



# Contribution to the biostratigraphy of the Middle-Upper Eocene rock units at North Eastern Desert; an integrated micropaleontological approach



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## ABSTRACT

Foraminifera and calcareous nannofossils have been integrated to improve the biostratigraphy of the Middle-Upper Eocene rocks at North Eastern Desert. Biostratigraphic analysis has enabled the identification of three planktic biozones, *Globigerinatheka kugleri/Morozovella aragonensis* (E9), *Morozovelloides crassatus* (E13) and *Turorotalia cerroazulensis pomeroli/T. cerr. cerroazulensis*. Meanwhile, the occurrence of calcareous nannofossils *Reticulofenestra dictyoda*, *Pontosphaera multipora* and *Reticulofenestra umbilica* within *Morozovelloides crassatus* Zone (E13) were attributed to *Discoaster saipanensis* Zone (NP17). Furthermore the quantitative analysis of small benthic foraminifera suggests four benthic assemblages (abundance zones) which correlated with their equivalents in the study area and neighboring areas. Therefore, a Middle Lutetian age (~45.8 Ma) is proposed for Observatory Formation which dated back to the Bartonian. While, the Qurn Formation is assigned to late Bartonian-early Priabonian age with paraconformity (~3.6 Ma) between the Observatory and Qurn formations as the result of tectonic instability at the late of Lutetian age. All of the recorded planktic species discontinue at the upper Eocene Maadi Formation of Priabonian age where the environment turned more shallowing inconsistent with planktic habitat. The Lutetian/Bartonian and Bartonian/Priabonian stage boundaries have been also discussed.

## 1. Introduction

The Middle-Late Eocene is characterized by a long term cooling which interrupted by the Middle Eocene Climatic Optimum (Bohaty and Zachos, 2003; Luciani et al., 2007; Bijl et al., 2009; Edgar et al., 2010; Sexton et al., 2011). Planktic foraminiferal and calcareous nannofossils were among the marine habitat undergo diversity reduction and productivity (Zachos et al., 2001; 2001; Boscolo Galazzo et al., 2014). The Larger benthic Foraminifera (LBF) commonly represented and make a greater contribution to primary production than phytoplankton (Sournia, 1976; Murray, 2006). The cross correlation between the planktic foraminifera and LBF is often difficult due to exclusive depositional environments for both (Cotton and Pearson, 2011).

The Eocene outcrops (Fig. 1) in Egypt cover about 21% of the surface area (Said, 1990) with well-marked and varied lithologies (Embabi, 2018). At north of the Eastern Desert, the Middle-Upper Eocene exposures are conspicuous in the mountainous blocks around Cairo-Suez road (Shukri and Akmal, 1953). The biostratigraphy, in particular, has been the focus of much recent research based on LBF and macrofossils (e.g. Faris and Abbass, 1961; Abdallah and Abdel-Hady, 1969; Barakat and

Abou Khadrah, 1971; Strougo and Abd-Allah, 1990; Strougo et al., 1992; Bignot and Strougo, 2002; Shahin et al., 2007) and calcareous nannofossils (Allam et al., 1988; El Dawoody, 1992; Faris and Strougo, 1992). Lotfy and Van der Voo (2007) suggested tropical paleogeography of Egypt during the Middle-Late Eocene, and determined the paleogeographic positions being at 15-17° N. So many important factors have influenced negatively these sediments, the shallow environments and the climatic change. It is of worth mentioning that, no unique benthic biozonation could be applied to represent the Middle-Upper Eocene particularly in Egypt because either different taxa were used in biozonations (Abdel El Naby et al., 2013; Farouk et al., 2015) or the shallow environments could be responsible for the rarity of planktic and calcareous nannofossils. Biostratigraphic analysis concerned the studied sections dated it back to the middle-upper Eocene. But none of these studies precisely defined the epoch as much of these sediments are devoid of planktic or calcareous nannofossils. So this study aims to subdivide the Middle-Upper Eocene biostratigraphically based on integrated foraminifera and calcareous nannofossils to achieve their age, biozonation and correlation with adjacent areas as well as discuss the stage boundaries.

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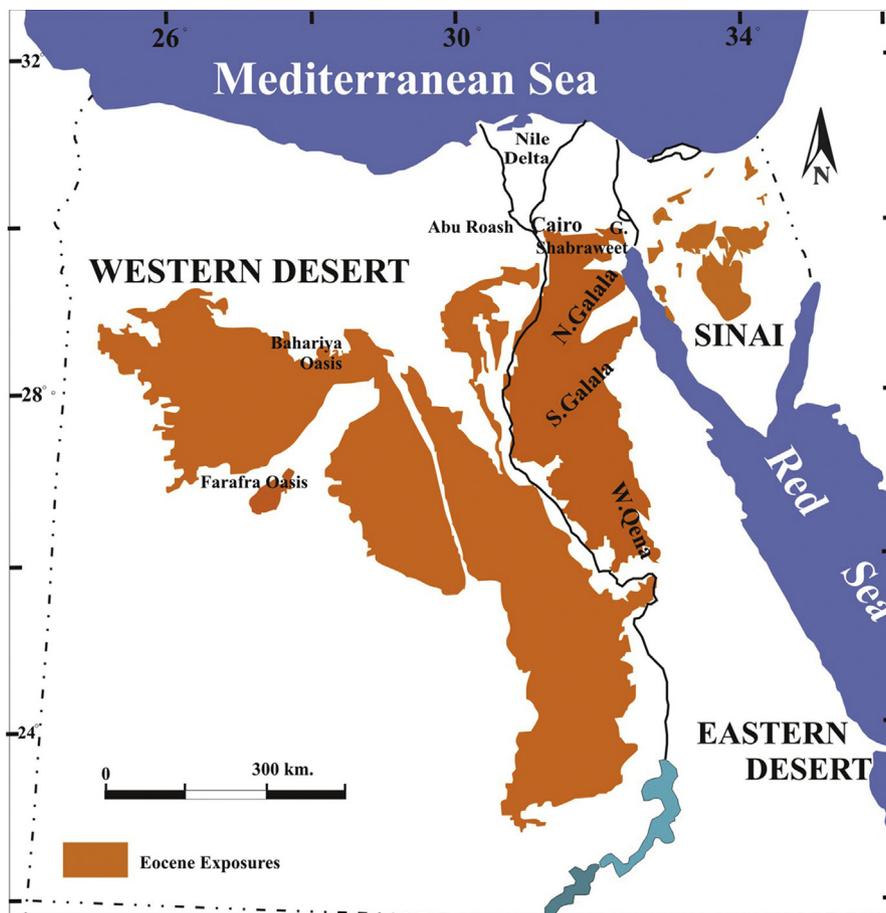


Fig. 1. Areal distribution of the Eocene rocks in Egypt (Compiled from the geological map of the Geological survey of Egypt, 1981).

2. Geological setting

The study area (Fig. 2) lies between latitude 29°52'N and 29°59'N and longitude 31°20'E and 32°00'E. The stratigraphy and geologic history was affected by the collision between African and European plates at the Lutetian time and its impact on the development and distribution of the different rock units (Issawi et al., 1999). The stresses originated from Lutetian event together with the Suez Gulf rifting resulted into the

break-up of the different stratigraphic successions, creating many grabens (Fig. 3a), half grabens, and horst blocks of variable sizes and amplitudes (Issawi and Osman, 2002).

3. Materials & Methods

Two lithostratigraphic sections namely Wadi Degla and Gebel Abu-Shama (Fig. 2) have been measured and sampled. A total of 83

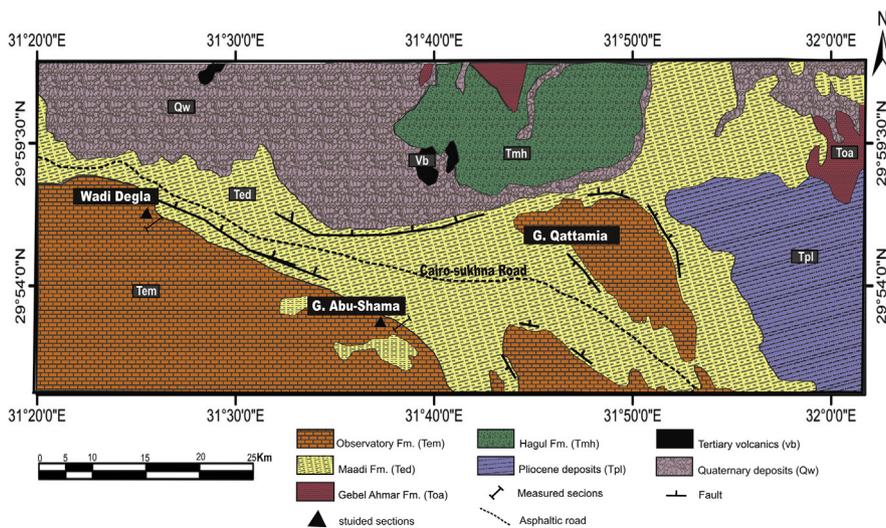
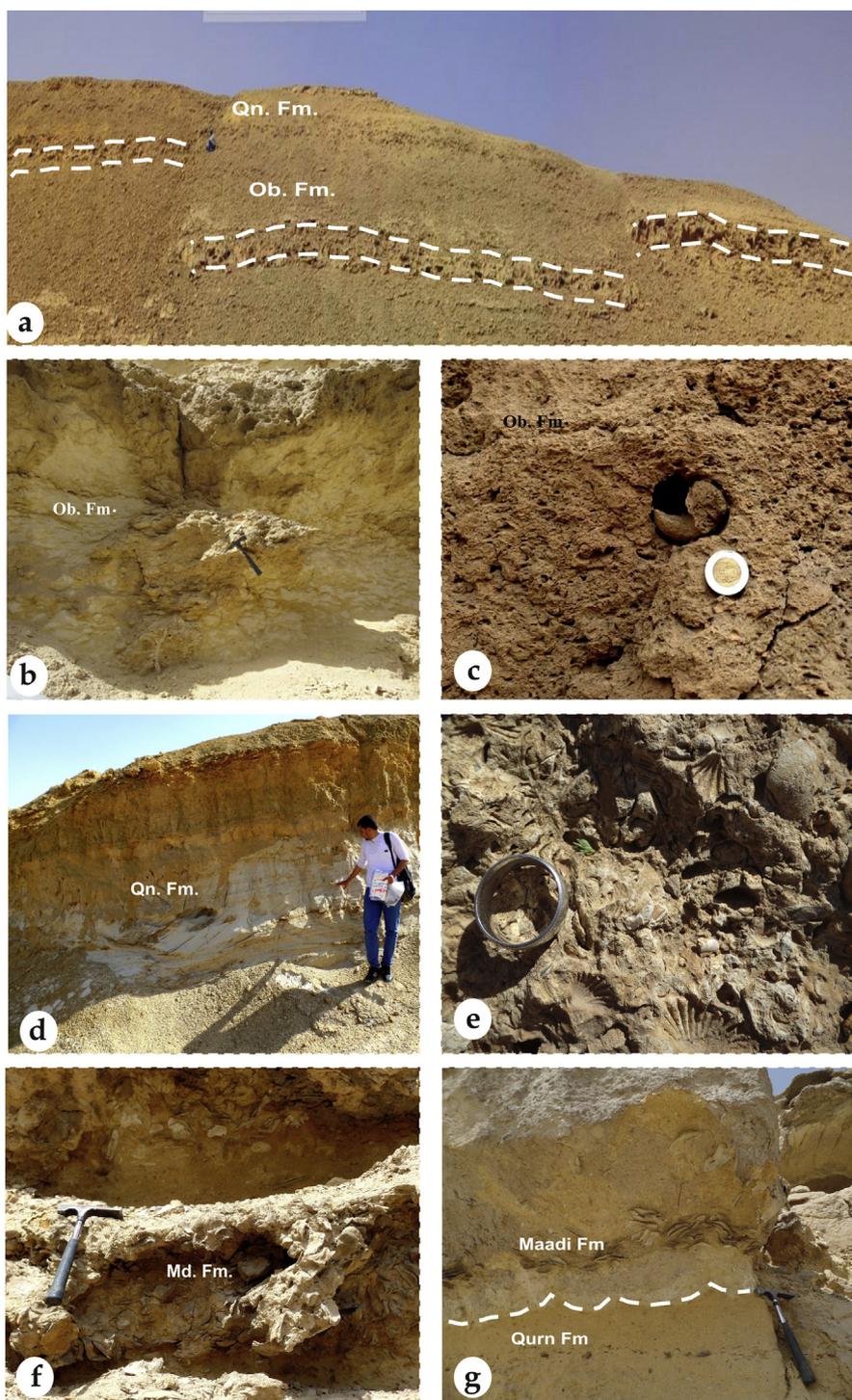


