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Miocene benthic foraminifera from the Soluq area, ne Libya: biostratigraphy and environmental significance

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ABSTRACT - Six stratigraphic sections along the north-south scarp that traverses the middle of the Soluq area of Libya, about 70 km southeast of Benghazi were studied. Based on their lithofacies and faunal content, two rock units (carbonate and mixed siliciclastic-carbonate) belonging to the Miocene Ar Rajmah Group are reported. The two rock units are separated by a well marked unconformity. The base of the Benghazi Formation has been dated as Lower to Middle Miocene based on the presence of an assemblage of benthic foraminifera. *Miogypsinoides complanatus* (Schlumberger), *Nephrolepidina* sp. and *Miogypsina* cf. *globulina* (Michelotti) are the main diagnostic taxa in the Aquitanian and Burdigalian. The Middle Miocene interval of Benghazi Formation is ascribed to the Langhian and Serravallian where *Operculina complanata* (Defrance) and *Borelis melo melo* (Fichtel and Moll) are the main time-specific diagnostic taxa; the latter taxon occurs also in other coeval deposits of Libya.

An Upper Miocene age is attributed to major deposits of the later rock unit. The last occurrence of *Amphistegina* cf. *lessonii* d'Orbigny, *Heterostegina* cf. *costata* (d'Orbigny) and the associated small benthic foraminifera characterize the contact between the Tortonian and the Messinian deposits of the Wadi al Qattarah Formation.

The variation in lithology and fossil assemblages discussed here reflects the variety of environmental settings characterizing the studied Miocene sequence, indicating an overall shallowing-upward trend, from open platform (Benghazi Formation) to restricted platform and restricted lagoon-salina conditions (Wadi al Qattarah Formation).

Key words: Libya, Benghazi Formation, Wadi al Qattarah Formation, Miocene, foraminifera, biostratigraphy, paleoenvironment.

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INTRODUCTION

Although previous reports by Abdulsamad and Bu-Argoub (2006) and Abdulsamad et al. (2009) have helped establishing the depositional history of Ar Rajmah Group in Cyrenaica, many of the stratigraphical aspects of this region's Miocene deposits remain poorly understood. Therefore, the objectives of this paper are: (1) to refine the bio-chronostratigraphy of the Miocene deposits in Cyrenaica; and (2) to interpret the depositional setting based on benthic foraminiferal assemblages and other biota.

The Benghazi Formation and the Wadi al Qattarah Formation, the two main lithostratigraphic units making up the Ar Rajmah Group, represent each a shallowing-upward sequence. The study area is broadly located between 31°-32°N latitude and 20°-21°E longitude (Fig. 1). The Lower to Upper Miocene deposits of the Ar Rajmah Group have been measured from six localities along the north-south scarp that runs through the middle of the Soluq area, located about 70 km southeast of Benghazi, Libya.

The scarp slopes upward toward the north, reaching an altitude of roughly 300 m above sea level at Wadi al Qattarah; in the Antelat area in the scarp's southern region, however, the group is made up of hills only a few meters high. The study area's plateau extends eastward, rising to an altitude greater than 450 m above sea level, and the plain (known as the Soluq plain) extends eastward, with a width of about 50 km to within 0.5 km of the Mediterranean coast (Fig. 1).

Several names have been used to identify different parts of the Miocene sedimentary rocks in northeast Libya; for consistency, here we have adopted the subdivision proposed by El-Hawat and Abdulsamad (2004) for the Miocene deposits in northern Cyrenaica. Based on field and sedimentological criteria, El-Hawat and Abdulsamad

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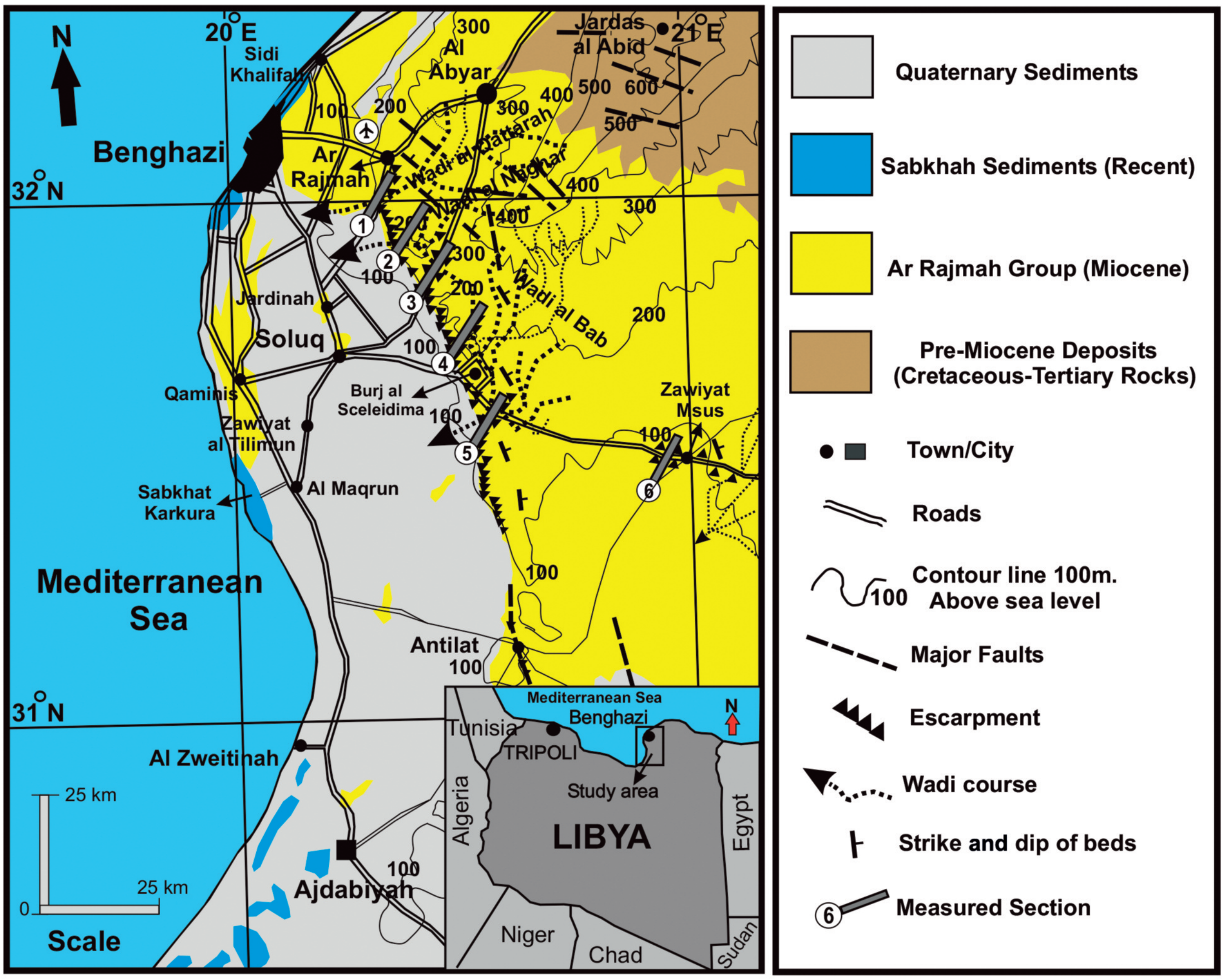


Fig. 1. Index map of NE Libya (compiled and modified after Francis and Issawi, 1977) and the location of the measured sections; 1-Wadi al Qattarah, 2-Soluq-Al Abyar, 3-Wadi al Naghar, 4-Burj al Sceleidima, 5-Al Sceleidima and 6-Zawiyat Msus.

