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Delta J. Sci. 2016 Vol.37; (147-173)

GEOLOGY

Stratigraical studies on the Upper Cretaceous - Lower Eocenerocks in Central Eastern Desert, Egypt

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Abstract An attempt has been made to construct the lithostratigraphic and biostratigraphic characters of the Upper Cretaceous-Lower Eocene rocks exposed at Gebel Duwi and Gebel Atshan sections, central Eastern Desert. Lithostratigraphically, the studied succession arerepresented by four rock units arranged from base to top as: Dakhla, Tarawan, Esna and Thebes formations.Detailed study of planktonic foraminifera and calcareous nannofossils has led to the recognition of forty five calcareous nannofossil and thirty one planktonic foraminiferal species. Twelve planktonic foraminiferal biozones, *Racemiguembelina fructicosa* Subzone (CF4), *Pseudoguembelina hariaensis* Subzone (CF3), *Pseudoguembelina palpebra* Subzone (CF2), *Parasubbotina pseudobulloides* Subzone (P1a), *Praemurica uncinata* Zone (P2), *Morozovella angulata* Zone (P3**,** subdivided into*Igorina pusilla* Subzone P3a and *Igorina albeari* Subzone P3b), *Globanomalina pseudomenardii* Zone (P4), *Morozovella velascoensis* Zone (P5), *Acarinina sibaiyaensis* Zone (E1), *Pseudohastigerina wilcoxensis-Morozovella velascoensis* Zone (E2), *Morozovella marginodentata* Zone (E3) and *Morozovella Formosa* Zone (E4) have been recognized as well as twelve calcareous nannofossil biozones; *Micula murus* Subzone (CC25c), *Micula prinsii* Subzone (CC26b), *Cruciplacolithus tenuis* Zone (NP2), *Ellipsolithus macellus* Zone (NP4), *Fasciculithus tympaniformis* Zone (NP5), *Heliolithus kleinpellii* Zone (NP6), *Discoastermohleri* Zone (NP7/ NP8), *Discoaster multiradiatus* Zone (NP9), *Tribrachiatus contortus* Zone (NP10) and *Discoaster binodosus* Zone (NP11).
The Cretaceous/Paleogene (K/Pg) boundary is marked by the absence of nannoplankton NP1 Zone and the planktonic (P0 and P1 Zones). The K/Pg boundary is located at the top of CC26b. This boundary lies in the middle part of the Dakhla Formation. The Danian/Selandian boundary can be placed inthe uppermost part of Zone NP4 and nearly at the top of P3a Subzone in the upper part of the Dakhla Formation. The Selandian/Thanetian boundary can be drawn at NP6/ NP7/8 zonal boundary, and the upper part of P4 Subzone within the Esna Formation. The Paleocene/Eocene (P/E) boundary can be traced at the base of the E1Zone and at the base of the NP9b Subzone in the upper part of Esna shale

Key words: Gebel Duwi, Paleocene/Eocene, Foraminifera, Calcareous Nanofossils, Biostratigraphy.

1. Introduction

The Upper Cretaceous-Lower Eocene successions in Egypt have attracted several studies with special emphasis on the general geology, stratigraphy and paleontology (e.g., Said and Kenawy (1956), Youssef and Abdel Malik (1969), Abdel Malik *et.al.* (1978), Masters (1984), Faris *et al.* (1986), Hewaidy (1987), Cherif *et al.* (1989), Shahin (1988, 1992 and 2001), Ziko *et al.* (1993), Khalil (1986, 1993, 1998 and 2001), Kora *et al.* (1994 and 2001), Ismail and El Saadany (1995),Tantawy et al. (2000), Kora *et al.* (2002) and Samir (2002), EL-Nady (2005), Obaidalla (2005), Obaidalla, et al. (2008)and EL-Azabi and Farouk (2010).

A relatively thick Cretaceous-Eocene succession was measured and sampled from Gebel Duwi and Gebel Atshancentral Eastern Desert (Fig.1).The studied area is located to the west of Qusseir at Gebel Duwi (N 26° 7′ 5.73″; E 34° 5′ 29.02″) and Gebel Atshan (N 26° 4′ 37.27″E 34° 9′ 24″) (Fig. 1).

The main objectives of the present study are to: 1) recognize the different lithostratigraphic units in the studied area and to correlate them with different rock units in Egypt. 2) integrate the data obtained from planktonic foraminifera and calcareous nannofossils to subdivide the Late Maastrichtian-Early Eocene into

several biostratigraphic units. 3) discuss somestage boundaries.

2. Materials and methods

The stratigraphic two sections were measured and sampled and a total of 353 rock samples were collected. For planktonic foraminiferal study, the samples have been washed and picked and the different species have been examined and identified using a binocular microscope with maximum 40x magnification. The first and last appearances of a species were identified based on random representative splits with 300-400 individuals from the > 63 μm size fraction. The remaining sample residue was investigated for rare species and any other vital observations.

For the calcareous nannofossil study, samples were processed by smear slide preparation from raw sediment samples (Perch-Nielsen, 1985).

3. Lithostratigraphy

The lithostratigraphic subdivisions of the studied succession in Gebel Duwi and Gebel Atshansections throughout the Late Cretaceous-Early Eocene interval are based mainly on field observations and lithologic characters. The Upper Cretaceous-Lower Eocene succession along the studied sections is differentiated into five lithostratigraphic units: Duwi, Dakhla, Tarawan, Esna and Thebes formations, (Fig. 2). A detailed lithostratigraphic description of the measured sections is summarized in (Figs. 3, 4). In the following a brief account on each of these rock units arranged from bottom to top:

3.1. Duwi Formation

Author and type section: The name Duwi Formation was introduced by Youssef (1957) to define this unit at Gebel Duwi, central Eastern Desert.

Stratigraphic boundaries and description: In the studied succession, the top most part of the Duwi Formation is represented by about 10 m thick of limestone, yellow, hard, dolomitic, highly fossiliferous (oyster band) in the lower part and marl, yellow to grey, fossiliferous with thin phosphatic bands in the upper part at Gebel El Duwi section. The Duwi Formation conformably underlies the Dakhla Formation (Figs 3, 5a, 5b).

