

# Stratigraphy and larger benthic foraminifera of Middle Eocene to Middle Miocene rocks along the Tobruk-Al Bardia scarps, northeastern Cyrenaica, Libya

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**ABSTRACT:** Six stratigraphic sections were investigated from the middle Eocene to middle Miocene carbonate deposits along the Tobruk-Al Bardia scarps of northeastern Cyrenaica, NE Libya. The studied sequence comprises five rock units; the Darnah, Al Bayda, Al Abra, Al Faidiyah, and Al Jaghub formations. Eleven carbonate facies were distinguished at outcrop-scale and several microfacies were recognized and the outcome indicates a shelf-carbonate platform complex.

The palaeohabitat of larger benthic foraminifera and associated biota in the studied sequence has been interpreted by comparison with its present-day counterpart.

Nine shallow benthic foraminiferal biozones are recognized based on first and last occurrences of diagnostic larger benthic foraminifera. The late middle Eocene Darnah Formation contains a nummulitic assemblage with variable species, including the *Nummulites gizehensis*/*Nummulites lyelli* group, which represents SBZ17-SBZ18 in the Bartonian. The recovery of *Nummulites vascus* and *Nummulites fichteli* and associated taxa ascribes the overlying deposits of the Al Bayda Formation to the early Oligocene (early Rupelian) larger foraminiferal zone SBZ21. The total nummulitid assemblage of the overlying Al Abra Formation is early Oligocene (late Rupelian) in age which corresponds to larger benthic foraminiferal zone SBZ22. The base of the zone correlates with the base of the Al Abra Formation and is defined by the first appearance of *Operculina complanata* and *Eulepidina* cf. *dilatata*. The top of the zone is present in the lower part of the Al Faidiyah Formation (early Chattian) and is marked by the first appearance of *Miogypsinoidea complanatus*. The middle part of the formation corresponds to larger foraminiferal zone SBZ23 (late Chattian). The base of this zone is marked by *Miogypsinoidea complanatus* whereas the top of the zone is marked by last occurrence of *Eulepidina* cf. *dilatata* and *Nephrolepidina* sp. and the first appearance of *Nephrolepidina* aff. *ournoueri*.

The upper stratigraphic levels of the Al Faidiyah Formation correspond to larger foraminiferal zone SBZ24 in the lower Miocene (Aquitian). The base of the zone is marked by the first occurrence of *Nephrolepidina* aff. *ournoueri* and the upper zone boundary is represented by the last occurrence of the latter taxa and the first appearance of *Miogypsina globulina*.

The last two larger benthic foraminifera zones which have been recognized in the deposits of the overlying Al Jaghub Formation represent zones SBZ25 in the Burdigalian (early Miocene) and SBZ26 in the Langhian and Serravallian (middle Miocene). The base of zone SBZ25 is marked by the last occurrences of *Miogypsinoidea complanatus* and *Nephrolepidina* aff. *ournoueri* and the first appearance of *Miogypsina globulina*. The top of SBZ25 and the base of the upper SBZ26, however, is marked by the last occurrence of the latter taxa and the first appearance of *Borelis melo melo*.

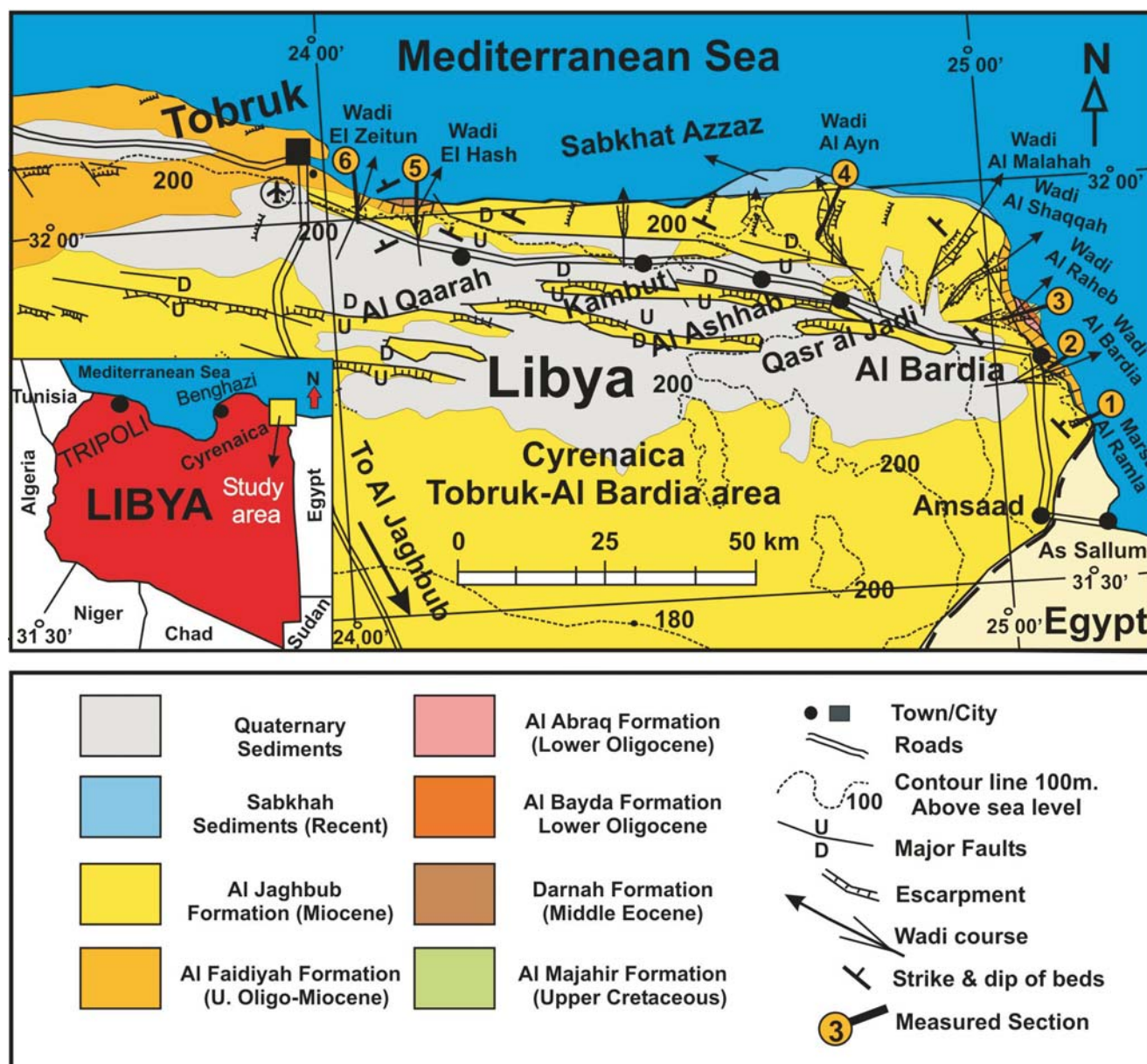
**Key words:** Stratigraphy, Larger Foraminifera, Eocene-Miocene, Cyrenaica, Libya

## INTRODUCTION

The Tobruk-Al Bardia area of northeastern Cyrenaica (NE Libya) represents a vast plateau where the coastal zone is a few kilometers wide and is marked generally by steep cliffs rising more than 100 m above the sea. Several scarps overlooking the sea are dissected by wadis coming down from these scarps. They are parallel to sub-parallel to the shoreline and are oriented in a southeast-northwest direction. Their alignment is structurally controlled either by jointing or by following a particular fault trend. Beds dip a few degrees towards either the northeast or the northwest (text-fig. 1). Along these wadis, six stratigraphic sections were investigated from southeast of the village of Al Bardia to the northwest near Tobruk city; the Marsa al Ramla section, the Al Bardia section, the Wadi al Raheb section, the Wadi al Ayn section, the Wadi el Hash sec-

tion and the Wadi el Zeitun section. They are located between latitudes 31° 30' and 32° 00' N and longitudes 24° and 25° E (text-fig. 1).

The sequence studied comprises five rock units. They are, from oldest to youngest, the Darnah, Al Bayda, Al Abra, Al Faidiyah, and Al Jaghub formations. Several authors, including Barr and Hammuda (1971), Barr and Weegar (1972), Klen (1974), Röhlich (1974), Zert (1974), El Khoudary (1976), Banerjee (1980), Barr and Berggren (1980), Eliagoubi and Powell (1980), Duronio et al. (1991), El Hawat and Shelmani (1993), Abdulsamad and Barbieri (1999), Elwerfalli et al. (2000), Yanilmaz et al. (2008), Abdulsamad et al. (2009), and Abdulsamad and El Zanati (2013) have contributed to the stratigraphy and depositional history of these rock units, both in outcrop and in the subsurface from different parts of northern Cyrenaica. The regional geology and tec-



TEXT-FIGURE 1

Index map of Libya showing the location of the measured outcrops. 1) Marsa al Ramla section, 2) Al Bardia section, 3) Wadi al Raheb section, 4) Wadi Al Ayn section, 5) Wadi el Hash section and 6) Wadi el Zeitun section.

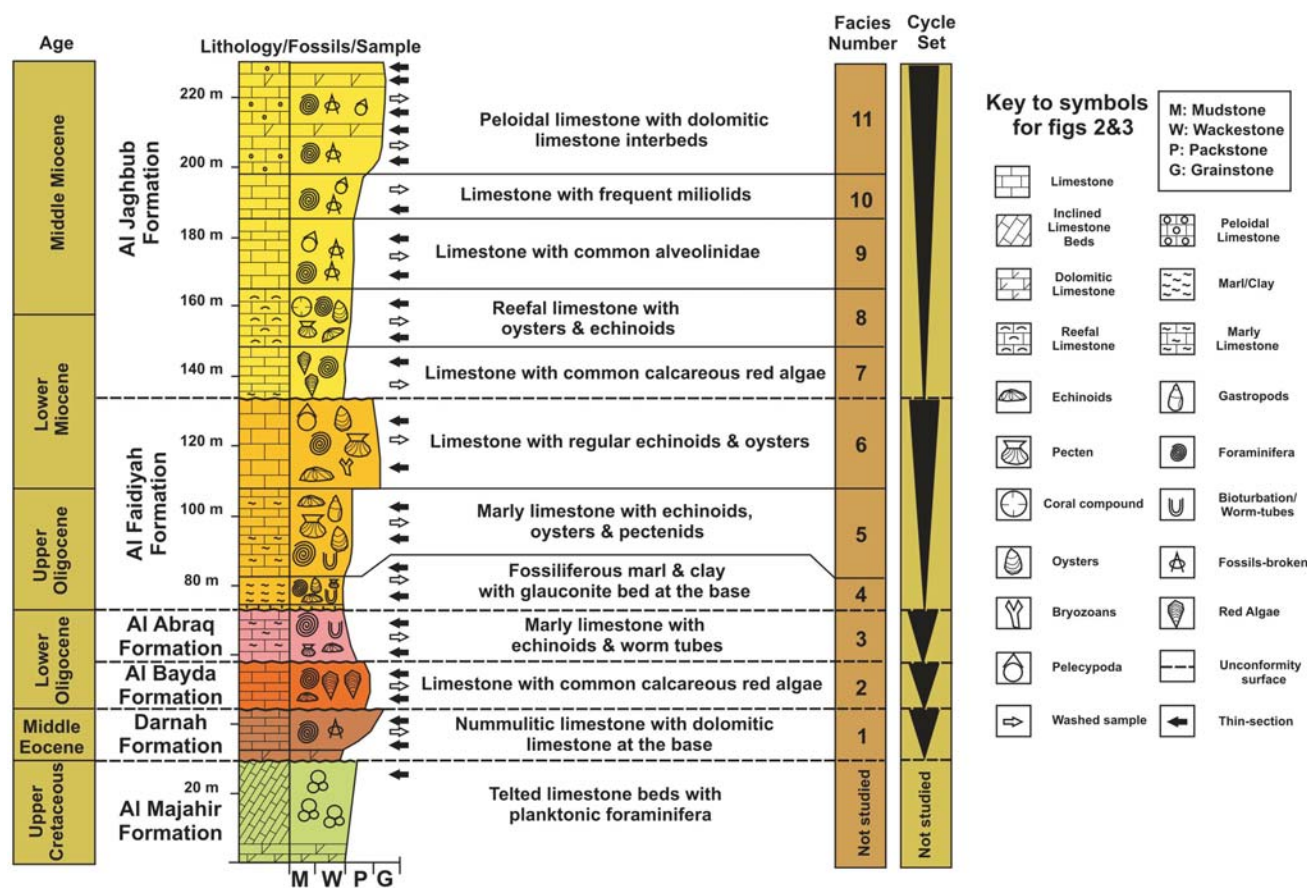
tonic development of the region have been investigated by Röhlich (1978, 1980), El Hawat and Abdulsamad (2004), El-Arnauti et al. (2008) and more recently by Arsenikos et al. (2013).