(2004) assigned the Miocene Ar Rajmah Formation of Klen (1974) and Röhlich (1974) to a group composed of the two units noted above: the Benghazi Formation in the lower part and the Wadi al Qattarah Formation in the upper part. Abdulsamad and Bu-Argoub (2006) and Abdulsamad et al. (2009) used stratigraphic and paleontological data to reach a similar conclusion about this stratigraphic subdivision.

MATERIALS AND METHODS

About 80 samples of mostly carbonate rocks (notably, limestone) and a few mixed siliciclastic-carbonates (marly limestone and sandy allochems limestone, sensu Mount 1985), evaporites (mainly gypsum), cherts and hybrid sandstones were collected from six outcrops throughout the Soluq area (see Fig. 1). All samples were collected at a maximum interval of 5 m; within lithologic facies changes the samples were more closely spaced. Composition, sedimentary structures, bed thickness and macrofossil content (notably bivalves, gastropods and echinoids) were defined and described using terms proposed by Tucker (2011).

The majority of the hard samples collected were subsequently processed for thin-section preparations, with several lithologies being documented. Their litho- and bioclastic components are generally expressed using terms recommended by Flügel (2010). Seventeen samples of soft lithologies were crushed and disaggregated by hydrogen peroxide solution and washed through a 63-µm sieve. Particular attention was given to the foraminiferal specimens, as they are the main group in the study material. Only a few dozen of small and large benthic foraminifera per sample showing good preservation were picked, identified and stored in cardboard slides.

STRATIGRAPHY AND PALAEONTOLOGY

As mentioned earlier, the Ar Rajmah Group was established (Fig. 2) and measured from six localities, namely, the Wadi al Qattarah, Soluq-Al Abyar, Wadi al Naghar, Burj al Sceleidima, Al Sceleidima and Zawiyat Msus sections (Fig. 1). A description of the lateral variation of the main deposits is shown in figure 3, as is an attempt to correlate the studied outcrops based on stratigraphical and paleontological criteria. The following sections summarize the main stratigraphic and paleontological characteristics of the studied rock units.

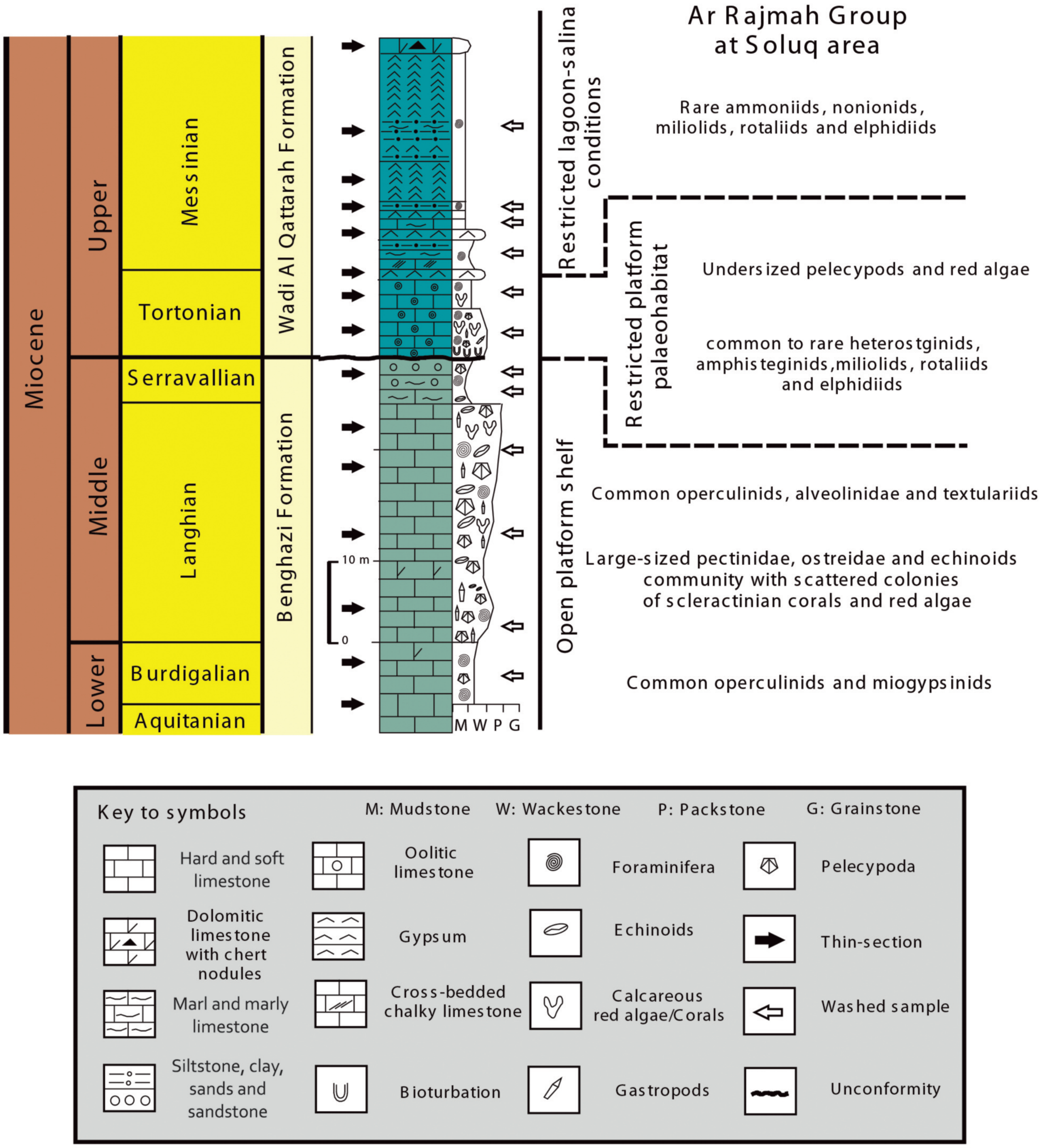


Fig. 2. Generalized stratigraphic column of the Ar Rajmah Group at Soluq area; the main biota components and their interpreted palaeohabitats are based on the palaeontological data recovered from all studied outcrops.

Benghazi Formation

The Benghazi Formation in the study area includes three basic outcrop-scale units. The oldest unit is represented by thin- to medium-bedded poorly fossiliferous and recrystallized limestone that is only a few meters thick at Wadi al Qattarah section. In Wadi al Naghar and Soluq-al Abyar sections, this unit is reduced in thickness and the limestone is quite rich in skeletal fragments of marine organisms such as foraminifera.