Age: Various workers (El Tarabili, 1966; Abd El Razik, 1967; Issawi, 1972) assign a Maestrichtian age to the entire Duwi Formation

3.2. Dakhla Formation

Author and type section: The name Dakhla Formation was introduced by Said (1961, 1962) to define this unit along the scarp north of Mut, Dakhla Oasis, Western Desert, Egypt.

Stratigraphic boundaries and description: In the studied succession, Dakhla Formation attains a thickness of about 60m in Duwi section. It is made up of calcareous shale, gypsiferous in the lower part. The middle part of the formation is about 5m thick and is composed of hard argillaceous limestone and dolomite. The upper part of the formation is composed of calcareous shale, grey to greenish grey, sometimes reddish, gypsiferous with reddish yellow marl intercalations. This unit conformably underlies the Tarawan Formation and overlies the Duwi Formation (Figs, 5, 6).

Age: The recorded Planktonic foraminiferal (CF4, CF3, CF2, P1a, P1b, P2, P3a, P3b) and calcareous nannofossil (Cc25c, Cc26b) biozones are suggested that this formation is assignanble to Late Maastrichtian-Middle Paleocene.

3.3. Tarawan Formation

Author and type section: The name Tarawan Formation was introduced by Awad and Ghobrial (1965) to define this unit at Gebel Teir/Tarawan, Kharga Oasis, Western Desert.

Stratigraphic boundaries and description: It attains 15m thick in the Gebel Duwi and its upper part (5m) only is measured in Gebel Atshansections. The Tarawan Formation is made mainly up of creamy white chalk with reddish yellow marl intercalations and chert nodules (Fig. 3, 5a). The Tarawan Formation lies conformably

between.shale units (Dakhla and Esna) with no remarkable hiatus in the studied sections (Fig. 5b).

Age: The recorded Planktonic foraminiferal (P4) and calcareous nannofossil (NP5) biozones are suggested that this formation is assignanble to Middle Paleocene.

3.4. Esna Formation

Author and type section: The term "Esna Shale" is firstly given by Beadnell (1905) to describe the laminated green and grey shale sequence in Gabal Owaina, opposite Esna, Nile Valley.

Stratigraphic boundaries and description: The Esna Formation is conformably underlies the Thebes Formation and overlies the Tarawan Chalk with sharp contact between them (Figs.3,4, 5c, 6b,c). It is measured in the two studied sections (G. Duwi and G. Atshan), and attains a thickness of about 60m and 55m respectively. The Esna Formation is composed mainly of calcareous shale, greenish grey, graded upwardly into marl and argillaceous limestone in the lower and upper parts. The middle part of Esna Shale is formed of shale, greenish grey, gypsiferous with reddish yellow to grey marl and siltstone and /or hard phosphatic limestone intercalations.

Age: The recorded Planktonic foraminiferal (P4, P5, E1) and calcareous nannofossil (NP5, NP6, NP7/8, NP9a, NP9b) biozones are suggested that this formation is assignanble to Late Paleocene – Early Eocene.

3.5. Thebes Formation

Author and type section: The name Thebes Formation was applied by Said (1960) to describe a thick sequence of limestone with chert interbeds at Gabal Gurnah, near Luxor.

Stratigraphic boundaries and description: The Thebes Formation conformably overlies the Esna Formation in the two studied sections (Figs. 3,4,5c,6a,b,c). This unit is about 150m thick and subdivided informally to lower, middle and upper members. The lower member is made up of argillaceous limestone in lower part and chalky in upper part with thin chert band and nodules. It is rich in marine macro- and micro-fauna especially*Turritella* and *Nummulites*. The middle one characterizes by limestone and chert bands intercalations. A disconformity surface is observed in the field within the middle part. Argillaceous limestones are the main components of the upper member of the Thebes Formation.

Age: The recorded Planktonic foraminiferal (E2, E3, E4) and calcareous nannofossil (NP10, NP11) biozones are suggested that this formation is assignanble to Early Eocene.

4. Biostratigraphy

The Cretaceous biostratigraphic zonation is used here and based on the (CF) zonal scheme of Li & Keller (1998), where the Paleocene and Early Eocene biozones are based on the zonal scheme of Berggern & Pearson (2005). Nannofossil biostratigraphic framework is applied according to the biozonation scheme of Sissingh (1977) and Prech-Nielsen (1981) for the Late Cretaceous. The Lower Paleogene Zonal Schemes of Martini (1971) and that of Romein (1979) have been followed.

Planktonic foraminifera and calcareous nannofossil assemblages are used to establish an integrated biostratigraphic zonation for the Paleocene-Lower Eocene successions in the area under consideration and to correlate the identified calcareous nannofossil biozones with time-equivalent zones worldwide. Planktonic foraminiferal and calcareous nannofossil biozones in the studiedsections are present in Figures (3,4).

4.1. Planktonic foraminiferal biostratigraphy

According to the vertical distribution of planktonic foraminifera, the Upper Maastrichtian – LowerEocene succession can be subdivided into nine biozones. The identified planktonic foraminiferal zones in the studied section are illustrated (Figs. 3, 4). Some selected planktonic foraminiferal species are illustrated on Plates 1, 2. The following is the description of the established planktonic foraminiferal biozones arranged from older to younger:

4.1.1. Late Maastrichtian biozones

***Abathomphalus mayaroensis* Zone (CF1, CF2, CF3, CF4 zones of Li & Keller, 1998)**

Author: Bronnimann (1952) as the *Globotruncana mayaroensis* Zone

Age: Late Maastrichtian

Definition: This zone was defined by the total range of the nominated species. It characterizes the Late Maastrichtian of low latitude deep-sea successions as well as the tethyan palaeogeographic realm. *A. mayaroensis* disappears prior to the K/Pg boundary in high latitude regions (Blow, 1979) and is rare or absent in shallow continental shelf sequences (Keller, 1988, 1989; Keller *et al*., 1995). In the present study, the *A. mayaroensis* species is not recorded in the studied samples. According to LI & Keller, 1998 the *A. mayaroensis* Zone is subdivided into four subzones namely in stratigraphic order: *Racemiguembelina fructicosa*, *Pseudoguembelina hariaensis, P. palpebra* and *Plummerita hantkeninoides* subzones. Only three subzones were recorded in the present study. *Plummerita hantkeninoides* Zone represents the latest Maastrichtian biozone, according to many authors: Pardo *et al.* (1996) in Spain, Arz et al.(2001) in Mexico, Darvishzad *et al.* (2007) in Iran and Anan (2007, 2008a, b, 2011a, b and 2012) in Egypt. The topmost Maastrichtian *Plummerita hantkeninoides* Subzone (CF1Zone of Li & Keller, 1998) is not recorded. Three subzones are described from base to top as follows:

***Racemiguembelina fructicosa* Subzone (CF4)**

Author: Li & Keller (1998)

Age: Late Maastrichtian

Definition: CF4 Subzone is defined to include the interval from the first appearance datum (FAD) of the *Racemiguembelina fructicosa*and the FAD of the *Pseudoguembelina hariaensis.*

Occurrence: Lowerpart of Dakhla Formation.

