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Biostratigraphy and palaeoecological interpretation of the Miocene–Pleistocene sequence at El-Dabaa, northwestern Egypt

MOHAMED I. A. IBRAHIM[1] & AHMED M. S. MANSOUR[2]
[1]Department of Environmental Sciences, Faculty of Science, University of Alexandria, Egypt (Current address: Department of Geology, Faculty of Science, University of Qatar, P.O. Box 2713, Doha, Qatar).
[2]Department of Geology, Faculty of Science, Alexandria University, Alexandria, Egypt.

ABSTRACT – Thirteen shallow boreholes were drilled by the Qattara Project Authority (QPA) on the top of the second limestone ridge in the El-Dabaa area, along the Mediterranean coast, northwest Egypt. Five foraminiferal biozones could be recognized in ascending stratigraphic order: the *Heterostegina costata*, *Praeorbulina sicana*, *Borelis melo melo*, *Globigerinoides obliquus extremus* zones and an un-named zone, embracing the Middle Miocene Marmarica Formation and the Pliocene–Pleistocene Alexandria Formation.

The deposition of the fossiliferous carbonate rocks of the Marmarica Formation probably took place in a warm water, inner shelf environment (0–20 m palaeodepth) subjected to some current activity, and with salinity ranging from normal to slightly hypersaline (35–50‰). The sediments of the oncolitic/shelly rocks were deposited in slightly deeper water than the overlying fossiliferous rocks and in less agitated conditions, as indicated from the high percentages of rotaliids and rarity of miliolids.

The foraminiferal associations in the Alexandria Formation indicate a clear, relatively agitated, near-shore marine depositional environment in a vegetated inner neritic zone (10–25 m palaeodepth) with 25°C surface water isotherms. On the other hand, the accumulation of the clayey sediments and some geosoils (basal part of the Alexandria Formation) occurred in less agitated, intertidal water conditions, as deduced from the occurrence of planktic foraminiferal species as *Globigerinoides trilobus trilobus*, *G. trilobus immaturus*, *G. obliquus extremus*, *G. obliquus obliquus*, *Globorotalia inflata*, and *Orbulina universa*. *J. Micropalaeontol*. **21**(1): 51–65, May 2002.

INTRODUCTION

Deposits related to Miocene–Pleistocene times mostly cover the northern part of the Western Desert of Egypt (Fig. 1). The Miocene sediments (Marmarica Formation) form an extensive plateau known as the Marmarica Plateau. The surface of this plateau is of Middle Miocene age and is composed of a shallow-marine biogenic carbonate sequence with some shale and marl intercalations. Along parts of the Mediterranean coastal plain, the Middle Miocene rocks are unconformably overlain by a mantle of thin shallow-marine carbonate beds or by small isolated hills or elongated ridges of conglomeratic and oolitic limestones of Pliocene to Pleistocene age (Alexandria Formation). Substantial variations in depositional environments and climatic conditions through Miocene–Pleistocene times are distinguished.

The late Tertiary to Quaternary sediments along the western Mediterranean coastal zone of Egypt have been briefly reviewed in terms of their sedimentology, stratigraphy, petrography, geochemistry and diagenetic history (e.g. Hilmy, 1951; Shukri *et al*., 1956; Butzer, 1960; El Shazly *et al*., 1964; El Shami *et al*., 1969; Gindy *et al*., 1969; Selim, 1974; Cherif *et al*., 1975; Hassouba, 1980, 1995; Anwar *et al*., 1981; El Asmar, 1991, 1994; Holail, 1993; Wali *et al*., 1994; El Shahat, 1995; Tamish *et al*., 1996; Holail *et al*., 1997 and Mansour, 1999).

In general, little research has been carried out on the biostratigraphy of the Miocene–Pleistocene rocks in the northern part of the Western Desert, with the exception of that by Mansour *et al*. (1969), Omara & Ouda (1968) and Ouda (1971). Recently, Ouda (1998) has studied the biostratigraphy and palaeoecology of the Middle and Upper Tertiary deposits. He selected 24 wells drilled along the entire northern stretch of the Western Desert, and concentrated on global planktic foraminiferal palaeoevents and larger benthic foraminiferal datum planes considered to be correlative and isochronous over the Mediterranean region.

The previous investigations were restricted mainly to the exposed Miocene–Pleistocene rock sequence along the northern part of the Western Desert. The present study aims to provide biostratigraphic information about part of the sub-surface Miocene–Pleistocene succession underlying the limestone ridges.

The present work deals with the study of the foraminiferal content in the sub-surface Miocene–Pleistocene stratigraphic rock sequence of the El-Dabaa area (Fig. 1), and defines their vertical distribution among the different rock units. Unfortunately, this rock sequence is barren of palynological elements (spores, pollen grains and dinoflagellates). The foraminiferal study has been undertaken in an attempt to interpret the environmental conditions prevailing during the deposition of these sediments and to determine the age of the recorded rock units.

GEOLOGICAL SETTING AND STRATIGRAPHY

The Marmarica Plateau extends from the Salum area to the western side of the Nile Valley and Delta and is limited northward by the Mediterranean coastal plain and southward by the Qattara and Siwa depressions (Fig. 1). The surface of this plateau is made up of a shallow-marine carbonate sequence with some shale and marl intercalations (Said, 1990) of Middle Miocene age (Marmarica Formation). The coastal zone north of the Miocene plateau is covered by Plio-Pleistocene limestone ridges running parallel to the present shoreline and extending

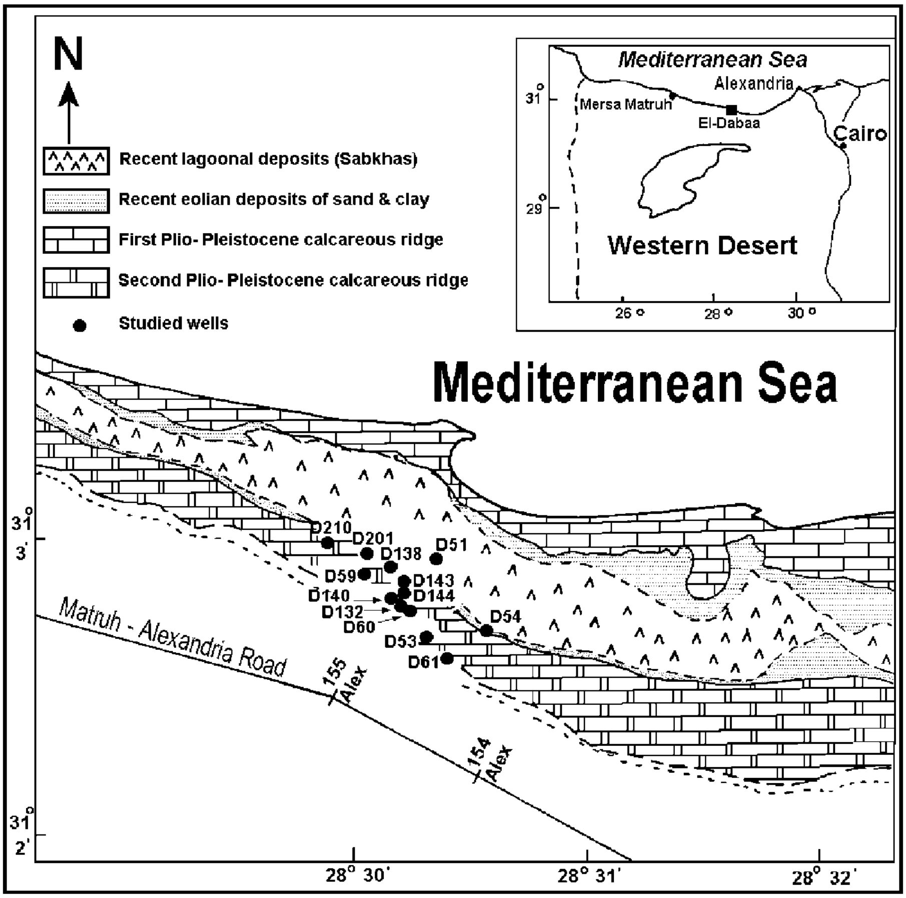


Fig. 1. Generalized geological map of the coastal plain and the Alexandria Formation in the El-Dabaa area and the location of the studied wells.

from Alexandria to Salum (Alexandria Formation) (Shata, 1955; Shukri *et al.*, 1956; Butzer, 1960; Hassouba, 1995). The El-Dabaa area occupies a small portion of the western Mediterranean coastal zone (Fig. 1) and lies midway between Alexandria and Mersa-Matruh (156 km from Alexandria). The coastal plain in this area slopes gently in a northward direction and merges gradually southwards into the great Marmarican homoclinal plateau. The surface is characterized by a number of beach-dune calcareous ridges of oolitic and biogenic components running parallel to the present coastline and separated by lowland areas (depressions) filled with lagoonal–sabkha deposits. Both the first and the second ridges are prominent, but the older ones are partially to highly eroded and are less morphologically distinct (El Shami *et al.*, 1969).

The lithostratigraphy of the sub-surface Miocene–Pleistocene sequence at the examined boreholes (D51, D53, D54, D59, D60, D61, D132, D138, D140, D143, D144, D201, D210, Fig. 1) is mostly composed of carbonate rocks with few siliciclastic intercalations and can be divided into two formations, the Marmarica Formation (fossiliferous carbonate) at the base and the Alexandria Formation (carbonate aeolianite) at the top (Fig. 2).

The Marmarica Formation (base)

This formation is represented by different fossiliferous carbonate rocks. According to its colour, lithology, and fossil contents, this rock unit is sub-divided into four informal lithological units from old to young as given by Mansour (1999).

Grey-white oncolitic/shelly limestones (Unit V; Beds 22–20). Grey, moderately hard, compacted algal dolomite to highly dolomitic limestone; very rich in white oncolitic grains with some bivalve, gastropod shell debris, bryozoan skeletal fragments and larger foraminifera. The rocks contain some argillaceous material and gypsum. This unit attains a thickness of 22–25 m.