The second unit is largely confined to the lower and middle parts of the formation and has been found in all studied sections. This unit is characterized by a thick skeletal limestone unit and is represented by yellowish and medium- to thick-bedded limestone. It varies in thickness throughout the studied sequence, reaching from 16 m in the Soluq-al Abyar section to 50 m in the Wadi al Naghar section. The macrofossils (bivalves) found within this unit are generally diverse and abundant, but they are almost dwarfed by the unit's large pectinids and ostreids community (Fig. 4). Numerous attached bivalves and high-spired, turreted and biconical gastropods are present in this unit, together with several ovoid, inflated and

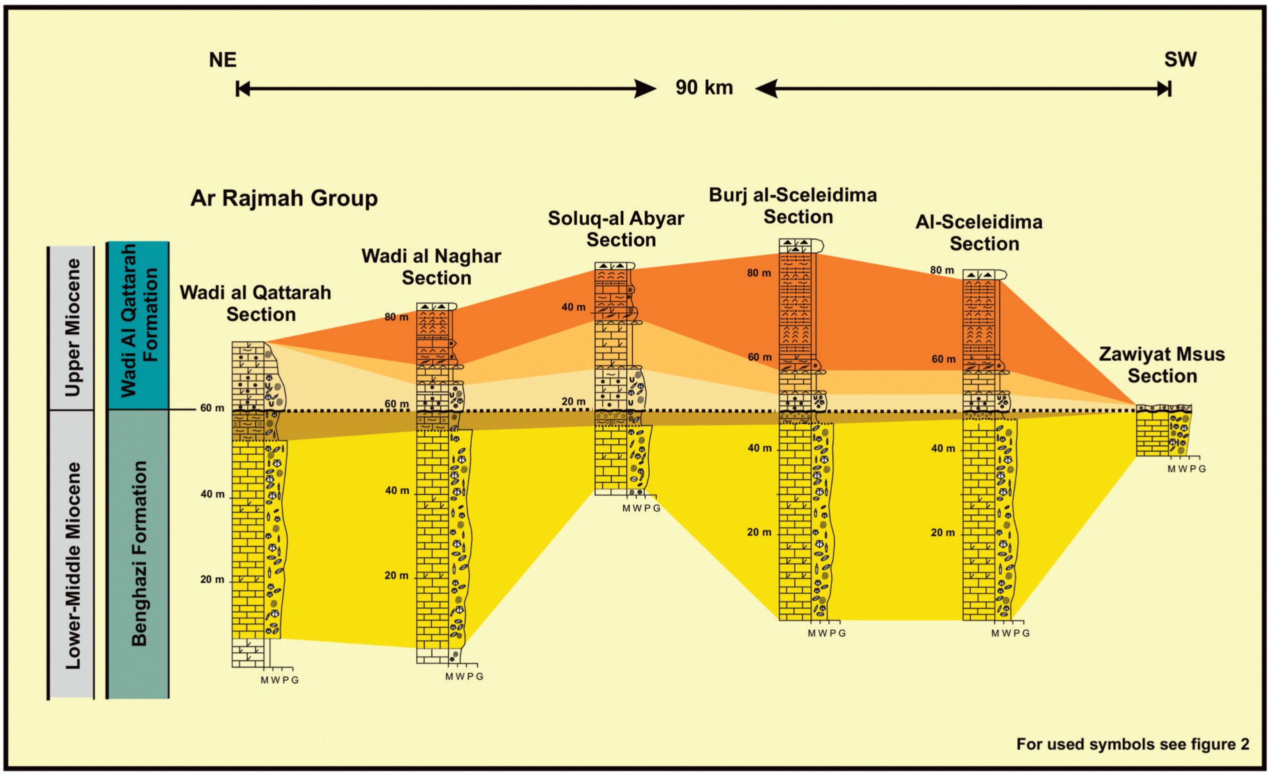


Fig. 3. Correlation panel of the measured sections of the Ar Rajmah Group at Soluq area; the correlation is based on stratigraphical and palaeontological criteria.

infaunal echinoids (notably, *Echinolampas* sp.), fragments of spatangoids, and spines of regular sea urchins. In the Zawiyat Msus section, the limestone of the Benghazi Formation is made up almost entirely of skeletal material of molluscans (coquina) (Fig. 5). Herein, equivalved elongated bivalves and shallow burrowing genera (mostly, *Tellina* spp.), small trochiform, biconical (particularly, *Conus* sp.), and turreted gastropods are abundant and very well preserved. Small-scale scattered colonies of scleractinian corals belonging to the family Poritidae

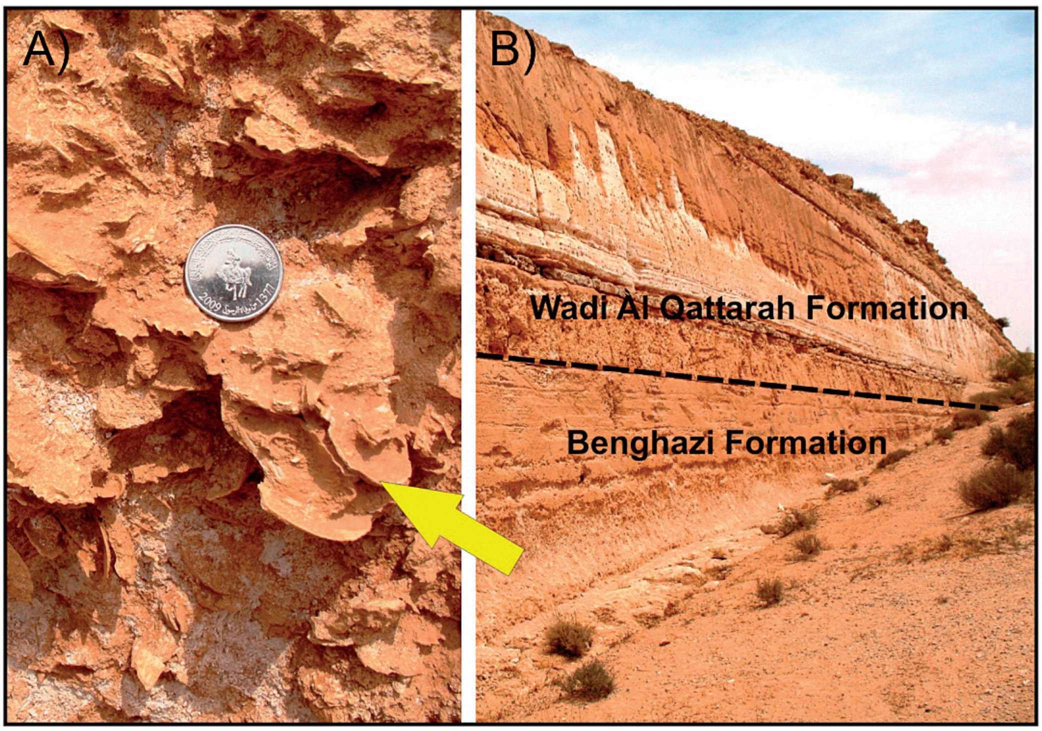


Fig. 4. A) A large-sized Pectinidae and Ostreidae community at the lower levels of the Soluq-Al Abyar section. B) Middle-Upper Miocene contact (dashed line) between the Benghazi Formation below and the Wadi al Qattarah Formation above.