Fig. 2. Geologic map of the study area (modified after the Geological Survey of Egypt, 2014).



**Fig. 3.** a. Conformable contact between the Observatory Formation (Ob. Fm) and Bartonian Qurn Formation (Qn. Fm) with development of graben in G. Abu Shama. b. yellowish white to dark gray chaly limestone in the lower part of Observatory Formation, G. Abu Shama. c. Gastropod cast within the fossiliferous limestone bed in the middle part of Observatory Formation, G. Abu Shama. d. upper part of Qurn Formation in Wadi Degla, Limestone interbedded with varicolored mud and shales. e. fossiliferous limestone with oysters hashes and bivalves moulds within Qurn Formation in Wadi Degla. f. oyster bank in the upper Eocene Maadi Formation, G. Abu Shama. g. unconformable wavy contact between the Qurn Formation and upper Eocene Maadi Formation in G. Abu Shama.

representative samples were collected at intervals ranging from 30 cm to 2 m based on the variation in lithology, bed thickness, geometry patterns, contacts and characteristic fossil contents. 100–500 grams of dried rock samples for benthic and planktic foraminifera respectively were soaked overnight in a solution of 20% dilute  $H_2O_2$  until full disintegration and washed over a 63  $\mu m$  sieve. This process was repeated under a gentle current of water, the residue was then dried and picked. Foraminifera was identified by using binocular microscope with magnification of 10, 20, and 40X. 500 smear slides of calcareous nannofossils were prepared following techniques of [Bown and Young \(1998\)](#). The slides were mounted using DPX, studied and photographed with a standard light microscope at a magnification of 1000X under normal and crossed nicols.

All of the identified foraminifera are photographed by the Scanning Electronic Microscope (SEM) at the Geological Survey of Egypt.

## 4. Results & Discussion

### 4.1. Lithostratigraphy

The studied sections have been differentiated into three rock units which are as follows from base to top: The Observatory, Qurn and Maadi formations. The main lithological characteristics, age and thickness for each rock unit are given below.

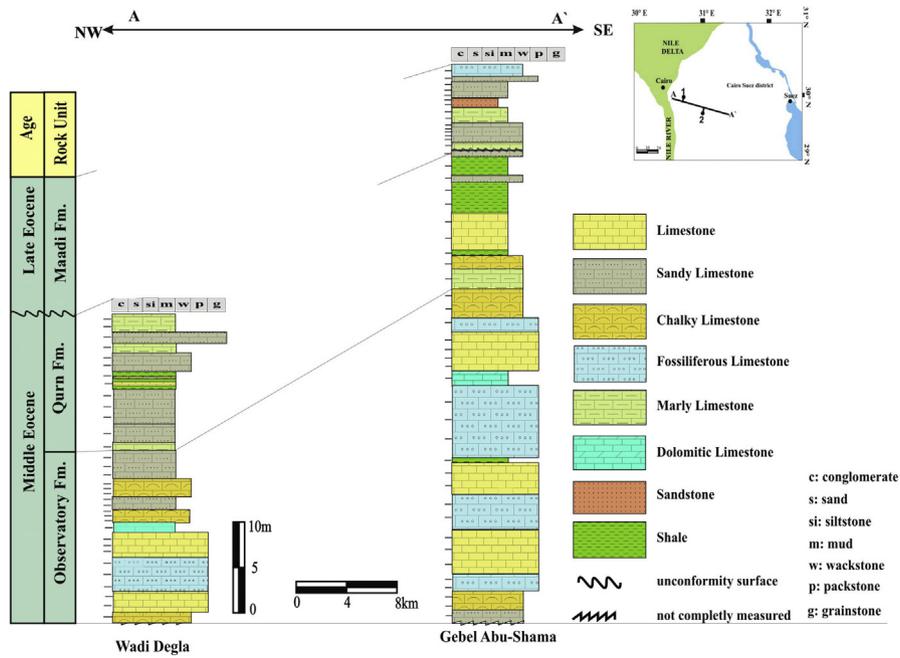


Fig. 4. Stratigraphic correlation of the recorded rock units in the studied sections.

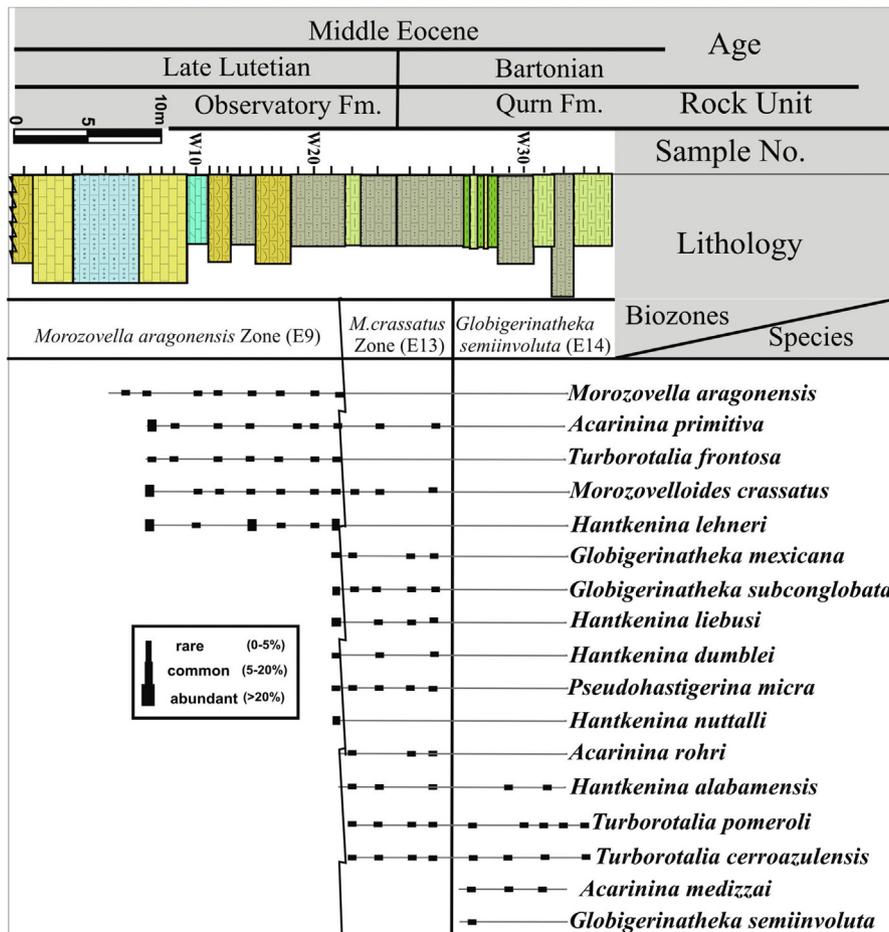
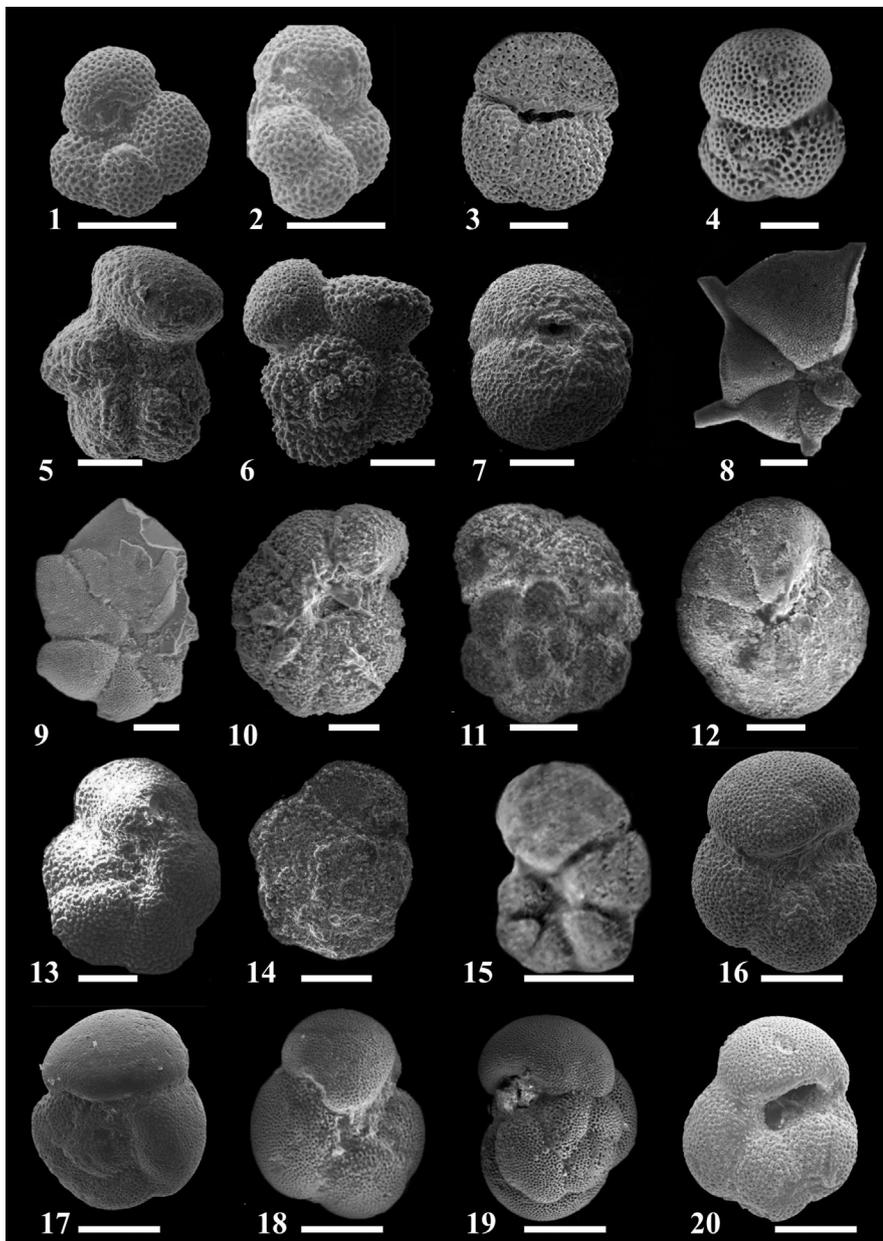