Yellow marly/shelly dolostones (Unit IV; Beds 19–14). Yellow, compacted, hard marly vesicular dolomite with ochre spots; fossiliferous, with bivalve shells, which are replaced by crystalline gypsum. Downwards, the rocks become less fossiliferous and more compacted; about 22–25 m thick.

White chalky/shelly dolostones (Unit III; Beds 13–3). White to creamy, hard, moderately porous fossiliferous chalky dolomite; rich in coarse to medium shell debris of bivalves and gastropods in addition to miliolid and alveolinid foraminifera and bryozoan shells; about 22–42 m thick.

Grey shelly dolostone (Unit II; Bed 2). Light to dark grey, very hard, vesicular shelly dolomite, highly fossiliferous with bivalve and gastropod shell debris, in addition to some badly preserved

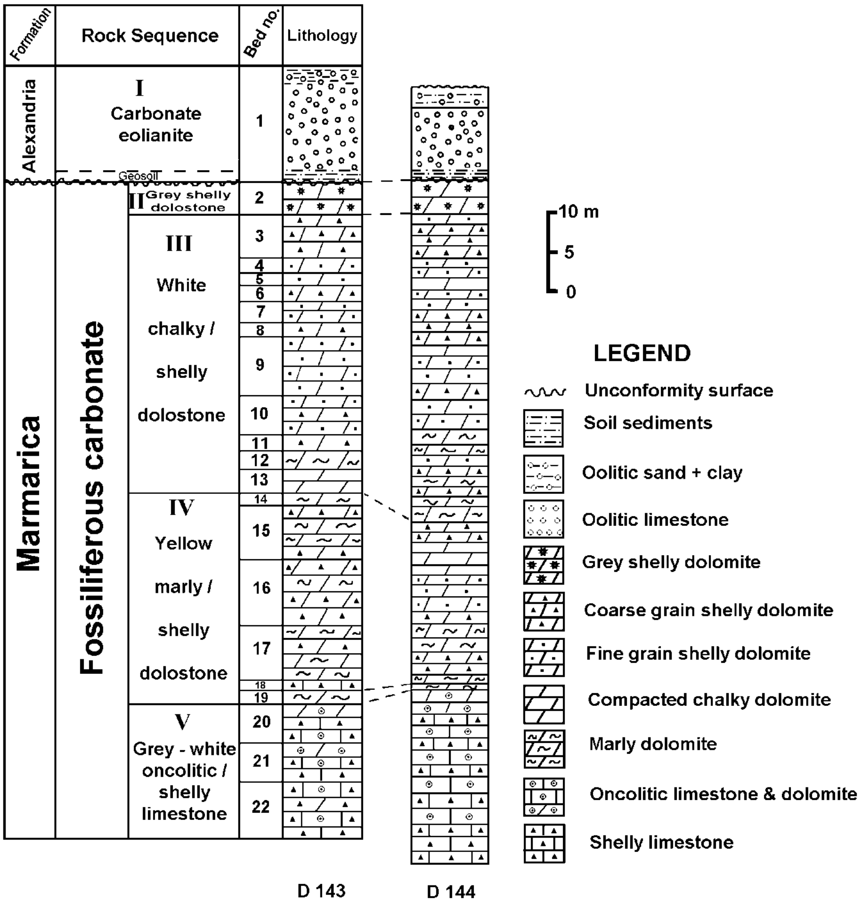


Fig. 2. Representative lithostratigraphical succession of the study wells.

foraminiferal tests, echinoid, algal and coral fragments. This unit attains a thickness of 5–15 m.

The Alexandria Formation (top) (Unit I; Bed 1)

Carbonate aeolianite which is intercalated with geosoil horizons and about 5 to 15 m thick. A thin layer of fine-grained carbonate sediment with a high content of siliciclastic material is observed at the base, with common planktic foraminifera.

MATERIAL AND METHODS

The present work is based on the study of core samples collected from thirteen shallow boreholes (maximum depth is about 100 m) drilled by the Qattara Project Authority on the surface of the second limestone ridge at El-Dabaa area (Figs 2, 3). Fifty-six samples representing the different rock types of the Marmarica and the Alexandria Formations were selected for microfaunal investigation. About 50 g of each rock sample was processed in steps including gentle mechanical disaggregation, oven drying, soaking in dilute solution of H_2O_2 (10%), wet sieving through a 63 µm screen and drying at 40°C.

FORAMINIFERAL BIOSTRATIGRAPHY

The sub-surface rock sequence under investigation in the El-Dabaa area, represents part of the Miocene to Pleistocene. The boundary between the Marmarica Formation of Miocene age and the Alexandria Formation of Plio-Pleistocene age can be defined micropaleontologically.

Biostratigraphic zones based on planktic and larger foraminifera, covering the Miocene in the northern part of the Western Desert were proposed by Ouda (1998): the *Praeorbulina sicana*, *P. glomerosa* zones (for the lower part of the Marmarica Formation), the *Heterostegina costata* zone (also for the lower part of the Marmarica Formation), and the *Borelis melo* zone (for the upper part of the Marmarica Formation) (Figs 4, 5).

In the present study, larger foraminiferal species are also used as zonal markers in some intervals due to the lack of planktic foraminifera. The studied sequence of Miocene to Plio-Pleistocene age is divided into four known biozones and an unnamed biozone representing the upper part of the Alexandria Formation. These biozones are discussed in ascending stratigraphical order as follows.

Heterostegina costata s.l. Zone

Definition. Biostratigraphic interval with zonal marker species to the first appearance of *Praeorbulina sicana* (Pl. 2, fig. 5; Pl. 3, figs 5, 6).

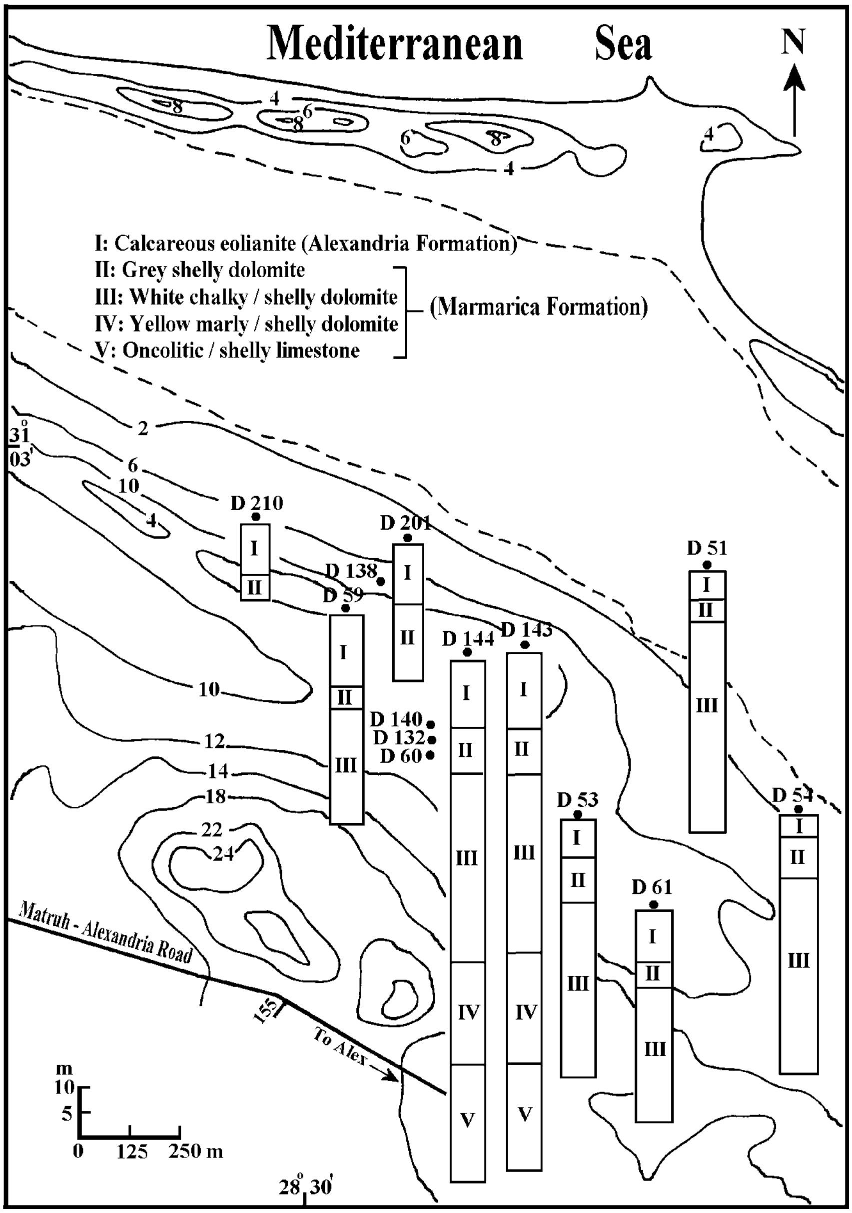


Fig. 3. Location map of some drilled wells on the top of the second limestone ridge (Alexandria Formation) in the El-Dabaa area associated with the stratigraphic sequence of the studied sections.

Author. Ouda (1971), emended by Ouda (1998).

Characteristics. Other species occurring in this zone besides the zonal marker species are *Ammonia beccarii*, *Ammonia* sp., *Cibicides rhodiensis*, *C. aknerianus*, *C. lobatulus*, *Elphidium crispum*, *E. macellum*, *Elphidium* sp., *Nonion communis*, *N. elongatus*, *Nonionella* sp. and *Eponides* sp., in addition to some larger foraminifera such as *Amphistegina lessonii* and *Operculina complanata* (Fig. 4).

Occurrence. Grey-white oncolitic/shelly limestones; lower part of Marmarica Formation, Unit V.

