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Taxonomical and biostratigraphical notes on *Nummulites* of Darnah Formation at Daryanah-Al Abyar area, Cyrenaica, NE Libya.

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Highlights

- **The paper deals with taxonomy investigations of the genus Nummulites in Middle Eocene Darnah exposed rocks from Al Jabal al Akhdar based on biometric measurements and/or morphological features from which five species are identified and illustrated.**
- **The studied species assigned to the N. gizehensis biozone.**

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ABSTRACT

Darnah Formation at Wadi Ekhil in Daryanah- Al Abyar area, Al Jabal al Akhdar, Northeast Libya has been subjected to micropaleontological and biostratigraphical analyses based on larger foraminifera "*Nummulites*" which has largely used as a time marker in the Tethyan region (Circum-Mediterranean). Taxonomical measurements were performed during this study from which the following five species were identified, *Nummulites gizehensis, N. lyelli, N. beaumonti, N. striatus* and *N.* sp.

The studied sections assigned to the i) *N. gizehensis* biozone Late Eocene "Late Lutetian" age due to the acme occurrence of the zonal marker species *N. gizehensis*; and ii) *N. lyelli* biozone Late Eocene "Biarritzian" due to the total range of the zonal marker species *N. lyelli*. The concerned nummulites-bearing sections of Darnah Formation indicate an inner neritic environment of bank settings as indicated by A/B ratio.

1. Introduction

Nummulites is a genus belonging to the order foraminiferida, with a shell made of a perforated low Mg-calcite hyaline wall. They are commonly extracted from limestones and dolomites but rarely with clastic sediments. The dimorphism phenomenon (alternation of generation between the asexually produced A-Form and the sexually produced B-Form) is well known in *Nummulites*. The speciation of *Nummulites* depends largely on morphological and structural features which depend largely on measurements done by using calibrated eyepiece micrometer, among these are 1) The relationship between diameter and thickness of the test; 2) Juvenile apparatus (protoconch); 3) Shape of both chamber and septa; 4) Septal filaments which are the only external morphological features besides granulations and nodes. 5) The spiral diagram which shows the relation between the number of whorls and the corresponding radii of both A- and B-forms as compared to Schaub (1981) and/or Racey (1995) spiral diagrams were also used in identifications of some species in the current study, depends on number of retrieved specimens.

Nummulites is the most useful diagnostic larger benthic foraminifera throughout the Paleogene of the Mediterranean region. The collected *Nummulites* tests used herein are retrieved from the Middle Eocene Darnah Formation in Al Jabal al Akhdar, NE Libya. The most valuable work using *Nummulites* in Al Jabal al Akhdar has been published by Abdulsamad (2000) who studied the larger foraminifera with detailed biometric descriptions of *Nummulites* from selected exposures in Al Jabal al Akhdar, NE Libya, where, *Nummulites gizehensis, N. lyelli, N. beaumonti, N. striatus, N. cyrenaicus*, and *N. discorbinus* are documented. Abdulsamad and Barbieri (1999), however, reported *N. gizehensis, N.* cf. *cuvillieri* and *N. subdiscorbinus* from Darnah Formation in the Well A1-36 drilled in Al Jabal al Akhdar southeast of Darnah city. Muftah and Boukhary (2013) reported the *N. fabianii* and *N. ruetimeyeri* as well as *Gaziryina pulchellus* from the Late Eocene Shahhat Marl Member of Al Bayda Formation. The main aim of this paper is to: 1) Produce a comprehensive systematic study of the retrieved *Nummulites* species from Darnah Formation in the area of study. 2) Establish the possible foraminiferal biozones with its regional extent. 3) Determine the depositional environment. The studied section of Wadi Ekhil is located in the lower escarpment of Al Jabal al Akhdar in the northeast of Libya (Fig. 1).

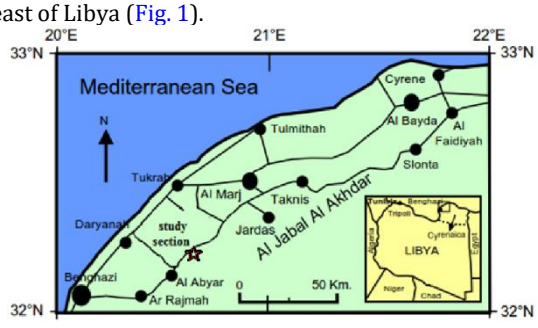

Fig. 1. Location map of the study area shows the location of Wadi Ekhil (Modified after Abdulsamad *et al*., 2009).