Characteristic planktonic foraminiferal assemblage: The dominant species in this subzone are *Rugoglobigerina hexacamerata, R. rugosa, Pseudotextularia deformis, P. elegans, P. intermedia, Heterohelix dentanta, H. globulosa, H. moremani, H. navarroensis, H. reussi, Pseudoguembelina costulata* and *P. palpebra*.

***Pseudoguembelina hariaensis* Subzone (CF3)**

Author: Li & Keller (1998)

Age: Late Maastrichtian.

Definition: CF3 Subzone was defined by Li & Keller (1998) as the partial range of the *Pseudoguembelina hariaensis*between its FAD and the last appearance datum (LAD) of *Gansserina gansseri* (Bolli). *Gansserina gansseri* (Bolli) is not recorded in the present samples. The upper boundary of the CF3 subzone is not clear.

Occurrence: Lower part of Dakhla Formation.

Characteristic planktonic foraminiferal assemblage: The dominant species in this subzone are *Rugoglobigerina hexacamerata, R. macrocephala, R. rugosa, Pseudotextularia deformis, P. elegans, P. intermedia, Heterohelix dentanta, H. globulosa, H. moremani, H. navarroensis, H. pulchra, H. reussi, H. striata, Pseudoguembelina costulata* and *P. palpebra*.

***Pseudoguembelina palpebra* Subzone (CF2)**

Author: Li & Keller (1998)

Age: Late Maastrichtian

Definition: CF2 *Pseudoguembelina palpebra* Subzonewas defined by Li & Keller (1998) as the partial range of the nominate taxon between the LAD of *Gansserina gansseri* to the FAD of *Plummerita hantkeninoides*. This subzone is indicated in the present study by the occurrence of *Pseudoguembelina palpebra* (Bronnimann).

Occurrence: Lower part ofDakhla Formation.

Characteristic planktonic foraminiferal assemblage: The dominant species in this subzone are *Rugoglobigerina hexacamerata, R. macrocephala, R. robusta, R. rugosa, R. scotti, Archaeoglobigerina blowi, Pseudotextularia deformis, P. elegans, Heterohelix dentanta, H. glabrans, H. globulosa, H. moremani, H. navarroensis, H. pulchra, H. reussi, H. striata, Pseudoguembelina costulata, P. palpebra,*

Globigerinelloides aspera, G. subcarinata and *Hedbergella holmdelensis.*

4.1.2. Paleocene-Early Eocene biozones

***Parasubbotina pseudobulloides* Partial range** (Subzone P1a).

Author: Bolli (1966) (renamed by Berggren and Pearson (2005) from *Parvularugoglobigerina eugubina-Subbotina triloculinoides--Zone* [P1a] of Berggren et al. 1995; emendation of Berggren and Miller, 1988).

Age: Early Paleocene (Early Danian).

Definition: Partial range of the nominate taxon between the HO of *Parvularugoglobigerina eugubina* and the LO of *Subbotina triloculinoides.*

Occurrence: The *Parasubbotina pseudobulloides* Zone is recorded from the middle part of the Dakhla Formation.

Characteristic planktonic foraminiferal assemblage: Besides the marker species, this zone is characterized by the presence of *Globanomalina compressa*, *Chiloguembelina midwayensis, Globanomalina archeocompressa, G. planocompressa, Praemurica polycamera, P. pseudoinconstans, P. taurica, Eoglobigerina edita, E. eobulloides, E. praedita, E. simplicissima* and *Subbotina trivialis.*

Remarks and correlation: The *P. pseudobulloides* zone represents the oldest identified Danian planktonic foraminiferal zone in the studied section. It is characterized by the disappearance of the Cretaceous planktonic foraminiferal species and by the incoming of the Paleocene forms. The *P. Pseudobulloides* Zone is conformably overlain by the *Subbotina triloculinoides* Zone.

This zone is equivalent to the lower part of the *Globigerina triloculinoides-Globoconusa daubjergensis* Zone of Berggren (1969) in Libya, The *Parasubbotina pseudobulloides* Zone is matched with the *Morozovella pseudobulloides* Zone of Faris (1985), Hewaidy (1987) in north east Sinai, Aref *et al.* (1988), Shahin (1992) in west central Sinai, Khalil (1993) in Araif El–Naga. It coincides with the *Subbotina pseudobulloides* Zone of Premoli-Silva & Bolli (1973), the *Morozovella pseudobulloides* Zone of Toumarkine and Luterbacher (1985). P1a Subzone is also correlated with *P. pseudobulloides* Zone described by El-Nady and Shain (2001), Obaidalla (2005) in southwestern Sinai, EL-Nady (2005) in northern Sinai and Galal and Kamel (2007) in the Eastern Desert**.**

***Subbotina triloculinoides* Lowest occurrence (Subzone P1b).**

Author: Berggren et al., 1995, renamed by Berggren and Pearson (2005) from *Subbotina triloculinoides-lobanomalina Compressa/Praemurica inconstans* Subzone [Plb], Berggren et al., 1995; emendation of Berggren and Miller, 1988).

Age: Early Paleocene (Early to Mid-Danian).

Definition: Biostratigraphic interval from the LO of the nominate taxon to the LOs of G. *compressa* and/or *P. inconstans*.

Occurrence: The *Subbotina triloculinoides*Zone is recorded from middle part of the Dakhla Formation.