Age and correlation. The present zone is equated with the lower part of the *Heterostegina costata* Zone of Ouda (1998) of independent Middle Miocene, Langhian age. The genus *Miogypsina*, which shows its last occurrence at the top of the lower Miocene Burdigalian (Berggren *et al*., 1995; Ouda, 1998) has not been recorded.

***Praeorbulina sicana* Zone**

Definition. Stratigraphic interval from the first appearance of zonal marker to the FAD of *Globorotalia fohsi* and *Borelis melo melo* (Pl. 1, figs 7, 8; Pl. 2, figs 8, 9; Pl. 4, figs 1, 2).

Author. Berggren *et al*. (1995).

Characteristics. The identified foraminifera from this zone are mostly benthic and include the taxa *Triloculina* sp.,

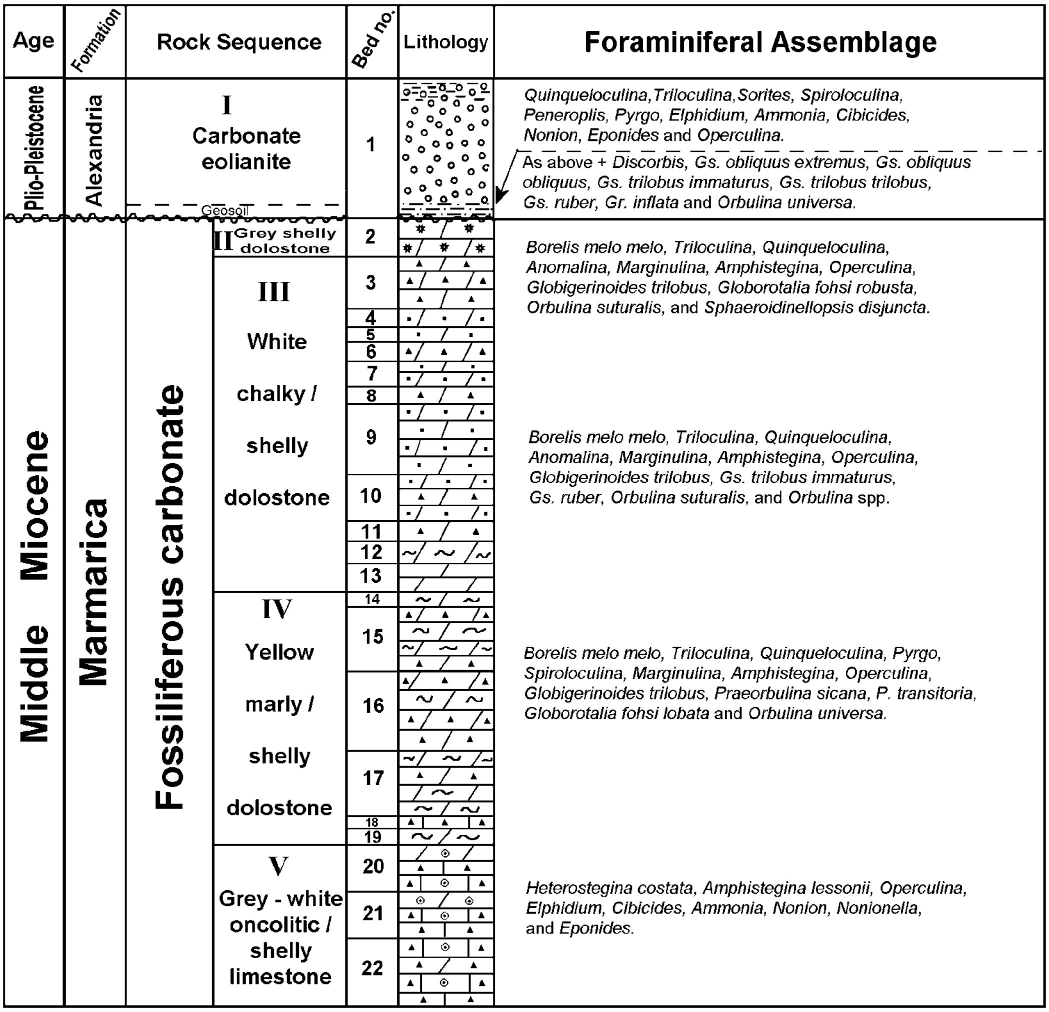


Fig. 4. Generalized sub-surface columnar section of the studied Middle Miocene–Pleistocene sequence in the El-Dabaa area, northern Western Desert and characteristic foraminiferal assemblages.

Quinqueloculina sp., *Marginulinopsis* sp. and rare *Textularia* sp., in addition to larger foraminifera such as *Amphistegina* sp. and *Operculina* sp. The observed planktic foraminifera include *Praeorbulina sicana*, *P. transitoria* and *Orbulina universa* (Fig. 4).

Occurrence. Lower part of the yellow marly/shelly dolomite; part of Marmarica Formation, lower part of Unit IV.

Age and correlation. The present zone can be equated with both the *Praeorbulina sicana* and *P. glomerosa* Zones of Ouda (1998) and Subzone M5a & b of Berggren *et al*. (1995) of Middle Miocene, early Langhian age.

Borelis melo melo Zone

Definition. Biostratigraphic total range zone of the marker species. The lower limit of this zone coincides with the FAD of *Orbulina suturalis* and *Globorotalia fohsi fohsi*.

Author. Bellini (1969).

Characteristics. The benthic foraminiferal assemblage includes the following taxa: *Textularia* sp., *Clavulina* sp., *Triloculina tricarinata*, *Quinqueloculina* sp., *Amphistegina* sp., *Ammonia* sp., *Anomalina* sp., *Marginulinopsis* sp., *Elphidium* sp., *Eponides* sp., *Nonion boueanum*, *Nonionella* sp., *Peneroplis armoricus*, *Operculina* sp., *Amphistegina* sp., *Spiroloculina* sp., *Cibicides* sp. and *Pyrgo* sp.

Rare planktic foraminifera were observed including *Globigerinoides trilobus trilobus* (Pl. 3, figs 1, 2), *G. trilobus immaturus*, *G. ruber* (Pl. 1, fig. 3), *Globorotalia fohsi fohsi*, *Globorotalia fohsi lobata* (Pl. 4, fig. 1), *Globorotalia fohsi robusta* (Pl. 1, figs 7, 8), *Sphaeroidinellopsis disjuncta* (Pl. 2, fig. 7), *Orbulina universa* (Pl. 2, fig. 2) and *Orbulina suturalis* (Pl. 2, figs 3, 4).

Occurrence. Upper part of the yellow marly/shelly dolomite, the white chalky/shelly dolomite and the grey shelly dolomite lithologic units; upper part of Marmarica Formation, upper part of Unit IV to Unit II.

Age and correlation. The present *Borelis melo melo* Zone is widely distributed in the Mediterranean region where it

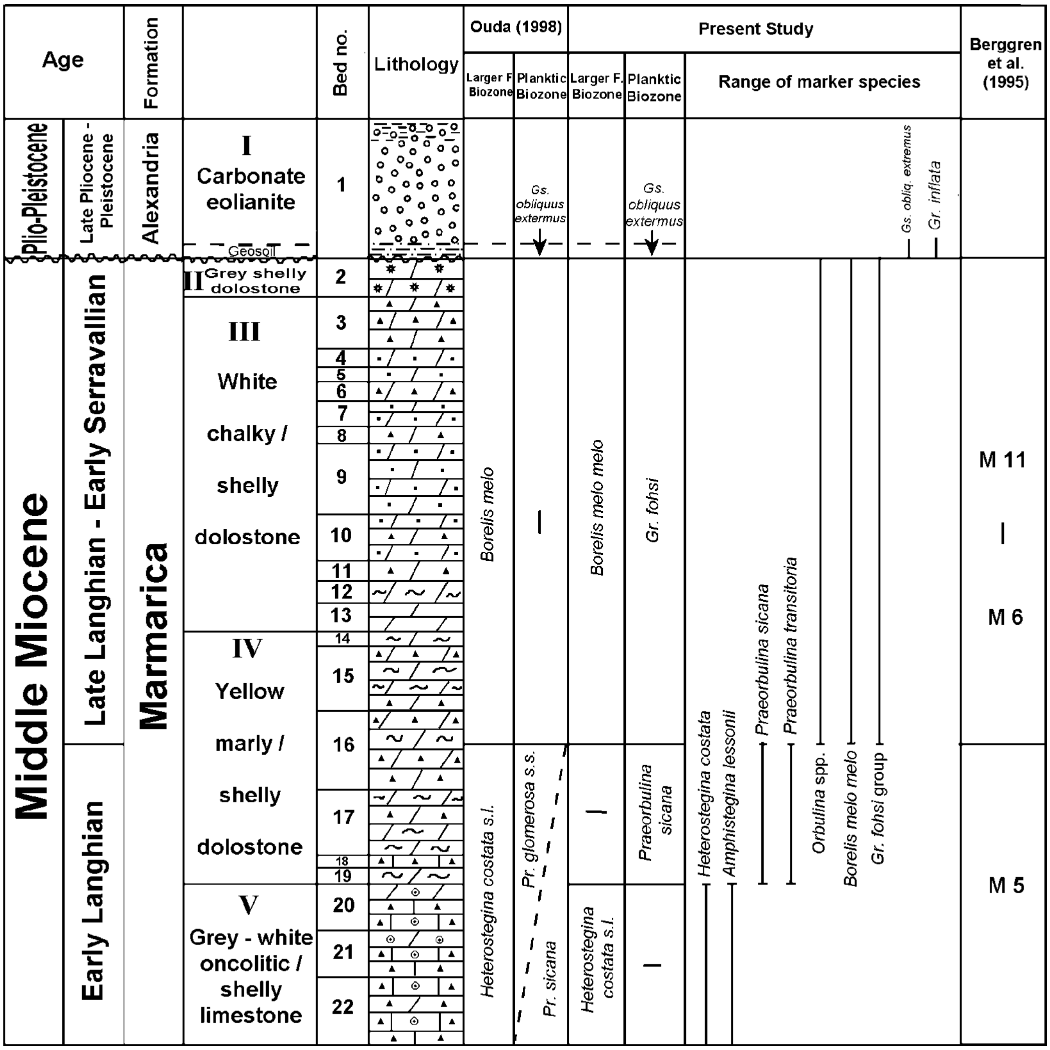


Fig. 5. Middle Miocene–Pleistocene biozones and their marker foraminiferal species in comparison with the biozones of Ouda (1998) and Berggren *et al.* (1995).

represents the youngest marine biostratigraphic zone of the Miocene succession (e.g. Adams, 1984; Sherif, 1991; Abuserwil, 1996; Ouda, 1998; Abdulsamad & Barbieri, 1999). The present zone is equivalent to the *Borelis melo melo* Zone of Ouda (1998). It can be equated also with the *Globorotalia fohsi fohsi*, *Gr. fohsi lobata* and *Gr. fohsi robusta* Zones (N10, N11 and N12 zones) of Blow (1969), which belong to the Middle Miocene. Accordingly, the present *Borelis melo melo* Zone is assigned to the Middle Miocene (late Langhian–early Serravallian).