In this work, the results of micropalaeontological analysis of larger benthic foraminifera of these lithostratigraphic units are described and discussed in terms of litho-biostratigraphic attributes. The study aims to refine the lithostratigraphy of this region which has been mapped by El Deftar and Issawi (1977). It also aims to refine the biostratigraphy which has been reported by Imam (1999) for the Eocene to Miocene deposits in the Tobruk-Al Bardia area of most northeastern Cyrenaica which

we feel, in many cases, to have been in error. This is used to provide an assessment of the palaeohabitat of larger benthic foraminifera based on present-day counterparts. In general, each of the five main lithostratigraphic units making up the middle Eocene-middle Miocene succession represents a shallowing upward sequence. These developed in various parts of a shelf-carbonate platform, the biotic content of which is generally hampered by several stratigraphic gaps.

#### MATERIALS AND METHODS

Approximately 200 outcrop samples of predominantly carbonate limestone and subordinately mixed siliciclastic-carbonates (marly limestone and sandy limestone), were collected from six



TEXT-FIGURE 2

Composite stratigraphic column of the deposits, the main lithological and biotic components and the main facies exposed at Tobruk-Al Bardia, northeastern Cyrenaica.

outcrops throughout the Tobruk-Al Bardia area of northeastern Cyrenaica (text-fig. 1). All samples were collected at a maximum interval of ever 5 m; near lithologic facies changes the samples were more closely spaced. Composition, sedimentary structures, bed thickness and macrofossil content were examined using terms proposed by Tucker (2011). The majority of the limestone samples collected were subsequently processed for thin-section analysis, with several lithologies being documented. Their litho- and bioclastic components are expressed using terms recommended by Flügel (2010).

Approximately 30 samples of soft lithologies were crushed and disaggregated in a hydrogen peroxide solution and washed through a 63 µm sieve. Particular attention was given to the larger benthic foraminiferal specimens, as they are the main group in the study material and the most useful for age dating. All recovered species of *Nummulites* (individual specimens and in thin section) were identified based on external and internal morphology and distinguished biometrically following Schaub (1981), Racey (1995) and Abdulsamad (2000). Radial benthic foraminifera (miogypsinids and lepidocyclinids) were distinguished based on the morphological characteristics used in BouDagher-Fadel (2008).

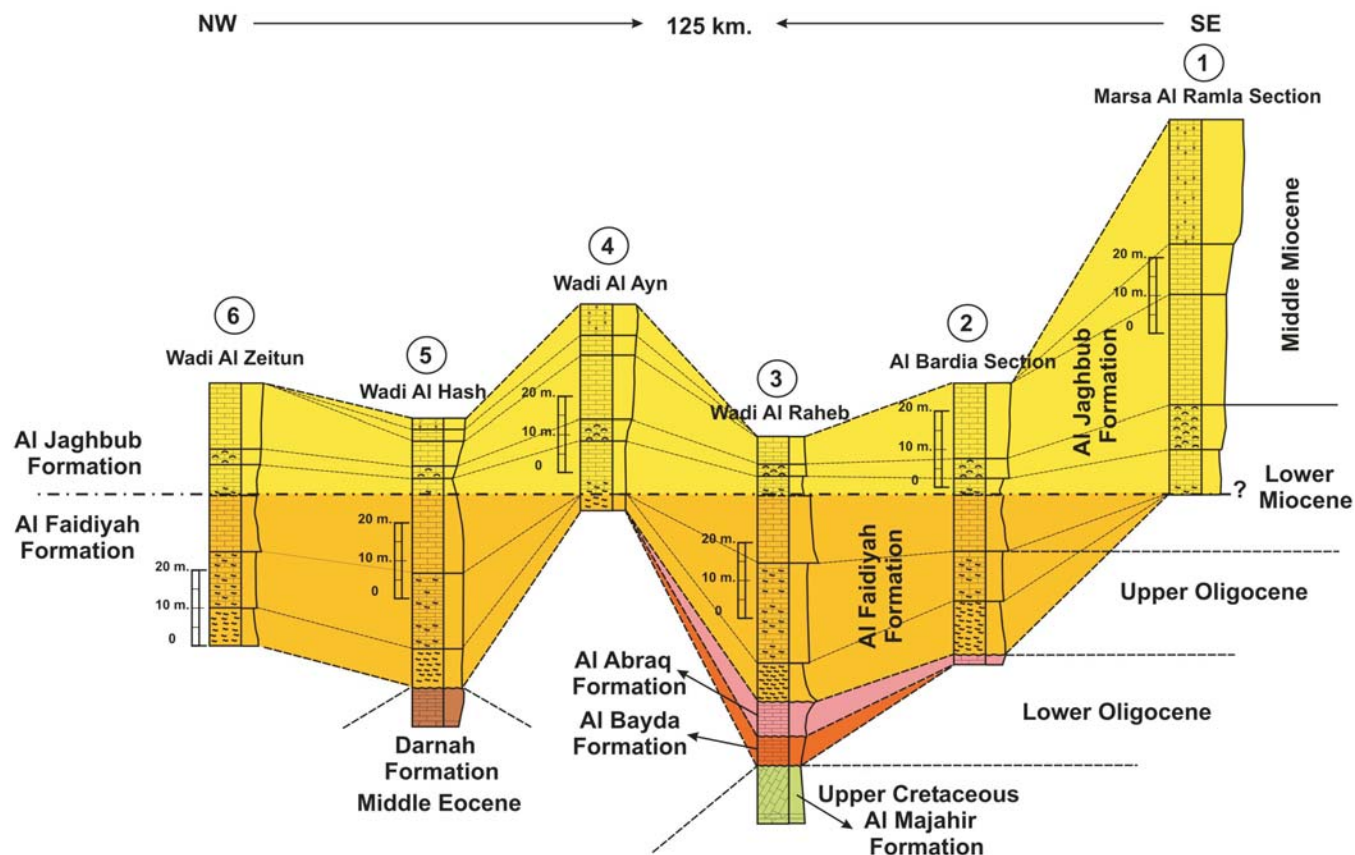
The study material is placed in the repository of the Geological Museum of the University of Benghazi (Benghazi, Libya).

## BACKGROUND AND LITHOSTRATIGRAPHY

Text-figure 2 represents the different characteristics of the middle Eocene to middle Miocene stratigraphy in study area. It shows a composite lithostratigraphic section of the studied succession, the main lithological and biotic components and the main facies exposed along the Tobruk-Al Bardia scarps of northeastern Cyrenaica. Eleven carbonate facies were distinguished at outcrop-scale and several microfacies were recognized and discussed in the following sections. In general, each of the five main lithostratigraphic units making up the succession studied represents a shallowing up sequence. These developed in various parts of a shelf-carbonate platform complex whose biotic content is frequently truncated by hiatuses and only occasionally by dolomitization of diagenetic origin.

To demonstrate the lateral variation of the studied rock units, a correlation of these outcrops, based on stratigraphic criteria, is summarized in text-figure 3. Five unconformity surfaces are recognised in this study (see text-fig. 3). The oldest one is an angular unconformity and has been recognised in Wadi al Raheb only. It separates the tilted Upper Cretaceous rocks of the Al Majahir Formation from the overlying lower Oligocene horizontal beds of the Al Bayda Formation (Algal Limestone Member). Here, the hiatus encompasses a measurable interval of geologic time since the entire Paleocene and Eocene deposits are missing. The second





TEXT-FIGURE 3

Correlation chart of the measured sections from southeast of Al Bardia village to northwest near Tobruk city. The correlation is based on all documented stratigraphical criteria.

contact is represented by a major disconformity and was recognized only in Wadi al Hash (see text-fig. 3). Herein, the deposits of the Al Faiadiyah Formation (upper Oligocene-lower Miocene) rest on the uneven erosional surface of the Darnah Formation (middle Eocene). The lower Oligocene deposits (Al Bayda and Al Abraq formations) are missing in this locality, suggesting a second cycle of emergence and intensive erosion in the studied area. At Wadi al Raheb, the third and fourth disconformity surfaces which are recognised between the Al Bayda, Al Abraq and Al Faiadiyah formations (lower Oligocene-lower Miocene) represent hiatuses of limited time-interval (between 1.0-0.5 Ma) as suggested by the studied fauna. The disconformity between the Al Abraq and Al Faiadiyah formations is submarine in origin based on the presence of a glauconite bed at the base of the Al Faiadiyah Formation. The fifth and youngest contact was recognised in almost all of the studied sections and is represented by a sharp contact between the Al Faiadiyah Formation and the overlying Al Jaghbub Formation. The duration of this hiatus is restricted based on the studied fauna (about 0.5 Ma). This contact, which has been chosen as a datum for our correlation presented in text-figure 3, has been interpreted as an erosional unconformity of submarine origin which may be related to carbonate dissolution and clastic influx on a carbonate shelf.

Detailed lithostratigraphic descriptions for the studied rock units are discussed below in stratigraphic order. It is worth not-

ing, however, that El Deftar and Issawi (1977) and more recently Imam (1999) mistakenly grouped the Cenozoic deposits of the Darnah, Al Bayda and Al Abraq formations as one rock unit named the "Al Khowaymat Formation". We follow the recommendation of Megerisi and Mamgain (1980) in disregarding this term. Our field data confirms that the Darnah, Al Bayda and Al Abraq formations in the study area correspond to their counterparts described elsewhere in Cyrenaica. For additional discussion regarding this issue, we refer to Abdulsamad and Tmalla (2008, p. 61).

#### Darnah Formation

The type section of the middle to upper Eocene Darnah Formation (Gregory 1911) is more than 100 m thick in Wadi Darnah, located 2 km south of Darnah city, and is about 800 m thick south of the type section on the escarpment described by Gregory (1911; see also Banerjee 1980).

In the study area, this formation is reduced in thickness to about 10 m and is present only in Wadi el Hash; here the lower contact is not visible and the upper contact is disconformable with the lower Miocene Al Faiadiyah Formation (see text-fig. 3). The Darnah Formation consists primarily of hard beds of fine- to coarse-grained, whitish to yellowish nummulitic limestone with intercalations of dolomitic limestone, particularly at lower levels. Molds and casts of mollusca are present and consistently distributed. Large-sized coiled Nautilida (here, identified as





TEXT-FIGURE 4

Coiled shell of *Nautilus* sp. preserved in the nummulitic limestone of the lower part of the Darnah Formation at Wadi el Hash.

*Nautilus* sp.) and nummulites of the *Nummulites gizehensis* group are documented in the lower and middle levels (text-fig. 4). At the mouth of Wadi el Hash, the lithology is mainly dolomitic limestone dominated by *Nummulites* and is distinguished by *bogaz*, a karstic surface (text-fig. 5).

#### Al Bayda Formation

The type section of the lower Oligocene Al Bayda Formation (Röhlich 1974) is approximately 40 m thick and is located 2.5 km northwest of the city of Al Bayda, northern Cyrenaica (Banerjee, 1980). The Al Bayda Formation is subdivided into two members; the Shahhat Marl is the lower member and the Algal Limestone is the upper member (Kleinsmiede and van den Berg 1968). It is worth noting that Muftah and Boukhary (2013) suggested a late Eocene age for the Shahhat Marl Member based on the new genus *Gaziryina* (Foraminifera), which was found in association with specimens of the *Nummulites fabianii* group. Shaltami et al., (2017), however, concluded the age of the rock unit was early Oligocene based on new strontium isotope analysis of crystalline calcite which provides an age of early Rupelian (33.1-33.5 Ma) confirming the previous record of Abdulsamad and Tmalla (2008). Lithologically, the

Shahhat Marl Member consists of fossiliferous yellowish limestone, soft marl and argillaceous limestone interbeds, whereas the Algal Limestone Member is made up of massive and thick-bedded, generally white, hard limestone enriched by calcareous red algae (Muftah and Erhoma 2002; Abdulsamad et al., 2009). Contact with the underlying Darnah Formation and the overlying Al Abraq Formation is disconformable in northern Cyrenaica.