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2. Materials and methods of study:

The Fourteen rock samples have been collected from the measured section at Wadi Ekhil (Fig. 2). After the separation of the *Nummulites* tests from the contained sediments by the Standard Micropaleontological Techniques for the separation of *Nummulites* (see Schaub, 1981; Racey, 1995; Abdulsamad, 1999). The small-sized *Nummulites* were picked using the binocular microscope, whereas the large-sized ones were picked by the naked eye. Most picked nummulites-tests were heated in a Bunsen flame until it is glowed red hot, then quickly dropped into a glass beaker of cooled water. The *Nummulites* consequently became equatorially split apart into two identical halves and the internal morphological features were examined and biometrically measured under the binocular microscope. Measurements of protoconch size, chamber geometry, septa shape and radii of successive whorls were essential to build up the spiral diagrams. Spiral diagrams were drawn for the available *Nummulites* as a technique to identify the *Nummulites* species using Schaub's (1981) monumental monograph. The *Nummulites* were biometrically analyzed, photographed and thin-sectioned axially, equatorially and externally. To calculate the A/B ratio, Kondo (1995a) method on a quadrat of 15×15 cm is performed in the outcrops.

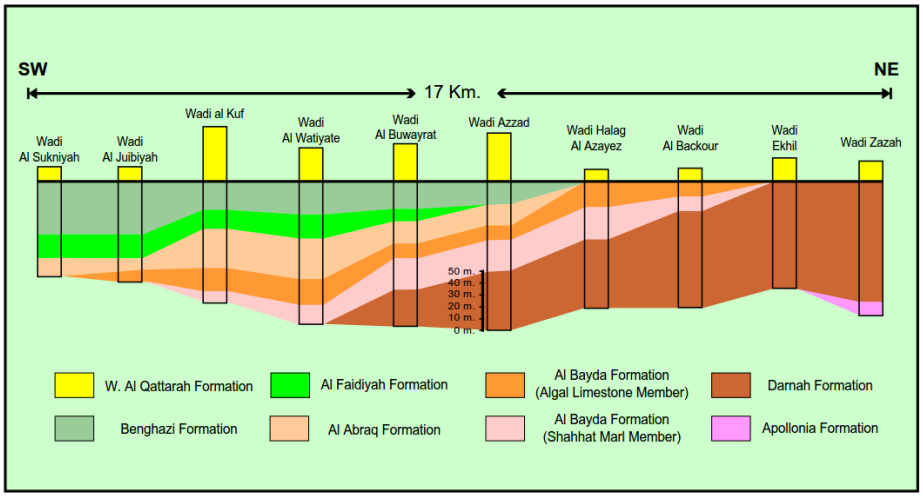

Fig. 2. Stratigraphic correlation of the study area including Wadi Ekhil (present study) (Abdulsamad *et al*., 2009).

3. Background and stratigraphy

The stratigraphy of the study area consists of five formations ranging in age from Middle Eocene to Late Miocene, which are Apollonia, Darnah, Al Bayda, Al Abraq and Wadi al Qattarah formations (see Abdulsamad *et al*., 2009). The best example to understand the stratigraphy of the study area and its environs are that conducted by Abdulsamad (2009), who included Wadi Ekhil in his stratigraphic logs correlation (Fig. 2). Only one outcrop has been sampled at Wadi Ekhil, from which only Darnah Formation are described herein and subdivided into two units (Figs. 3 and 4), the lower one is made of Foraminiferal wackestone-packstone, whitish yellow, very hard, massive bedded, rich in *Nummulites* spp. and some *Sphaerogypsina globula* with some echinoderm remains (Fig. 4a).

However, the upper one is nummulithoclastic packstone, white to creamy colored, moderately soft- medium hard, massive, and rich in *Nummulites* spp., nummulitic debris and some Gastropoda (Fig. 4b).

Darnah Formation at the study area yields a thickness of about 90m and consists of two nummulitic limestone units varying in texture between wackestone to packstone particularly in the lowermost two units (Fig. 3). The bioclastic grains are mainly *Nummulites* of small-sized *"N. striatus* and *N. beaumonti*" and large-sized "*N. gizehensis*, *N. lyelli* and *N*. sp.". Rare specimens of *Sphaerogypsina globula* are also occurred in the lowermost unit. Nummulithoclasts, with *N. beaumonti* and *N. lyelli*, *N. striatus* and *N*. sp. however, dominate the middle and upper part of the studied section (Fig. 3).

