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

Hatem F. Hassan*, Asmaa H. Korin
Department of Geology, Faculty of Science, Port Said University, Egypt

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ABSTRACT
Foraminifera and calcareous nanofossils 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 Turborotalia cerroazulensis pomeroli/T. cerr. cerroazulensis. Meanwhile, the occurrence of calcareous nanofossils 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 nanofossils 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 nanofossils (Allam et al., 1988; El Dawoody, 1992; Faris and Strougo, 1992). Lofy 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 nanofossils. Biostratigraphic analysis concerned the studied sections dated it back to the Bartonian age. But none of these studies precisely defined the epoch as much of these sediments are devoid of planktic or calcareous nanofossils. So this study aims to subdivide the Middle-Upper Eocene biostratigraphically based on integrated foraminifera and calcareous nanofossils to achieve their age, biozonation and correlation with adjacent areas as well as discuss the stage boundaries.

* Corresponding author.
E-mail address: hatem99_eg@yahoo.com (H.F. Hassan).

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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
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 H₂O₂ until full disintegration and washed over a 63 μm 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.

| Middle Eocene | Age | Rock Unit | Sample No. | Lithology | Biozones | Species |
|---------------|-----|-----------|------------|-----------|----------|---------|
| Late Lutetian | Late Lutetian | Observatory Fm. | Qurn Fm. | M. crassatus Zone (E9) | M. crassatus Zone (E13) | Morozovella aragonensis | Morozovella aragonensis |
| Bartonian | Bartonian | Morozovella aragonensis | Morozovella aragonensis | Morozovella aragonensis |
| | | Acarinina primitiva | Acarinina primitiva | Acarinina primitiva |
| | | Turborotalia frontosa | Turborotalia frontosa | Turborotalia frontosa |
| | | Morozovelloides crassatus | Morozovelloides crassatus | Morozovelloides crassatus |
| | | Hankenina lehneri | Hankenina lehneri | Hankenina lehneri |
| | | Globigerinatheka mexicana | Globigerinatheka mexicana | Globigerinatheka mexicana |
| | | Globigerinatheka subconglobata | Globigerinatheka subconglobata | Globigerinatheka subconglobata |
| | | Hankenina liebusi | Hankenina liebusi | Hankenina liebusi |
| | | Hankenina dumblei | Hankenina dumblei | Hankenina dumblei |
| | | Pseudohastigerina micra | Pseudohastigerina micra | Pseudohastigerina micra |
| | | Hankenina nutalli | Hankenina nutalli | Hankenina nutalli |
| | | Acarinina rohri | Acarinina rohri | Acarinina rohri |
| | | Hankenina alabamensis | Hankenina alabamensis | Hankenina alabamensis |
| | | Turborotalia pomeroli | Turborotalia pomeroli | Turborotalia pomeroli |
| | | Turborotalia cerroazulensis | Turborotalia cerroazulensis | Turborotalia cerroazulensis |
| | | Acarinina medizzai | Acarinina medizzai | Acarinina medizzai |
| | | Globigerinatheka semiinvoluta | Globigerinatheka semiinvoluta | Globigerinatheka semiinvoluta |

Fig. 5. Range chart of the identified planktic species in Wadi Degla.
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 (Archiac and Haime), Nummulites aff pullchellus (Hantken), Nummulites thalmanni (Schaub), Rhabdorites minimia (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
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, vari-coloured 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 provides 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 primitive (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 inaequispina, Morozovella aragonensis (Nuttall), Acarinina primitive (Finlay) (Fig. 6, 3-4), Acarinina bullbrooki (Bolli), Pseudohastigerina micra (Cole) (Fig. 6, 15), Igorina broedermanni (Cushman and Bermúdez) (Fig. 6, 10-11), Turborotalia posagnoensis (Toumarkine and Bolli) (Fig. 6, 18-19) and Turborotalia frontosa (Subbotina) which approve E9 Zone.

4.2.1.2. Morozovelloides crassatus zone (E13). Biostratigraphic interval characterized by the partial range of the nominate taxa between the HO and the LO of Morozovelloides crassatus (Cushman and Bermúdez) (Fig. 6, 5-6) attributed the lower limit of this zone to reoccur to 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.

4.2.2. Rock Unit

Age

Sample No.