Globigerinoides obliquus extremus Zone

Definition. Stratigraphic interval of the zonal marker from the LAD of the Middle Miocene marker species to the LAD of the nominated species.

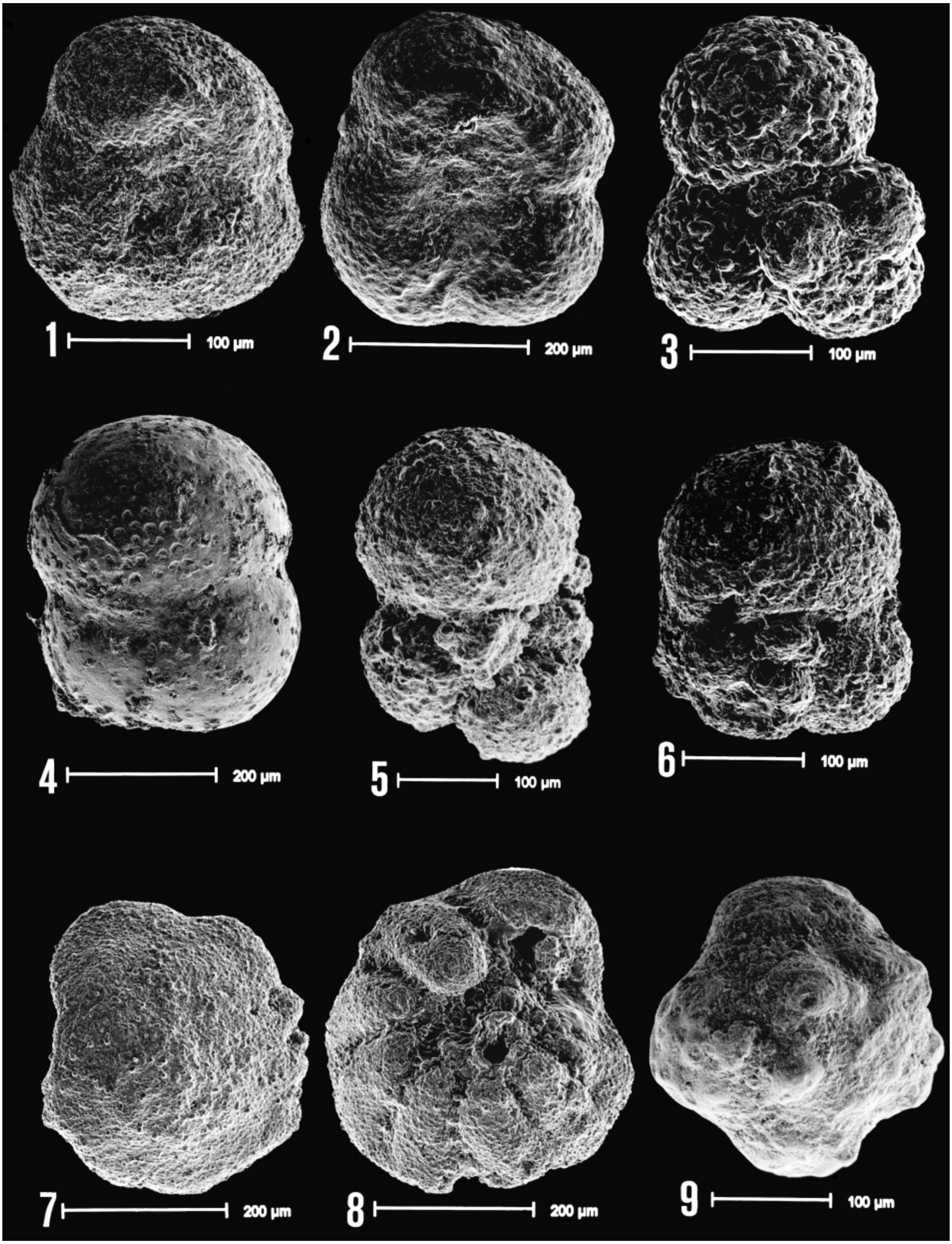
Author. Cita (1973).

Characteristics. The present zone contains a benthic assemblage which includes *Quinqueloculina bicarinata*, *Q. costata*, *Q. lamarckiana*, *Q. seminula*, *Triloculina tricarinata*, *Triloculina* sp., *Pyrgo* sp., *Ammonia beccarii*, *Elphidium advenum*, *E. crispum*, *E. macellum*, *Cibicides aknerianus*, *C. lobatulus*, *C. rhodiensis*, *Sorites* sp., *Spiroloculina communis*, *Spiroloculina* sp., *Nonion boueanum*, *N. elongatum*, *Peneroplis planatus*, *Operculina* sp., *Eponides repandulus*, *Discorbis candeiana*, *Discorbis* sp., *Lagena striata*, *Oolina* sp., *Bolivina* sp., *Asterigerina* sp., *Nodosaria* sp., *Uvigerina* sp., *Textularia* sp. and *Clavulina* sp.

The associated planktic foraminifera includes *Globigerinoides trilobus trilobus*, *G. trilobus immaturus*, *G. obliquus extremus*, *G. obliquus obliquus*, *Globorotalia inflata* and *Orbulina universa*.

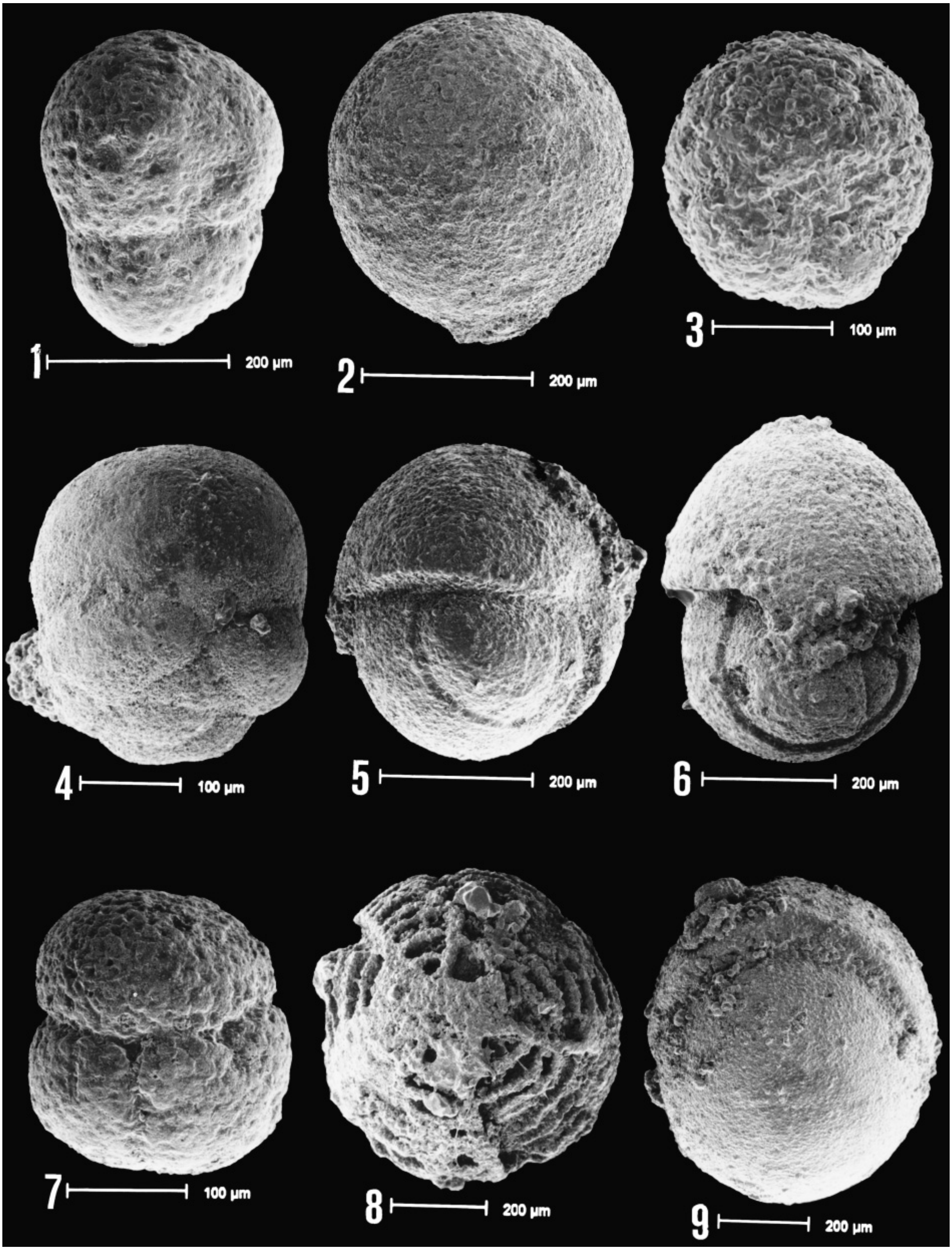
Occurrence. Geosoil horizons (fine-grained clayey sediments) at the base of the second limestone ridge; lower part of Alexandria Formation.