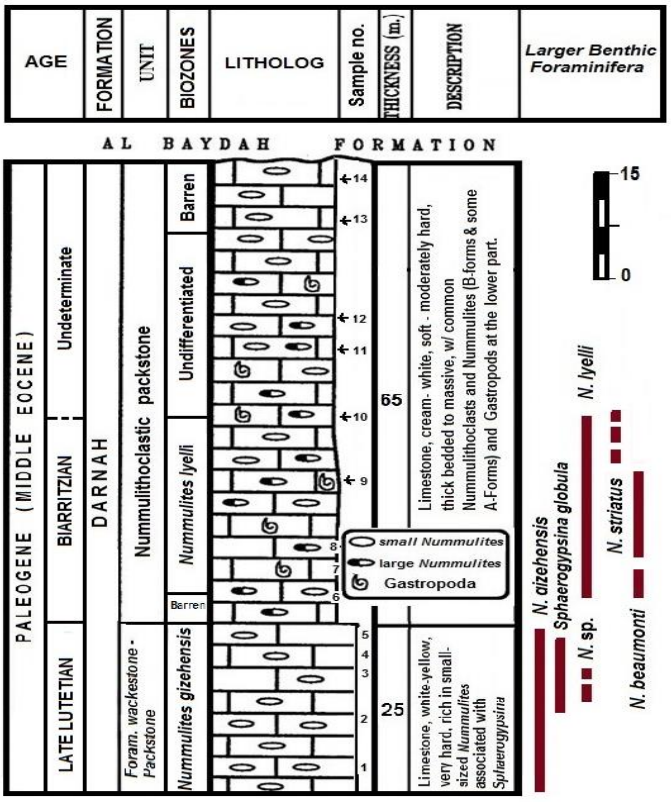

Fig. 3. Columnar section of Darnah Formation at Wadi Ekhil, with larger Foraminifera distribution chart.

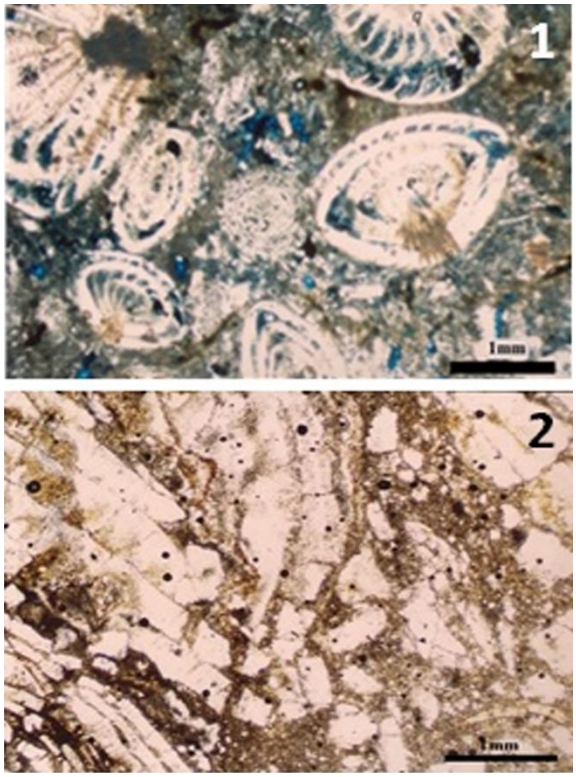

Fig. 4. a) Foraminiferal packstone of Darnah Formation, shows the *Nummulites* sp. (A- Form). and *Sphaeogypsina globula*; and b) Nummulithoclast wackestone-packstone dominated by nummulithoclasts and *Nummulites* sp. at Wadi EKhil.

4. Systematic paleontology

The classification of Loeblich and Tappan (1988) are followed herein for the suprageneric ranks. The studied material will have a final repository in the Geological Museum of the University of Benghazi (Benghazi, Libya).

Order: Foraminiferida Eichwald, 1830
Suborder: Rotaliina Delage and Herouard 1896
Superfamily: Nummulitacea de Blainville1827
Family: Nummulitidae de Blainville 1827
Genus: *Nummulites* Lamarck (1801)
Type species: *Camerina laevigata* (Bruguiere), 1792
Nummulites gizehensis (Forskål, 1775)

(Pl. I, Figs. 1-6)

1775 *Nautilus gizensis* (Forskål), p.140.