Fig. 5. Range chart of the identified planktic species in Wadi Degla.



**Fig. 6.** 1-2: *Acarinina medizzai* (Tourmarkine and Bolli), 1. ventral view, 2. Lateral view. 3-4: *Acarinina primitiva* (Finlay), 3. Ventral view, 4. Dorsal view. 5-6: *Acarinina rohri* (Bronnimann & Bermudez), 5. Ventral view, 6. Dorsal view. 7: *Globigerinatheka index* (Finlay), ventral view. 8: *Hantkenina alabamensis* Cushman. 9: *Hantkenina liebusi* Shokhina. 10-11: *Igorina broedermanni* (Cushman and Bermúdez), 10. ventral view, 11. dorsal view. 12: *Morozovella aragonensis* (Nuttal), ventral view. 13-14: *Morozovelloides crassatus* (Cushman), 13. ventral view, 14. dorsal view. 15: *Pseudohastigerina micra* (Cole). 16-17: *Turborotalia cerroazulensis* (Cole) 16. ventral view, 17. dorsal view. 18-19: *Turborotalia possagnoensis* (Tourmarkine and Bolli), 18. Ventral view, 19. Dorsal view. 20: *Turborotalia pomeroli* (Tourmarkine and Bolli) ventral view (scale bar equal 100  $\mu$  m).

#### 4.1.1. Observatory Formation

The term Observatory was first proposed by Farag and Ismail (1959) to describe a white to golden-tan, marly and nodular limestones exposed in the Observatory Plateau, East of Helwan. In the study area, The Observatory Formation is composed of pinkish to yellowish white thickly bedded nodular limestone at the base occasionally siliceous but commonly chalky (Fig. 3b). It grades to yellowish white hard fossiliferous limestone with bryozoans in both Gebel Abu Shama and Wadi Degla. Intercalated in the middle parts with sandy, fossiliferous limestone (Fig. 3c) and dolomite beds. Minor shale beds encountered in G. Abu Shama whereas, the upper parts grade to hard, thickly bedded siliceous, fossiliferous limestone and chalky limestone. Although, the lower boundary of Observatory Formation is unexposed but the presence of pinkish nodular limestone at the base indicates unconformity which confirm the absence of Gebel Hof Fm in G. Abu Shama due to highly pulsating seismicity (Sallam et al., 2018). The observatory Formation conformably underlies the Qurn Formation, and commonly rich in LBF such as *Nummulites beaumonti* d'Archiac and Haime, *Nummulites aff pulchellus* (Hantken), *Nummulites thalmani* (Schaub), *Rhabdorites minima*

(Henson), *Pseudolacazina schwagerinoides* (Blanckenhorn), *Periloculina cf. dalmatina* Drobne, *Idalina cuvillieri* Bignot and Strougo and *Dictyoconus egyptiensis* (Chapman). Many authors (e.g. Strougo and Abdallah, 1990, Shahin et al., 2007, Abu-Ellil, 2004 and Sallam et al., 2015a,b) dated the Observatory Formation to Bartonian age based on LBF but Farag and Ismail (1959) considered a Lutetian age due to its stratigraphic position. Observatory Formation measures 22 m at Wadi Degla, and 48.2 m at G. Abu-Shama (Fig. 4).

#### 4.1.2. Qurn Formation

The term Qurn was first introduced by Farag and Ismail (1959) to describe the sequence of chalky and marly limestones alternating with sandy marls at Qurn high area, East of Helwan. The lower part of Qurn Formation is composed of yellowish white, moderately compact limestone with thin marly limestone and marl interbeds. The upper part is characterized by faint brownish cavernous chalky limestone, siliceous in parts, interbedded with varicoloured mud and shales (Fig. 3d) fairly fossiliferous with oyster's hashes (Fig. 3e). The Qurn Formation is conformably overlies the Observatory Formation and underlies

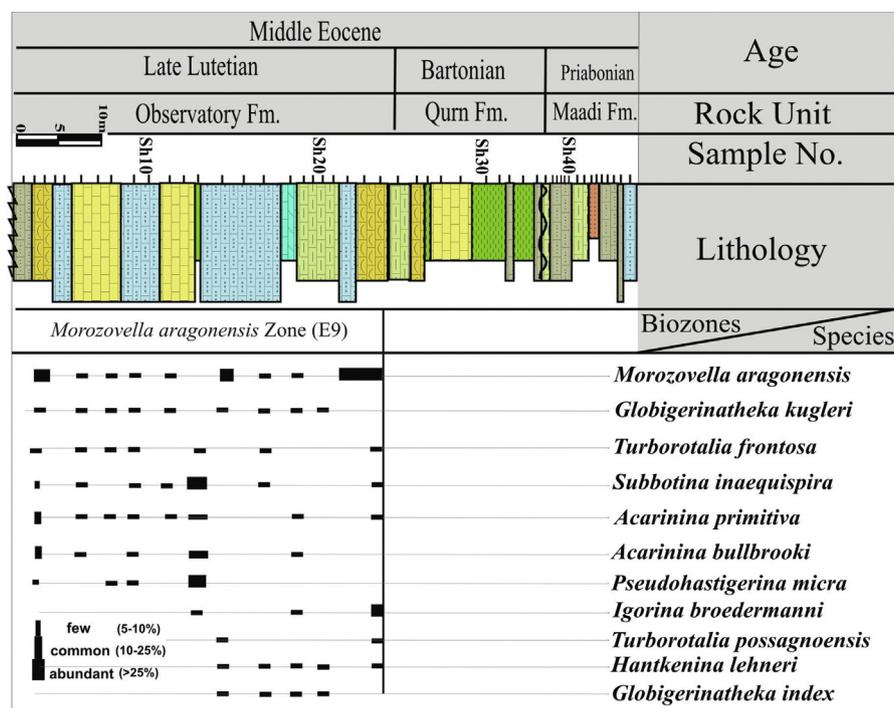


Fig. 7. Range chart of the identified planktic species in G. Abu Shama.

unconformably the Maadi Formation in Gebel Abu-Shama (Fig. 4). It attains 18 m in both Wadi Degla and Gebel Abu-Shama. Isothickness of Qurn Formation represents a phase of peneplanation just after observatory Formation. Qurn Formation is assigned to middle Eocene and that was confirmed by many authors (e.g. Strougo, 1985; Strougo and Boukhary, 1987; Said, 1990; Boukhary et al., 2002; Sallam et al., 2015a).

#### 4.1.3. Maadi Formation

Maadi Formation was proposed by Said (1962) to describe a clastic succession with minor carbonate beds rich in oyster and *Carolia placunoides* Cantraine, overlying the Mokattam Formation at Gebel Mokattam. It is composed of fossiliferous yellowish white marly limestone, varicoloured shales, sandstone and sandy marl interbeds with several levels of oyster banks (Fig. 3f). It overlies Qurn Formation with wavy contact in-between indicating an unconformity contact (Fig. 3g). The upper part of Maadi Formation is characterized by sandy clay with gradually increasing sand ratio upward until it unconformably underlies the Oligocene Gebel Ahmer Formation. It is only recorded in Gebel Abu-Shama and attains 12.5 m thick (Fig. 4). Maadi Formation is assigned to Priabonian age (Said, 1990; Sallam et al., 2015a, 2015b).

#### 4.2. Biostratigraphy

Although benthic foraminifera mostly have a wide stratigraphic range but they can provide relatively valued information about the age of the beds in which they occur (Elewa, 2004). Biostratigraphic analysis was quantitatively analyzed using SBF where they afford continuous stratigraphic range enable to correlate the identified assemblages/biozones with their equivalence in neighboring areas.