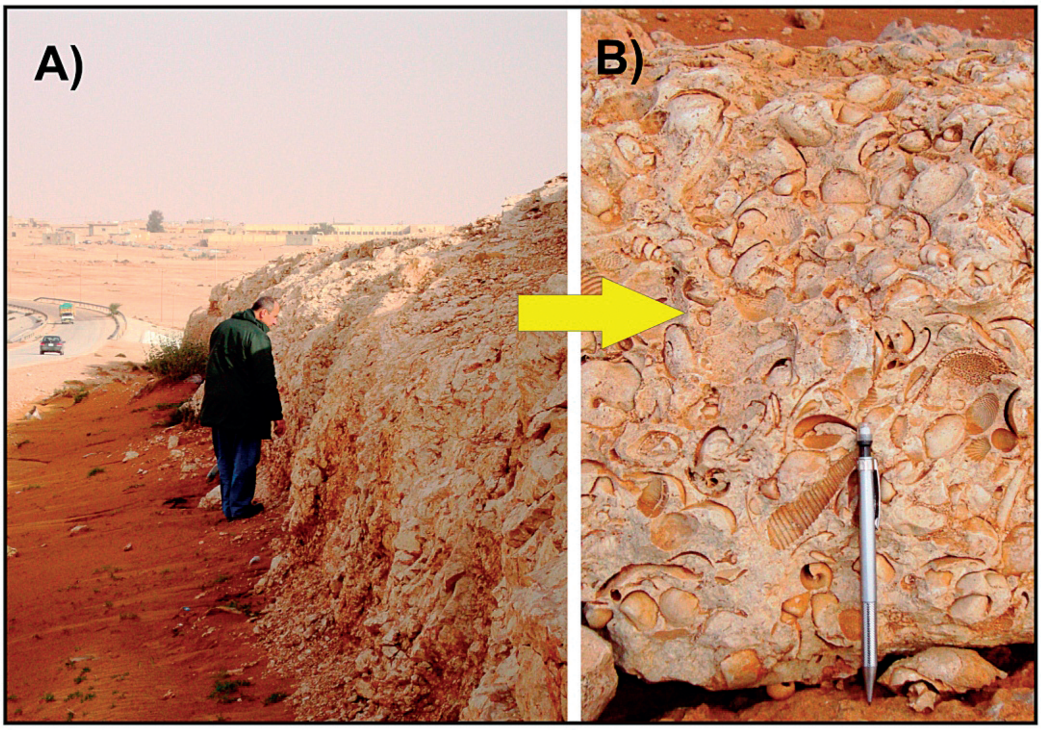


Fig. 5. A) Wadi al Qattarah Formation at the entrance of the Zawiyat Msus village. B) Detail of the internal and external molds of gastropods and bivalves that entirely constituted the limestone.

showing moderate diversity along the road to the Zawiyat Msus section.

The third unit is only a few meters thick, and it marks the upper part of the formation at the Wadi al Qattarah section. This unit is characterized by soft marly thin- to medium-bedded limestone that is whitish in appearance and poorly fossiliferous. In the Wadi al Naghar and Soluq-al Abyar sections, the unit becomes sandy allochems limestone (sensu Mount, 1985) containing fossil casts of bivalves and gastropods. In the Burj al-Sceleidima and al-Sceleidima sections, the top part of the Benghazi Formation is generally characterized by cross-bedded, yellowish to reddish hybrid sandstone, with local well-sorted sandstones.

Wadi al Qattarah Formation

The Wadi al Qattarah Formation lies on the eroded surface of the Benghazi Formation. The contact between the two rock units is visible only in the central part of the study area, and can be easily observed in the Wadi al Naghar and Soluq-al Abyar (Fig. 4). Above the contact, the presence of numerous elongated cylindrical bivalve shells preserved in their burrows characterizes a several meters-thick, yellowish to brownish intensively bioturbated limestone unit. Up-section the latter unit is terminated by yellowish-white oolitic limestone. In the Zawiyat Msus section, however, this level is represented only by scattered patches of poorly fossiliferous and recrystallized limestone.

Above the bioturbated unit, the Wadi al Qattarah Formation is characterized by a conspicuous cross-bedded chalky limestone unit of variable thickness. This unit is absent in the Zawiyat Msus section, where it is replaced by eroded white oolitic limestone bed.

Upwards, the Wadi al Qattarah Formation consists of mixed carbonate-siliciclastic deposits of variable thickness. A composite exposure with a thickness of roughly 40 m was measured near Burj al-Sceleidima section. Here, the lower part mainly consists of a few meters of, poorly fossiliferous medium- to thick–bedded limestone that is whitish to yellowish in appearance. This quite hard crystalline limestone has common solution cavities with casts of gastropods and bivalves. The upper part consists of a large, thick unit of green clay interbedded with soft marly limestone, siltstone and fine-grained hybrid sandstone. Gypsum crystals, several centimeter-thick gypsum bands and small chert nodules are also present in this unit, usually found at the top of the studied sequence.

Unlike other sections of the Wadi al Qattarah Formation, the uppermost part at the Wadi al Naghar section consists primarily of numerous lenses and irregular bodies of white to earthy gypsum of about 5 m thickness (Fig. 6). Elsewhere in the study area, some gypsum lenses are interbedded with microcrystalline limestone.

RESULTS AND DISCUSSION

Bio-Chronostratigraphy

In the present study, the facies control on the fossil range and abundance hinders the acquisition of complete

Fig. 6. A) The upper part of the Wadi al Qattarah Formation at the Wadi al Naghar section is primarily represented by Messinian evaporites. B) Close-up view of the crystalline gypsum.

biostratigraphic data. It similarly restricts the application of a formal zonal scheme and the use of quantitative or semi-quantitative methods of biostratigraphic correlation. Moreover, the development of a locally applicable zonation requires confirmation of its lateral extent through studies on other biostratigraphically suitable sections. Yet despite these complications arising from facies changes and stratigraphic gaps, analyses of the Ar Rajmah Group foraminiferal distribution indicate that the studied sequence exhibits distinctive age-related microfossil content.

A composite stratigraphic distribution chart of the main genera among the studied smaller and larger benthic foraminifera is shown in figure 7; this figure illustrates where first and last occurrences can be observed within the studied Miocene sequence.

Age diagnostic-taxa are represented by several species of larger benthic foraminifera, either in thin-section or as isolated specimens; these include *Miogypsinoides complanatus* (Schlumberger) (Pl. 1, Fig. 1); *Nephrolepidina* sp. (Pl. 1, Fig. 2) and *Miogypsina* cf. *globulina* (Michelotti) (Pl. 1, Fig. 3). This assemblage is of Aquitanian to Burdigalian age and corresponds to the shallow benthic foraminiferal biozones SBZ 24 and SBZ 25 of Cahuzac and Poignant (1997). The base and top of biozone SBZ 24 are characterized in the studied sequence by the first and last appearance of *Miogypsinoides complanatus* (Schlumberger) and associated taxa (see Fig. 7). The last appearance of the latter taxon and the first appearance of *Miogypsina* cf. *globulina* (Michelotti) marks the contact between the Aquitanian and Burdigalian. The biozone SBZ 25 is defined by the total range of *Miogypsina* cf. *globulina* (Michelotti), and according to Cahuzac and Poignant (1997) SBZ 25 closely corresponds to the Burdigalian stage. The Middle and Upper Miocene time-interval corresponds to the shallow benthic foraminiferal biozone SBZ 26 of Cahuzac and Poignant (1997). Here, the Middle Miocene sequence is defined by the first occurrence of *Borelis melo melo* (Fichtel and Moll) (Pl. 1, Fig. 4) and the disappearance of *Miogypsina*. The assemblages include also *Operculina complanata* (Defrance) (Pl. 1, Fig. 5) in the Langhian and *Heterostegina* cf. *costata* (d'Orbigny) (Pl. 1, Fig. 6) in the Serravallian. Of special significance, however, is the recovery of *Borelis melo melo* (Fichtel and Moll) from the deposits of the Benghazi Formation. Currently, the species of *Borelis* fall into two main groups defined through a length/diameter index (Hottinger, 1974; Sherif, 1991): a group of ovoid to fusiform species (Oligocene to Recent), and a group of spherical forms (Middle-Upper Eocene to Recent). Well-known from Lower to Middle Miocene strata (Hottinger, 1974), *Borelis melo melo* (Fichtel and Moll) has only a spherical morphology in the Mediterranean region (Adams, 1984). Based on the stratigraphic data provided by Jones et al. (2006), one can conclude that *Borelis melo melo* (Fichtel and Moll) is abundant from the Middle Miocene deposits of the Mediterranean region, whereas this subspecies is infrequent from the Upper Miocene in the same region (e.g., Messinian of southeastern Spain, Cabo de Gata, Province Almeria; see Betzler and Schmitz, 1997). *Borelis melo melo* (Fichtel and Moll) has been observed in Libya by Berggren (1967) and Sherif (1991) from the Middle Miocene Al Khums Formation (northwest Libya), by Abdulsamad and Barbieri (1999) from the A1-36 and D1-