In the current study, the maximum thickness of the Al Bayda Formation is about 10 m at Wadi al Raheb (see text-fig. 3). Here, the formation is only represented by the Algal Limestone Member and is separated from the underlying Upper Cretaceous deposits of the Al Majahir Formation by an angular unconformity. The Al Majahir Formation largely consists of tilted beds of microcrystalline to fine-grained limestone rich in planktonic foraminifera whereas the beds of the Al Bayda Formation are mostly horizontal (text-fig. 6). At the mouth of Wadi el Raheb, the upper contact is sharp and disconformable with the overlying deposits of the Al Abraq Formation (text-fig. 7). Lithologically, the Algal Limestone Member is chiefly characterized by white, hard limestone and calcareous red algae, echinoids and small-sized and reticulate nummulites are the main bioclasts.





TEXT-FIGURE 5

Dolomitic limestone with common nummulites characterized by bogaz (Slavic.) karstic surface in the lower part of Darnah Formation at the mouth of Wadi el Hash.

These deposits are not reported from the geological map of the region (El Deftar and Issawi 1977). Imam (1999) included this rock unit in the Al Faidiyah Formation.

#### **Al Abraaq Formation**

The type section of the lower Oligocene Al Abraaq Formation (Röhlich 1974) is approximately 36 m thick and is located 4 km north of the village of Al Abraaq, northern Cyrenaica (Banerjee 1980). Typically, the formation consists of limestone (partly calcarenite) interbedded with dolomitic limestone, dolomite and marl. According to Banerjee (1980) the lithology of the Al Abraaq Formation is variable in Cyrenaica due relative sea level change in the Oligocene-Miocene, as attested by major slump structures (contorted bedding) west of Wadi al Kuf. Elsewhere in Cyrenaica, the basal part of the Al Abraaq Formation is nummulitic with marly or clayey siltstone containing glauconitic grains, and intercalations of algal limestone (see Abdulsamad et al. 2009).

In the study area, the thickness of this rock unit is approximately 10 m in Wadi el Raheb (see text-fig. 3). Both contacts

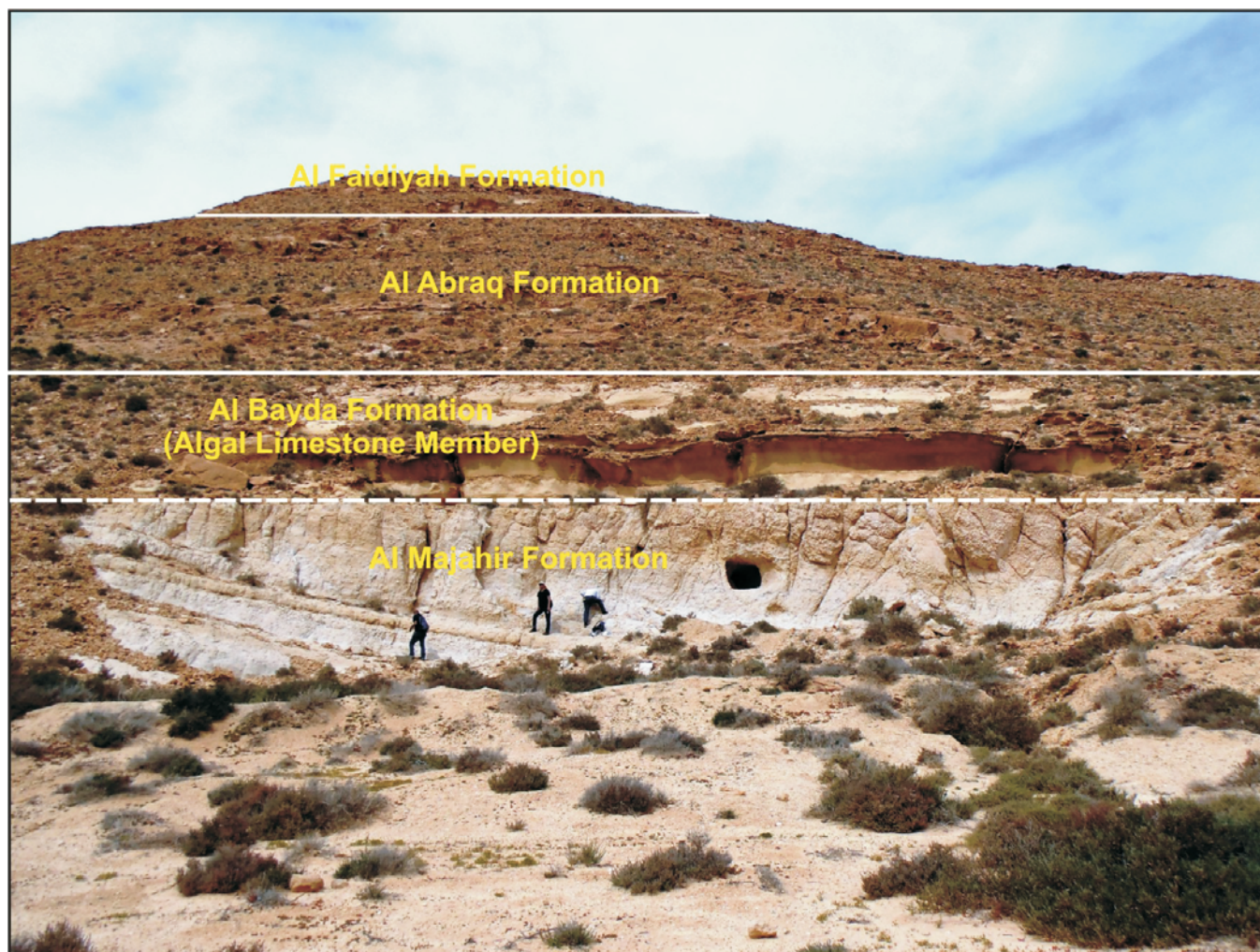
with the underlying Al Bayda Formation (Algal Limestone Member) and the overlying Al Faidiyah Formation are disconformable (see text-fig. 6). Lithologically, the rock unit is chiefly represented by yellowish marly limestone enriched in small and thick reticulate nummulites and echinoids, particularly in the lower levels. At the al Bardia section, however, a 2 m thick section of similar lithology with exceptionally well-preserved and large-sized echinoids has been observed and ascribed to the Al Abraaq Formation (see also Abdulsamad et al., 2009). The lower contact is covered while the upper contact is disconformable and easily recognised below the typical base layer of the Al Faidiyah Formation, which is a green clay.

The Al Abraaq Formation is not reported for this area on the geological map of the region compiled by El Deftar and Issawi (1977); Imam (1999) incorrectly included this rock unit in the Al Faidiyah Formation.

#### **Al Faidiyah Formation**

The type section of the upper Oligocene-lower Miocene Al Faidiyah Formation (the Al Faidia Formation of Pietersz 1968)





TEXT-FIGURE 6

Wadi el Raheb section, showing an angular unconformity (dashed line) between the tilted beds of Al Majahir Formation (below) and the horizontal beds of Al Bayda Formation above. It shows also the other contacts between different rock units.

is approximately 45 m thick in the vicinity of the village of Al Faidiyah, northern Cyrenaica. Elsewhere, the maximum thickness of this formation is about 150 m (Zert 1974). It consists of two main units; a lower of soft, yellow-brown, glauconitic marl with intercalated green clays and an upper unit of white to brownish limestone. Normally, the base of the Al Faidiyah Formation is marked by a layer of green clay and the lower boundary is generally sharp and disconformable, with erosion traces left on the underlying Al Abraaq Formation (Banerjee 1980). The upper boundary in northern Cyrenaica is normally unconformable with the overlying middle Miocene limestones of the Benghazi Formation (Abdulsamad et al. 2009). El Deftar and Issawi (1977) considered the Al Faidiyah Formation as one unit of carbonate and clay interbeds unconformably overlying their “Al Khowaymat Formation” (see above) and overlain conformably by the Al Jaghub Formation (see below).

The Al Faidiyah Formation covers large parts of the study area and its thickness is variable; it is a few meters thick in Wadi al Ayn to approximately 50 m in Wadi el Hash. In the Marsa al Ramla section the rock unit is missing (see text-fig. 3). In gen-

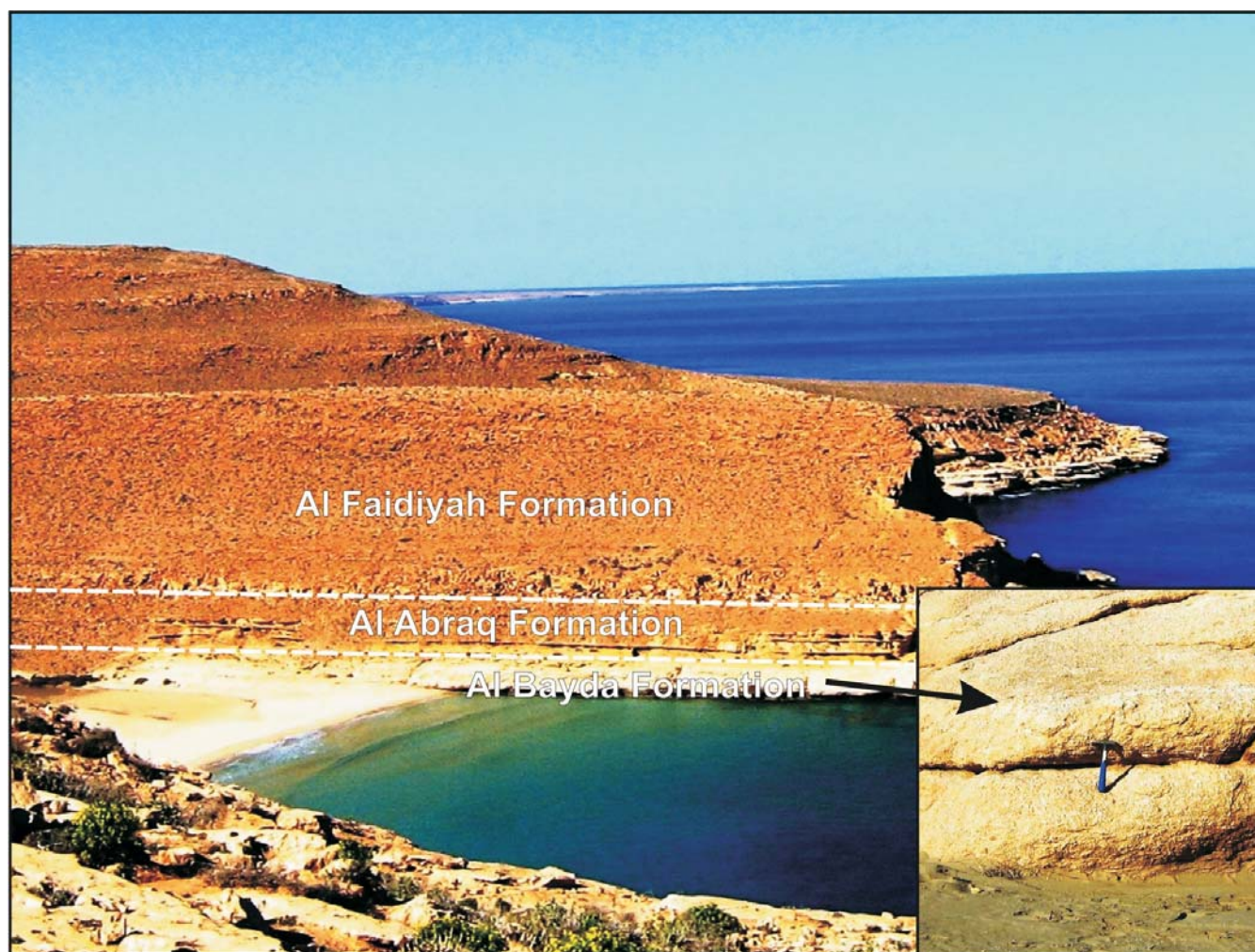
eral, the lower boundary is disconformable with the underlying Al Abraaq Formation and is easily recognized by the glauconite marl horizon as seen in Wadi el Raheb. The upper boundary, though, is sharp and disconformable with the overlying Al Jaghub Formation and can be easily recognized in the Al Bardia section (text-fig. 8).

The Al Faidiyah Formation consists essentially of soft and dark-grey, argillaceous limestone with exceptional calcareous worm tubes identified in the local literature as *Fistulana cirenaica* Cheisa (text-fig. 9) in the lower part. Up-section, the rock unit is regularly represented by marly limestone with quite hard and thick-bedded limestone at the top.