Age and correlation. Late Pliocene according to Sprovieri (1993). Along the northern Western Desert, the Early Pliocene is characterized by open marine deposits and is restricted to the Gulf of Salum in the northwestern corner and exhibit



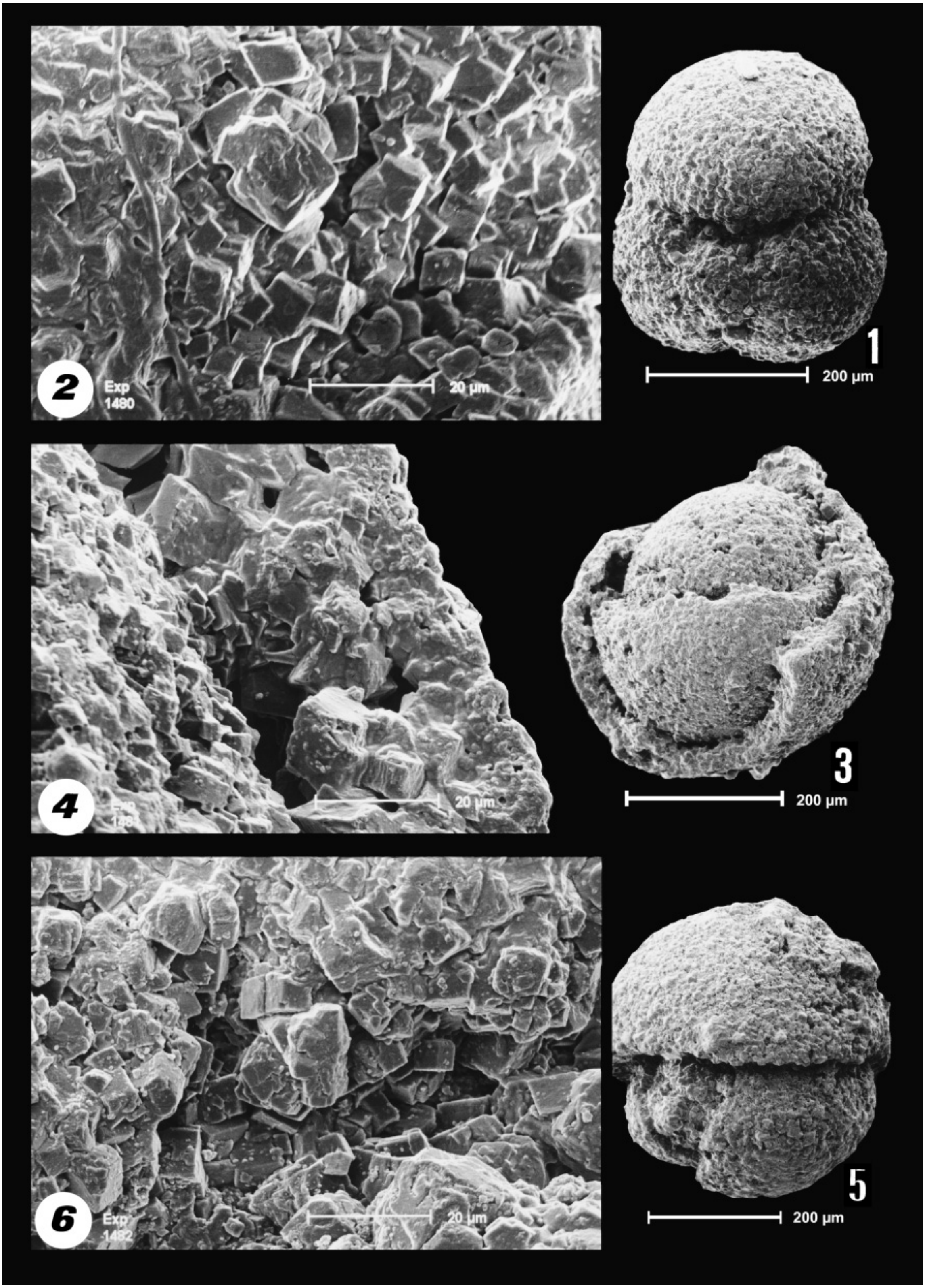
Explanation of Plate 1

Each taxon is followed by the well number and depth of sample. Magnification is represented by a bar scale under each figure. **Fig. 1**. *Globigerinoides obliquus extremus* Bolli & Bermudez (D59,13.5 m). **Fig. 2**. *Globigerinoides obliquus obliquus* Bolli (D59, 13 m). **Fig. 3**. *Globigerinoides ruber* (d'Orbigny) (D54, 44 m). **Fig. 4**. *Globigerinoides trilobus immaturus* LeRoy (D59, 13.5 m). **Fig. 5**. *Globigerinoides trilobus* (Reuss) (D143, 56 m). **Fig. 6**. *Globigerinoides trilobus* (Reuss) (D54, 16 m). **Figs 7, 8**. *Globorotalia fohsi robusta* Bolli (D59, 13.75 m). **Fig. 9.** *Globorotalia inflata* (d'Orbigny) (D144, 12.5 m).



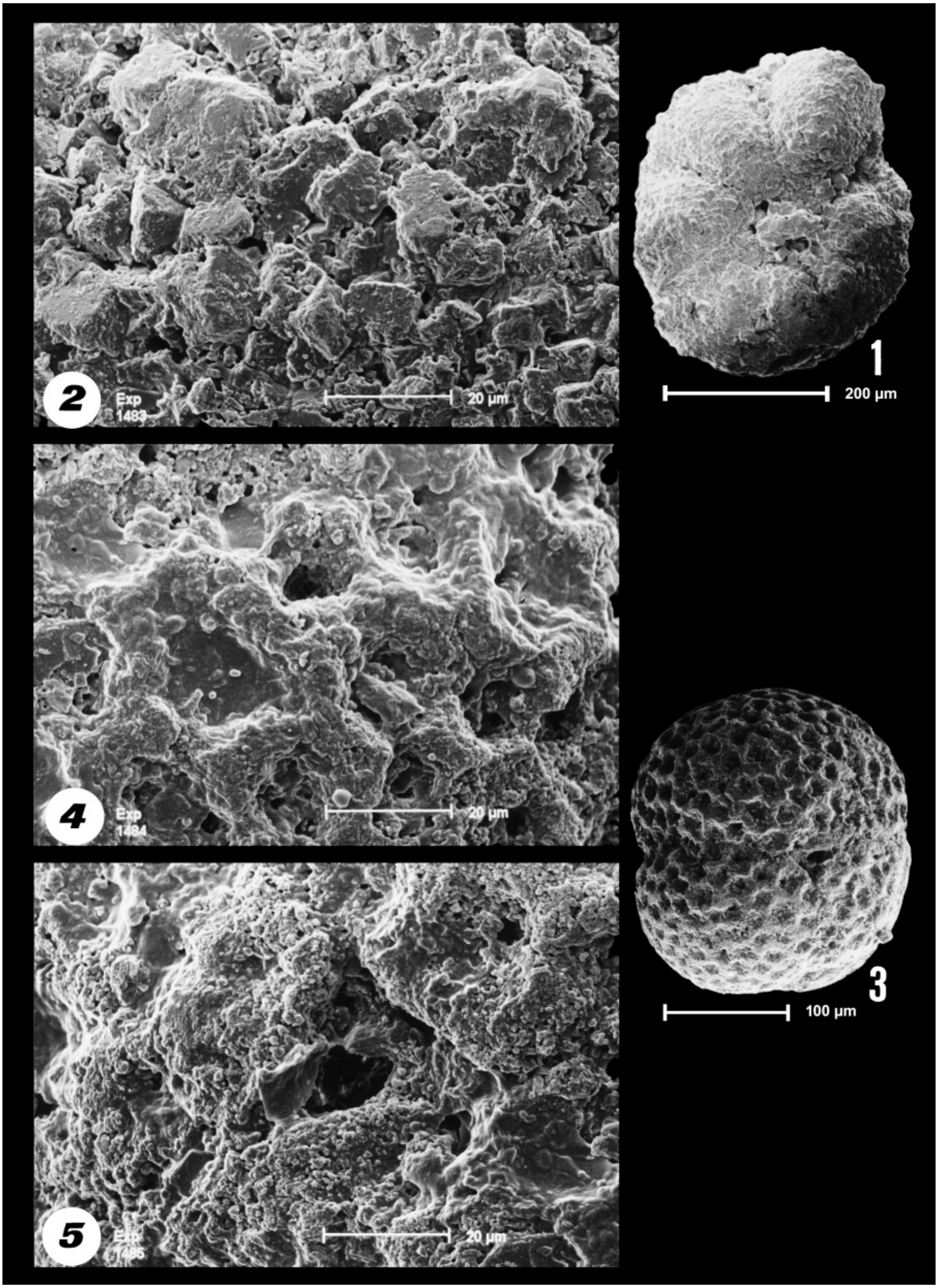
Explanation of Plate 2

Each taxon is followed by the well number and depth of sample. Magnification is represented by a bar scale under each figure. **Fig. 1**. *Orbulina bilobata* (d'Orbigny) (D61, 5.25 m). **Fig. 2**. *Orbulina universa* d'Orbigny (D61, 9 m). **Fig. 3**. *Orbulina suturalis* Brönnimann (D54, 44 m). **Fig. 4**. *Orbulina suturalis* Brönnimann (D144, 13 m). **Fig. 5**. *Praeorbulina sicana* (Blow) (D143, 68.5 m). **Fig. 6**. *Praeorbulina transitoria* (Blow) (D143, 68.5 m). **Fig. 7**. *Sphaeroidinellopsis disjuncta* (Finaly) D144, 13 m). **Figs 8, 9**. *Borelis melo melo* (Fichtel & Moll) (D144, 13 m).