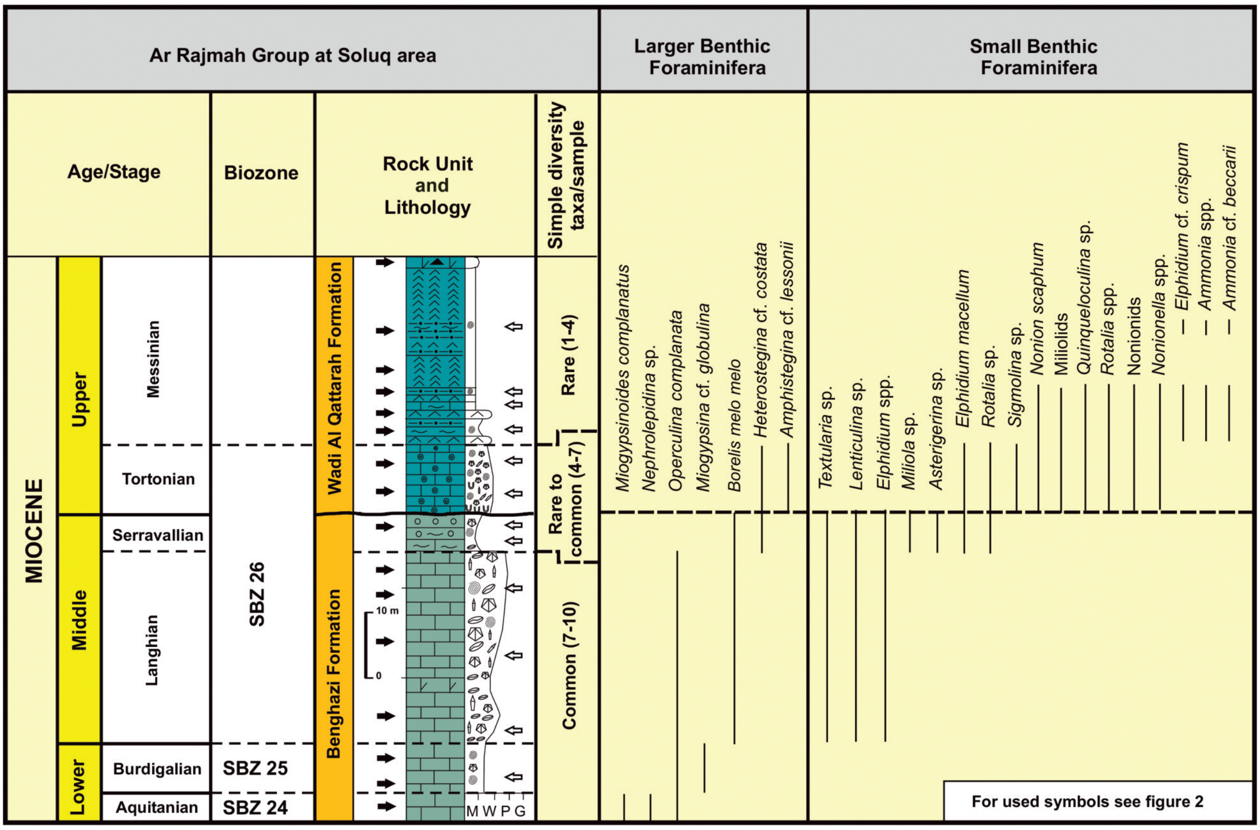


Fig. 7. Composite stratigraphic distribution chart of the studied benthic foraminifera in the Ar Rajmah Group at Soluq area; the age/stage boundaries are interpreted based on the first and last occurrences of age diagnostic taxa of larger benthic foraminifera. SBZ represents the shallow benthic foraminiferal biozonation of Cahuzac and Poignant (1997).

41 boreholes in Cyrenaica and, more recently, by Abdulsamad and Bu-Argoub (2006) from the same rock units in the southeast of Benghazi City.