1965 *Nummulites gizehensis* (Forskål), Bozorgnia and Kalantari, pl. 6

1982 *Nummulites gizehensis* (Forskål), Boukhary, Blondeau and Ambroise, p. 72, pl. 1, Figs. 13, 14

Materials: 129 (B-Form) specimens and 402 (A-Form) specimens

Description:

*B-Form***:** Test lenticular, surface undulated, septal filaments flexuous to meandering, granulated in the juveniles while none granulated in the adults. Diameter ranges from 33-43.6 mm and thickness ranges from 7.8-9.8 mm.

Equatorial section: The spiral diagram (Fig. 5) the relation between the number of whorls and the corresponding radius in the median section. The spire is regular, the steps of coiling are lax and the number of whorls is as follows: 43 whorls in a radius of 23.1 mm, 41 whorls in a radius of 22.4 mm, 33 whorls in a radius of 18.3 mm 20 whorls in a radius of 9.4 mm and 10 whorls in a radius of 3.7 mm, septa are thin, regular, vertical at the base and then slightly arched near the end. The marginal cord is thick; chambers are mostly higher than long and longer than height in last whorls.

*A-Form***:** Test lenticular and truncated, septal filaments flexuous to sigmoidal, granulation present on and between filaments. Diameter ranges from 6-7.5 mm and thickness ranges from 3.3-4.3 mm.

Equatorial section: The spire is regular; all whorls are lax and regular. The numbers of whorls per radius are shown on the spiral diagram (Fig. 5) and as follows: 5 whorls in a radius of 3.6 mm, 4 whorls in a radius of 3.5 mm, and 4 whorls in a radius of 2.4-3.1 mm. The septa are arched at first whorls then straight at the base and inclined at the top. The marginal cord is thick; chambers are more or less isometric. The size of protoconch ranges from 1.15-1.8 mm. A characteristic taphonomical feature in form of boring tests is commonly observed in the B-Form tests (Fig. 6).

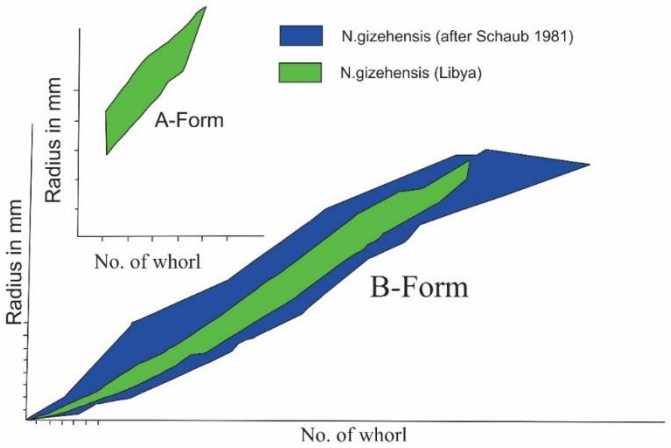

Fig. 5. Spiral diagram showing the relation between the number of whorls and the corresponding radius in equatorial section of *N. gizehensis*

Fig. 6. *Nummulites gizehensis* (A- and B-forms) shows the bored B-Form, Darnah Formation at Wadi Ekhil section.

Occurrence: *Nummulites gizehensis* are found in Darnah Formation at Wadi Ekhil at 185-190 meters above sea level. It also reported by Abdulsamad and Barbieri (1999) in the Darnah Formation from the surface exposure at Cyrene-Apollonia roadcut section as well as in subsurface A1-36 Well.

Age: Middle-Late Lutetian (Racey, 1995 and Hottinger *et al*., 1964).

Nummulites lyelli d'Archiac & Haime, 1853

(Pl. II, Figs. 1, 2, 4, 5)

1853 *Nummulites lyelli* d'Archiac and Haime, p.95, pl. 3, Figs.1a, 1b, 2

1981 *Nummulites lyelli* d'Archiac and Haime, Schaub, p. 116, table. 6, fig. e; pl. 38, figs. 18-20.

1995 *Nummulites lyelli* d'Archiac and Haime, Racey, p. 52, pl. 5, Figs. 7, 10-11

Materials: 65 (B-Form) specimens and 206 (A-Form) specimens

Description:

B-Form: Test flat with slight thickening at center, septal filaments flexuous to meandering, granulation appear in the juvenile test, while disappear on the adult's surfaces. Diameter ranges from 33.5–64.2 mm and thickness ranges from 6.2–11.6 mm.