Explanation of Plate 3

Each taxon is followed by the well number and depth of sample. Magnification is represented by a bar scale under each figure. **Fig. 1**. *Globigerinoides trilobus trilobus* (Reuss) (D143, 66 m). **Fig. 2**. Wall ultrastructure of figure 1 showing its dolomitic composition of euhedral dolomite rhombs. **Fig. 3**. *Orbulina universa* d'Orbigny (D143, 66 m), broken outer wall. **Fig. 4**. Wall ultrastructure of *Orbulina universa* showing a complete dolomitization for both the outer and inner layers. **Fig. 5**. *Praeorbulina sicana* (Blow) (D143, 68.5 m). **Fig. 6**. Wall ultrastructure of figure 5 showing the dolomitization of the test.



Explanation of Plate 4

Each taxon is followed by the well number and depth of sample. Magnification is represented by a bar scale under each figure. **Fig. 1**. *Globorotalia fohsi lobata* Bermudez (D143, 66 m). **Fig. 2**. Wall structure of figure 1 showing its dolomitic composition of unhedral to subhedral dolomite rhombs. **Fig. 3**. *Sphaeroidinellopsis disjuncta* (Finaly) (D144, 13 m). **Figs 4, 5**. Wall ultrastructure of figure 3. Wall is massive, of very microcrystalline texture, distinctly pitted and not affected by the weakly developed cortex. Aperture boarded by a rounded lip (flange).

deep-water facies. To the east, the Upper Pliocene deposits rest unconformably on the Middle Miocene limestone, with variable thickness and exhibit a shallow-marine facies. The Late Miocene was a period of regional emergence and a marked drop in sea-level, and active subaerial erosion in the entire northern Western Desert based on palaeontological criteria, as documented by Ouda & Masoud (1993) and Ouda & Obaidallah (1995). Following Ouda (1998), the occurrence of *Globigerinoides obliquus extremus* and *Globorotalia inflata* in the present sediments indicate a Late Pliocene age. Also, the fine-grained clay-rich carbonate sediments comprise a shallow-water, benthic foraminiferal assemblage as *Elphidium*, *Ammonia*, *Cibicides*, *Discorbis*, as well as various miliolids which are observed in different localities in the northern Western Desert (Hammad *et al.*, 1976; Boukhary *et al.*, 1976) and ranging in age from the latest Pliocene to the Pleistocene. Consequently, it is suggested that this fine-grained clay-rich carbonate bed can be assigned to the Late Pliocene (Fig. 5).

Un-named Zone

Definition. Stratigraphic belt of rock that is rich in long-ranging benthic foraminifera but barren of any planktic taxa.

Characteristics. This zone is characterized by the same benthic foraminiferal assemblage as that found in the underlying geosoil horizons.

Occurrence. Second limestone ridge; upper part of Alexandria Formation or the carbonate aeolianites.

Age and correlation. For the carbonate aeolianites, no index planktic foraminifera were found. However, from their stratigraphic position, they can be considered to be Pleistocene in age. Ouda (1998) also recorded this shallow-water benthic assemblage of an inner shelf-type from the Mersa Matruh and Burg El Arab-1 wells, confined to the oolitic limestone which caps the open-marine Pliocene clays and ranging in age from the late Pliocene to the Pleistocene. Accordingly, no planktic foraminifera referable to the *Globorotalia inflata* Zone (latest Pliocene) have been encountered anywhere in the onshore sediments of the Medditerranean coastal plain, and the sediments younger than the *Globigerinoides obliquus extremus* Zone are dominantly shallow-water facies.

PALAEOECOLOGICAL INTERPRETATION

Marmarica Formation (fossiliferous carbonate rocks)

The Miocene is represented by the Marmarica limestone plateau of Middle Miocene age, which is composed of shallow-marine, fossiliferous, partly chalky carbonate intercalated with a few marl and shale horizons.

Generally, the grey-white oncolitic/shelly limestone rock unit (Unit V) is moderately rich in benthic foraminifera. The upper more clayey 'oncolitic beds' contain more foraminifera than the underlying shelly carbonate beds. The identified foraminiferal taxa mostly belong to the rotaliid group. No planktic foraminifera were observed (Planktic/Benthic ratio=*c.* 0).

The yellow marly/shelly dolostone rock unit (Unit IV) is slightly fossiliferous with rare specimens of foraminifera. The recognized foraminifera through the rocks of this unit are the smaller benthic types, in addition to larger foraminifera such as *Borelis melo melo*, *Amphistegina* sp., *Operculina* sp. Planktic foraminifera are rarely observed (P/B ratio=*c.* 0.01) (Figs 4, 5).

The distribution of the foraminifera varies through the white chalky/shelly dolostone beds (Unit III) where the coarse-grained rocks are richer in foraminifera than the fine-grained ones. Generally, the foraminiferal assemblage in this unit resembles that of the overlying bed with the same foraminiferal groups but with low frequency. Rare planktic foraminifera were observed (P/B ratio=*c.* 0.01) including *Globigerinoides trilobus trilobus*, *G. trilobus immaturus*, *G. ruber* and *Orbulina suturalis*.

The grey shelly dolostone bed (Unit II) contains a reasonable number of foraminifera. Benthic specimens are dominant, with very few planktic individuals (P/B ratio=*c.* 0.01). The identified benthic foraminiferal assemblage belongs to the following groups: miliolids (42%), alveolinids (30%), rotaliids (20%) and lagenids (7%). This bed contains an assemblage of benthic foraminifera slightly different from that of the overlying oolitic limestones and geosoil (Unit I) (Fig. 4). It is characterized by the presence of *Anomalina*, *Marginulinopsis* and *Borelis*, which are not found in the aeolianite sediments, in addition to the presence of large numbers of *Triloculina* spp. Planktic foraminifera are represented by only a few specimens of *Globigerinoides trilobus trilobus*, *Globorotalia fohsi robusta*, *Orbulina suturalis*, *Orbulina* sp. and *Sphaeroidinellopsis disjuncta.*

It can be noted that common benthic foraminiferal specimens, with rare planktic ones, characterize the fossiliferous carbonate rocks of the Marmarica Formation. The planktic/benthic ratio in this rock unit is very low (0–0.01), indicative of a shallow-water, inner shelf environment (Murray, 1991). The distribution of the foraminiferal fauna is varied throughout the different units. It increases in the upper grey bed and decreases gradually downward in the white and yellow rock units. The most abundant fossils observed in these units belong to the genera *Triloculina*, *Quinqueloculina*, *Marginulinopsis*, *Anomalina* and *Borelis*, with rare *Nonion*, *Nonionella*, *Peneroplis*, *Operculina* and *Amphistegina*. This foraminiferal assemblage is characterized by the presence of some larger foraminifera, which inhabited warm shallow-water environments in the proximity of reefs (Murray, 1991). According to Haynes (1981) and Murray (1991), the above foraminiferal assemblage indicates clear carbonate environments, characterized by a surface water temperature of 25°C, subject to some current activity, with salinity ranging from normal to slightly hypersaline (35–50‰), and coral and algal substrates in inner-shelf or lagoons (0–20 m palaeodepth). The decreasing trend in the number of tests downward could be due to the prevailing strong currents which break down most of the shells, as in the white chalky beds, or due to the effect of clastic materials, as in the yellow marly beds.

In the lower oncolitic beds, an increase in foraminiferal tests was observed and the identified fossils belong to the genera *Elphidium*, *Cibicides*, *Ammonia*, *Nonion*, *Eponides*, in addition to the presence of some large foraminifera as *Heterostegina*, *Operculina* and *Amphistegina* (i.e. high percentages of rotalids and rarity of miliolids) indicating a slightly deeper-water middle neritic environment (El-Deeb, 1995). It can be concluded that the sediments of the oncolitic/shelly rocks were deposited in