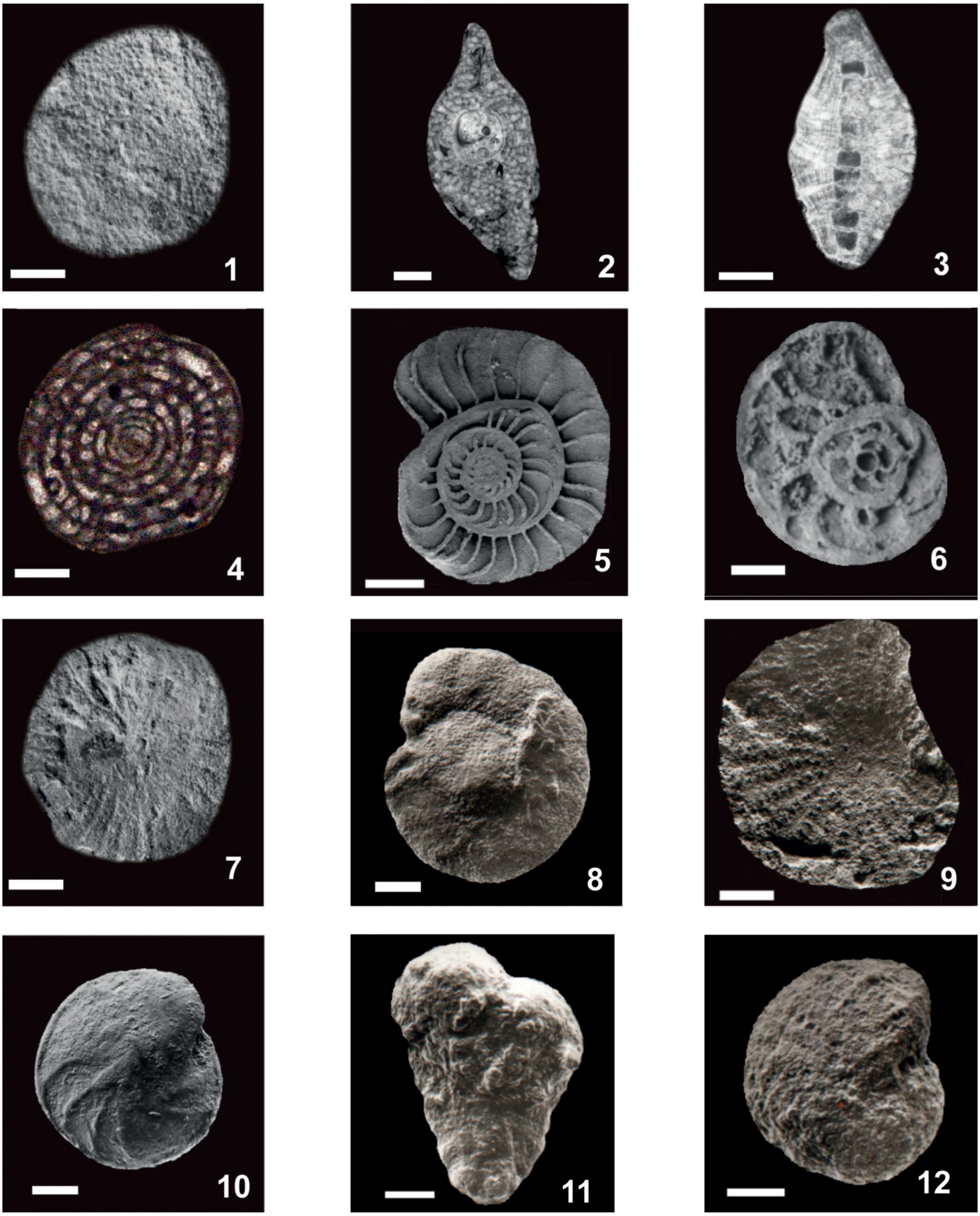
Based on above data, a Lower to Middle Miocene age can be ascribed to the sedimentary deposits of the Benghazi Formation. The Serravallian-Tortonian boundary is clearly established based upon the disappearance of *Borelis melo melo* (Fichtel and Moll) and the associated taxa (Fig. 7). Only a few genera such as *Heterostegina* have crossed the boundary with no noticeable changes. However, important and new fossil taxa appear at the base of the Upper Miocene deposits, such as *Amphistegina* cf. *lessonii* d'Orbigny (Pl. 1, Fig. 7) and the associated smaller benthic foraminifera (see Fig. 7). The last occurrence of *Heterostegina* cf. *costata* and *Amphistegina* cf. *lessonii* and the appearances of *Ammonia* cf. *beccarii* (Linnaeus) (Pl. 1, Fig. 8) and *Elphidium* cf. *crispum* (Linnaeus) (Pl. 1, Fig. 9) point to the contact between the Tortonian and the Messinian of the Wadi al Qattarah Formation (see Fig. 7).

PALEOENVIRONMENTS AND PALEOBATHYMETRY

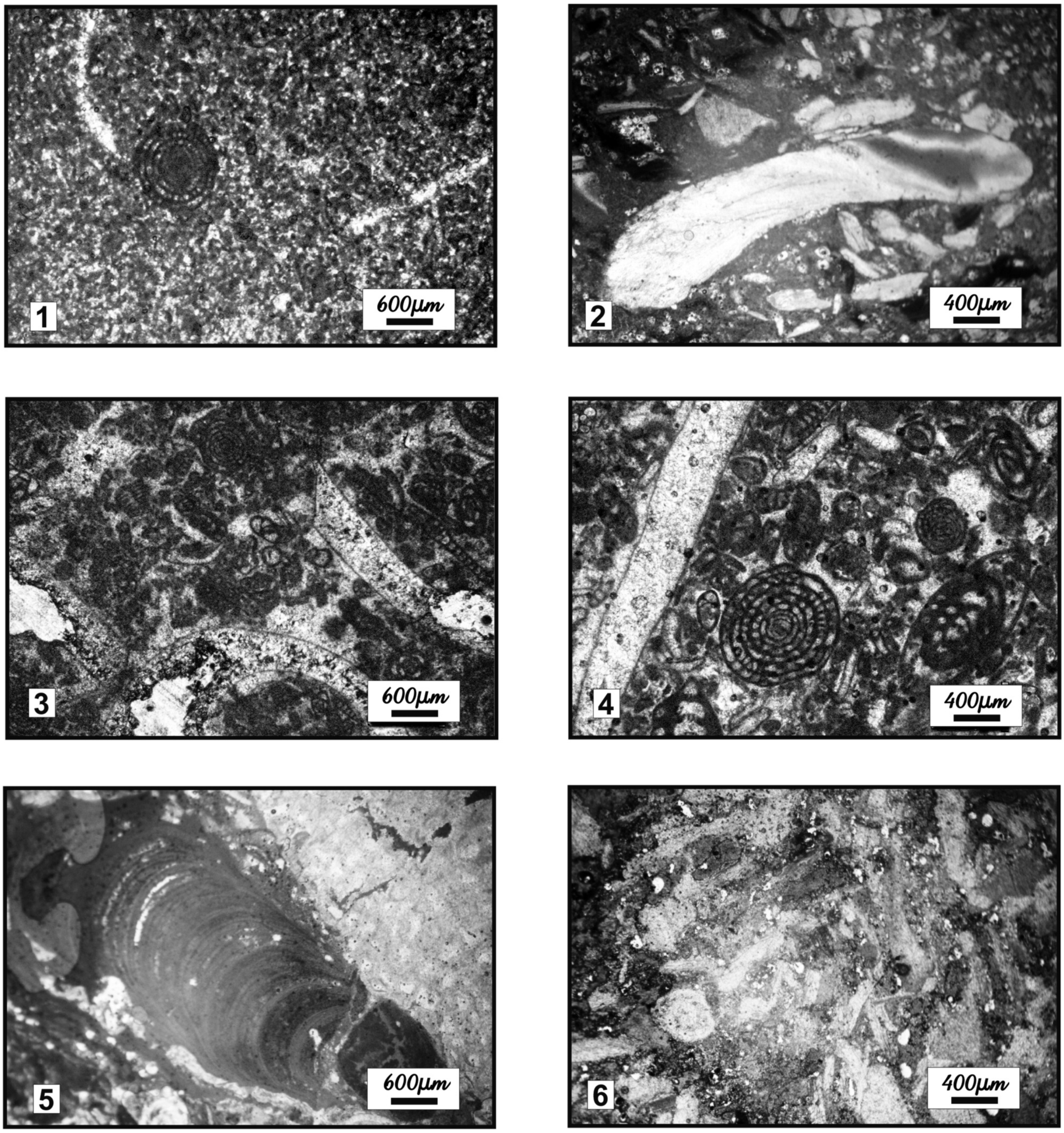
Benghazi Formation

The Benghazi Formation is composed primarily of bioclastic wackestone to packstone, especially in the lower and middle parts of the formation (Pl. 2, Figs. 1 and 2). The gradual decline of micrite observed in the upper levels appears to be as the result of decreasing water depth and increasing energy, which together led to the development of the packstone to grainstone texture (Pl. 2, Figs. 3 and 4).