Equatorial section: As shown on the spiral diagram "Winding diagram" (Fig. 7) the relation between the number of whorls and the corresponding radii in the median section, the spire is rather regular, the steps of coiling and number of whorls are as follows: 30 whorls in a radius of 12-18.95 mm, 40 whorls in a radius of 22.3 mm and 57 whorls in a radius of 26.8 mm. Septa are thin, regular, vertical straight in the first part and then slightly arched near the end. The marginal cord is thick; chambers are higher than length in the majority of the whorls and slightly longer than height in the peripheral whorls in some individuals.

A-Form: Test lenticular with a sharp edge, septal filaments are flexuous to undulated, granulation is visible, with more concentration toward the periphery. Diameter ranges from 5 to 8 mm and thickness ranges from 2.1 to 3.69 mm.

Equatorial section: The spire is regular, lax in the early two whorls to tight in most part of the whorls. The number of whorls per radius is shown on the spiral diagram (Fig. 7) and as follows: 5 whorls in a radius of 2.6–3.5 mm, and 6 whorls in a radius of 2.9–4.1 mm. The septa in the internal whorls are inclined and somewhat irregular, while in the external part, they are regular or isometric and mostly straight to relatively inclined. Chambers are higher than length with some exceptions in the last two whorls. The size of protoconch ranges between 1.07–1.61 mm. The measurement of the present study of the *N. lyelli* in comparison with that of Schaub (1981) is listed in Table 1.

Remarks: Pillars in *Nummulites lyelli* de La Harpe are radiates from the pole, while in *Nummulites gizehensis* are zoned in the middle.

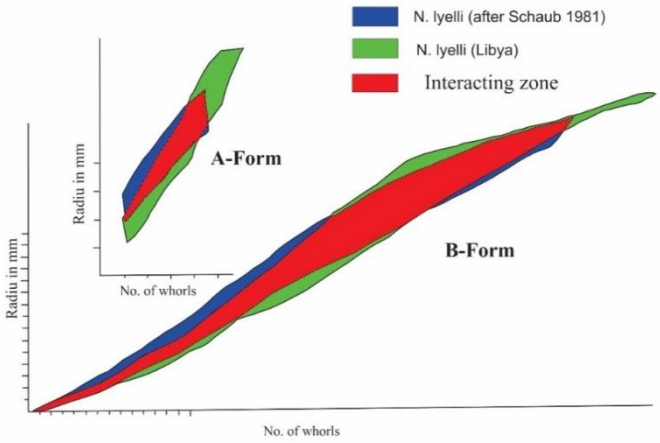

Fig. 7. Spiral diagram showing the relation between the number of whorls and the corresponding radius in an equatorial section of *N. lyelli*

Occurrence: Darnah Formation, at Wadi Ekhail 200 meters above sea level.

Age: Late Lutetian (Biarritzien) Racey, (1995); Hottinger *et al.*, (1964); and Boukhary and Kamal (2003).

Table 1

Dimensions of *Nummulites lyelli* (present study) compared with Schaub, (1964).

Measurements	*N. lyelli* Schaub, 1981	*N. lyelli* **(present study)**
Diameter & Thickness	B-form D/20-25 nan T/3-6.5 mm	B-form D/33.5-64.2 mm T/6.2-11.6 mm
	A-form D/5-7 mm T/2-3 mm	A-form D/6-8 mm T/2.1-3.6 mm
Granulation	Present	Present
No. of Whorls	B-form 50 whorls in a radius of 25 mm 44 whorls in a radius of 23-25.7 mm 41 whorls in a radius of 18.5 mm	B-form 57 whorls in a radius of 26.8 mm 41 whorls in a radius of 18 -22.3 mm 30 whorls in a radius of 12 – 18.95 mm
	A-form 5 whorls in radius of of3 4-3,7 mm 6 whorls in radius of 3.l-3.S mm 7 whorls in a radius of 4 mm	A-form 5 whorls in a radius of 2.6 -3.5 mm 6 whorls in a radius of 2.9-4. 1 mm
Protoconch size	B-form	A-form
	1-1.5mm	1.07-1.61 mm

Nummulites sp.

(Pl. II, Figs. 3, 6)

Materials: 2 (B-Form) specimens and 2 (A-Form) specimens

Description:

B-Form: Test lenticular, surface undulated, with a thin margin. Diameter ranges from 33.5-38.5 mm and thickness ranges from 6.7-9.2 mm.