#### Al Jaghub Formation

The type section of the middle Miocene Al Jaghub Formation (the Serie di Giarabub of Desio, 1928) is approximately 120 m thick in Al Jaghub Oasis. According to Banerjee (1980), the formation is composed of relatively hard, white, grey and yellowish, sometimes sandy, highly fossiliferous limestone alternating





TEXT-FIGURE 7

Mouth of Wadi el Raheb, showing the boundary (dashed line) between the Al Bayda Formation (below) and the Al Faiidiah Formation (above). Arrow shows a close-up view of the calcareous red algae beds of the Al Bayda Formation.

with soft clays, clay marl, marls and random sand layers. The lower contact is disconformable with the Al Faiidiah Formation. This contact is identified by the first appearance of carbonate and/or marl beds over the proper clay beds of the Al Faiidiah Formation (Banerjee 1980). The Al Jaghub Formation is overlain by Quaternary deposits over the entire region. According to El Deftar and Issawi (1977), the maximum development of this rock unit was recorded from Al Bardia area where the limestones are in part reefal. In Egypt, Said (1962) described the same rock unit from the other side of the Libyan border naming it the Marmarica Formation. Omara and Ouda (1972) argued against replacing the original name (Al Jaghub Formation) with the replacement term (Marmarica Formation; El Deftar and Issawi 1977).

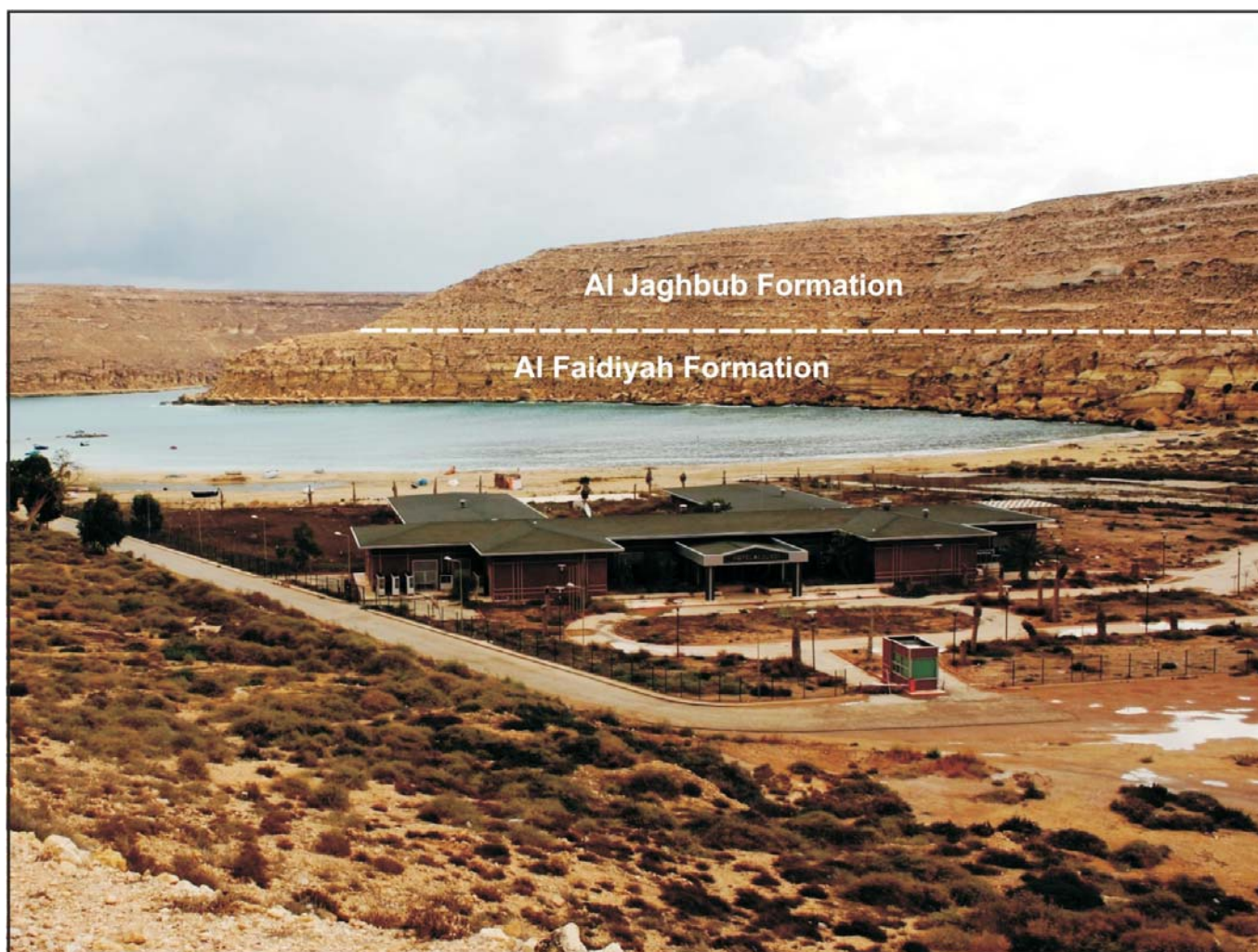
In the study area, the Al Jaghub Formation covers a wide portion of the study area and its thickness is variable, between about 20 m in Wadi el Hash to more than 100 m in Marsa Al Ramla (see text-fig. 3). The lower boundary is disconformable with the underlying Al Faiidiah Formation (see text-fig. 8) and the upper contact is overlain by Quaternary deposits. It is regu-

larly composed, in the lower levels, of limestone rich in calcareous red algae and interbedded with marly limestone and locally by coral-reefal limestone (text-fig. 10). In the Marsa al Ramla section (text-fig. 11) frequent small-scale scattered colonies of scleractinian corals belonging to the family Poritidae and showing moderate diversity have been observed in the basal and middle parts. The upper part, however, is characterized by peloidal limestone, sandy limestone and dolomitic limestone.

## RESULTS AND DISCUSSION

The composite stratigraphic section with selected foraminiferal taxa is shown in text-figure 12. The selected taxa were recovered both in thin-sections and from the washed residues and the results were analyzed to provide biostratigraphic control using established shallow benthic zones (SBZ). Nine shallow benthic foraminiferal biozones of Cahuzac and Poignant (1997) and Serra-Kiel et al. (1998) are recognised in the study area and are discussed below. Supplementary details concerning the depositional nature of the studied rock units are explained in terms of Wilson (1974; 1975), Hallock and Glenn (1986); Jones (1997) and by Abdulsamad et al. (2009). Details related to





TEXT-FIGURE 8

Al Bardia section, showing the boundary (dashed line) between the Al Faidiyah Formation (below) and the Al Jaghbub Formation (above).

paleobiogeography, however, are summarized and discussed in Abdulsamad (1999). As many of the ecological factors, such as temperature, substrate, turbulence, light, oxygen, nutrients and salinity are depth related and are commonly used to infer relative depth in environmental reconstructions (see Kovács 2005), the palaeohabitat of the studied deposits has been interpreted when possible by comparison to present-day water depths. In the following section, the fossil assemblages of larger benthic foraminifera and associated biota are examined in light of the known ecological information including water-depth, and in the assumption that patterns of fossil abundance and distribution are similar to those found for living foraminiferal assemblages (Dodd and Stanton, 1990).

#### Darnah Formation

The Darnah Formation is recognised only in Wadi el Hash and is typically several meters thick at outcrop-scale (see text-fig. 2, Facies 1). The formation is separated from the overlying upper Oligocene-lower Miocene Al Faidiyah Formation by a major unconformity. Alleged upper Eocene sediments reported by Imam (1999) based on planktonic foraminifera at Wadi el Hash

and Wadi el Raheb cannot be confirmed in this study. The upper part of the Darnah Formation is limited to a few outcrops in the central part of al Jabal al Akhdar of northern Cyrenaica, where the late Eocene *Nummulites fabianii* group is well-recorded in both surface and subsurface sections (see Abdulsamad et al., 2009). Lithologically, this unit consists of bioclastic wackestone to packstone (Pl. 1, figs. 1-5) with common A and B-forms of *Nummulites gizehensis* (Forskål) (megalospheric and microspheric tests respectively) (Pl. 4, figs. 1-6). They are associated with *Nummulites* aff. *cyrenaicus* Schaub and *Nummulites discorbinus* (Schlotheim) (Pl. 4, figs. 9-11) in the lower and middle parts. This stratigraphic interval represents larger foraminiferal zone SBZ17 of Serra-Kiel et al. (1998). The recovery of *Nummulites cyrenaicus* Schaub (Pl. 4, figs. 7 & 8), *Orbitolites complanatus* Lamarck (Pl. 1, fig. 4 & Pl. 5, fig. 2) and *Sphaerogypsina globula* (Reuss) (Pl. 1, fig. 5 & Pl. 5, fig. 1) along with the disappearance of the flat and large-sized *Nummulites gizehensis* group at the top of this formation suggests placement in the SBZ18 zone of Serra-Kiel et al. (1998). This zone has been subdivided into three subzones (SBZ18a-SBZ18c) by Less and Özcan (2012) based on the distribution of Eocene heterosteginid





TEXT-FIGURE 9

Lower part of the Al Faiadiyah Formation at Wadi el Hash, showing common and large-sized worm-tubes identified as *Fistulana cirenaica* Cheisa. Hammer is for scale.

populations. Since we did not recover the latter populations from our samples, we were not able to subdivide zone SBZ18. The presence of both biozones SBZ17 and SBZ18 suggests that the sediments of the Darnah Formation in the study area were deposited during the Bartonian (late middle Eocene) (see text-fig. 12).

Large and flat tests of nummulitids such as those from the *N. gizehensis* group were adapted to low light and/or low energy conditions, while the more convex shaped taxa were adapted to more light, and higher energy conditions (see Kovács, 2005). The prevalence of A-Form nummulites in the studied samples, however, is considered by Aigner (1982) as parautochthonous. The lack of sedimentary structures is obvious in the studied sections and the available data were not sufficient to exclude the possibility that the accumulation of nummulites was autochthonous (*sensu* Arni, 1965). According to Anketell and Mriheel (2000) the absence of sedimentary structures is indicative of autochthonous accumulation. Unfortunately, the explanation of Jorriy et al. (2005) for nummulites accumulation based

on porosity and density of *Nummulites* tests is hard to verify in our samples. Although the idea of developing a systematic physical and palaeobiological investigation for different sedimentary settings under which nummulite-banks developed is still valid (Papazzoni, 2008), our data from Cyrenaica are better explained in terms of the classical work of Arni (1965) with some modification by Anketell and Mriheel (2000) and Nebelsick et al. (2005). Here, we limit our ecological assessment of the recovered biota based on lithological characteristics along with its relationship to present-day counterparts.

As *Nummulites* were widespread in water depths from 30 to 80 meters (see for example Kovács, 2005) the sediments of the lower and middle parts of Darnah Formation are interpreted to be deposited at water depth between 80 to 100 meters. This assessment is based on the recovery of *Nautilus* sp. (see text-fig. 4) which was found in association with the *Nummulites gizehensis* group at Wadi el Hash. According to Dunstan et al. (2011), the limiting maximum temperature for living *Nautilus* of around 25°C equates to a water depth of 100 m. The change





TEXT-FIGURE 10

A well-developed and *in situ* coral-reef community in Wadi el Hash is frequently preserved in the lower parts of Al Jaghub Formation. Pen is for scale.

from wackstone in the basal part of the formation to a packstone to coarse grained grainstone texture up-section (Pl. 1, fig. 5) with frequent porcellaneous flat Soritidae (*Orbitolites*), however, indicates a shallowing upward trend and suggests an evolution towards a more restricted paleoenvironment at the end of nummulite deposition. Typically, *Orbitolites complanatus* as well as other very flat foraminifera are suggestive of soft-substrate microenvironments (Kovács and Arnaud-Vanneau, 2004). Living larger soritids, however, such as *Marginopora*, *Sorites* and *Amphisorus* are the closest genera to *Orbitolites* and are normally described as epiphytes thriving in shallow lagoonal environments, although none appear to be restricted to seagrass leaves (Zamagni et al., 2008). Moreover, living *Marginopora* species thrive in somewhat sheltered waters on reef flats and in backreef regions and have been reported below 40 m water depth by Kovács and Arnaud-Vanneau (2004). In agreement with the depth distribution of the attached globular shells of *Sphaerogypsina globula* (Reuss), which thrives in backreef regions (Hottinger, 1983), a water depth of up to 50-60 m (see Drobne et al. 2017) is suggested for the upper part of Darnah Formation in study area.

Therefore, the basal and middle Darnah Formation was deposited in a shallow open shelf environment (possibly near protecting patch reefs) where large and flat monospecific nummulites assemblages thrived (Arni, 1965). The absence of discocyclinids in the Darnah is a result of water depth. They were described from Eocene carbonates of northern Italy in association with *Nummulites* from the upper part of the outer shelf (Bassi, 2005); in more distal environments, discocyclinids could presumably tolerate water depths of more than 100 m where dominant (Geel, 2000). The upper part of Darnah Formation represents deposition in a restricted setting at the end of nummulite deposition. The entire Darnah Formation is interpreted as a coarsening-upward sequence represented by one sedimentary-cycle (see text-fig. 2).