##### 4.2.1. Planktic foraminifera

The complete assemblage of planktic foraminifera was classified by species to identify the bioevents used for the identification of the standard biostratigraphic zones of Wade et al. (2011). The taxonomy follows the concepts in the Atlas of Eocene planktic foraminifera (Pearson et al., 2006).

4.2.1.1. *Globigerinatheka kugleri*/*Morozovella aragonensis* (E9) zone. Biostratigraphic interval characterized by the concurrent range of the nominate taxa between the lowest occurrence (LO) of *Globigerinatheka kugleri* (Bolli, Loeblich, and Tappan) and the highest occurrence (HO) of *Morozovella aragonensis* (Nuttall), it dated back to middle Eocene (Lutetian). The planktic assemblage in Wadi Degla (Fig. 5) contains *Morozovella aragonensis* (Nuttall) (Fig. 6, 12), *Acarinina primitiva* (Finlay), *Turborotalia frontosa* (Subbotina) and *Morozovelloides crassatus* (Cushman) (Fig. 6, 13-14) suggests that the lower part of Observatory Formation can tentatively be attributed to Zone E9 (45.8–43.6 Ma) (Pearson et al., 2006). On the other hand, planktic assemblage in G. Abu Shama (Fig. 7) is characterized by *Subbotina inaequispira*, *Morozovella aragonensis* (Nuttall), *Acarinina primitiva* (Finlay) (Fig. 6, 3-4), *Acarinina bullbrooki* (Bolli), *Pseudohastigerina micra* (Cole) (Fig. 6, 15), *Igorina broedermanni* (Cushman and Bermúdez) (Fig. 6, 10-11), *Turborotalia possagnoensis* (Toumarkine and Bolli) (Fig. 6, 18-19) and *Turborotalia frontosa* (Subbotina) which approve E9 Zone. Pearson et al. (2006) recorded that, the LO of *Hantkenina dumblei* Weinzierl and Applin is high in the E9 Zone. Farouk et al. (2018) confirmed the same conclusion in the Eocene Apollonia Formation at the North Western Desert. It's of worth mentioning that, very rare forms of *Morozovella aragonensis* (Nuttall) were recorded in all the studied samples and *Igorina broedermanni* (Cushman and Bermúdez) outnumbered the marker species.

4.2.1.2. *Morozovelloides crassatus* zone (E13). Biostratigraphic interval characterized by the partial range of the nominate taxon between the HO of *Orbulinoides beckmanni* and the HO of the nominate taxon. Pearson et al. (2006) modify the definition of the upper limit of this zone to reflect the distinct horizon at which Eocene *Morozovelloides* disappears which assigned at a level very close to the extinction of *Acarinina* (Wade, 2004). Pearson et al. (2006) estimated E13 Zone between 40.0 to 38.0 Ma of late Bartonian age. In Wadi Degla (Samples W23-W25) contain; *Acarinina primitiva* (Finlay), *Morozovelloides crassatus* (Cushman), *Globigerinatheka mexicana mexicana* (Cushman), *Globigerinatheka subconglobata subconglobata* (Shutskaya), *Hantkenina liebusi* Shokhina (Fig. 6, 9), *Hantkenina dumblei* Weinzierl and Applin, *Pseudohastigerina micra* (Cole) and *Acarinina rohri* (Brönnimann and Bermúdez) (Fig. 6, 5-6) attributed the lower

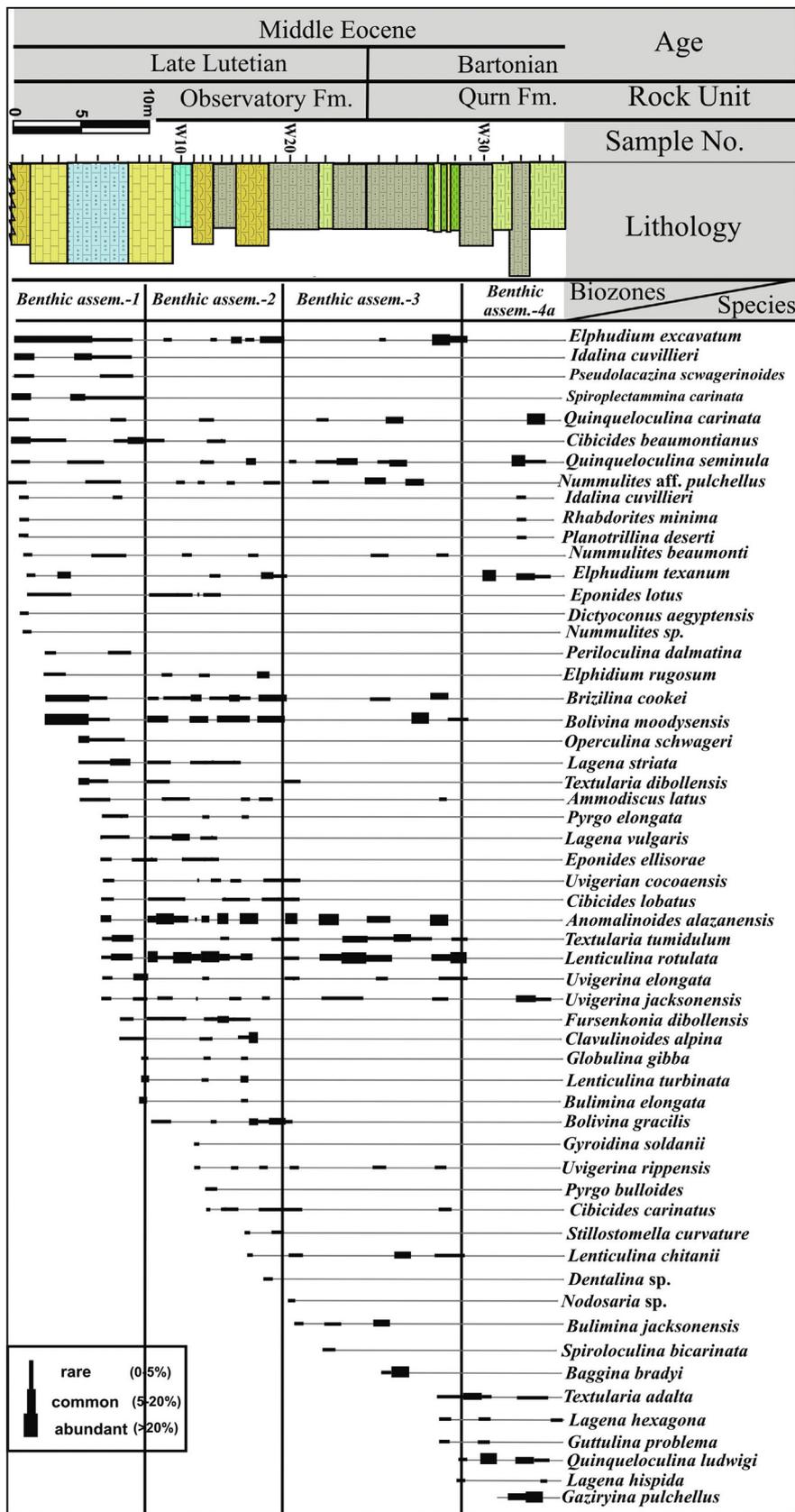


Fig. 8. Range chart of the identified benthic species in Wadi Degla.

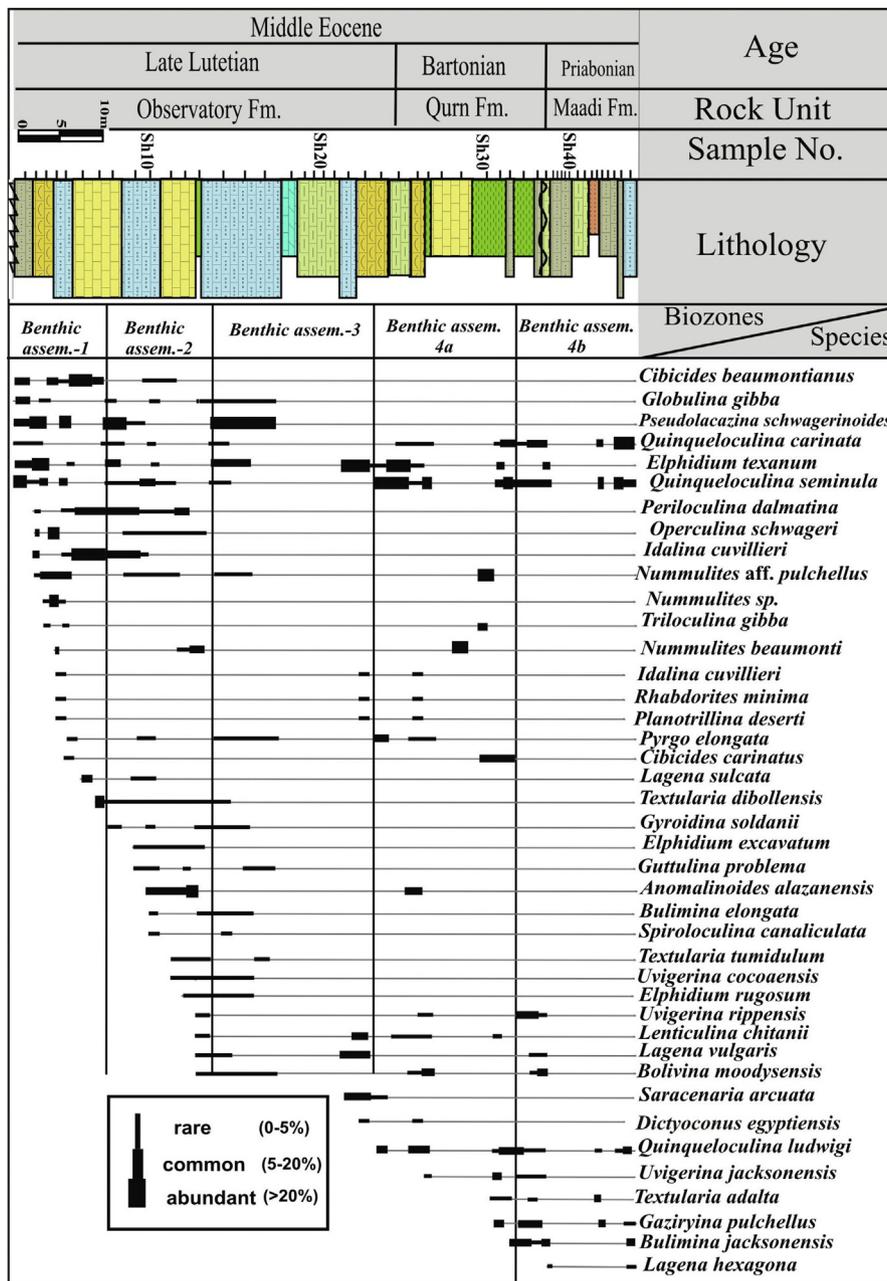


Fig. 9. Range chart of the identified benthic species in G. Abu Shama.