Characteristic planktonic foraminiferal assemblage: In addition to the index species, the planktonic foraminifers include; *Parasubbotina pseudobulloides*, *P. moskvini, Subbotina trivialis, Chiloguembelina midwayensis, C. morsi, Globanomalina planocompressa, Praemurica polycamera, P. pseudoinconstans, P. taurica, Globanomalina compressa*, *Praemurica inconstans*, *Morozovella praecursoria*, *Globoconusa daubjergensis, Eoglobigerina edita, E. eobulloides, E. pentagona* and *Woodringina hornerstownensis.*

Remarks and correlation: The *S. triloculinoides* Subzone is unconformably overlain by the *Praemurica uncinata* Subzone P2. Subzone P1b is identical to the *Subbotina triloculinoides-Globanomalina compressa/Praemurica inconstans* Interval Subzone (Plb) of Berggren et al., (1995). It is also equivalent to the*Subbotina triloculinoides*Zone described by Obaidalla (2005) in southwestern Sinai and Galal and KAamel (2007) in the Eastern Desert**.**

***Praemurica uncinata* Lowestoccurrence (Zone P2).**

Author: Bolli (1966), renamed by Berggren and Pearson (2005) from *Praemurica uncinata-Morozovella angulata*

zone [P2] of Berggren et al., 1995; emendation of, but biostratigraphically equivalent to *Morozovella uncinata-Igorina spiralis* zone [P2] ofBerggren and Miller, 1988.

Age: Late Early Paleocene (Late Danian).

Definition: Biostratigraphic interval between the LO of *Praemurica uncinata* and the LO of *Morozovella angulata*.

Occurrence: The *Praemurica uncinata* Zone is recorded from the middle part of the Dakhla Formation.

Characteristic planktonic foraminiferal assemblage: The characteristic planktonic foraminifers in this zone include: *Parasubbotina pseudobulloides*, *Subbotina triloculinoides*, *Praemurica trinidadensis*, *P.inconstans*, *Morozovella praecursoria*, *Globoconusa daubjergensis* and *Eoglobigerina* sp.

Remarks and correlation: The current zone is equivalent to the *Globorotalia uncinata* Zone defined by Bolli (1957 & 1959) in Trinidad, Bolli & Cita (1960) in Italy, Bolli (1966) in his general zonation, Premoli-Silva & Bolli (1973), Stainforth *et al.* (1975), *Globorotalia* (*Acarinina*) *praecursoria* Zone of Blow (1979), *Morozovella uncinata-Igorina spiralis* Zone (P2) of Berggren & Miller (1988). It coincides with the **P2** zone proposed by Toumarkine and Luterbacher (1985), the same zone of Berggren and Pearson (2005). *Morozovella angulata* Zone conformably overlies this zone.

In Egypt, *Praemurica uncinata* Zone P2 is equivalent to that defined by El-Naggar (1966) in the Nile Valley, Youssef & Abdel Malik (1969) in southwestern Sinai, Beckman *et al.* (1969), Abdel Malik *et al.* (1978) in west central Sinai, Faris (1985) at Ain Amur (NW Kharga), Hewaidy (1987) at El-Ain and El-Falig (NE Siani), Shahin (1988) at Gabal Nazzazat (SW Sinai) and El-Deeb & El-Gammal (1994) at southwestern Sinai, Shahin (1992) in west central Sinai and Khalil (1993) in Araif El–Naga area. *Parasubbotina pseudobulloides* subzone is also correlated with *P. pseudobulloides* Zone described by El-Nady and Shain (2001), EL-Nady (2005) in northern Sinai, Galal and KAamel (2007) in the Eastern Desert and Khalil and Al Sawy (2014) in the wesren Desert**.**

***Morozovella angulata* Lowestoccurrence (Zone P3).**

Author: Alimarina (1963), renamed by Berggren and Pearson (2005) from *Morozovella angulata-Globanomalina pseudomenardii* zone [P3] of Berggren et al. (1995); emendation of Berggren and Miller (1988).

Age: Early Late Paleocene (Selandian)

Definition: Biostratigraphic interval between the LO of *Morozovella angulata* and the LO of *Globanomalina pseudomenardii*.

Occurrence: The *Morozovella angulata* Zone is recorded from the upper part of the Dakhla Formation.

Characteristic planktonic foraminiferal assemblage: The planktic assemblage of this zone is predominated by: *Globanomalina compressa, Luterbacheria chapmani, Morozovella angulata, M. acutispira, M. aequa, M. conicotruncata, M. acuta, M. simulatiltes, Igorina pusilla, I. albeari, Acarinina primitive, A. subsphaerica, Muricoglobigerina mckannai* and *Subbotina irregularis.*

Remarks and correlation: Based on higher resolution studies of material from DSDP Site 384, Berggren et al. (2000) renamed the *Morozovella angulata*Zone to accord with the convention that the nominate taxon should be present within the zone. This zone is biostratigraphically identical to the *Morozovella angulata-Globanomalina pseudomenardii* Interval Zone (Zone P3) of Berggren et al., (1995).*Morozovella angulata*Zone P3 coincides with that of Premoli-Silva and Bolli (1973), Stainforth *et al.* (1975), Toumarkine and Luterbacher (1985), the lower *Morozovella angulata* (P3a) subzone of Berggren & Miller (1988) and P3 Zone of Berggren and Pearson (2005).

In Egypt, this zone is equivalent to the *Globorotalia angulata* Zone described by Beckmann *et al.* (1969), Faris (1984) at the Red Sea Coast and Faris (1985) at Ain Amur section. It is also correlated with the *Morozovell*a *angulata* Zone of Hewaidy (1987) at El Quseima section, El-Deeb & El-Gammal (1994) at southwestern Sinai, Shahin (1992) in west central Sinai, Khalil (1993) in Araif El–Naga area, Faris *et al*. (2000) in Sinai, EL-Nady (2005) in northern Sinai, Galal and Kamel (2007) in the Eastern Desertand Khalil and Al

Sawy (2014) in the wesren Desert.Recently, Obaidalla et al. (2009) divided this interval into three zones: *Morozovella angulata*, *Igorina albeari/Praemurica carinata* and *Igorina albeari* Zones. This subdivision cannot be applied in this study because it needs more high-resolution sampling.