Equatorial section: The spire is irregular; the steps of coiling are more or less tight to lax. Septa are thin, vertical at the base then slightly arched near the end. The marginal cord is thick; chambers are isometric at first half of the whorls then subrectangular.

A-Form: Test lenticular, granulation present all over particularly around the poles of the test. Diameter ranges from 6.1-6.6 mm and thickness ranges from 3.0-3.3 mm.

Equatorial section: The spires tend to be lax but start to be tight after the first two whorls. The septa are arched at first whorls then straight to inclined in the successive whorls. Chambers are higher than long. The size of protoconch ranges from 1.46-1.54 mm.

Occurrence: Darnah Formation, at Wadi Ekhail 185-190 meters above sea level.

Age: Middle Eocene (Lutetian)

Nummulites beaumonti d'Archiac and Haime, 1853

(Pl. III, Figs. 1-2)

1853 *Nummulites beaumonti* d'Archiac & Haime, p. 133, pl. 8, figs.1 a-e, 2, 3.

1981 *Nummulites beaumonti* d'Archiac & Haime; Schaub, p. 135, table 14, fig. p, pl. 53, figs. 17-19, 22-25.

Materials: 2 (B-Form) specimens and 2 (A-Form) specimens

Description:

B-Form: Test lenticular with rounded margin, septal filaments flexuous from the center, granulation absent. Diameter ranges from 7.1-12.2 mm and thickness ranges from 3.1-5.6 mm.

Equatorial section: The spire is regular, septa start straight then inclined, and the marginal cord is thick and chambers sub rectangular.

A-Form: Test lenticular and globular, septal filaments are flexuous, granulation absent. Diameter ranges from 3.2-3.5 mm. and thickness ranges from 1.6- 1.9 mm.

Equatorial section: The spire is regular and lax, the marginal cord is thick, and the chambers are sub rectangular. The size of the protoconch is very small and ranges from 0.1- 0.13 mm.

Occurrence: Found in Darnah Formation, in the Wadi Ekhail section at an elevation of 200 meters above sea level. It also reported by Abdulsamad (1999) from the Darnah Formation at Cyrene-Apollonia roadcut section.

Age: Middle Eocene (latest Lutetian –earliest Biarritzian) Racey, 1995; Blondeau, (1972).

Nummulites striatus (Bruguiere, 1792)

(Pl. III, Figs. 3-5)

1853 *Nummulites striata* d'Orbigny; Archiac & Haime, p. 135, pl. 8, Figs.9-12.

1972 *Nummulites striatus* (Bruguiere); Blondeau, p. 148, pl. 24, Figs. 1-10.

Materials: 2 (B-Form) specimens and 2 (A-Form) specimens

Description:

B-Form: Test lenticular with a thin margin, septal filaments radiating from the center, granulation absent. Diameter ranges from 6.4-10.08 mm and thickness ranges from 3.08-4.9 mm.

Equatorial section: The spire is more or less tight to lax; septa are arched, vertical to inclined. The marginal cord is thick; chambers are higher than length

A-Form: Test lenticular with a thin margin, septal filaments are radiating, granulation absent. Diameter ranges from 3.08-3.23 mm and thickness ranges from 1.54-1.8 mm.

Equatorial section: The spire is regular and lax, the marginal cord is thick, chambers are higher than length except in the earlier whorls chambers are isometric, and the size of protoconch is small and ranging from 0.12- 0.15 mm (two specimens are measured only).

Occurrence: Found at Darnah Formation, in Wadi Ekhail section at 200 meters above sea level.

Age: Middle Eocene (latest Lutetian –earliest Biarritzian), Racey (1995); Blondeau (1972).

5. Results and discussions

The collected ten samples from the Darnah Formation at Wadi Ekhil yield larger benthic foraminifers (i.e. *Nummulites*) *Nummulites gizehensis* and *N. lyelli* of both forms with minor elements of *N. striatus*, *N. beaumonti*, and *N.* sp. and *Sphaerogypsina globula*. The only established local biozones in Wadi Ekhil area are the *Nummulites gizehensis* Biozone and the overlying *Nummulites lyelli* biozone.