#### Al Bayda Formation

The Al Bayda Formation is represented by the Algal Limestone Member in the study area and rests unconformably on the inclined beds of the Upper Cretaceous deposits in Wadi el Raheb. It is several meters thick unit at outcrop-scale (text-fig. 2, Facies 2). Lithologically, this unit consists of poorly sorted packstone and grainstone with a frequent assemblage of nummulitids and en-



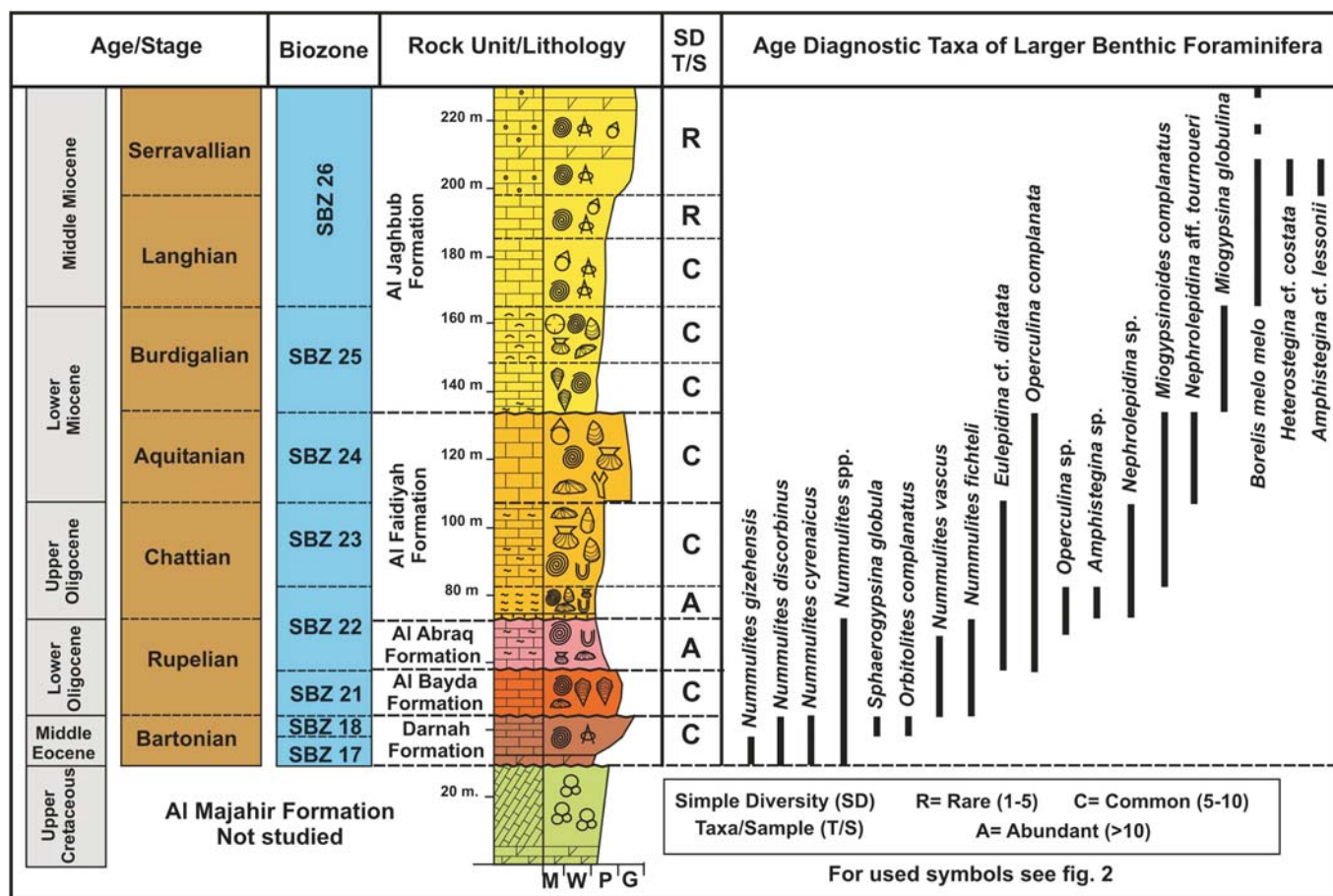


TEXT-FIGURE 11  
Marsa al Ramla section (close to the Egyptian border), showing the complete sequence of lower-middle Miocene deposits of the Al Jaghbub Formation.

crusting coralline red algae (Pl. 1, figs. 6-8). The documentation of *Nummulites vascus* Joly & Leymerie (Pl. 4, fig. 12) and *Nummulites fichteli* Michelotti (Pl. 4, fig. 14) from washed residues places this unit in the earliest Oligocene (Rupelian) larger foraminiferal zone SBZ21 of Cahuzac and Poignant (1997). The base of this zone is marked by the first appearance of *Nummulites fichteli*, whereas the top of the zone is identified by the first appearance of *Eulepidina* cf. *dilatata* (Michelotti), *Operculina complanata* (Defrance) and associated taxa at the base of the overlying rock unit (see text-fig. 12).

The absence of large flat nummulitid shells and the dominance of small-sized, thick and reticulate nummulites (see above) associated with abundant calcareous red algae is indicative of deposition on a carbonate platform. According to Hassan and Ghosh (2003), the coralline algal assemblage in the Algal Limestone Member of the Al Bayda Formation indicates a shallow water environment (ca 40 m in depth), in agreement with the depth distribution of non-geniculate coralline algae, as suggested by Adey (1979) for Caribbean and Pacific sites (see also Abdulsamad et al., 2009). Elsewhere in Cyrenaica, a platform

produced by *in situ* coral colonies (ecological reef *sensu* Dunham 1970, equals to Wilson's SMF 5) was recognized by Abdulsamad and Barbieri (1999). In the current study, however, the algal assemblage is dominated by corallinaceans (chiefly melobesioids such as *Mesophyllum* and *Lithothamnion*). The sediments appear largely encrusted and the coral-algal framework is very reduced and infilled by mud and sand. The deposits studied are interpreted to have been deposited in the shallow fore-reef of an organic reef complex, a composite physiographic element that may develop from the surf zone down to 40-50 m water depth (Wilson 1975; Perrin et al. 1995). The dominance of reticulate nummulites over calcareous red algae in the uppermost part of the Al Bayda Formation indicates a shallowing upward trend. Muftah and Erhoma (2002) came to a similar conclusion based on coralline red algae and a shallowing trend that allowed for the deposition of several microfacies within the Algal Limestone Member. Supporting evidence is indicated by the poorly sorted coarse grained grainstone texture documented upsection. Based on the above data, the studied deposits of the Al Bayda Formation represent one coarsening upward cycle (see text-fig. 2).



TEXT-FIGURE 12

A composite stratigraphic occurrence chart of the studied larger benthic foraminifera in the Tobruk-Al Bardia area, northeastern Cyrenaica. The age/stage and biozone boundaries are interpreted based on the first and last occurrences of age diagnostic taxa of larger benthic foraminifera recovered from the studied stratigraphic sections.

### Al Abraaq Formation

The Al Abraaq Formation in the study area is represented by a single unit, several meters thick at outcrop-scale (see text-fig. 2, Facies 3). Lithologically, this unit consists of wackestone to packstone and locally by packstone with a common assemblage of small sized reticulate nummulites (Pl. 2, figs. 1 & 2). *Nummulites vascus* (Pl. 4, fig. 13), *Nummulites fichteli* (Pl. 4, fig. 15) and *Operculina complanata* (Pl. 5, fig. 4) represent the main bioclastic components recovered from washed residues of the studied samples at the Wadi el Raheb section. *Operculina* sp. (Pl. 5, fig. 3) is frequent in the uppermost Al Abraaq Formation.

Based on the entire nummulitid assemblage, this formation is early Oligocene (late Rupelian) in age and corresponds to the larger benthic foraminiferal zone SBZ22 of Cahuzac and Poinant (1997). Since no *Cycloclypeus* have been recovered from the studied samples, separation of SBZ22a from SBZ22b was not possible (see text-fig. 12). The base of SBZ22, however, is marked by the local first appearance of *Operculina complanata* and *Eulepidina* cf. *dilatata*, whereas the top of the zone is well defined in the overlying rock unit (see text-fig. 12).

The larger foraminiferal assemblage recovered from this unit is assumed to be *in situ* and is characteristic of a shallow shelf with a vegetated, soft substrate. This is indicated by the abundant and consistent distribution of small and thick specimens of *Operculina complanata* and small-sized reticulate nummulites. Thick walled foraminifera built more robust shells in high energy environments whereas thin-walled shells dominated in quiet environments (see Renema, 2001).

The absence of *Cycloclypeus* in the studied assemblage may be related to water depth; the majority of survivor species of this genus colonize the deep environments, down to the lower limit of the photic zone (Langer and Hottinger 2000). A shallowing-up trend in the Al Abraaq Formation is suggested by the dominance of packstone to grainstone texture at the top of the formation (Pl. 2, fig. 3), and the broken nature of the majority of bioclasts may be the product of a mid to high energy habitat. Supporting evidence of a shallowing upward trend is suggested by the presence of siliciclastics in this stratigraphic level, which may be continentally-derived sediment input attributable to sea-level lowering. The entire sequence is one sedimentary-cycle (see text-fig. 2).



### Al Faidiyah Formation

The Al Faidiyah Formation in the study area is represented by three different units at outcrop-scale (see text-fig. 2, Facies, 4-6) which have been distinguished in most of the studied sections. The base of facies 4 is characterized by a soft glauconitic bed, where common rounded to subrounded glauconite pellets are the main allochems (Pl. 2, fig. 4). Up section, the lithology is wackestone to packstone in the basal section and packstone with an association of lepidocyclinids, amphisteginids and operculinidids in the upper section (Pl. 2, figs. 5 & 6). The recovered larger benthic foraminifera from this facies include *Operculina complanata* (Pl. 5, fig. 4), *Eulepidina* cf. *dilatata* (Pl. 5, fig. 5) and *Amphistegina* sp. (Pl. 5, fig. 6) suggesting placement in the larger foraminiferal zone SBZ22 of Cahuzac and Poignant (1997). The base of this zone is at the base of the underlying rock unit (Al Abraq Formation) and is defined by the first appearance of *Operculina complanata* and *Eulepidina* cf. *dilatata*. The top of the zone is marked by the first appearance of *Miogypsinoides complanatus* (Schlumberger) (see text-fig. 12).

The middle part of the Al Faidiyah Formation (Facies 5) is primarily a packstone to grainstone (Pl. 2, fig. 7). Herein, the larger foraminifera are similar to those recovered from the underlying facies but calcareous red algae are quite frequent in