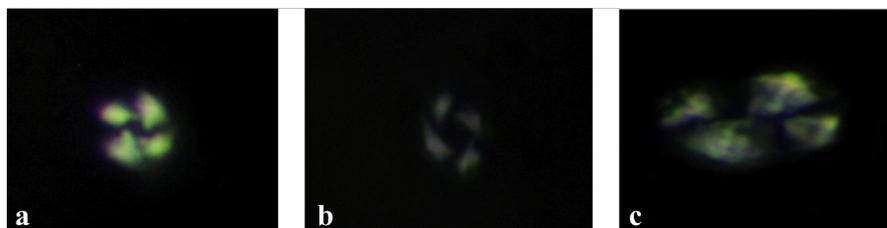
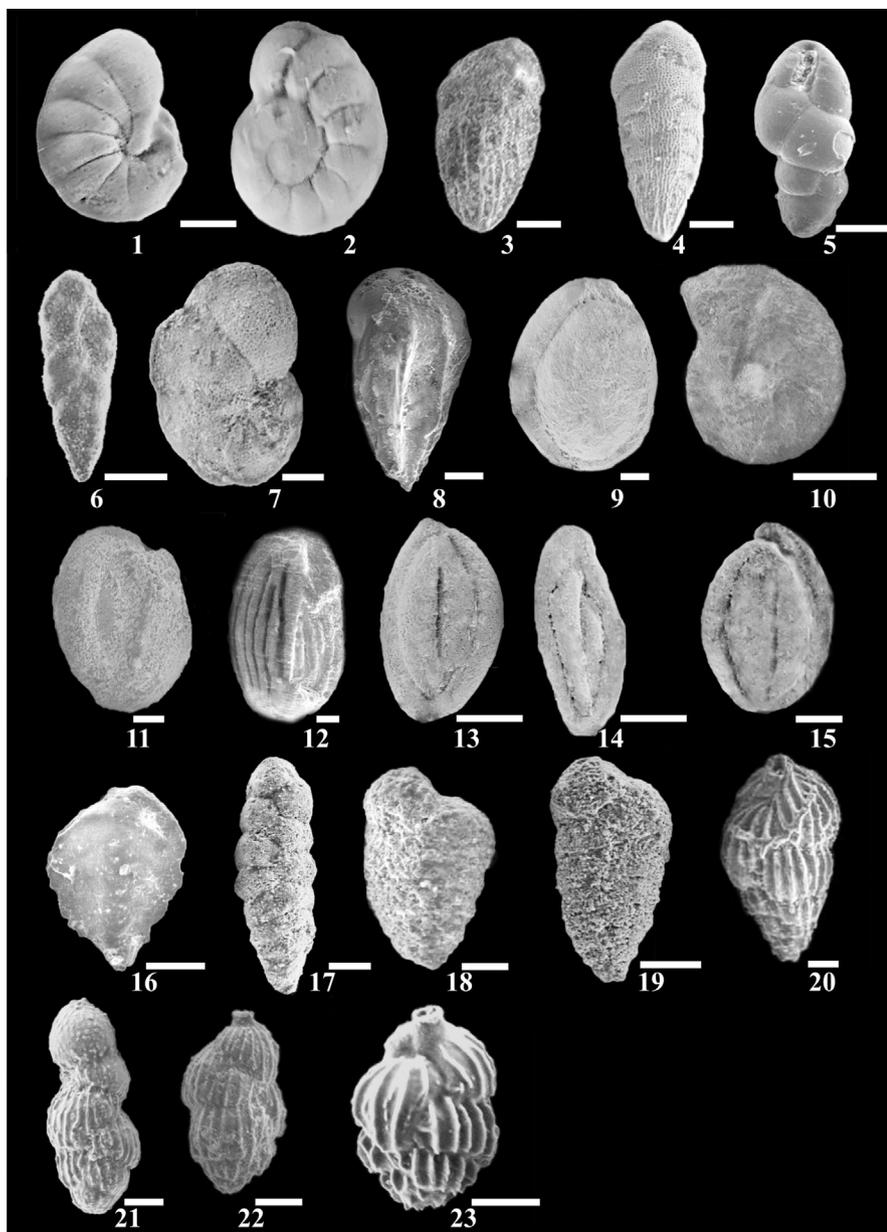


Fig. 10. a *Reticulofenestra dictyoda* (Deflandre and Fert), b *Reticulofenestra umbilica* (Levin), c *Pontosphaera multipora* (Kamptner), Qurn Formation, Wadi Degla, Sample W21.

part of Qurn Formation to *Morozovelloides crassatus* Zone (E13). Rare, moderately to well preserved calcareous nannofossils *Reticulofenestra dictyoda*, *Pontosphaera multipora* and *Reticulofenestra umbilica* (Fig. 10, 1, 2, and 3) within the same samples were attributed to *Discoaster*

*saipanensis* Zone (NP17) of Martini (1971).

4.2.1.3. *Turborotalia cerroazulensis pomeroli*/*Turborotalia cerroazulensis cerroazulensis* zone. Due to the very rare occurrence of the



**Fig. 11.** 1-2: *Anomalinoidea alazanensis* (Nuttall), 1, ventral view, 2, dorsal view, Qurn Formation, Gebel Abu-Shama; Sample Sh26. 3: *Bolivina moodysensis* Cushman and Todd, Observatory Formation, Gebel Abu-Shama; Sample Sh13. 4: *Brizalina cookei* (Cushman), Observatory Formation, Wadi Degla; Sample W10. 5: *Bulimina elongata* d'Orbigny, front view, Observatory Formation, Gebel Abu-Shama; Sample Sh14. 6: *Bulimina jacksonensis* Cushman, Maadi Formation, Gebel Abu-Shama; Sample Sh49. 7: *Cibicides beaumontianus* (d'Orbigny), dorsal view, Observatory Formation, Gebel Abu-Shama; Sample Sh10. 8: *Fursenkoina dibollensis* (Cushman and Applin), Observatory Formation, Wadi Degla; Sample W14. 9: *Idalina cuvillieri* Bignot, front view, Observatory Formation, Gebel Abu-Shama; Sample Sh2. 10: *Lenticulina chittanii* (Yabe and Asano), side view, Qurn Formation, Gebel Abu-Shama; Sample Sh30. 11: *Periloculina dalmatina* Drobne, front view, Observatory Formation, Gebel Abu-Shama; Sample Sh12. 12: *Pseudolacazina schwagerinoides* (Blanckenhorn), Observatory Formation, Gebel Abu-Shama; Sample Sh10. 13: *Quinqueloculina carinata* d'Orbigny, Qurn Formation, Wadi Degla; Sample W33. 14: *Quinqueloculina ludwigi* Reuss, Maadi Formation, Gebel Abu-Shama; Sample Sh45. 15: *Quinqueloculina seminula* (Linné), Observatory Formation, Gebel Abu-Shama; Sample Sh11. 16: *Spiroplectammina (Spiroplectinella) carinata* (d'Orbigny), Observatory Formation, Wadi Degla; Sample W4. 17: *Textularia adalta* Cushman, Maadi Formation, Gebel Abu-Shama; Sample Sh45. 18: *Textularia dibollensis* Cushman and Applin, Observatory Formation, Gebel Abu-Shama; Sample Sh14. 19: *Textularia tumidulum* Cushman, Observatory Formation, Gebel Abu-Shama; Sample Sh13. 20: *Uvigerina cocoaensis* Cushman, Observatory Formation, Gebel Abu-Shama; Sample Sh11. 21: *Uvigerina elongate* Cole, Qurn Formation, Wadi Degla; Sample W24. 22: *Uvigerina jacksonensis* Cushman, Qurn Formation, Gebel Abu-Shama; Sample Sh31. 23: *Uvigerina rippensis* Cole, Qurn Formation, Wadi Degla; Sample W24.

*Globigerinetheka semiinvoluta* (Keijzer) in Wadi Degla (sample W27) an alternative zone, *Turborotalia cerroazulensis pomeroli/Turborotalia cerroazulensis cerroazulensis* Zone based on the evolutionary lineage of the *Turborotalia cerroazulensis* (Cole) as proposed by Toumarkine and Bolli (1970) emended Toumarkine in; Toumarkine and Luterbacher (1985) has been used. Farouk et al. (2015) considered the LO of *Globigerinatheka semiinvoluta* (Keijzer) is not considered a reliable marker for global correlation, but may be a useful correlative species in the Middle East. It is defined as the interval between the last occurrence of *Turborotalia cerroazulensis possagnoensis* (Toumarkine and Bolli) to the extinction of the genus *Truncorotalides* and other spine forms which indicated by the last appearance of *Acarinina primitive* (Finlay), *Acarinina rohri* (Brönnimann and Bermúdez) as well as *Morozovelloides crassatus* (Cushman). While the non-umblicate forms belonging to the *Globigerinatheka* group are either absent or rare in the basal part. Many authors (El Heiny et al., 1990; Haggag, 1992; Nassif et al., 2008) in Egypt applied this zonation due to the scare of reliable Middle/late Eocene biomarkers. Based on the faunal assemblage, it could be tentatively correlated with the *Globigerinatheka semiinvoluta* Zone (E14) of Pearson et al. (2006). Pearson et al. (2006)

estimated Zone E14 between 38.0 to 35.8 Ma of late Bartonian to early Priabonian age. The planktic foraminiferal assemblage of this zone are *Hantkeina alabamensis* Cushman (Fig. 6, 8), *Turborotalia pomeroli* (Toumarkine and Bolli) (Fig. 6, 20), *Turborotalia possagnoensis* (Toumarkine and Bolli), *Acarinina medizai* (Toumarkine and Bolli) (Fig. 6, 1-2) and *Globigerinatheka semiinvoluta* (Keijzer). It attains a thickness of 10.8 m at Wadi Degla. The small sized *Acarinina medizai* (Toumarkine and Bolli) is low in abundance but represent reliable stratigraphic range, as considered among the small acarininids that continue into the Late Eocene (Wade, 2004).