***Igorina pusilla* Partial range (Subzone P3a).**

Author: Bolli 1957a, emended by Berggren eta al. (1995) and renamed by Berggren and Pearson (2005).

Age: early late Paleocene (Selandian).

Definition: Biostratigraphic interval defined by the partial range of *Igorina pusilla* between the LO of *Morozovella angulata* and the LO of *Igorina albeari.*

Occurrence: The *Igorina pusilla* Subzone is recorded from the upper part of the Dakhla Formation.

Remarks and correlation: This subzone is equivalent to P3a Subzone of Berggren et al. (1995); Berggren and Pearson (2005), Galal and Kamel (2007) in the Eastern Desert, Khalil and al Sawy (2014) and to *Morozovella angulata* Zone of Obaidalla (2006).

***Igorina albeari* Lowest occurrence (Subzone P3b).**

Author: Bolli 1957a, emended by Berggren eta al. (1995) and renamed by Berggren and Pearson (2005).

Age: early late Paleocene (Selandian).

Definition: Biostratigraphic interval defined by the partial range of *Igorina pusilla* between the LO of *Morozovella angulata* and the LO of *Igorina albeari.*

Occurrence: The *Igorina albeari* Subzone is recorded from the upper part of the Dakhla Formation and the Tarawan Formation.

Remarks and correlation: This subzone is equivalent to P3b Subzone of Berggren et al. (1995); Berggren and Pearson (2005), Galal and Kamel (2007) in the Eastern Desert, Khalil and Al Sawy (2014), and to the the combined *Igorina albeari* and *Igorina albeari/Praemuricacarinata* Zones of Obaidalla (2006).

***Globanomalina pseudomenardii* Taxon range (Zone P4).**

Author: Bolli (1957a) as *Planorotalites pesudomenardii* Zone.

Age: Late Paleocene (late Selandian-Thanetian).

Definition: This zone was originally introduced by Bolli(1957), and it is defined as the biostratigraphic interval characterized by the total range of the nominate taxon *Globanomalina pseudomenardii.*

Occurrence: The *Globanomalina pseudomenardii* Zone occurs within the topmostpart the Tarawan and the lower part of Esna Formation.

Characteristic planktonic foraminiferal assemblage:

The *Globanomalinapseudomenardii* Zone includes the following species in addition to the marker species; *Igorina pusillapusilla*, *Morozovella occlusa* and *Pseudohastigerina wilcoxensis.*

Correlation: This zone is equivalent to the *Globorotalia pseudomenardii* Zone defined by Bolli (1957 & 1959) in Trinidad, Bolli & Cita (1960) in Italy, Bolli (1966) in his general zonation, Berggren (1969), Premoli-Silva & Bolli (1973), Stainforth *et al.* (1975), Toumarkine & Luterbacher (1985) and Berggren & Miller (1988). It coincides with P3 Zone of Berggren and Pearson (2005). The current subzone corresponds to the P4a, P4b and P4c Subzones of Berggren et al. (1995) and Berggren and Pearson (2005).

In Egypt, the *Globanomalina pseudomenardii* Zone coincides with the *Planorotalites pseudomenardii* proposed by El-Naggar (1966) in the Nile Valley as a subzone in the *Globorotalia velascoensis* Zone, Abdel Malik *et al.* (1978) in west central Sinai, Faris (1984), Faris *et al.* (1986) at Abu Had, El Serai and Taramsa sections, Hewaidy (1987) in El-Qusaima area, Aref *et al.* (1988) along the Red Sea Coast, El-Deeb & El-Gammal (1994) at southwestern Sinai, Faris *et al*. (2000) in north and southwest Sinai, Galal and Kamel (2007) in the Eastern Desert and Khalil and al Sawy (2014) in the western Desert.

Morozovella velascoensis Partial range (Zone P5).

Author: Bolli (1957).

Age: Late Paleocene (latest Thanetian).

Definition: This zone was originally defined by Bolli (1957a) from the Upper Paleocene rocks of Trinidad. It includes the biostratigraphic interval characterized by the partial range of the nominate taxon between the HO of

Globanomalina pseudomenardii and the LO *of. Acarinina sibaiyaensis.*

Occurrence: This zone is recorded from the upper part of the Esna Shale.

Characteristic planktonic foraminiferal assemblage: This zone is characterized by the diversification of planktonic species including *Morozovella aequa*, *M. conicotruncata*, *M. acuta*, *M. occlusa*, *Acarinina soldadoensis*, *A. mckannai*, *A. primitiva*, *A. nitida*, *Subbotina velascoensis* and *Subbotina linaperta.*

Correlation: The *Morozovella velascoensis* Zone was recorded firstly from the Lizard Springs Formation of Trinidad by Bolli (1957, 1966). It coincides with that of Bolli and Cita (1960) in Italy, Postuma (1971) world wide, Premoli-Silva and Bolli (1973) in Italy, Stainforth *et al.* (1975) world wide and Toumarkine & Luterbacher (1985) in their general zonation.

In Egypt, it is equivalent to that described by Abdel Malik *et al.* (1978) in west central Sinai, Hewaidy (1987) in El-Qusaima area, Aref *et al.* (1988) in Red Sea Coast, Shahin (1988) at Gebel Nezzazat, El-Deeb & El-Gammal (1994) at southwestern Sinai, Galal and Kamel (2007) in the Eastern Desert and Khalil and al Sawy (2014) in the western Desert.

***Acarinina sibaiyaensis* Lowest occurrence (Zone E1).**

Author: Molina et al., 1999; emended by Berggren and Pearson, 2005

Age: earliest Eocene (earliest Sparnacian).

Definition: Biostratigraphic interval between the LO of the nominate taxon *Acarinina sibaiyaensis* and the LO of *Pseudohastigerina wilcoxensis.*

Occurrence: This zone is recorded from the uppermostpart of the Esna Formation.

Characteristic planktic foraminiferal assemblage: The zone is marked by the presence of; *Planorotaliteschapmani*, *Morozovellaaequa*, *M. caucasica*, *M. subbotinae*, *M. marginodentata*, *M. quetra* and *M. gracilis.*

Remarks and correlation: The base of this zone coincides with the defined Global Stratotype Section and Point (GSSP) for the base of Eocene Series, in the Dababya section, south of Luxor, Nile Valley, where the *Acarinina sibaiyaensis* is so far the most common taxon among the three excursion taxa and occur in large number in some of the CIE interval (Berggren and Ouda, 2003a).