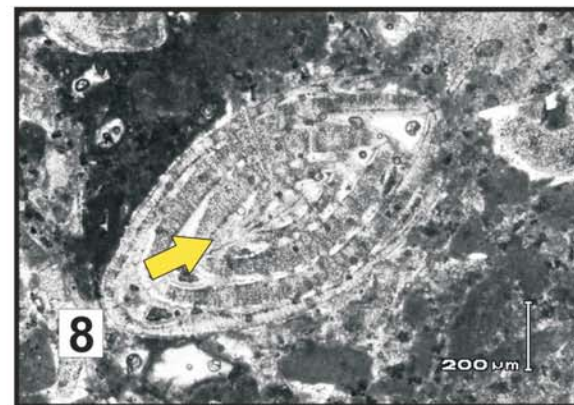
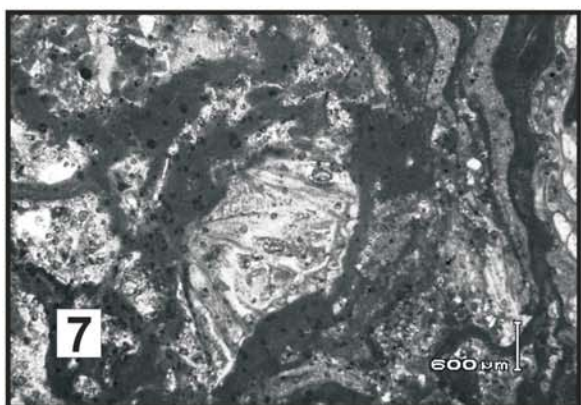
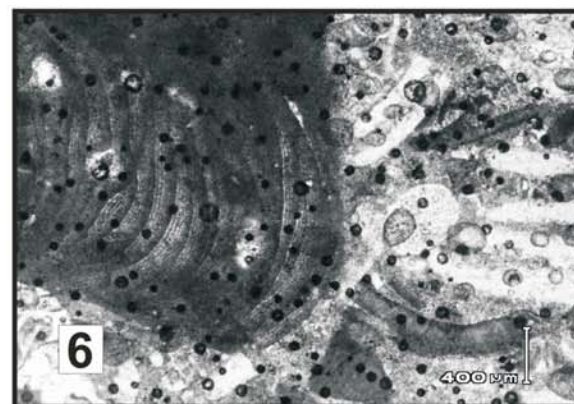
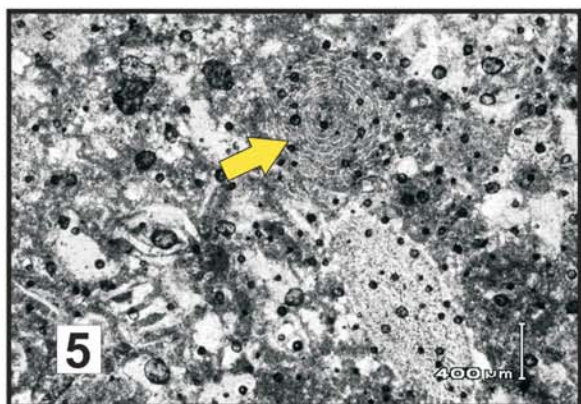
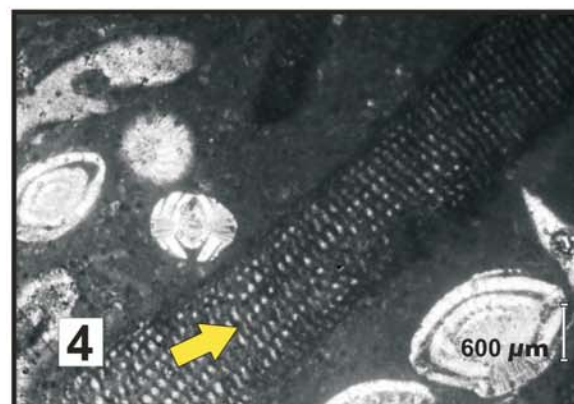
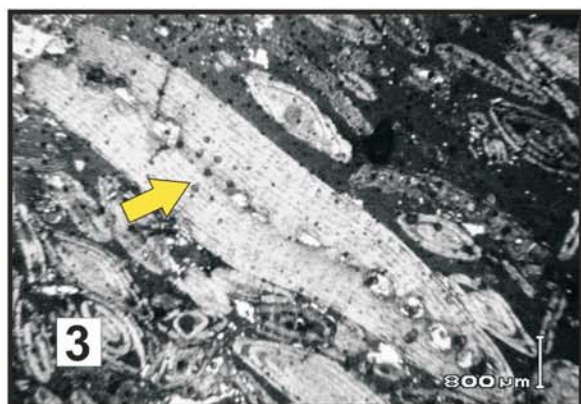
thin-sections and at outcrop-scale. This stratigraphic level corresponds to larger foraminiferal zone SBZ23 of Cahuzac and Poignant (1997). The base of the zone is marked by the first appearance of *Miogypsinoides complanatus* (Pl. 5, fig. 10) and the top of the zone is marked by the last occurrence of *Eulepidina* cf. *dilatata* and *Nephrolepidina* sp. (Pl. 5, fig. 8), along with the appearance of *Nephrolepidina* aff. *tournoueri* (Lemoine & Douvill ) (see text-fig. 12).

The upper part of the formation (Facies 6) largely consists of packstone to grainstone (Pl. 2, fig. 8), and locally by grainstone. Herein, larger benthic foraminifera are quite frequent but dominated by a few species such as *Operculina complanata* and *Miogypsinoides complanatus*. This section is placed in larger foraminiferal zone SBZ24 of Cahuzac and Poignant (1997) based on the first occurrence of *Nephrolepidina* aff. *tournoueri* (Pl. 5, fig. 9). The upper boundary of this zone is represented by the last occurrence of *Nephrolepidina* aff. *tournoueri* and the first appearance of *Miogypsina globulina* (Michelotti) (Pl.5, fig. 11). Based on the above data the age of the Al Faidiyah Formation is late Oligocene (early Chattian) to early Miocene (late Aquitanian).

The recovered assemblage of larger benthic foraminifera is represented by lepidocyclinids, amphisteginids, nummulitids

## PLATE 1

- 1,2 Lowermost part of the Darnah Formation at Wadi el Hash showing wackestone to packstone with small nummulites and other shell fragments.
- 3 Lower part of the Darnah Formation at Wadi el Hash, showing packstone with abundant nummulites, including a large axial section of B-form *Nummulites gizehensis* (Forsk l).
- 4 Upper part of the Darnah Formation at Wadi el Hash, showing wackestone to packstone with common small nummulites. Arrow points to a fragment of *Orbitolites complanatus* Lamarck.
- 5 Uppermost part of the Darnah Formation at Wadi el Hash, showing packstone to grainstone with common remains of nummulites and an equatorial section of *Sphaerogypsina globula* (Reuss).
- 6,7 Lower part of the Al Bayda Formation (Algal Limestone Member) at Wadi al Raheb, showing bioclastic packstone to grainstone with common remains of nummulitids and encrusting calcareous red algae.
- 8 Uppermost part of the Al Bayda Formation (Algal Limestone Member) at Wadi al Raheb, showing bioclastic packstone to grainstone with calcareous red algae, echinoid plates and an axial section of *Nummulites vascus* Joly and Leymerie.





(*Operculina*) and miogypsinids. This association is representative of open to restricted platform. Interestingly, abundant operculinid assemblages, which were assumed to have thrived in open shelf settings down to few tens meters water depth (Hottinger 1983), are limited to the lower part of the formation, suggesting an upward trend towards more restricted conditions.

The sporadic occurrence of small and thick specimens of *Amphistegina* sp. (see text-fig. 12) in the lower levels of the Al Faidiyah Formation may indicate a water depth of less than 30 m. According to Renema (2001), the highest densities of *Amphistegina* species, collected from the Spermonde shelf of South Sulawesi, have been found on shallow, soft substrates (down to 25 meters depth). The maximum depth, however, varies from 9 to 30-33 m around the midshelf reefs. He noted that this pattern is similar to what Troelstra et al. (1996) reported, but they found much higher densities on the reef flat. The amphisteginids test morphology based model for paleodepth reconstruction (Thickness/Diameter ratios) proposed by Mateu-Vicens et al. (2008), however, suggests a development of *Amphistegina* at a water-depth < 30 m, based on specimens from Italy. The prevalence of miogypsinoides upsection, though, is attributed to deposition in a restricted platform palaeohabitat.

The depositional texture of the rock, which consists of wackestone to packstone in the lower part (Facies 4) and packstone to grainstone and locally by grainstone in the upper part (Facies 6) is consistent with deposition in a shallowing environment (see text-fig. 2). In terms of salinity the recovered taxa preferred normal marine conditions.

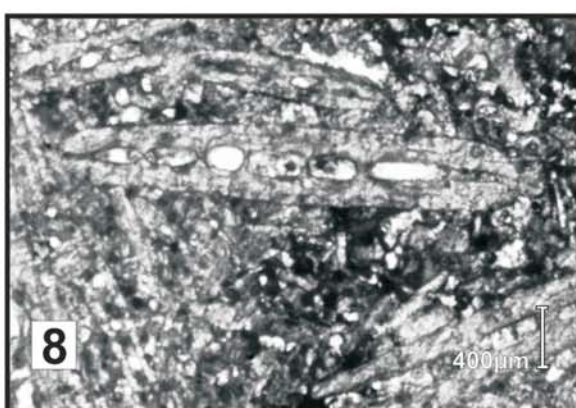
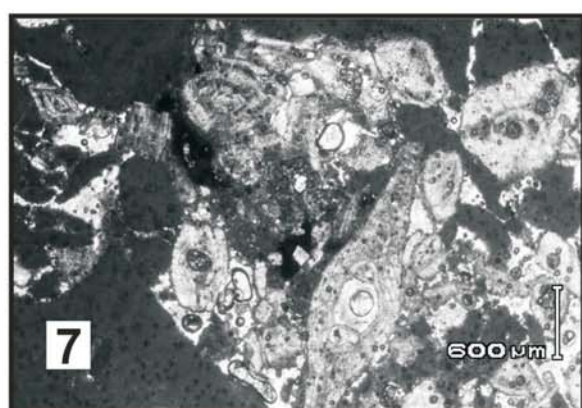
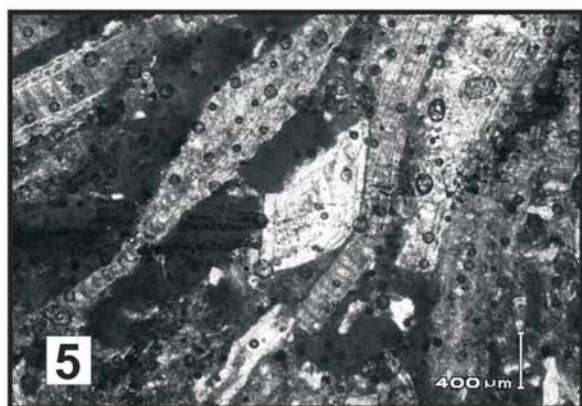
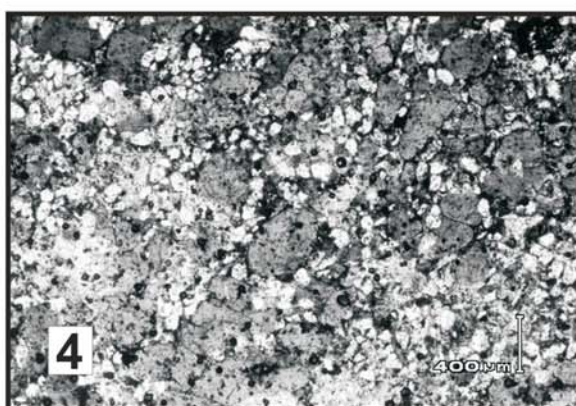
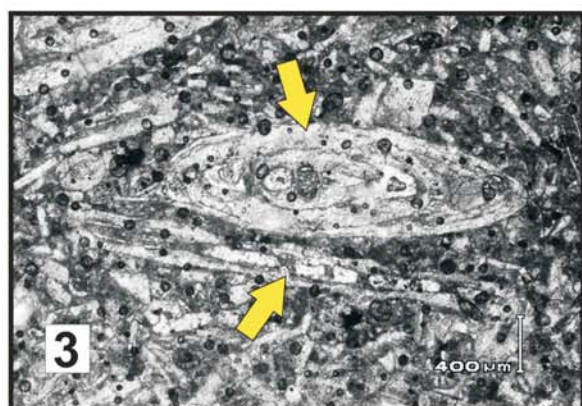
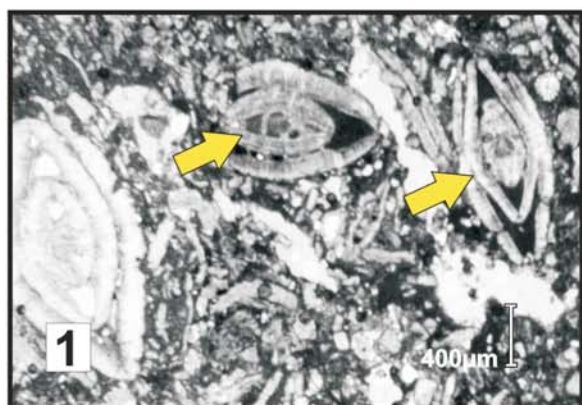
#### Al Jaghbub Formation

The Al Jaghbub Formation is represented in the study area by five different units at outcrop-scale (text-fig. 2, Facies 7-11). They represent one sedimentary cycle and have been identified at the Marsa al Ramla, Wadi al Ayn, and Wadi el Hash sections (text-fig. 3). Facies 7, 8 and 9 are recognised only from the Al Bardia, Wadi al Raheb, and Wadi el Zeitun sections. Two larger benthic foraminifera zones (SBZ25 and SBZ26) are present in this formation. SBZ25 corresponds to the Burdigalian and the base of the zone is marked by the last occurrences of *Miogypsinoides complanatus* and *Nephrolepidina* aff. *touroueri* and the first appearance of *Miogypsina globulina* (Pl. 5, fig. 11). The top of the zone is marked by the last occurrence of the latter taxa and the first appearance of *Borelis melo melo* (Fichtel & Moll) (Pl. 5, fig. 12). Facies 7 and 8 (see text-fig. 2), represents the lower part of the formation. Mudstone grading upsection to packstone and grainstone char-

## PLATE 2

- 1,2 Lower and upper parts of the Al Abraq Formation at Wadi al Raheb, showing bioclastic wackestone to packstone with common nummulitids including *Nummulites vascus* Joly & Leymerie (fig. 1) and *Nummulites fichteli* Michelotti (fig.2).
- 3 Uppermost part of the Al Abraq Formation at Wadi al Raheb, showing packstone to grainstone texture with common broken nummulitids. Arrows point to axial sections of *Nummulites* spp. and *Operculina* sp.
- 4 Base of the Al Faidiyah Formation at Wadi el Hash, showing common rounded to subrounded glauconite pellets (light grey color).
- 5,6 Lower part of the Al Faidiyah Formation at Wadi el Hash, showing bioclastic wackestone to packstone with common association of lepidocyclinids, amphisteginids and operculinids.
- 7 Middle part of the Al Faidiyah Formation at Wadi el Zeitun, showing packstone to grainstone with common calcareous red algae, lepidocyclinids, amphisteginids and operculinids.
- 8 Upper part of the Al Faidiyah Formation at Wadi el Hash, showing packstone to grainstone with longitudinal sections of bryozoa and miogypsinids.





acterizes the lower part of the Al Jaghub Formation (Pl. 3, figs. 1-4).