#### 4.2.2. Benthic foraminifera

Biozonation based on the benthic foraminifera are somewhat accepted particularly where they provide a correlative tool. The Middle-upper Eocene in the study area and neighboring areas are generally subdivided based on the both LBF and SBF. However, this application of local interest but the usage of quantitative analysis will improve the resolution of benthic biozones. Based on the cluster analysis using Bary Curtis with Cophen correlation of 0.7. Four benthic assemblages/

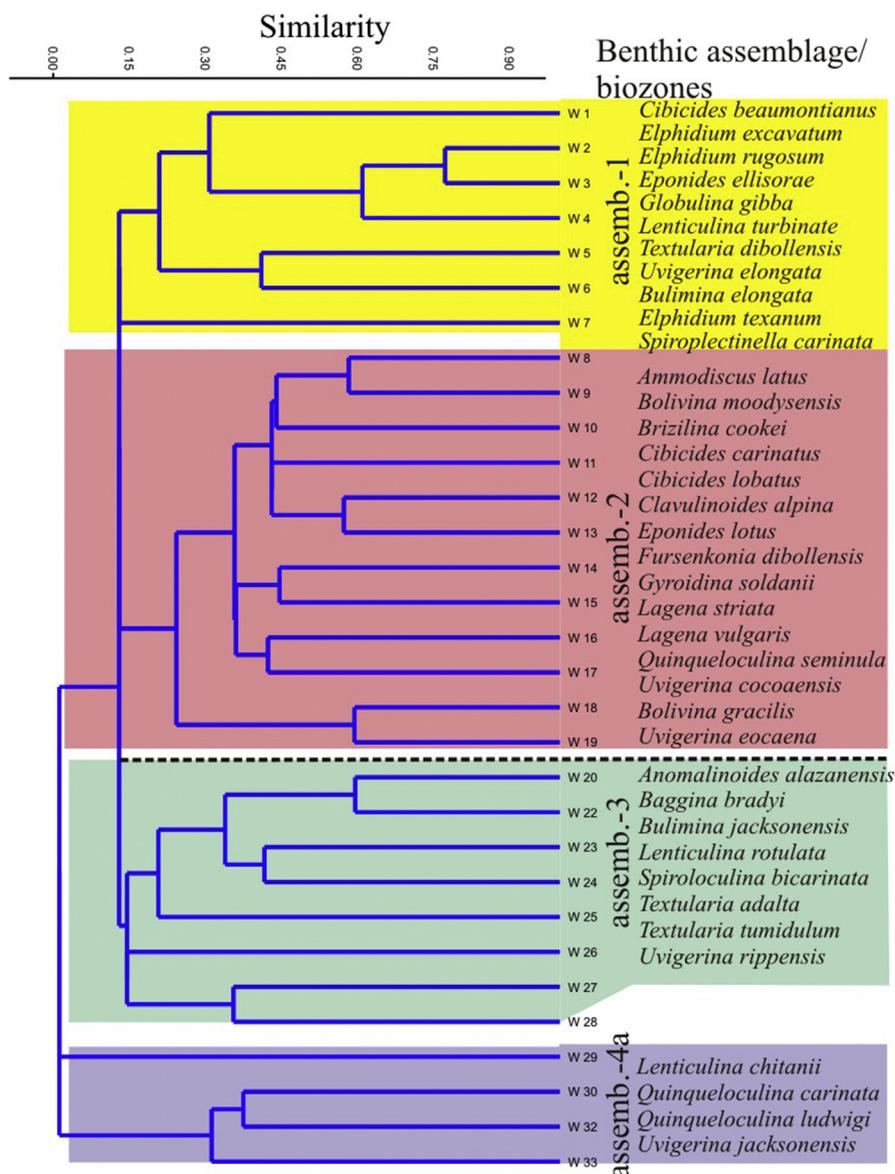


Fig. 12. R-mode cluster analysis (Bray Curtis) of the benthic foraminifera in Wadi Degla.

biozones are suggested referred as cluster-1 to 4a and b/benthic assemblage 1-4a and b or biozones, most of the common and abundant species are photographed and illustrated in Fig. 11.

4.2.2.1. *Benthic assemblage-1*. This cluster analysis allows the identification of four main clusters of benthic foraminiferal taxa, clusters 1 to 4 in Wadi Degla (Fig. 12) and 1-4a and b in Abu Shama (Fig. 13). It is recorded in both Wadi Degla and Abu-Shama in the basal part of Observatory Formation, attains a thickness of 9.7m and 10.9m respectively among the high abundance species recorded are both *Cibicides beaumontianus* and *Elphidium excavatum* in Wadi Degla, *Cibicides beaumontianus* and *Idalina cuvillieri* in Gebel Abu Shama.

Benthic assemblage -1 has been characterized by association composed of *Cibicides beaumontianus*, *Elphidium excavatum*, *Elphidium rugosum*, *Elphidium texanum*, *Eponides ellisorae*, *Globulina gibba*, *Lenticulina turbinata*, *Spiroplectammina carinata*, *Textularia dibollensis*, *Uvigerina elongata* and *Bulimina elongata* (Fig. 12). Where in Gebel Abu Shama it characterized by *Cibicides beaumontianus*, *Globulina gibba*, *Lagena sulcata*, *Nummulites thalmani* and *Operculina libyca* (Fig. 13). It is equivalent to the lower part of *Nummulites cf. syrticus* Zone (Strougo et al., 1992) from North Eastern Desert (Table 1). It is equivalent to the lower part of

*Bulimina jacksonensis* (Table 1) in the Eocene rocks North Eastern Desert (Shahin et al., 2007). The benthic assemblage in the study area is equated with the lower part of the *Bulimina jacksonensis* - *Uvigerina jacksonensis* Zone (Elewa, 2004) from Gebel Mokattam, Greater Cairo (Table 1). It is also correlated with the lower part of *Dictyoconus egyptiensis* - *Nummulites beaumonti* Zone (Abu-Ellil, 2004) of Lutetian-Bartonian age in Cairo-Suez Road (Table 1). It is also correlated with the lower part of *Nummulites aff. pulchellas* Zone (Boukhary et al., 2002) from the Observatory Formation in Helwan area. It could be correlated with the lower part of *Margulinopsis cf. fragaria* Zone of Eocene rocks (Abul-Nasr, 2000) in the West Central Sinai (Table 1). In addition, it is correlated with the lower part of *Norcottia danvilensis* - *Altistoma aegyptiaca* Zone of Middle Eocene (Shahin, 2000) in western Sinai.

Among the LBF taxa recorded in benthic assemblage-1 are; *Dictyoconus egyptiensis* Chapman, *Rhabdorites minima* Henson, *Idalina cuvillieri* Bignot and Strougo, *Pseudolacazina schwagerinoides* (Blanckenhorn) and *Nummulites migiurtinus* (Azzaroli) and accordingly a Bartonian age was assigned as suggested by Hassan et al. (1984), Kolkila et al. (1984), Said (1990), Strougo and Abdallah (1990), Shahin et al. (2007) and Sallam et al. (2015a,b). Although some of the recorded species are not represent a definite stratigraphic range where *Dictyoconus egyptiensis* recorded

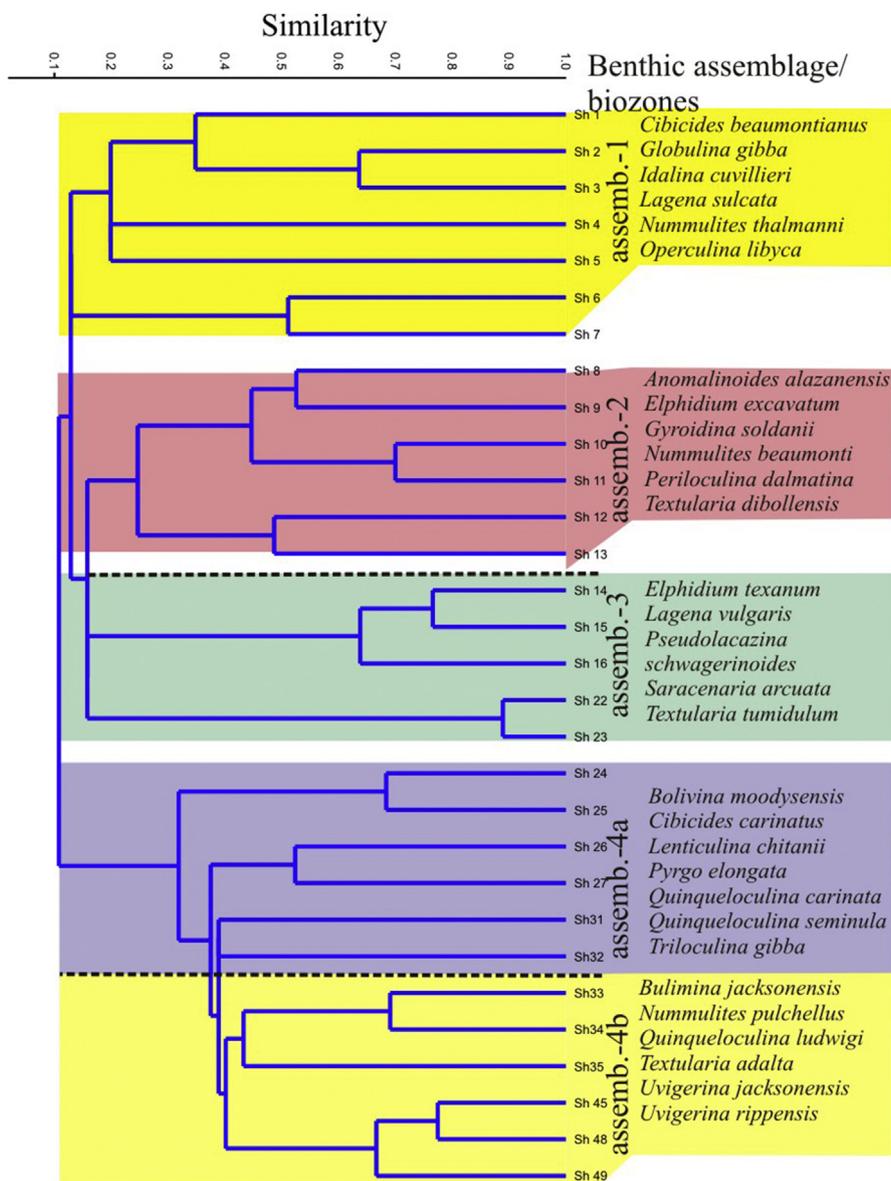


Fig. 13. R-mode cluster analysis (Bray Curtis) of the benthic foraminifera in G. Abu Shama.