This zone may be equivalent to both the subzones P5b and one P5c of Molina *et al.* (1999).The *Morozovella edgari* Zone may be correlated with the *Globorotalia aequa* Zone of Luterbacher (1964). It corresponds to the lower part of the *Globorotalia subbotinae* Zone of Stainforth *et al.* (1975), the lower part of the subzone P6b of Berggren & Miller (1988) andE1 zone of Berggren and Pearson (2005).

In Egypt, this Zone coincides with the *Globorotalia wilcoxensis* Zone of El-Naggar (1966), the *Morozovella edgari* Zone of Faris *et al.* (2000), to the same zone described by Nassif & Omran (2001) in Wadi Watir area, Subzone P5b of Galal and Kamel (2007) in the Eastern Desert and E1 Zone Khalil and al Sawy (2014) in the western Desert.

***Pseudohastigerina wilcoxensis*- *Morozovella velascoensis* Concurrent range (Zone E2).**

Author: (Berggren and Pearson, 2005)

Age: Early Eocene**.**

Definition: Biostratigraphic interval characterized by the concurrent biostratigraphic ranges of the nominate taxa between the LO of *Pseudohastigerina wilcoxensis* and the HO of *Morozovella velascoensis.*

Occurrence: This zone is recorded from the lower part of Thebes Formation.

Characteristic planktic foraminiferal assemblage: This zone is characterized by the presence of the following species; *Planorotalites chapmani*, *Morozovella aequa*, *M. caucasica*, *M. subbotinae*, *M. marginodentata*, *M. quetra*, *M. formosa formosa*, *M. formosa gracilis*, *M. lensiformis*, *Acarinina soldadoensis*, *A. primitiva* (Finlay), *A. nitida* and *Pseudohastigerina wilcoxensis.*

Remarks and correlation: The current zone is biostratigraphically identical to the upper part of *Morozovella velascoensis* (P5) Zone of Berggren et al. (1995) and to *Pseudohastigerina wilcoxensis* Subzone of Molina et al. (1999). It is also equivalent to Subzone P5c

of Berggren and Ouda (2003b) and E2 Zone of Berggren and Pearson (2005) and Khalil and al Sawy (2014) in the western Desert.

***Morozovella marginodentata* Partial range Zone (E3).**

Author: Berggren and Pearson (2005**)**

Age: Early Eocene

Definition: Biostratigraphic interval characterized by the partial range of the nominate taxon between the HO of *Morozovella velascoensis* and LO of *Morozovella formosa*.

Occurrence: This zone comprises the middle part of Thebes Formation.

Characteristic planktic foraminiferal assemblage: This zone is characterized by the presence of *Morozovella aequa, M. edgari, M. gracilis, M. marginodentata, M. subbotinae, Acarinina coalingensis, A. angulosa, A. pseudotopilensis, A. wilcoxensis* and *A. soldadoensis.*

Correlation: The current zone is identical to Zone E3 of Berggren and Pearson (2005) and Khalil and Al Sawy (2014). It is also closely equivalent to the *Globorotalia rex*Zone of Bolli (1957b); *Acarinina berggerni* Zone (P7) of Blow (1979) and the *Morozovella subbotinae – Pseudohastigerina wilcoxensis* Zone (P6b) of Berggren and Miller (1988).

***Morozovella Formosa* Lowest occurrence (Zone E4).**

Author: Berggren and Pearson (2005**)**

Age: EarlyEocene

Definition: Biostratigraphic interval between the LO of the nominate taxon *Morozovella formosa*and the LO of *Morozovella aragonensis.*

Occurrence: This zone comprises the upper part of Thebes Formation.

Characteristic planktic foraminiferal assemblage: The nominate species coexists with a characteristic association including; *Morozovella subbotinae, A. soldadoensis, A. primitiva, A. nitida, Globigerina linaperta* and *Pseudohastigerina wilcoxensis,*

Correlation: The E4 Zone is equivalent to the *Globorotalia Formosa Formosa* of Premoli-Silva & Bolli (1973), *M. formosa formosa* of Toumarkine and Luterbacher (1985) and E4 Zone of Berggren and Pearson (2005**)**.

In Egypt, this zone is equivalent to the *Globorotalia formosa formosa* Zone ofBeckmann *et al.* (1969) and to the *M. formosa formosa* Zone described by Ayyad (1996) in Wadi Qena. In Sinai, it coincides with the upper part of *G. rex* Zone of Youssef & Abdel Malik (1969) in Tayiba–Feiran area, to the *M. formosa formosa* Zone defined by Faris *et al.* (1986) in Gebel Qabeliat, by Faris *et al*. (2000) at Wadi Matulla and Feiran, by Nassif &Omran (2001) in the Wadi Watir area and by Khalil and Mashaly (2004) in Sinai and Khalil and Al Sawy (2014) in the Western Desert.

4.2. Calcareous nannofossil biostratigraphy

Nannofossil biostratigraphic framework is applied according to the biozonation scheme of Sissingh (1977) and Prech-Nielsen (1981) for the Late Cretaceous. Meanwhile, the Lower Paleogene rocks comprise many zones from NP1 to NP11 according to the Zonal Scheme of Martini (1971). Furthermore, the subdivisions of the Paleocene biozones proposed by Romein (1979) have been followed For the Paleocene and Eocene, we adopt the biozonation proposed by Martini (1971) and emended by Aubry *et al*. (2000).

.A total of 82 nannofossil species were identified from the Upper Cretaceous-Early Eocene rocks of the studied sections. Some representative calcareous nannofossil species are illustrated in Plates (3,4). Calcareous nannofossils are common to abundant in most studied samples and generally well preserved. The recognized biozones, subzones and the correlation between them are discussed below from base to top:

4.2.1. Late Maastrichtian biozones

***Miculamurus* Subzone (CC25c)**

Author: Romein (1979)

Age: Late Maastrichtian.

Definition: It is defined as the interval from the FO of *Micula murus* to the FO of *N. frequens*.

Occurrence: Lower part from Dakhla formation.