***Nummulites gizehensis* Biozone (Middle-Late Lutetian):**

The zonal marker *N. gizehensis* is widely distributed in the Eocene sediments of Mediterranean belt and is documented by Abdulsamad (2000); Abdulsamad *et al*., (2009); Abdulsamad and Barbieri (1999) in Al Jabal al Akhdar region. *Nummulites gizehensis* bed are documented by Aigner (1982) in the Lutetian Mokattam Formation in Giza Pyramid Plateau West of Cairo and Mokattam Hill East of Cairo. It is recognized herein due to the common occurrence of the zonal marker *Nummulites gizehensis* to the occurrences (FO) of *N.* sp.. In association with *Sphaerogypsina globula.* It was described from Sirt Basin by Arni (1965). This biozone is established by Kenawy *et al*., (1993) within Samalut Formation in the Nile Valley, who defined it as the interval from the first appearance of *N. gizehensis* to the first appearance of *N. beaumonti*. Bristot and Duronio (1985) covering the interval range of Early-Middle Lutetian also document it in Bouri Oil field as Nummulites gizehensis (Reineche horizon) Loculicytheretta semirugosa Biozone. However, the species is reported in Oman within Middle Lutetian *N. beucharnensis* biozone to Late Lutetian of *N. aturicus* by Schaub (1981) and Racey (1995).

***Nummulites lyelli* Biozone (Biarritzian)**

It is recognized herein due to the total range of the zonal marker *Nummulites lyelli.* In association with *Nummulites beaumonti, Nummulites striatus* with the absence of *Nummulites gizehensis*. It is widely distributed in the Eocene sediments of the Mediterranean belt. Abdulsamad (2000) documents the zonal marker from surface and subsurface successions, Abdulsamad *et al*., (2009); Abdulsamad and Barbieri (1999) in Al Jabal al Akhdar region.

Depositional process:

The ratio between asexual form (Form-B) to sexual form (Form-A) in most recent works of normal ratio of A /B is 10/1 Moody (1998). Louks *et al*., (1998) considered the A/B ratio due to the biological reproductive strategy and linked to changing environmental conditions and not by hydraulic sorting. The in-situ accumulation of *Nummulites* is expressed by A/B ratio of (10/1) as suggested by Blondeau (1972); Kondo (1995b) and Aigner (1982, 1983, 1985). In Middle Eocene of Pederiva di Grancona and Mossano sections in Veneto of northern Italy, the bank sediments with A/B ratio being low in comparison with the "normal" nummulitic limestone (Seddighi and Papazzoni, 2011). The A/B ratio in the present study has been calculated for *N. gizehensis* specimens and found to be of larger proportions 167/24 (≈7/1). This higher A/B ratio revealed that the original *Nummulites* assemblages were winnowed in situ with the extensive boring particularly within B-Form tests (Fig. 6), although good preservation noted in A-forms suggesting a bank depositional setting. In addition to that and due to the absence of the outer ramp indicators "discocyclinids and globigeriniids" as well as the inner ramp indicators "miliolids and textulariids" Cotton and Pearson, (2011), therefore, a shallow neritic bank environment is highly suggested to the lower part of the studied Darnah Formation at Wadi Ekhil section. A comparison of the A/B ratio with other studies is listed in Table 2, which shows close similarities except that of Braiser and Green (1993) from Barton Clay in the Isle of Wight.

Table 2

A/B ratio from present studies and others.

Author	A/B ratio	Formation	Age	Country
Aigner (1983)	7/1	Mokhattam	Eocene	Egypt
Abdulsamad and Barbieri, 1999	15/1	Darnah	Middle Eocene	Libya (Al Jabal al Akhdar) CA section.
Brasier and Green, 1993	59/1	Barton Clay	Late Eocene	Isle of Wight
Blondeau (1972)	10/1	Al Garia	Early Eocene	Tunisia
Present study	7/1	Darnah	Middle Eocene	Libya (Al Jabal al Akhdar) Wadi Ekhil

6. Conclusions

1- Darnah Formation at this section subdivided into two litho-units (foraminiferal wackestone-packstone and the overlying nummulithoclastic packstone).

2- Five *Nummulites* taxa "*N. gizehensis, N. lyelli, N. beaumonti, N. striatus* and *N*. sp. are identified, described and illustrated from Wadi Ekhil, at Daryana-Abyar area, NE Libya.

3- The *Nummulites gizehensis* and *N. lyelli* are recognized within the section.

4- The studied Darnah Formation at Wadi Ekhil section is deposited under a shallow neritic bank environment as suggested from the A/B ratio.