from the early Lutetian sediments (Tawadros, 2011; Robinet et al., 2013) and other species (e.g. *Nummulites syrticus*, *Nummulites migiurtinus* and *Nummulites beaumonti*) were recorded from the early and middle Lutetian in the Bahariya Depression (Afify et al., 2016). Hottinger (2007) confirmed that *Rhabdorites minimus* of lower Lutetian age as dated by their association with alveolinids and nummulitids in Egyptian Eocene. The benthic assemblage-1 is dated to the Middle Lutetian age within the E9 Zone.

4.2.2.2. *Benthic assemblage -2*. It is recorded in the middle part of the Observatory Formation in Wadi Degla (Fig. 8) whereas, it extends from the upper part of the Observatory to the lower part of Qurn Formation in G. Abu Shama (Fig. 9). It measures 10.2m and 12.2m respectively. It is characterized by abundant of benthic assemblage composed of *Ammodiscus latus*, *Bolivina moodysensis*, *Brizilina cookie*, *Cibicides carinatus*, *Cibicides lobatus*, *Clavulinoides alpina*, - *Eponides lotus*, *Fursenkonia dibollensis*, *Gyroidina soldanii*, *Lagena striata*, *Lagena vulgaris*, *Quinqueloculina seminula*, *Uvigerina cocoaensis*, *Bolivina gracilis* and *Uvigerina eocaena* (Fig. 12). While in G. Abu Shama the benthic assemblage contains, *Anomalinoidea alazanensis*, *Elphidium excavatum*, *Gyroidina soldanii*,

*Nummulites beaumonti*, *Periloculina dalmatina* and *Textularia dibollensis* (Fig. 13). Many species undergo their HO within this Zone such as; *Cibicides beaumontianus* (d'Orbigny), *Eponides lotus* (Schwager), *Elphidium rugosum* (d'Orbigny), *Lagena striata* (d'Orbigny), *Textularia dibollensis* Cushman and Applin, *Ammodiscus latus* Grzybowski, *Lagena vulgaris* Williamson, *Eponides ellisorae* Garrett, *Uvigerina cocoaensis* Cushman, *Fursenkonia dibollensis* (Cushman and Applin), *Clavulinoides alpina* Cushman and *Bolivina gracilis* Cushman and Applin. Also many taxa have been continued from the underlying Zone (Figs. 6–7). It is considered of Middle Lutetian age as indicated in planktic biostratigraphy (see Table 1).

4.2.2.3. *Benthic assemblage -3*. It is recorded from the middle part of the Qurn Formation in Wadi Degla and extends from the upper part of Qurn Formation in Gebel Abu-Shama. It attains 13.11 m at Wadi Degla and 19.2 m at Gebel Abu-Shama. Benthic assemblage -3 containing assemblage composed of *Anomalinoidea alazanensis*, *Baggina bradyi*, *Bulimina jacksonensis*, *Lenticulina rotulata*, *Spiroloculina bicarinata*, *Textularia adalta*, *Textularia tumidulum*, *Uvigerina rippensis* where in Abu Shama it composed of *Elphidium texanum*, *Lagena vulgaris*, *Pseudolacazina*

**Table 1**  
Correlation of the LBF and SMF biozones in the study area with their equivalents in Egypt.

Age	Strougo et al. (1992)		Abul Nasr (2000)		Shahin (2000)		Boukhary et al. (2002)		Eleva (2004)		Abu-Elilil (2004)		Shahin et al. (2007)		Present Study	
		North Eastern Desert	Western Sinai	Western Sinai	Helwan area	Gebel Mokattam	South Cairo-Suez District	Qattamia area	Wadi Degla	G. Abu Shama						
<b>EOCENE</b>	<b>Upper</b>	<b>Priabonian</b>	†	†	†	<i>Nummulites</i> Sp. <i>gr. incrassatus</i>	†	<i>Quinqueloculina carinata</i>	†	<i>Bulimina jacksonensis</i>	†	<i>Bulimina jacksonensis</i>	<b>Priabonian</b>	†	Benthic ass-5	
	<b>MIDDLE</b>	<b>Bartonian</b>	<i>Idalina cavillieri</i>	<i>Uvigerina eocaena-Uvigerina steyeri</i>	<i>Uvigerina ripensis/Uvigerina churchi</i>	<i>Nummulites cf. beaumonti/Nummulites pulchellas</i>	<i>Bulimina jacksonensis/Uvigerina jacksonensis</i>	<i>Nummulites cf. beaumonti/Nummulites striatus</i>	<i>Bulimina jacksonensis/Uvigerina jacksonensis</i>	<i>Uvigerina mediterranea</i>	<i>Bulimina jacksonensis</i>	<i>Bulimina jacksonensis</i>	<b>Bartonian</b>	Benthic ass-4	Benthic ass-4	
			<i>Fabularia schwagerinoides</i>	<i>Uvigerina continuaosa/Eponites cf. haeringensis</i>		<i>Nummulites bullatus</i>	<i>Bulimina jacksonensis</i>	<i>Dicyoconus egyptiensis/Nummulites striatus</i>	<i>Bulimina jacksonensis</i>	<i>Bulimina jacksonensis</i>	<i>Bulimina jacksonensis</i>	<i>Bulimina jacksonensis</i>		Benthic ass-3	Benthic ass-3	
		<b>Lutetian</b>	<i>Nummulites cf. syrticus</i>	<i>Margulinopsis cf. fragaria</i>	<i>Norcotia damvilensis/Alitstoma aegyptiaca</i>	<i>Nummulites bullatus</i>	<i>Nummulites aff. puchellas</i>	<i>Dicyoconus egyptiensis/Nummulites beaumonti</i>	<i>Dicyoconus egyptiensis/Nummulites beaumonti</i>	<i>Dicyoconus egyptiensis/Nummulites beaumonti</i>	<i>Dicyoconus egyptiensis/Nummulites beaumonti</i>	<i>Dicyoconus egyptiensis/Nummulites beaumonti</i>	<b>Middle Lutetian</b>	Benthic ass-2	Benthic ass-2	
														Benthic ass-1	Benthic ass-1	

† Bold represents age.  
‡ Not recorded.  
† Not studied.

*schwagerinoides*, *Saracenaria arcuata* and *Textularia tumidulum*. It is considered of Middle Lutetian to early Priabonian as indicated.

4.2.2.4. *Benthic assemblage -4a*. It is recorded in the upper part of Qurn Formation in both Wadi Degla and Abu Shama, measuring 7.4m and 16.7m respectively. In Wadi Degla It is characterize by the following abundant species *Lenticulina chitanii*, *Quinqueloculina carinata*, - *Quinqueloculina ludwigi* and *Uvigerina jacksonensis* (Fig. 12). Whereas in G. Abu Shama it is characterized by *Bolivina moodysensis*, *Cibicides carinatus*, *Lenticulina chitanii*, *Pyrgo elongate*, *Quinqueloculina carinata*, *Quinqueloculina seminula* and *Triloculina gibba* (Fig. 13). It is dated to early Priabonian.

4.2.2.5. *Benthic assemblage -4b*. It is recorded in the late Eocene Maadi Formation in G. Abu Shama (Fig. 9) and attains 14.5m thickness. Benthic assemblage-4b is characterized by assemblage composed of *Bulimina jacksonensis*, *Nummulites pulchellas*, *Quinqueloculina ludwigi*, *Textularia adalta*, *Uvigerina jacksonensis* and *Uvigerina ripensis*. It is correlated with *Carolia placunoides* Zone (Abdel-Shafy et al., 1989) in the Upper Eocene succession at Gulf of Suez. It is also correlated with the *Quinqueloculina carinata* Zone (Abu-Elilil, 2004) from the Upper Eocene rocks at Cairo-Suez Road. Benthic assemblage-4b in Gebel Abu-Shama is equivalent to the *Nummulites* sp. gr. *incrassatus* Zone (Boukhary et al., 2002) from the Qurn Formation in Helwan area (Table 1). The absence of benthic assemblage 4b in Wadi Degla indicating an uplift phase that occurred after deposition of Qurn Formation which allowed the deposition of Maadi Formation in G Abu Shama rather than W. Degla. The Maadi Formation in the study area is poorly fossiliferous in planktic foraminifera but rich in *Ostrea multicosata* Deshayes and *Carolia placunoides* Cantraine, which tentatively assign Priabonian age (Sallam et al., 2015a,b; El-Shazly et al., 2016; Saber and Salama, 2017). On the other hand *Gaziryina pulchella* (Hantken) has been recorded within this assemblage and indicates upper Eocene age (Mufthah and Boukhary, 2013). Other abundant species, *Quinqueloculina ludwigi*, was recorded in North Hafit area, UAE (Cherif and El Deeb, 1984) among the late Eocene fauna.

