino S., Napoleone C., Rögl F., Rotzel R., Spezzaferri S., Tateo F., Villa G. & Zevenboon D. (1997b). Proposal for the Global Stratotype Section and Point (G.S.S.P.) for the base of the Neogene (the Paleogene/Neogene boundary). In Montanari A., Odin G.S. & Coccioni R. (eds.), *Miocene Stratigraphy. An Integrated Approach. Development in Paleontology and Stratigraphy*, 15: 125-147.
- Theodoridis S. (1984). Calcareous Nannofossil biozonation of the Miocene and revision of the Helicoliths and Discoasters. *Utrecht Micropaleontological Bulletin*, 32: 271.
- Wright T. (1855). On fossil Echinoderms from the Island of Malta: with Notes on the stratigraphical distribution of the Fossil Organisms in the Maltese beds. *Annals & Magazine of Natural History*, 15: 101-127.

Manuscript received 26 January 2006

Revised manuscript accepted 09 November 2007