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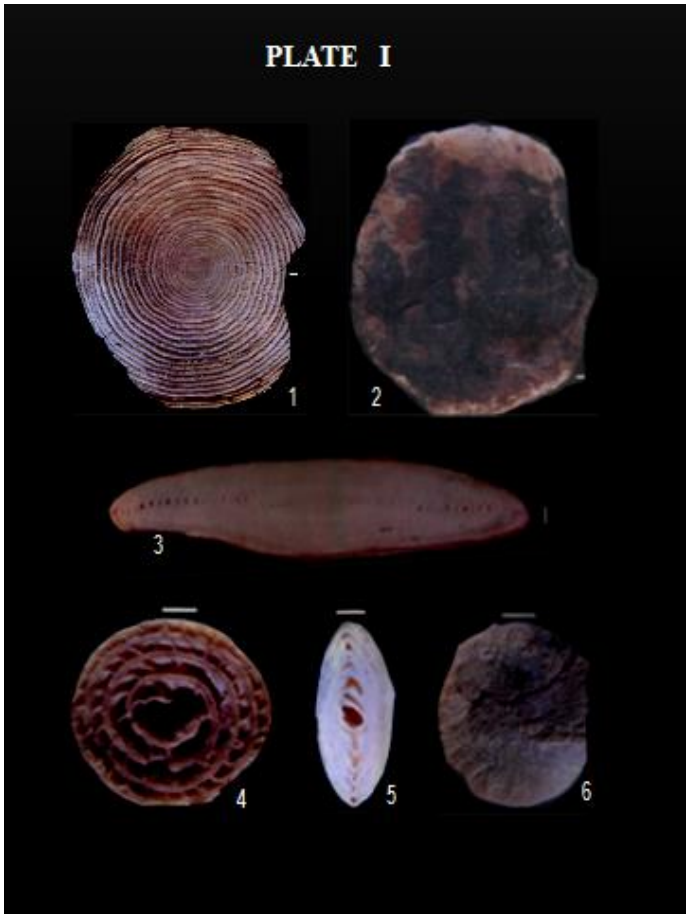


Explanation of Plate 1 (All scale bar = 1 mm)

1, 2, 3: *Nummulites gizehensis* (B-Forms) equatorial section, an external view and axial section respectively (each photograph represents a different specimen).

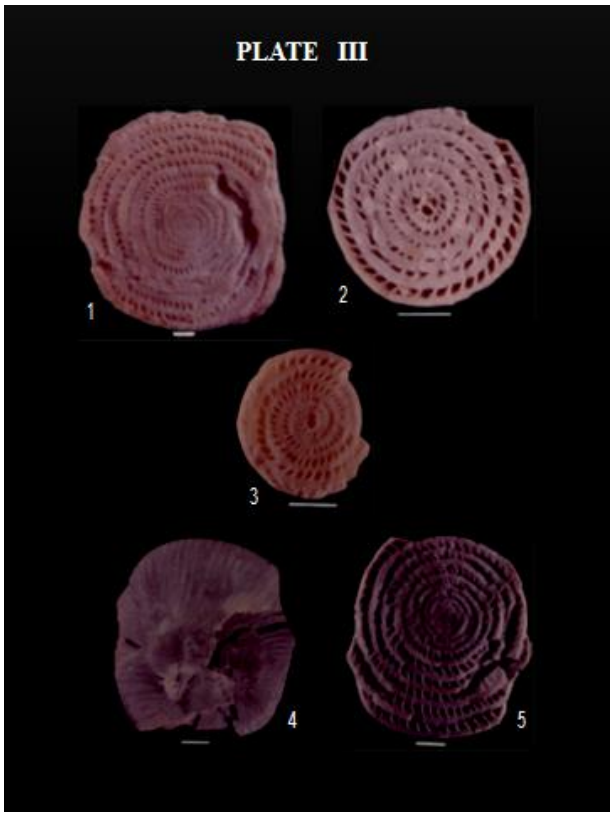
4, 5, 6: *Nummulites gizehensis* (A-Form) equatorial sections, axial section and external view respectively (each photograph represents a different specimen).

Explanation of Plate II (All scale bar = 1 mm)

1, 2: *Nummulites lyelli* (B-Form) axial section and equatorial section respectively (each photograph represents a different specimen).

4, 5: *Nummulites lyelli* (A-Form) equatorial and axial sections respectively (each photograph represents a different specimen).

3, 6: *Nummulites* sp. equatorial sections of B- and A-forms respectively.



Explanation of Plate III (All scale bar = 1 mm)

1, 2: *Nummulites beaumonti* equatorial sections of B & A forms respectively

3, 5: *Nummulites striatus* equatorial section of A& B forms respectively.

4: *Nummulites striatus* external view.