This shallowing-upward trend is accompanied by an increase in the amount of calcareous red algae (Pl. 2, Fig. 5) and oysters (Pl. 2, Fig. 6). Herein, *Ostrea digitalina* Fuchs, as identified by Francis and Issawi (1977), at outcrop-scale represents the main taxon. In the present-day Adriatic Sea, this species is confined to up to 10 m water depth (Milisic, 1991). Additionally, the presence of such oysters may indicate a relatively low salinity, possibly due to a local and temporary influence of a fresh water supply, which also caused contamination by terrigenous quartz grains (e.g. Abdulsamad and Bu-Argoub, 2006). The presence of common small benthic foraminiferal taxa such as the lenticulinids including *Lenticulina* sp. and textulariids (notably, *Textularia* sp.) (see Fig. 7 and Pl. 1, Figs. 10 and 11) are quite significant and confirm our suggestion. These microfaunas are quite common in normal marine sediments and have a wide range of depth and temperature tolerance (Murray, 1973, 1991). However, larger foraminifera (notably, *Borelis*, *Heterostegina* and *Operculina*), whose depth distribution is largely determined by their symbionts (Leutenegger, 1984), and thus their depth range is limited to the euphotic zone (Hottinger, 1983), typify warm-water habitats (Murray,



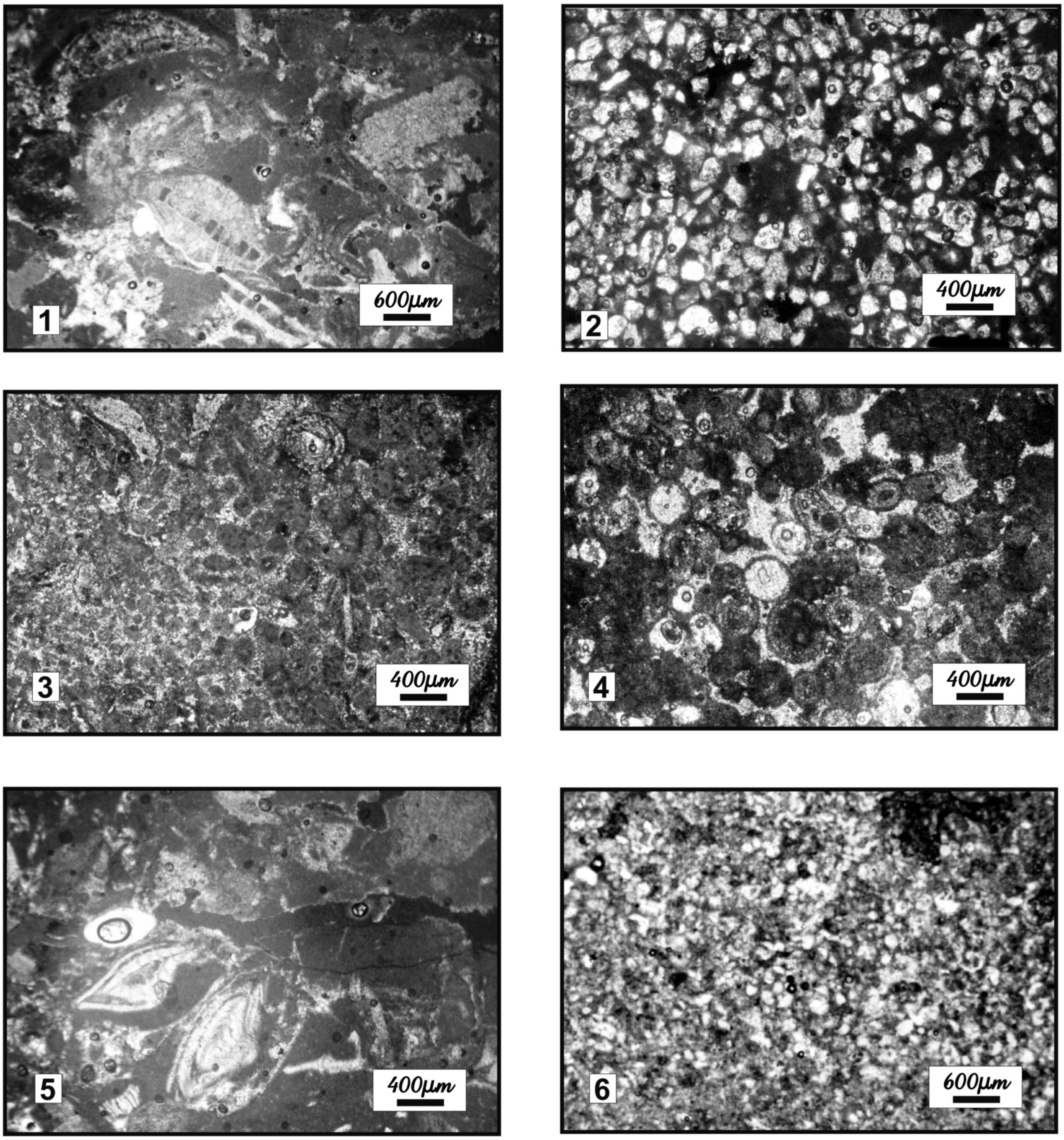
Pl. 1. 1) *Miogypsinoides complanatus* (Schlumberger), equatorial view, base of the lower part of Benghazi Formation, Wadi al Naghar section, sample no. BF-001, X 20; 2) *Nephrolepidina* sp, axial view, lower part of the Benghazi Formation, Soluq-Al Abyar section, sample no. BF-002, X 45; 3) *Miogypsina* cf. *globulina* (Michelotti), axial view, top of the lower part of Benghazi Formation, Soluq-Al Abyar section, sample no. BF-008, X 25; 4) *Borelis melo melo* (Fichtel and Moll), equatorial view, upper part of Benghazi Formation, Zawiyat Msus section, sample no. BF-028, X 25; 5) *Operculina complanata* (Defrance), equatorial view, top of the middle part of Benghazi Formation, Wadi al Naghar section, sample no. BF-021, X 20; 6) *Heterostigina* cf. *costata* (d'Orbigny), equatorial view, upper part of Benghazi Formation, Wadi al Naghar section, sample no. BF-026, X 25; 7) *Amphistgina* cf. *lessonii* d'Orbigny, external view, lower part of Wadi al Qattarah Formation, Soluq-Al Abyar section, sample no. WQ-001, X 25; 8) *Ammonia* cf. *beccarii* (Linnaeus), spiral view, upper part of Wadi al Qattarah Formation, Soluq-Al Abyar section, sample no. WQ-032, X 45; 9) *Elphidium* cf. *crispum* (Linnaeus), external view, upper part of Wadi al Qattarah Formation, Soluq-Al Abyar section, sample no. WQ-032, X 40; 10) *Lenticulina* sp., umbilical view, middle part of Benghazi Formation, Burj al Sceleidima section, sample no. BF-020, X 45; 11) *Textularia* sp., lateral view, middle part of Benghazi Formation, Burj al Sceleidima section, sample no. BF-021, X 45; 12) *Elphidium macellum* (Fichtel and Moll), lateral view, lower part of Wadi al Qattarah Formation, Al Sceleidima section, sample no. WQ-003, X 45.