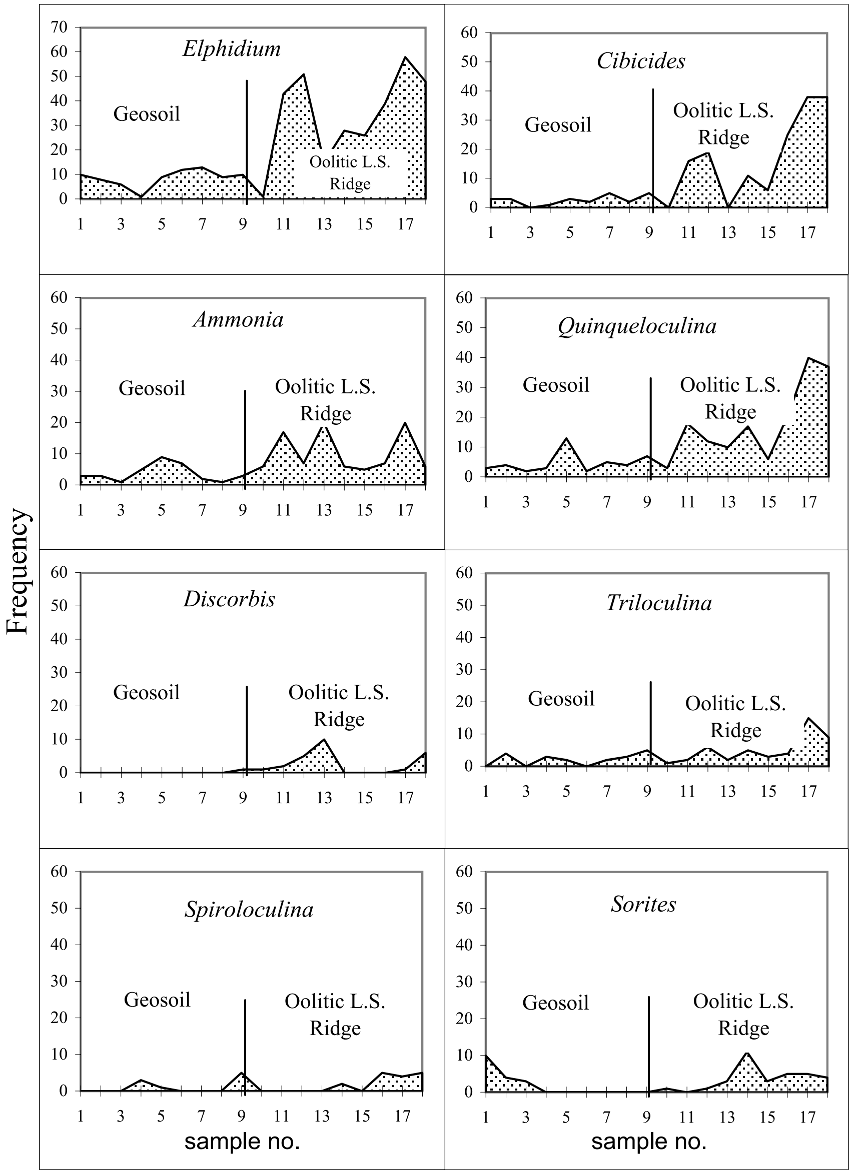


Fig. 6. Frequency distribution of the common benthic foraminiferal genera in the second limestone ridge.

slightly deeper water than the overlying fossiliferous rocks and in less agitated conditions.

Alexandria Formation (carbonate aeolianite sediments)

Pliocene deposits are distributed along the coastal plain of the Western Desert and mostly represented by soft clays and soft non-porous, fine-grained or partly oolitic limestone sometimes with a basal conglomeratic band. The Quaternary deposits are represented by the calcareous limestone ridges parallel to the shoreline, the lagoonal, sabkha, beach and coastal dune deposits (Shata, 1955; Shukri *et al.*, 1956; Said, 1962; El Shami *et al.*, 1969; Ouda, 1998).

A good and well-preserved assemblage of benthic foraminifera was detected from the sediments of the second limestone ridge, including the oolitic limestones and the intercalated geosoil horizons. Some of these foraminiferal genera are present in large numbers while others are very rare and may be represented by only one specimen. The frequency of the most common benthic genera in this rock unit is shown in Figure 6.

The more clay-rich limestone and some of the geosoils are characterized by higher numbers of benthic foraminifera than in the white oolitic rocks, but the two rock units have almost the same assemblage. The more clay-rich rocks are characterized by the presence of *Discorbis* sp., which is not found in the white oolitic rocks. On the other hand, *Sorites* sp. is more common in the white oolitic rocks than in the geosoil and the clay-rich sediments (Fig. 6).

Very rare planktic foraminifera were observed in the fine-grained clay-rich sediments at the base of the second ridge (P/B ratio=*c*. 0.02). The identified planktic foraminifera includes *Globigerinoides trilobus trilobus*, *G. trilobus immaturus*, *G. obliquus extremus*, *G. obliquus obliquus*, *Globorotalia inflata* and

Orbulina universa. These species are not recorded from the white oolitic limestone.

The above foraminiferal assemblage of the limestone ridge indicates the predominance of benthic foraminifera and the rarity of planktic ones. The presence of planktic foraminifera in low diversity indicates shallow, open-marine environments (Murray, 1973, 1991). Also, the dominance of the families Miliolidae and Elphididae indicates shallow, warm marine water (Omara & Ouda, 1968) and a relatively quiet depositional environment (Cherif *et al*., 1975). According to Murray (1973), *Cibicides* lives on sea grasses in relatively quiet conditions. Hageman (1979) mentioned that *Quinqueloculina seminula* might flourish in open shallow-marine conditions, with a vegetated substrate. The species is slightly tolerant to reduced salinities, a water depth of 25–35 m, and an inner to middle neritic setting. Murray (1991) indicates that *Elphidium* and *Quinqueloculina seminula* are commonly dominant in shallow water of normal salinity environments in middle latitudes worldwide. According to Sherif (1991), *Elphidium crispum* inhabits open normal marine inner neritic to middle neritic (0–90 m) environments. The presence of *Ammonia beccarii* in high numbers indicates ordinary warm shallow-marine water (Omara & Ouda, 1968), in normal salinity inner to middle neritic environments (Hageman, 1979). According to Cherif *et al*. (1988), *Ammonia beccarii* seems generally to increase in coasts affected by influxes of freshwater coming from a river system or from a hinterland with some reasonable rainfall. This species favours lagoonal environments with salinity <10‰, 15–20°C and <10 m depth (Murray, 1991). El Deeb (1995) suggested that the presence of *Quinqueloculina*, *Triloculina* and *Spiroloculina* is indicative of littoral to shallow-marine conditions and an increase in their numbers indicates normal marine lagoons and carbonate platforms.

It can be concluded that the foraminiferal associations in the studied limestone ridge indicate a warm, clear, relatively agitated, shallow-marine depositional environment in a vegetated inner neritic platform or lagoon (10–25 m in depth). According to Murray (1973), the presence of *Sorites* is confined to shallow agitated intertidal to subtidal, tropical to subtropical marine conditions with 25°C surface water temperatures. The relative increase of *Sorites* in the white oolitic sediments indicates that the deposition of these sediments was under warmer water conditions during marine transgression. Moreover, the presence of *Discorbis* in the clay-rich oolitic limestones and some geosoils suggests less agitated, intertidal water conditions (El Nahass & El Fayumy, 1986). The increase in the clastic content and oolites in these sediments confirm that they were deposited near shoreline.

CONCLUSIONS

Forty-six benthic and 14 planktic foraminiferal species have been identified from sediments of the Marmarica (Middle Miocene) and Alexandria (late Pliocene to Pleistocene) Formations sub-cropping in the El-Dabaa area, northern part of the Egyptian Western Desert. Larger benthic foraminifera can be used as zonal markers in intervals which lack planktic taxa.

Five foraminiferal biozones are established: *Heterostegina costata* and *Praeorbulina sicana* zones (early Langhian), *Borelis melo melo* Zone (late Langhian–Serravallian), *Globigerinoides obliquus extremus* Zone (late Pliocene), and an un-named zone (late Pliocene–Pleistocene). The late Miocene and early–middle Pliocene was a period of regional emergence and active subaerial erosion in the entire northern Western Desert as indicated by palaeontological criteria.

In general, the foraminiferal assemblage recovered from the Marmarica Formation indicates warm, clear, shallow carbonate environments (0–20 m palaeodepth), about 25°C surface water temperature, with some current and salinity ranging from normal to slightly hypersaline (35–50‰). The Alexandria Formation was deposited in a warm, clear, relatively agitated, shallow-marine depositional environment. The presence of *Discorbis* and rare planktic species in the basal part of the Alexandria Formation suggests less agitated conditions.

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APPENDIX: ALPHABETIC TAXONOMIC LIST

Benthic foraminifera

Ammonia beccarii (Linné)
Ammonia sp.
Amphistegina lessonii d'Orbigny
Amphistegina sp.
Anomalina sp.
Asterigerina sp.
Bolivina sp.
Borelis melo melo (Fichtel & Moll)
Cibicides aknerianus (d'Orbigny)
Cibicides lobatulus (Walker & Jacob)
Cibicides rhodiensis (Terquem)
Clavulina sp.
Discorbis candeiana (d'Orbigny)
Discorbis sp.
Elphidium advenum (Cushman)
Elphidium crispum (Linné)
Elphidium macellum (Fichtel & Moll)
Elphidium sp.
Eponides repandus (Fichtel & Moll)
Eponides sp.
Heterostegina costata (d'Orbigny)
Lagena striata (d'Orbigny)
Marginulinopsis sp.
Nodosaria sp.
Nonion boueanus (d'Orbigny)
Nonion communis (d'Orbigny)
Nonion elongatus (d'Orbigny)
Nonionella sp.
Oolina sp.
Operculina complanata (Defrance)
Operculina sp.
Peneroplis armoricus (d'Archiac)
Peneroplis planatus (Fichtel & Moll)
Pyrgo sp.

Quinqueloculina bicarinata d'Orbigny
Quinqueloculina costata d'Orbigny
Quinqueloculina lamarckiana d'Orbigny
Quinqueloculina seminula (Linné)
Quinqueloculina sp.
Sorites sp.
Spiroloculina communis (Cushman & Todd)
Spiroloculina sp.
Textularia sp.
Triloculina sp.
Triloculina tricarinata d'Orbigny
Uvigerina sp.

Planktic foraminifera

Globigerinoides obliquus extremus Bolli & Bermudez
Globigerinoides obliquus obliquus Bolli
Globigerinoides ruber (d'Orbigny)
Globigerinoides trilobus immaturus Le Roy
Globigerinoides trilobus trilobus (Reuss)
Globorotalia fohsi lobata Bermudez
Globorotalia fohsi robusta Bolli
Globorotalia inflata (d'Orbigny)
Orbulina bilobata (d'Orbigny)
Orbulina suturalis Brönnimann
Orbulina universa d'Orbigny
Praeorbulina sicana (Blow)
Praeorbulina transitoria (Blow)
Sphaeroidinellopsis disjuncta Finaly

REFERENCES

Abdulsamad, E.O. & Barbieri, R. 1999. Foraminiferal distribution and palaeoecological interpretation of Eocene–Miocene carbonates at Al Jabal al Akhdar (northeast Libya). *Journal of Micropalaeontology*, **18**: 45–65.

Abuserwil, A.K. 1996. Foraminiferal study of the Miocene from well D2-NC41, northwestern offshore, Libya. *Petroleum Research Journal*, **8**: 25–48.