Lithology

Biozones

Species

Morozovella aragonensis

Globigerinatheka kugleri

Turborotalia frontosa

Subbotina inaequispina

Acarinina primitive

Acarinina bullbrooki

Pseudohastigerina micra

Igorina broedermanni

Turborotalia posagnoensis

Hantkenina lehneri

Globigerinatheka index

Fig. 7. Range chart of the identified planktic species in G. Abu Shama.
Fig. 8. Range chart of the identified benthic species in Wadi Degla.
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 *Discaster saipanensis* Zone (NP17) of *Martini* (1971).

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

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**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.
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 *Hantkeinina alabamensis* Cushman (Fig. 6, 8), *Turborotalia pomeroli* (Toumarkine and Bolli) (Fig. 6, 20), *Turborotalia possagnoensis* (Toumarkine and Bolli), *Acarinina medissai* (Toumarkine and Bolli) (Fig. 6, 1-2) and *Globigerinathëka semiinvoluta* (Keijzer). It attains a thickness of 10.8 m at Wadi Degla. The small sized *Acarinina medissai* (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/
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 ellissorae, 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 thalmanni 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 Late Bartonian age in Cairo-Suez Road (Table 1). It is also correlated with the lower part of Nummulites aff. pulchellas Zone (Bakhyary et al., 2002) from the Observatory Formation in Helwan area. It could be correlated with the lower part of Marginulinopsis 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, Rhabdotorites 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 Salim et al. (2015a,b). Although some of the recorded species are not represent a definite stratigraphic range where Dictyoconus egyptiensis records.
from the early Lutetian sediments (Tawadros, 2011; Robinet et al., 2013) and other species (e.g. *Nummulites syrticus*, *Nummulites migartinus* 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 moodyensis*, *Brittillina 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 cocoaena* (Fig. 12). While in G. Abu Shama the benthic assemblage contains, *Anomalinoides 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 *Anomalinoides alazanensis*, *Baggina bradyi*, *Bolivina jacksonensis*, *Lenticulina rotulata*, *Spiriloculina bicarinata*, *Textularia adalta*, *Textularia tundilum*, *Uvigerina rippeniss* where in Abu Shama it composed of *Elphidium texanum*, *Lagena vulgaris*, *Pseudolacazina*.
**4.2.2.4. Benthic assemblage -4a.** It is recorded in the upper part of Qurn 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 adulta*, *Uvigerina jacksonensis* and *Uvigerina rippensis*. 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-Elil, 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 *Gasiryina pulchella* (Hantken) has been recorded within this assemblage and indicates upper Eocene age (Mufah and Boukhray, 2013). Other abundant species, *Quinqueloculina ludwigi*, was recorded in North Haft area, UAE (Cherif and El Deeb, 1984) among the late Eocene fauna.

| Table 1 Contribution of the LBF and SMF biozones in the study area with their equivalents in Egypt. |
| --- |
| **Eocene** |
| **Upper** |
| Benthic assemblage - 4a. |
| Benthic assemblage - 4b. |
| **Priabonian** |
| Benthic assemblage - 5. |
| **Bartonian** |
| Benthic assemblage - 4. |
| **Middle Lutetian** |
| Benthic assemblage - 3. |
| **Late Lutetian** |
| Benthic assemblage - 2. |
| **Early Priabonian** |
| Benthic assemblage - 1. |

**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 adulta*, *Uvigerina jackonensis* and *Uvigerina rippensis*. 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-Elil, 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 *Gasiryina pulchella* (Hantken) has been recorded within this assemblage and indicates upper Eocene age (Mufah and Boukhray, 2013). Other abundant species, *Quinqueloculina ludwigi*, was recorded in North Haft 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 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 *Gasiryina pulchella* (Hantken) has been recorded within this assemblage and indicates upper Eocene age (Mufah and Boukhray, 2013). Other abundant species, *Quinqueloculina ludwigi*, was recorded in North Haft area, UAE (Cherif and El Deeb, 1984) among the late Eocene fauna.
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 difficult 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 (Bowsworth et al., 1998). Other criteria includes turnover of benthic foraminifera reaches to 78% with the dominance of Carola placunoides Cantraine at the base of Priabonian which indicates stress environment at boundary. The massive accumulation of Carola 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; Seifert 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 Carola placunoides banks are directly overlaying 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; Globigerinatheke kugleri/Morozovella argonautensis (E9) Zone, Morozovelloides crassatus (E13) and Turborotalia cerroazulensis pomerolii/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, Pontosphera multipora and Reticulofenestra umbilica which were attributed to Discocystis paipanensis 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, 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 Carola placunoides which indicates stress environment at boundary.
Declarations

Author contribution statement

Hatam 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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