Characteristic nannofossil assemblage: Besides the marker species, this zone is dominated by *Micula*

decussata, Watznaueria barnesae, Thoracosphaera operculata, Prediscosphaera cretacea, Eiffellithus gorkae, Arkhangelskiella cymbiformis, Eiffellithus turrisieffelii and *Cyclagelosphaera reinhardtii*. The most important calcareous nannofossil species that appear in this zone include; *Lithraphidites quadratus*, *Manivitella pemmatoidea*, *Chiastozygus amphipons/litterarius*, *Ahmuellerella octoradiata* and *Prediscosphaera grandis*.

Remarks and correlation: The present subzone is equivalent to the lower part of *Lithraphidites quadratus* Zone of Roth (1978) and Doeven (1983) and the upper part of *Arkhangelskiella cymbiforms* of Sissingh (1977), *Lithraphidites quadratus* Zone of Thierstein (1976) and Verbeek (1977), CC25b Subzone of Perch-Nielsen (1985a), CC25c Subzone of Khalil and Zahran (2014) in Sinai.

***Miculaprinsii* Subzone (CC26b)**

Author: Perch-Nielsen (1979)

Age: Late Maastrichtian.

Definition: The *Micula prinsii* Subzone is defined as the interval from the FO of *Micula prinsii* Perch-Nielsen to the increased frequency of *Thoracosphaera operculata* Bramlette & Martini.

Occurrence: Lower part from Dakhla formation.

Characteristic nannofossil assemblage: Besides the marker species, this zone is dominated by *Eiffellithus gorkae*, *Arkhangelskiella cymbiformis*, *Eiffellithus turrisieffelii*and *Cyclagelosphaera reinhardtii*. The most important calcareous nannofossil species that appear in this zone include; *Lithraphidites quadratus*, *Manivitella pemmatoidea*, *Chiastozygus amphipons/litterarius*, *Ahmuellerella octoradiata* and *Prediscosphaera grandis*.

Remarks and correlation: The upper limit cannot be determined with accuracy in the two studied sections due to a large hiatus observed at the base of the Paleocene.

4.2.2. Paleocene-Early Eocene biozones

***Cruciplacolithus tenuis* Zone (NP2)**

Author: Mohler and Hay in Hay et al. (1967), emend Martini (1970)

Age: Early Paleocene (Danian).

Definition: This is defined as the interval from the first occurrence FO of *Cruciplacolithus tenuis* to the FO of *Chiasmolithus danicus.*

Occurrence: Middle part from Dakhla formation.

Characteristic nannofossil assemblage: In addition to the marker species, this zone is characterized by the presence of *Watznaueria baranesae, Eiffellithus gorkae, Eiffellithus turresreffeli, Cylindralithus gallica, Arkhangelskiella cympiformis, Ericsonia universa, Sphenolithus primus, Ericsonia robusta, Ericsonia subpertusa*and*Thoracosphaera sexa.*

Remarks and correlation: *Cruciplacolithus tenuis* Zone represents the earliest Paleocene zone in the studied sections.

***Ellipsolithus macellus* Zone (NP4)**

Author: Martini (1970)

Age: latest Danian-early Selandian

Definition: The *Ellipsolithus macellus* Zone is defined as the interval from the FO of *Ellipsolithus macellus* to the FO of *Fasciculithus tympaniformis*.

Occurrence: Middle part of Dakhla formation.

Characteristic nannofossil assemblage: The calcareous nannofossil assemblage characteristic of this zone contains *Chiasmolithus danicus*, *Cruciplacolithus primus. Cr. tenuous*, *Placozygus sigmoides* and *Ellipsolithus* spp. are occurred rarely in this zone. The first representatives of *Fasciculithus* (*F. billii*, *F. ulii*and, *F. janii*); *Sphenolithus* (*Sphenolithus primus*) were also observed in this zone.

Remarks and correlation: In the study sections, Zone NP4 corresponds to the same zone described byFaris and Farouk (2012), Faris et al. (2012), Khalil and Zahran (2014) and Khalil and Al Sawy (2014). The present zone is also equivalent to CP3 Zone of Okada and Bukry (1980); Faris and Abu Shama (2007).

***Fasciculithus tympaniformis* Zone (NP5)**

Authors: Mohler and Hay in Hay et al. (1967)

Age: Middle Paleocene (Selandian)

Definition: The *Fasciculithus tympaniformis* Zone is defined as theinterval from the FO of *Fasciculithus tympaniformis* to theFO of *Heliolithus kleinpellii*.

Occurrence: Upper part from Dakhla Formation, Tarawan Formation and the lowermost part of Esna Formation.

Characteristic nannofossil assemblage: *Arkhangelskiella cympiformis, Ericsonia universa, Fasciculithus involutus, Sphenolithus primus, Fasciculithus ulii, Coccolithus peligicus, Ericsoniacava, Toweius eminens, Chiasmolithus danicus, Thoracosphaera sexa, Cruciplacolithustenuis, Heliolithus contabriae* and *Bombolithus elegans* dominated this zone besides the marker species.

Remarks and correlation: *Fasciculithus tympaniformis* Zones equivalent to NP5 Zone of Martini (1971), the *Fasciculithus tympaniformis* zone of Romien (1979), and the CP4 Zone of Okada and Bukry (1980).Zone NP5 was previously recorded in many areas in Egypt: El Ain (Faris, 1988a), Um el Huetat (Faris, 1988b), El Shagab (Faris et al., 1999), west central Sinai (Abu Shama & Faris, 2005), Faris and Abu Shama (2007), Faris and Salem (2007), Western Desert (Khalil and Al Sawy, 2014) and Sinai (Khalil and Zahran, 2014).

***Heliolithus kleinpellii* Zone (NP6)**

Authors: Mohler and Hay in Hay et al. (1967)

Age: Middle Paleocene (latest Selandian)

Definition: The *Heliolithus kleinpellii* Zone is defined as the interval from the FO of *Heliolithus kleinpellii* to the FO of *Discoaster mohleri*.

Occurrence: Esna Formation.