4.3. Stage boundaries

4.3.1. The Lutetian/Bartonian boundary

The Lutetian/Bartonian boundary was defined in the Contessa Highway section (Jovane et al., 2007), central Italy with an astronomically calibrated age of 41.23 Ma. Bignot and Strougo (2002) recorded larger benthic assemblage equivalent to NP16 and/or NP17 biozone in G. Abu Shama but they can't establish the exact position of the Lutetian-Bartonian boundary. The base of Lutetian in the studied sections has been recorded where Farouk et al. (2013) indicated that the lowest occurrence of *Turborotalia frontosa* (Subbotina) is used to best record the exact boundary between the Ypresian//Lutetian which has been recorded in the studied materials 10 meters above the base of the Observatory Formation in Wadi Degla and 1m in G. Abu Shama. The Lutetian/Bartonian boundary in the study area is marked by an abrupt lithological change that correspond with the boundary between the Observatory and Qurn formations where chalky, siliceous limestone pass into sandy/marly limestone with oyster and bryozoans which indicate shallowing at the boundary. The Benthic foraminifera have experienced sudden disappearance where 43% of taxa disappear (Table 2). In addition to appearance of taxa such as; *Quinqueloculina ludwigi* Reuss, *Baggina bradyi* (Brotzen), *Guttulina problema* d'Orbigny, and others (Table 2). The stratigraphic relationship indicates the presence of paraconformity surface between the Middle Lutetian *Globigerinatheka kugleri/Morozovella aragonensis* (E9) Zone and the *Morozovelloides crassatus* Zone (E13) of the late Bartonian age.

**Table 2**  
Distribution of the identified benthic foraminifera and bioevents through Middle/Upper Eocene transitions in the study area.

Species	Occurance		
	Lutetian	Bartonian	Priabonian
<i>Bolivina gracilis</i> Cushman and Appline	+++++		
<i>Bulimina elongata</i> d'Orbigny	+++++		
<i>Cibicides beaumontianus</i> (d'Orbigny)	+++++		
<i>Cibicides lobatulus</i> (Walker and Jacob)	+++++		
<i>Clavulinoides alpina</i> Cushman	+++++		
<i>Elphidium rugosum</i> (d'Orbigny)	+++++		
<i>Eponides ellisorae</i> Garrett	+++++		
<i>Fursenkoina dibollensis</i> (Cushman and Applin)	+++++		
<i>Globulina gibba</i> d'Orbigny	+++++		
<i>Gyroldina soldanii</i> d'Orbigny, 1826	+++++		
<i>Lagena striata</i> (d'Orbigny)	+++++		
<i>Lenticulina turbinata</i> (Plummer)	+++++		
<i>Nummulites</i> sp.	+++++		
<i>Pyrgo elongata</i> (d'Orbigny)	+++++		
<i>Saracenaria arcuata</i> d'Orbigny	+++++		
<i>Spiroloculina canaliculata</i> d'Orbigny	+++++		
<i>Spiroplectammina</i> ( <i>Spiroplectinella</i> ) <i>carinata</i> (d'Orbigny)	+++++		
<i>Stilostomella curvatura</i> (Cushman)	+++++		
<i>Textularia dibollensis</i> Cushman and Applin	+++++		
<i>Uvigerina cocoaensis</i> Cushman	+++++		
<i>Ammodiscus latus</i> Grzybowski	+++++	+++++	
<i>Anomalinoidea alazanensis</i> (Nuttall)	+++++	+++++	
<i>Bolivina moodysensis</i> Cushman and Todd	+++++	+++++	
<i>Brizalina cookei</i> (Cushman)	+++++	+++++	
<i>Cibicides carinatus</i> (Terquem)	+++++	+++++	
<i>Elphidium excavatum</i> (Terquem)	+++++	+++++	
<i>Elphidium texanum</i> (Cushman and Applin)	+++++	+++++	
<i>Eponides lotus</i> (Schwager)	+++++	+++++	
<i>Idalina cuvillieri</i> Bignot	+++++	+++++	
<i>Lagena vulgaris</i> Williamson	+++++	+++++	
<i>Lenticulina chitanii</i> (Yabe and Asano)	+++++	+++++	
<i>Lenticulina rotulata</i> (Lamarck)	+++++	+++++	
<i>Nummulites beaumonti</i> d'Archiac and Haime	+++++	+++++	
<i>Operculina schwageri</i> Silvestri	+++++	+++++	
<i>Periloculina dalmatina</i> Drobne	+++++	+++++	
<i>Pseudolacazina schwagerinoides</i> (Blanckenhorn)	+++++	+++++	
<i>Pyrgo bulloides</i> (d'Orbigny)	+++++	+++++	
<i>Textularia tumidulum</i> Cushman	+++++	+++++	
<i>Triloculina gibba</i> d'Orbigny	+++++	+++++	
<i>Uvigerina elongata</i> Cole	+++++	+++++	
<i>Uvigerina jacksonensis</i> Cushman	+++++	+++++	
<i>Uvigerina rippensis</i> Cole	+++++	+++++	
<i>Bulimina jacksonensis</i> Cushman	+++++	+++++	+++++
<i>Nummulites</i> aff. <i>pulchellus</i> (Hantken)	+++++	+++++	+++++
<i>Quinqueloculina carinata</i> d'Orbigny	+++++	+++++	+++++
<i>Quinqueloculina seminula</i> (Linné)	+++++	+++++	+++++
<i>Quinqueloculina ludwigi</i> Reuss	+++++	+++++	+++++
<i>Textularia adalta</i> Cushman	+++++	+++++	+++++
<i>Baggina bradyi</i> (Brotzen)	+++++	+++++	
<i>Guttulina problema</i> d'Orbigny	+++++	+++++	
<i>Lagena hexagona</i> (Williamson)	+++++	+++++	
<i>Lagena sulcata</i> (Walker and Jacob)	+++++	+++++	
<i>Spiroloculina bicarinata</i> Terquem	+++++	+++++	
<i>Gaziryina pulchellus</i> (Hantken)			+++++

+++++ stratigraphic range.

#### 4.3.2. The Bartonian/Priabonian boundary

The Bartonian-Priabonian transition is associated with widespread biotic turnover in the marine realm (Cotton et al., 2017). However the boundary is not formally defined, and the Global Stratotype Section and Point (GSSP) is currently under discussion. Consequently, there is still uncertainty concerning the definition and recognition of global geological stage and age boundaries (Agnini et al., 2011; Wade et al., 2011; Strougo et al., 2013). In addition, the Middle/Upper Eocene boundary has often proved difficulty to determine in the Neo-Tethys area, because the age species differ from place to place (Farouk et al., 2015). Two criteria have been applied in the study area, to define the

Bartonian/Priabonian boundary, lithologic criteria encompass the presence of unconformity surface between the Qurn/Maadi formations which is recorded in G. Abu-Shama where it indicates sea level regression or uplift associated with the Gulf of Suez rifting (Bosworth et al., 1998). Other criteria includes turnover of benthic foraminifera reaches to 78% with the dominance of *Carolia placunoides* Cantraine at the base of Priabonian which indicates stress environment at boundary. The massive accumulation of *Carolia placunoides* indicates deposition in shelf edges under brackish water conditions (Carbonel and Pujos, 1981) associated with sea level regression and emergence which were recorded at the type locality of Priabonian (Barbin, 1988) and globally (Mancin et al., 2003; Seiffert et al., 2008; Boudagher-Fadel, 2013) is drawn at the extinction level of the spinose Middle Eocene genera.

## 5. Conclusions

Foraminifera and calcareous nannofossils have been integrated biostratigraphically to determine the Middle-Upper Eocene stages at the North of Eastern Desert. Although, the study area classified as being within the fracture zone but the Middle-Upper Eocene succession represented by Observatory, Qurn and Maadi formations are seemingly continuous. However, an evidence of unconformity is recorded between the Qurn and Maadi formations where the *Carolia placunoides* banks are directly overlying the Middle Eocene rocks with wavy contact in-between. Planktic contents (planktic foraminifera and calcareous nannofossils) of the studied sections have biostratigraphically applied and intergrated. Where the identification of 23 planktic foraminiferal species have enabled to record three biostratigraphic zones; *Globigerinatheka kugleri/Morozovella aragonensis* (E9) Zone, *Morozovelloides crassatus* (E13) and *Turborotalia cerroazulensis pomeroli/Turborotalia cerroazulensis cerroazulensis* Zone based on the evolutionary lineage of the *Turborotalia cerroazulensis* (Cole) as proposed by Toumarkine and Bolli (1970) emended Toumarkine in: Toumarkine and Luterbacher (1985). On the other hand, examination of 500 smear slides of calcareous nannofossils have enabled to identify only three species; *Reticulofenestra dictyoda*, *Pontosphaera multipora* and *Reticulofenestra umbilica* which were attributed to *Discoaster saipanensis* Zone (NP17) of Martini (1971) and occurred simultaneously within Zone E13.

Biostratigraphic analysis have also been analyzed quantitatively based on the SBF and therefore four benthic assemblages have been recorded in both the studied sections, benthic assemblage 1 to 4a and b. All of the recorded assemblages have been correlated with their equivalents in neighboring areas and also correlated with the planktic biozones. It is concluded that, all of the recorded taxa are of endemic nature, although the studied sections are separated by 27.6 km but two different benthic assemblages/biozones are suggested based on the quantitative analysis, supporting the fact of benthic dependent environments. It is imply that, a Middle Lutetian age (~45.8 Ma) is proposed for Observatory Formation which dated back to the Bartonian. While, the Qurn Formation is assigned to late Bartonian-early Priabonian age with paraconformity (~3.6 Ma) between the Observatory and Qurn formations as the result of tectonic instability at the late of Lutetian age. Combination of microfossils data, including vertical and lateral distribution as well as bioevents with lithology and unconformity/hiatuses can be tentatively applied to indicate the stage boundaries in the study area. The Lutetian/Bartonian boundary was defined by an abrupt lithological change that correspond with the boundary between the observatory and Qurn formations, where 43 % of the benthic foraminifera have experienced sudden disappearance. The Bartonian/Priabonian boundary has been also characterize by presence of unconformity surface between the Qurn/Maadi formations which indicates sea level regression or uplift due to consequence of Gulf of Suez rifting and disappearance of 78% in both benthic foraminifera with the dominance of *Carolia placunoides* which indicates stress environment at boundary.

## Declarations

### Author contribution statement

Hatem Hassan: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Asmaa Korin: Analyzed and interpreted the data, contributed reagents, materials, analysis tools or data.

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