Pl. 2. 1, 2) Lower and middle parts of Benghazi Formation at Soluq-Al Abyar section showing bioclastic wackestone to packstone with *Borelis melo melo* (Fichtel and Moll) (Fig.1) and large-sized remains of oysters (Fig. 2). Sample no. BF-03 and BF-06 respectively; 3, 4) Middle and upper parts of Benghazi Formation at Zawiyat Msus section showing packstone to grainstone with common association of miliolids; peneroplids; and alveolinids, including *Borelis melo melo* (Fichtel and Moll). Sample no. BF-09 and BF-12 respectively; 5) Upper part of Benghazi Formation at Wadi al Qattarah showing packstone to grainstone with common calcareous red algae. Sample no. BF-17; 6) Lower part of Benghazi Formation at Wadi al Naghar section showing bioclastic packstone to grainstone with abundant remains of oysters. Sample no. BF-02b.

1973). Moreover, it has long been recognized that *Borelis* indicate shallow water with a depth of up to 35 m and a temperature around 30°C (Hottinger, 1974, 1977; Bignot and Guernet, 1976; Abdulsamad et al., 2009).

The infrequent occurrence of *Miogypsina* cf. *globulina* (Michelotti) (Pl. 3, Fig. 1) and other miogypsinides in the lower levels of the Benghazi Formation at the Wadi al Naghar and Soluq-al Abyar sections, may indicate a water depth of less than 50 m with normal salinity (see Geel, 2000). In the Burj al-Sceleidima and al-Sceleidima sections, the upper part of the Benghazi Formation is generally characterized by yellowish to reddish hybrid cross-bedded sandstone and locally by well-sorted sandstones (Pl. 3, Fig. 2). On the road to the Zawiyat Msus section, the upper levels of the Benghazi Formation are represented by numerous miliolids; peneroplids and



Pl. 3. 1) Lower part of Benghazi Formation at Wadi al Naghar section showing bioclastic packstone to grainstone with *Miogypsina* cf. *globulina* (Michelotti). Sample no. BF-03c; 2) Top of Benghazi Formation at Burj al-Sceleidima showing well-sorted sandstones with no bioclasts. Sample no. BF-22a; 3) Base of Wadi al Qattarah Formation at Wadi al Naghar showing bioclastic packstone to grainstone with abundant rounded and fine-grained fecal pellets. Sample no. WQ-02a; 4) Lower part of Wadi al Qattarah Formation at Burj al-Sceleidima showing bioclastic packstone to grainstone with abundant spherical carbonate ooids. Sample no. WQ-04b; 5) Middle part of Wadi al Qattarah Formation at Soluq-Al Abyar showing bioclastic wackestone to packstone with *Amphistegina* cf. *lessonii* d'Orbigny. Sample no. WQ-19; 6) Upper part of the Wadi al Qattarah Formation at Wadi al Naghar showing sediment composed entirely of gypsum. Sample no. WQ-31a.

alveolinids, including *Borelis melo melo* (Fichtel and Moll) (see Pl. 2, Figs. 3 and 4). This assemblage represents an open-shelf setting down to a water depth of a few dozen meters water (Hottinger, 1983).

Taken together, the observed conditions confirm that open shelf were likely the primary formations in the study area during the Lower-Middle Miocene.

Wadi al Qattarah Formation

The lower unit of the Wadi al Qattarah Formation is dominated by limestone deposits ranging from packstone to grainstone (Pl. 3, Figs. 3 and 4). The biotic content from this unit is represented by undersized pelecypods, gastropods, and small benthic foraminifera such as nonionids, rotaliids, elphidiids and miliolids (Fig. 7). This assemblage is considered by Murray (1991) to indicate restricted platform conditions. The inconsistent occurrences and damaged condition of the shells of alveolinids and operculinids present in the base of Wadi al Qattarah Formation, however, indicate that these taxa have been subjected to general reworking. The absence of the *Borelis melo melo* (Fichtel and Moll) and the associated taxa up-sequence confirm this hypothesis. Additionally, the presence of diverse species of elphidiids, including *Elphidium macellum* (Fichtel and Moll) (Pl. 1, Fig. 12), and miliolids with *Sigmoilina* sp. are indicative of an inner shelf, as these species thrive in water with a depth range of 0-50 m (e.g. Murray, 1973).

The sporadic occurrences of heterosteginids and amphisteginids, including *Amphistegina* cf. *lessonii* d'Orbigny (Pl. 3, Fig. 5), from this unit suggest shallow, relatively warm and oligotrophic waters and a maximum water depth range of about 50-60 m (Chapronière, 1975; Hallock and Glenn, 1986).

Conversely, the amphisteginid test morphology (T/D ratios)-based model for paleodepth reconstruction proposed by Mateu-Vicens et al. (2008) suggests a growth of *Amphistegina* at a water-depth < 30 m, based on specimens collected in Italy. Moreover, populations of amphisteginids from Greece identified as *Amphistegina lessonii* (d'Orbigny) thrive in environments from very shallow water to up to 20 m depth (Triantaphyllou et al., 2003).

In general, however, the nature of the sediments and associated microfauna suggests that the sediments found in the lower unit of the Wadi al Qattarah Formation were deposited in a restricted platform environment with a maximum water depth less than 30 m.

The remaining lithofacies in the basal part of the upper unit of the Wadi al Qattarah Formation consist primarily of wackestone to packstone and locally mudstone with gypsum (Pl. 3, Fig. 6). Here, the studied microfauna shows similarities with the miliolid-small rotaliniid facies of the modern restricted platform and lagoon settings defined by Hallock and Glenn (1986). Betzler and Chapronière (1993) assigned a shallow and protected platform environment to similar Miocene deposits from Australia. Up-sequence, however, green clay interbedded with soft marly limestone, siltstone, and fine-grained hybrid sandstone have been recorded at and around the study area's Burj al-Sceleidima section. This represents a shallowing-upward trend, which is also indicated by the gradual disappearance of deep-water microfauna where the foraminifera are limited to a few poorly preserved miliolids, rotaliids and ammoniids (Fig. 7).

The overall nature of the lithology and the scarcity of microfauna in the study area point to restricted lagoon-salina conditions during the deposition of the upper unit of the Upper Miocene. The recovery of only a few small benthic species such as *Ammonia* cf. *beccarii* (Linnaeus) (see Pl. 1, Fig. 8) and *Elphidium* cf. *crispum* (Linnaeus) (see Pl. 1, Fig. 9) from this stratigraphic level can be associated with periodic storm action and/or debris flows.

CONCLUSIONS

When combined with previously published observations detailing the Miocene deposits of this region (Abdulsamad and Bu-Argoub, 2006; Abdulsamad et al., 2009), the findings discussed here expand our knowledge on the depositional history of the Ar Rajmah Group. Based on larger foraminifera and associated biota, each of the two main lithostratigraphic units making up the Ar Rajmah Group represents an overall shallowing-upward trend, from open platform (Benghazi Formation) to restricted platform and restricted lagoon-salina conditions (Wadi al Qattarah Formation).

The available biostratigraphic data, however, have permitted deposits of the Ar Rajmah Group in the studied succession to be attributed to the Lower-Upper Miocene.

In this time-interval three shallow benthic foraminiferal biozones of Cahuzac and Poignant (1997), namely SBZ 24 and SBZ 25 which closely correspond to the Aquitanian and Burdigalian stages respectively and SBZ 26 which corresponds to the Langhian-Tortonian, were identified. It is important to mention that the Lower Miocene deposits of Ar Rajmah group are limited to the Soluq area and no evidence of this time interval has been reported from the same rock unit in Al Jabal al Akhdar of northern Cyrenaica.

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