Zone SBZ26 corresponds to the Langhian and Serravallian (middle Miocene). The base of the zone is marked by the last appearance of *Miogypsina globulina* and the first appearance of *Borelis melo melo*.

The separation between the Langhian and Serravallian stages (see text-fig. 12) is tentatively based on the co-occurrence of the latter taxa with *Heterostegina* cf. *costata* (d'Orbigny) (Pl. 5, figs. 13 & 14) and *Amphistegina* cf. *lessonii* d'Orbigny (Pl. 5, fig. 15). Both species have been previously recovered by Abdulsamad and El Zanati (2013) from the Serravallian and Tortonian deposits of the Ar Rajmah Group at Soluq, southeast of Benghazi city. Herein, the middle part of the Al Jaghub Formation is Langhian in age and is dominated by a grainstone texture (Pl. 3, fig. 5) and locally by wackestone with frequent miliolids (Pl. 3, fig. 6). In the Serravallian, however, the limestone is characterized by abundant pellets of fecal origin cemented by sparry calcite (Pl 3, fig. 7) in the basal section and by dolomitic limestone (>50% dolomite) in the upper section (Pl 3, fig. 8).

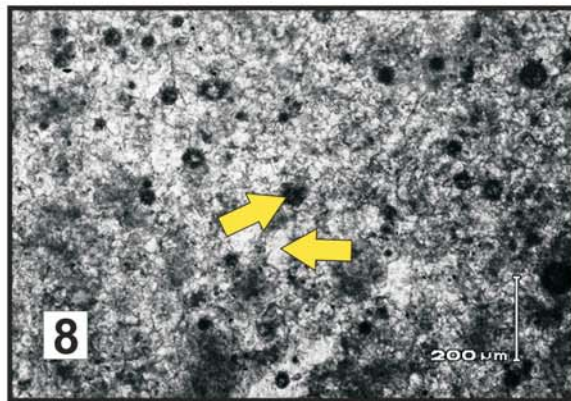
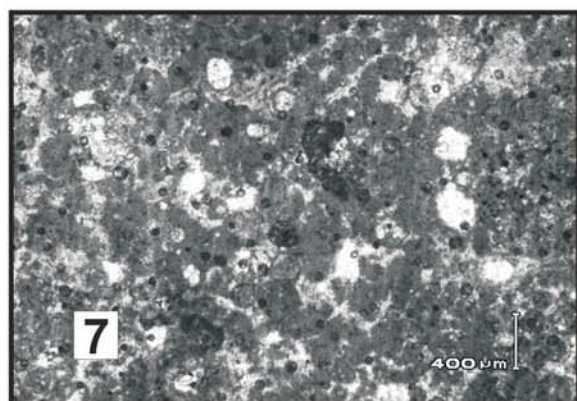
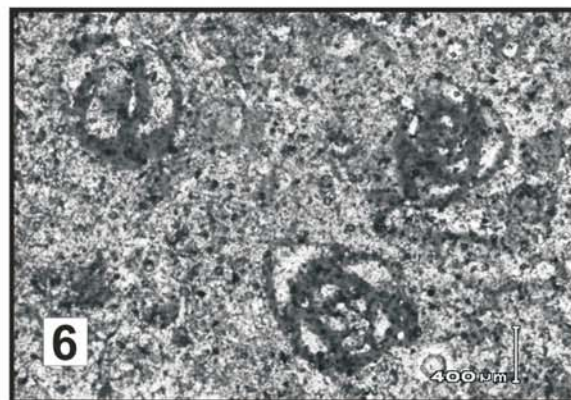
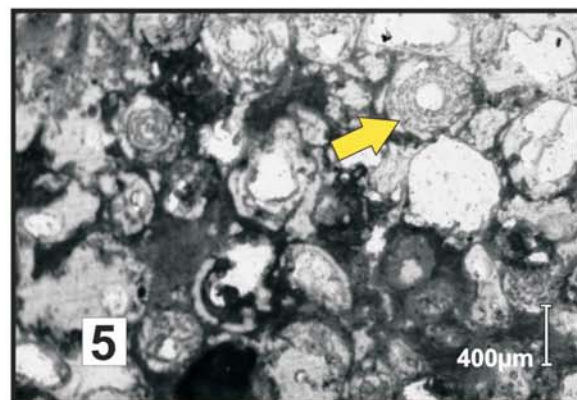
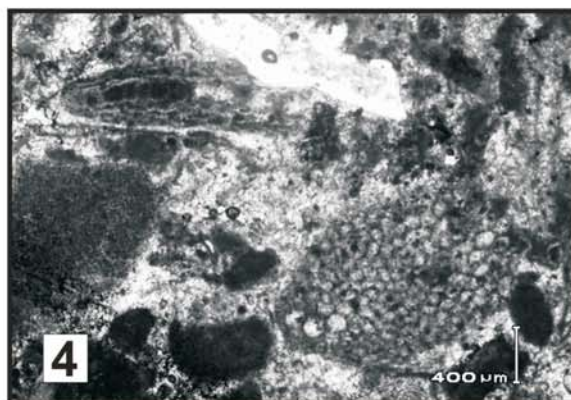
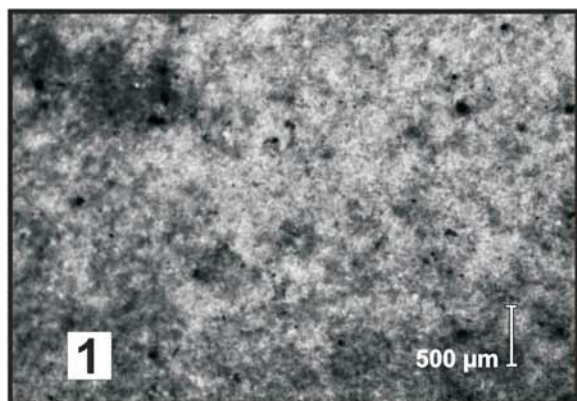
The basal Al Jaghub Formation (Facies 7 and 8), which is early Miocene in age, includes an abundance of open shelf miogypsinids; the middle Miocene sediments of the Al Jaghub (Facies 9-11) are mostly represented by lagoonal to back-reef alveolinids (*Borelis*). This compositional change in larger benthic foraminifera documents a decrease in paleobathymetry up section. The common occurrences of *Miogypsina globulina* and other miogypsinids in the basal Al Jaghub Formation most likely indicates a water depth of < 50 m with normal salinity (see Geel, 2000), whereas the presence of *Borelis* in the upper section indicates shallow water with a depth of up to 35 m and a temperature of 30°C (Hottinger 1974, 1977; Bignot and Guernet 1976; Langer and Hottinger 2000; and Abdulsamad and El Zanati 2013).

The temporary occurrences of *Amphistegina* cf. *lessonii* in the middle of the sequence reflects shallow, soft substrates with maximum depth up to 33 m (see Troelstra, et al. 1996 and Renema et al. 2001). In fact, the latter species shows a very broad depth range in the Indo Pacific from 0-90 meters (Hohenegger et al. 1999), with highest densities around 10-25 meters (Hallock 1984; Hohenegger 1996). It has been reported to have either a preference for sandy (Hallock 1984) or solid substrates (Hollaus and Hottinger 1997).

### PLATE 3

- 1 Base of the Al Jaghub Formation at Wadi al Ayn, showing a mudstone with rare and fine-grained allochems.
- 2,3 Lower part of the Al Jaghub Formation at Wadi el Hash, showing bioclastic packstone to grainstone with common encrusting calcareous red algae (fig. 2), and relatively longitudinal section of scleractinian coral fragments with irregular arrangement of septa (fig. 3).
- 4 Top of the lower part of the Al Jaghub Formation at Wadi el Hash, showing bioclastic packstone to grainstone with *Miogypsina globulina* (Michelotti).
- 5 Middle part of the Al Jaghub Formation at Marsa al Ramla, showing grainstone with equatorial sections of *Borelis melo melo* (Fichtel and Moll).
- 6 Middle part of the Al Jaghub Formation at Wadi el Hash, it showing wackestone with common miliolids.
- 7 Upper part of the Al Jaghub Formation at Marsa al Ramla, showing abundant pellets of fecal origin cemented largely by sparry calcite.
- 8 Upper part of the Al Jaghub Formation at Wadi el Hash, showing a dolomitic limestone with >50% dolomite. Grains of gypsum, iron oxide crystals and tiny unidentifiable bioclasts are also present.





In the Marsa al Ramla section, the upper section of the Al Jaghub Formation is represented by numerous miliolids with infrequent *Borelis melo melo*. According to Hottinger (1983), this assemblage represents an open-shelf setting down to a water depth of a few dozen meters water (see also Abdulsamad and Bu-Argoub 2006). Taken together, the observed conditions confirm that an open shelf environment prevailed in the study area during the early Miocene whereas restricted platform palaeohabitats prevailed in the middle Miocene.

## SUMMARY AND CONCLUSIONS

Six stratigraphic sections were investigated from Cenozoic carbonate deposits along the Tobruk-Al Bardia scarps of northeastern Cyrenaica, NE Libya. The studied sequence comprises five rock units; they are, from oldest to youngest, the Darnah, Al Bayda, Al Abra, Al Faidiyah, and Al Jaghub formations. Based on larger benthic foraminifera and associated microfacies, each of the five main lithostratigraphic units that make up the middle Eocene-middle Miocene represents a shallowing-up sequence. These developed in various parts of a shelf-carbonate platform complex and are separated by hiatuses.

In Wadi el Hash, the middle Eocene (Bartonian) Darnah Formation is present and is overlain by the upper Oligocene to lower Miocene Al Faidiyah Formation. Here, shallow open-shelf environment deposits are indicated by the dominance of large and flat nummulites in the lower and middle parts of the Darnah Formation. The prevalence of common porcellaneous flat Soritidae (Orbitolites) in the upper part, however, indicate a shallowing-up trend and suggests an evolution towards more restricted settings at the end of the nummulite deposition.

In Wadi al Raheb, the Upper Cretaceous deposits of the Al Majahir Formation are separated by an angular unconformity from the overlying lower Oligocene deposits which are mostly represented by the Algal Limestone Member of the Al Bayda Formation. Here, the algal assemblage is dominated by corallinaceans (chiefly melobesioids) in the lower section whereas thick and reticulate nummulitids are the main faunal components of the upper section. Up section, the lower Oligocene deposits of the Al Abra Formation are characterized by the consistent presence of thick and reticulate nummulitids which are interpreted to have thrived in a shallow-shelf palaeohabitat with a vegetated and soft substrate. A disconformity marks the contact between the Al Abra Formation and the overlying upper Oligocene to lower Miocene Al Faidiyah Formation and a basal transgressive glauconite facies of the Al Faidiyah Formation is well-developed.