Adams, C.G. 1984. Neogene larger foraminifera, evolutionary and geological events in the context of datum planes. *In* Ikebe, N. & Tsuchi, R. (Eds), *Pacific Neogene Datum planes*, 44–67. University of Tokyo Press, Tokyo.

Anwar, Y.M., El Askary, M.A. & Nasr, S.M. 1981. Petrography and origin of the oolitic carbonate sediments of Arab's Bay, western part of the continental shelf of Egypt. *Neues Jahrbuch für Geologie und Paläontologie Monatshefte*, **2**: 65–75.

Bellini, E. 1969. Biostratigraphy of the "Al-Jaghbub" (Giarabub) Formation in Eastern Cyrenaica (Libya). *Proceedings of the Third African Micropaleontological Colloqium, Cairo (1968)*, 165–183.

Berggren, W.A., Kent, D.V., Swisher, C.C. & Aubry, M.P. 1995. A revised Cenozoic geochronology and chronostratigraphy. *In* Berggren, W.A. & Kent, D. (Eds), *Geochronology time scales and global stratigraphic correlation*. SEPM, Special Publication, **54**: 134–175.

Blow, W.H. 1969. Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. *In* Bronniman, P. & Renz, H.H. (Eds), *Proceedings of the first International Conference on Planktonic Microfossils, Geneva*, **II**: 199–421. E.J. Brill, Leiden.

Boukhary, M.H., Yehia, M.A., Moussa, S. & Boussaina, M. 1976. Microfacies of Neogene–Quaternary sediments of El Alamein–Qattara area, Western Desert, Egypt. Ninth Arab Petroleum Congress, paper 127(B-3).

Butzer, K.W. 1960. On the Pleistocene shore lines of Arabs Gulf, Egypt. *Journal of Sedimentary Petrology*, **68**: 626–637.

Cherif, O.H., Bassiouni, M.A. & Ghanima, S.A. 1975. Stratigraphy, paleoecology and climates of the Neogene and Quaternary of the Mersa Matrouh area, north Western Desert, Egypt. *Annals of Geological Survey of Egypt*, **5**: 137–147.

Cherif, O.H., El-Sheikh, H. & Labib, F. 1988. The foraminifera of the Pleistocene coastal ridges of the area to the west of Alexandria, Egypt. *Revue de Paléobiologie*, **2**: 735–740.

Cita, M.B. 1973. Pliocene biostratigraphy and chronostratigraphy. *In* Ryan, W.B.F. & Hsu, K.J (Eds), *Initial Report of the DSDP*, **13**: 1343–1379.

El Asmar, H.M. 1991. *Old shorelines of the Mediterranean coastal zone of Egypt in relation with sea level change*. Ph D thesis, El-Mansoura University, Faculty of Science, Mansoura (Egypt), 1–219.

El Asmar, H.M. 1994. Recognition of diagenetic environments of the Pleistocene carbonate rocks at El Hammam, NW Mediterranean coast of Egypt using stable and electron microprobe. *Neues Jahrbuch für Geologie und Paläontologie Monatshefte*, **1**: 7–22.

El Deeb, W.Z.M. 1995. Late Miocene–Pliocene foraminiferal paleoecology of Baltim well no.1, Nile Delta, Egypt. *Al-Azhar Bulletin of Science*, **6**: 513–529.

El Nahass, H.A. & El Fayumy, I.F. 1986. Remarks on some paleoecological faunal indicators from the coastal calcarenite ridges, West Alexandria, Egypt. *Mansoura Faculty of Science Bulletin*, **13**: 299–313.

El Shahat, A. 1995. Quaternary dune carbonates from the Mediterranean coast of Egypt: Petrology and Diagenesis. *Journal of Environmental Science, Mansoura University, Egypt*, **9**: 1–27.

El Shami, I., El-Shazly, M. & Shata, A. 1969. Contribution to the geology of El-Dabaa area "Western Mediterranean littoral zone". *Bulletin of the Institute of Desert, Egypt*, **19**: 63–94.

El Shazly, M.M., Shata, A.A. & Farag, I.M. 1964. Lithology of the Neogene and post-Neogene sediments in Mersa Matruh area. *Journal of Geology, U.A.R.*, **8**: 21–45.

Gindy, A.R., Abdou, H.F. & El-Askary, M.A. 1969 Litho- and biostratigraphy of the exposed Middle Miocene succession of the Siwa Depression area, Western Desert, Egypt. Egypt. Proceedings of the Sixth Arab Science Congress, Damascus (4.B.).

Hageman, J. 1979. Benthonic foraminiferal assemblages from Plio-Pleistocene open bay to lagoonal sediments of the western Peloponnesus (Greece). *Utrecht Micropaleontological Bulletin*, **20**: 1–170.

Hammad, F.A., Mosa, B.M., Bassiouni, M.A. & Boukhary, M.A. 1976. Contribution to the stratigraphy and petrography of the area between El Alamein and the Qattara Depression (Western Desert, Egypt). Ninth Arab Petroleum Congress, Paper 132 (B-3).

Hassouba, A.H. 1980. *Quaternary sediments from the coastal plain of northwestern Egypt (from Alexandria to El Omayid)*. PhD thesis, Imperial College, London, 1–320.

Hassouba, A.H. 1995. Quaternary sediments from the coastal plain of northwestern Egypt (from Alexandria to El Omayid). *Carbonate and Evaporites*, **10**: 8–44.

Haynes, J.R. 1981. *Foraminifera*. Macmillan Publication Ltd., John Wiley and Sons, Inc, New York (Halsted Press), 1–433.

Hilmy, M.E. 1951. Beach sands of the Mediterranean coast of Egypt. *Journal of Sedimentary Petrology*, **21**: 109–120.

Holail, H.M. 1993. Diagenetic trends of the Pleistocene calcareous ridges, Mersa Matruh area, Egypt. *Chemical Geology*, **106**: 375–388.

Holail, H.M., Tamish, M.O., El-Askary, M.A. & Sadek, A. 1997. Geochemistry and diagenesis of Middle Miocene carbonate rocks, northern Western Desert, Egypt. *Neues Jahrbuch für Geologie und Paläontologie Monatshefte*, **4**: 191–212.

Mansour, A.S. 1999. *Sedimentological and paleoenvironmental studies of the subsurface Miocene–Pleistocene sequence at El-Dabaa, North Western Desert, Egypt*. PhD Thesis, Faculty of Science, Alexandria University, Egypt, 1–247.

Mansour, A.T., Barakat, M.G. & Abdel Hady, Y. 1969. Marine Pliocene planktonic foraminiferal zonation, south-east of Salum, Egypt. *Rivista Italiana de Paleontologia e Stratigrafia*, **75**: 833–846.

Murray, J.W. 1973. *Distribution and ecology of living benthonic foraminifera*. Heinemann Educational Books, New York, 1–274.

Murray, J.W. 1991. *Ecology and paleoecology of benthic foraminifera*. Longman, 1–397.

Omara, S. & Ouda, Kh. 1968. Pliocene foraminifera from the subsurface rocks of Burg El-Arab Well no. 1, Western Desert, Egypt. *Proceedings of the Third African Micropalaeontological Colloquiun, Cairo*, 581–601.

Ouda, Kh. 1971. *Biostratigraphic studies of some surface and subsurface Miocene formations from the Western Desert, Egypt*. PhD thesis, Assiut University, Assiut, Egypt, 1–579.

Ouda, Kh. 1998. Biostratigraphy, paleoecology and paleography of the middle and late Tertiary deposits of the northern Western Desert, Egypt. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, **207**: 1–84.

Ouda, Kh. & Masoud, M. 1993. Sedimentation history and geological evolution of the Gulf of Suez during the Late Oligocene–Miocene. *Geodynamics and sedimentation of the Red Sea–Gulf of Aden rift system*. Geological Society of Egypt, Special Publication, **1**: 47– 88.

Ouda, Kh. & Obaidalla, N. 1995. The geological evolution of the Nile Delta during the Oligocene–Miocene. *Egypt Journal of Geology*, **39**: 77–111.

Said, R. 1962. *Geology of Egypt*. Elsevier, Amsterdam, 1–377.

Said, R. 1990. Cenozoic. *In* Said, R. (Ed.), *The geology of Egypt*, 451–486. Balkema, Rotterdam.

Selim, A.A. 1974. Origin and lithofacies of the Pleistocene carbonates of the Salum area, western coastal plain of Egypt. *Journal of Sedimentary Petrology*, **44**: 70–78.

Shata, A. 1955. An introductory note on the geology of the northern portion of the Western Desert of Egypt. *Bulletin of the Desert Institute of Egypt*, **5**: 96–106.

Sherif, Kh.A.T. 1991. Biostratigraphy in Al Khums area, northwestern Libya. *In* Salem, M.J., Hammuda, O.S. & Eliagoubi, B.A. (Eds), *The Geology of Libya*, **IV**: 1421–1456. Elsevier.

Shukri, N.M., Philip, G. & Said, R. 1956. The geology of the Mediterranean coast between Rosetta and Bardia. Part II: Pleistocene sediments – Geomorphology and microfacies. *Bulletin of the Desert Institute of Egypt*, **37**: 395–433.

Sprovieri, R. 1993. Pliocene-early Pleistocene astronomically forced planktonic foraminifera abundance fluctuations and chronology of Mediterranean calcareous plankton bio-events. *Rivista Italiana de Paleontologia e Stratigrafia*, **99**: 371–414.

Tamish, M.O., Holail, H.M., El-Askary, M.A. & Sadek, A. 1996. Lithostratigraphy, facies analysis and depositional environments of the Middle Miocene carbonate rocks, north Western Desert, Egypt. *Bulletin of the faculty of Science, Alexandria University*, 1, **36**: 251–264.

Wali, A.M.A., Brookfield, M.E. & Schreiber, B.C. 1994. The depositional and diagenetic evolution of the coastal ridges of northwestern Egypt. *Sedimentary Geology*, **90**: 113–136.