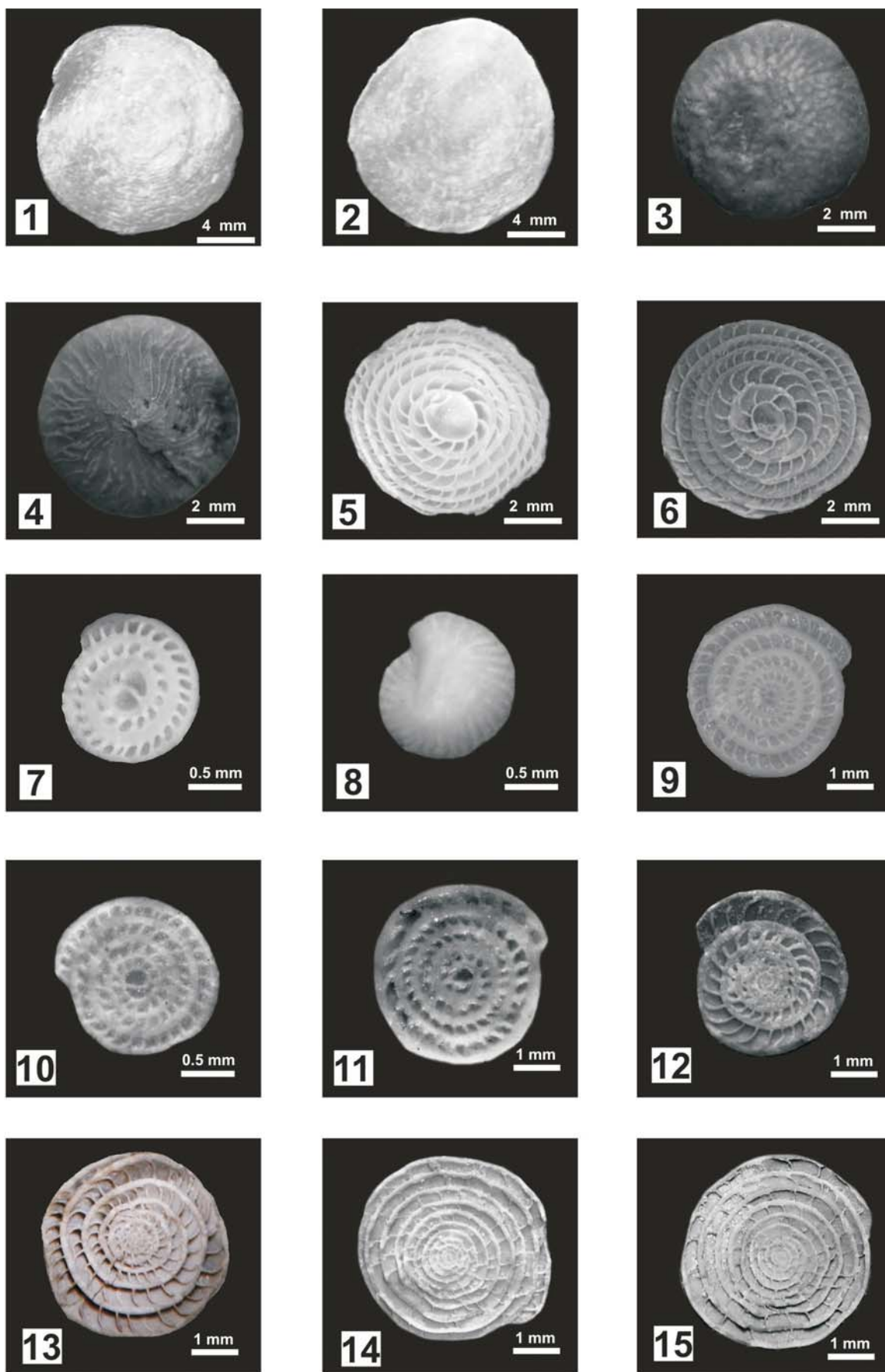
The deposits of the Al Faidiyah Formation are recognized everywhere in the study area and are represented by frequent assemblages of lepidocyclinids, amphisteginids, operculinids and miogypsinids. These associations are commonly associated with an open to restricted platform.

The youngest investigated rock unit is represented by the late lower to middle Miocene sequence of the Al Jaghub Formation. It constitutes the majority of the deposits and has been recognized with sharp and disconformable boundary almost everywhere in the study area. The Al Jaghub Formation is represented largely by open platform deposits with common Miogypsinoides in the basal sections. Restricted settings with common alveolinids (*Borelis*), however, typify the upper levels.

## PLATE 4

- |   |   |
|---|---|
| <p>1,2 <i>Nummulites gizehensis</i> (Forskål), equatorial views of B-Forms, lower part of the Darnah Formation, Wadi el Hash.</p>         | <p>12 <i>Nummulites vascus</i> Joly &amp; Leymerie, internal view of B-Forms, lower part of the Al Bayda Formation (Algal Limestone Member), Wadi el Raheb.</p> |
| <p>3,4 <i>Nummulites gizehensis</i> (Forskål), external views of A-Forms, upper part of the Darnah Formation, Wadi el Hash.</p>           | <p>13 <i>Nummulites vascus</i> Joly &amp; Leymerie, internal view of B-Forms, lower part of the Al Abra Formation, Wadi el Raheb.</p>                           |
| <p>5,6 <i>Nummulites gizehensis</i> (Forskål), internal views of A-Forms, upper part of the Darnah Formation, Wadi el Hash.</p>           | <p>14 <i>Nummulites fichteli</i> Michelotti, internal views of B-Forms, upper part of the Al Bayda Formation, Wadi el Raheb.</p>                                |
| <p>7,8 <i>Nummulites cyrenaicus</i> Schaub, internal and external views of A-Forms, upper part of the Darnah Formation, Wadi el Hash.</p> | <p>15 <i>Nummulites fichteli</i> Michelotti, internal views of B-Forms, lower part of the Al Abra Formation, Wadi el Raheb.</p>                                 |
| <p>9-11 <i>Nummulites discorbinus</i> (Schlotheim), internal views of A-Forms, uppermost part of the Darnah Formation, Wadi el Hash.</p>  |   |





## ACKNOWLEDGMENTS

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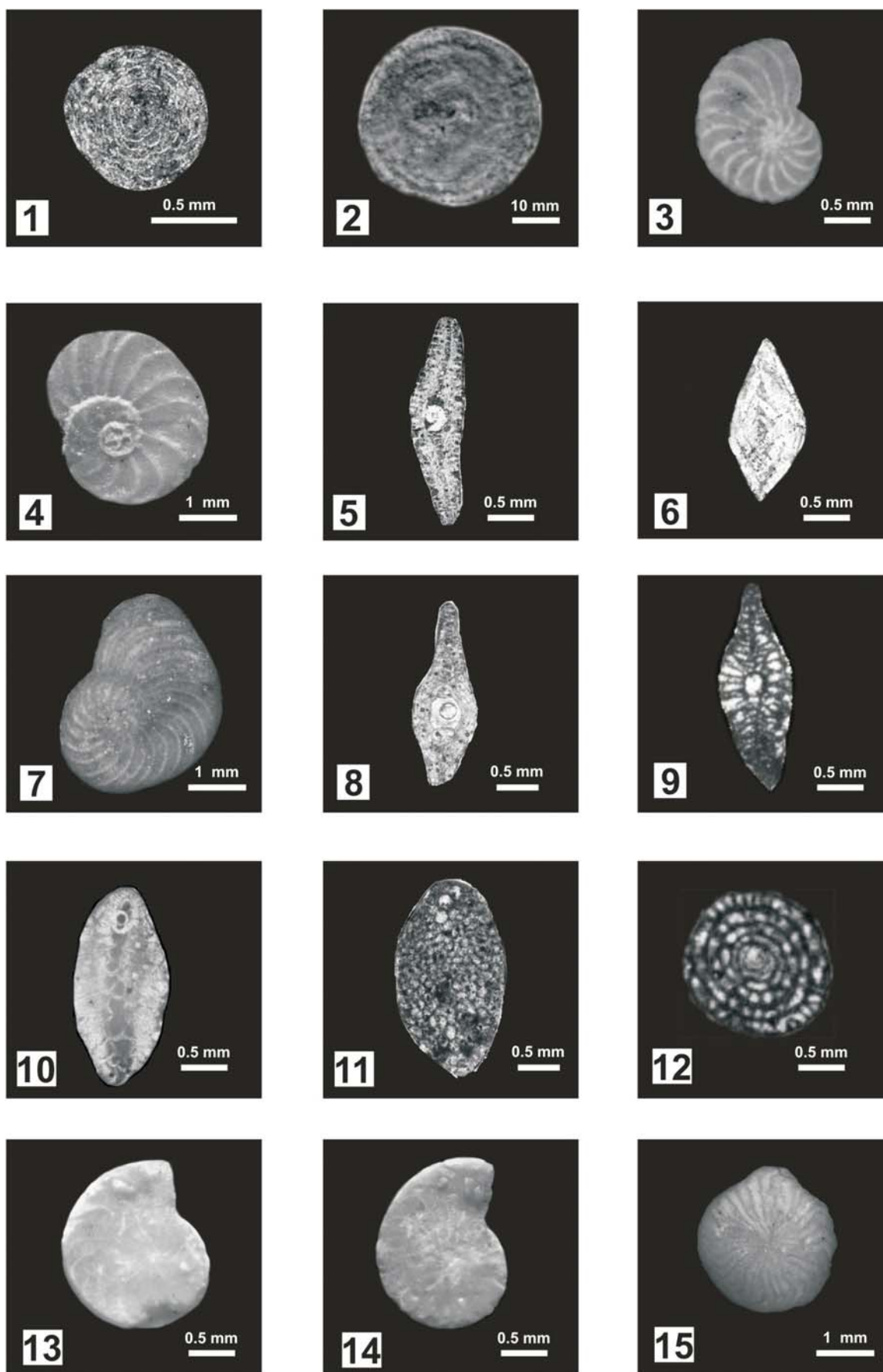
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- 1 *Sphaerogypsina globula* (Reuss), equatorial view, uppermost part of the Darnah Formation, Wadi el Hash.
- 2 *Orbitolites complanatus* Lamarck, equatorial view, uppermost part of the Darnah Formation, Wadi el Hash.
- 3 *Operculina* sp., external side view, uppermost part of the Al Abraq Formation, Wadi el Raheb.
- 4 *Operculina complanata* (Defrance), external side view, upper part of the Al Abraq Formation, Wadi el Raheb.
- 5 *Eulepidina* cf. *dilatata* (Michelotti), axial view, lower part of the Al Faidiyah Formation, Wadi el Hash.
- 6 *Amphistegina* sp. axial view, lower part of the Al Faidiyah Formation, Wadi el Hash.
- 7 *Operculina complanata* (Defrance), external side view, lower part of the Al Faidiyah Formation, Al Bardia.
- 8 *Nephrolepidina* sp., axial view, middle part of the Al Faidiyah Formation, Wadi el Zeitun.
- 9 *Nephrolepidina* aff. *tournoueri* (Lemoine & Douvillé), axial view, upper part of the Al Faidiyah Formation, Wadi el Zeitun.
- 10 *Miogypsinoidea complanatus* (Schlumberger), axial view, upper part of the Al Faidiyah Formation, Al Bardia.
- 11 *Miogypsina globulina* (Michelotti), equatorial view, top of lower part the Al Jaghub Formation, Marsa al Ramla.
- 12 *Borelis melo melo* (Fichtel & Moll), equatorial view, middle part the Al Jaghub Formation, Marsa al Ramla.
- 13, 14 *Heterostegina* cf. *costata* (d'Orbigny), side view, upper part of the Al Jaghub Formation, Marsa al Ramla.
- 15 *Amphistegina* cf. *lessonii* d'Orbigny, external view, upper part of the Al Jaghub Formation, Marsa al Ramla.

## PLATE 5





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## APPENDIX 1

Alphabetical list of taxa recovered from all studied sections

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*Amphistegina* cf. *lessonii* d’Orbigny  
*Amphistegina* sp.  
*Borelis melo melo* (Fichtel & Moll)  
*Eulepidina* cf. *dilatata* (Michelotti)  
*Eulepidina* spp.  
*Heterostegina* cf. *costata* (d’Orbigny)  
*Heterostegina* spp.  
*Lepidocyclina* sp. 1  
*Lepidocyclina* spp.  
*Miogypsina globulina* (Michelotti)  
*Miogypsinoidea complanatus* (Schlumberger)  
*Nephrolepidina* aff. *tournoueri* (Lemoine & Douvillé)  
*Nephrolepidina* sp.  
*Nummulites* aff. *cyrenaicus* Schaub  
*Nummulites* cf. *lyelli* d’Archiac & Haime,  
*Nummulites cyrenaicus* Schaub  
*Nummulites discorbinus* (Schlotheim)  
*Nummulites fichteli* Michelotti  
*Nummulites gizehensis* (Forskål)  
*Nummulites* sp. 1  
*Nummulites* sp. 2  
*Nummulites* sp. 3  
*Nummulites* spp.  
*Nummulites vascus* Joly & Leymerie  
*Operculina complanata* (Defrance)  
*Operculina* sp.  
*Operculina* spp.  
*Orbitolites complanatus* Lamarck  
*Sphaerogypsina globula* (Reuss)