Characteristic nannofossil assemblage: This zone dominated besides the marker species by the following species: *Arkhangelskielle cympiformis, Ericsonia universa, Fasciculithus involutus, Sphenolithus primus, Fasciculithus ulii, Coccolithus pelagicus, Ericsoniacava, Toweius eminens* and *Chiasmolithus danicus.*

Remarks and correlation: *Heliolithus kleinpellii* Zones equivalent to NP6 recorded by Abu Shama and Faris (2005), Faris and abu Shama (2007), Faris and Salem (2007) and Khalil and Al Sawy, 2014).

***Discoastermohleri* Zone (NP7/ NP8)**

Authors: Hay (1964)

Age: Late Palaeocene (Thanetian)

Definition: *Discoastermohleri* Zones defined by the LO of *Discoaster mohleri* at the base and the LO of *Discoaster multiradiatus* at the top.

Characteristic nannofossil assemblage: This zone dominated besides the marker species by the following species: *Arkhangelskielle cympiforms, Ericsonia, universa, Fasciculithus involutus, Sphenolithus primus, Fasciculithus ulii, Coccolithus pelagicus, Ericsoniacava, Toweius eminens, Chiasmolithus danicus,* and *Thoracosphaerasexa.*

Remarks and correlation: This zone is equivalent to the combined NP7 and NP8 Zones of Martini (1971), the combined CP6 and CP7 Zones of Okada and Bukry (1980), and to the NP7/8 Zone of Faris and Abu Shama (2007), Faris and Salem (2007), Faris et al (2012) and Khalil and Al Sawy, 2014).

Occurrence: Upper part of Tarawan Formation.

***Discoaster multiradiatus* Zone (NP9)**

Authors: Bramlette and Sullivan (1961): emended by Martini (1971)

Age: Late Thanetian–Early Eocene age.

Definition: includes the interval from LO of *Discoaster multiradiatus* to the LO of *Tribrachiatus bramlettei*.

Occurrence: Esna Formation.

Characteristic nannofossil assemblage: This zone dominated by *Discoaster mahmoudii, D. binodosus, D. falcatus, D. lenticularis, D. araneus D. barbadiensis, D. diastypus* and *Zygrhablithus bijugatus.*

Remarks and correlation: The present zone corresponds to NP9 Zone of Martini (1971), Romein (1979), Tantawy (2006), Faris and Salem (2007) and CP8 Zone of Okada and Bukry (1980). The NP9 Zone is well represented in several localities in Egypt (Faris et al., 1985, 1986; Faris, 1988a and Faris, 1991). It corresponds to NP9 Zone of Faris *et al.* (2012), Khalil and Al Sawy (2014) and Khalil and Zahran (2014).

Aubry *et al.* (1999) subdivided the *Discoaster multiradiatus* Zone into two subzones (NP9a and NP9b) based on LO of *Rhomboaster* spp. and/or *Discoaster araneus*. This subdivision is applied here. The datum event of NP9a/NP9b subzonal boundary areadopted by the International Sub-commission on Paleogene

Stratigraphy (ISPS) as one of the most important events that characterize the Paleocene/Eocene boundary interval.

***Tribrachiatus contortus* Zone (NP10)**

Author: Hay (1964)

Age: Early Eocene (Ypresian)

Definition: The *Tribrachiatus contortus* Zone is defined as the interval from the FO of *Tribrachiatus bramlettei* to the LO of *T. contortus*.

Occurrence: Lower part of Thebes Formation**.**

Characteristic nannofossil assemblage: In the present study, other nannofossil species occur in Zone NP11, such as *Zygrahablithus bijugatus*, *Discoaster barbadiensis*, *Discoaster binodosus*, *C. pelagicus*, *E. cava*, and *Chiasmolithus solitus.*

Remarks and correlation: The *Tribrachiatus contortus* Zone is widely distributed in the Lower Eocene sediments in Egypt (e.g. Strougo & Faris, 1993; Tantawy, 1998; Faris *et al*., 1999, Khalil and Al Sawy (2014) and Khalil and Zahran (2014). The NP10 zone corresponds to the *Tribrachiatus contortus* (NP10) Zone of Martini (1971), Romein (1979) and CP9a Subzone of Okada and Bukry (1980).

Aubry (1996) subdivided this zone based on the *Tribrachiatus* lineage into four subzones (NP10a, NP10b, NP10c and NP10d). None of these subdivisions can be differentiated in the current study. This may be attributed to large space of sampling and/or small hiatus.

***Discoaster binodosus*Zone (NP11)**

Author: Mohler and Hay in Hay et al. (1967)

Age: Early Eocene (Ypresian).

Definition: The *Discoaster binodosus* Zone is defined as the interval from the LO of *T. contortus* and the FO of *Discoaster lodoensis*.LO of *Tribrachiatus contortus* to FO of *Discoaster lodoensis*.

Occurrence: Middle to upper part of Thebes Formation.

Characteristic nannofossil assemblage: In the present study, other nannofossil species occur in Zone NP11, such as *Zygrahablithus bijugatus*, *Discoaster barbadiensis*, *Discoaster binodosus*,*C. pelagicus*,*E. cava* and *Chiasmolithus solitus.*

Remarks and correlation: *Discoaster binodosus* Zone (NP11)is equivalent to NP11 Zone recorded by Faris et al. in northern Oman and Khalil and Al Sawy (2014) in the western desert.

4.3. Stage Boundaries

The boundaries between stages are delineated based on the calcareous nannofossil and planktonic foraminiferal datum events as follow:

1- The Cretaceous/Paleogene (K/Pg) boundary

The Cretaceous/Tertiary boundary is marked by the absence of the latestMaastrichtian nannofossil Zone; CC26c, as well as the earliest Paleocene nannofossil biozones NP1. This boundary is also marked by the absence of the earliest Paleocene planktonic zones P0 and P1.At Gebel Duwi section the boundary is placed at the top of CC26b, in the lower part of the Dakhla Formation.

2- Danian/Selandian boundary

In the present study, in Gabal Gebel Duwi and Gebel Rewagen sections, the Danian/ Selandian boundary, lies at the uppermost part of Zone NP4 and nearly at the top of P3a subzone. It is located lithologically in the middle part of the Dakhla Formation

4-Selandian/Thanetian boundary

The Selandian/ Thanetian boundary corresponds to the lower part of the planktonic foraminifera P4 Zone (Berggren *et al.,* 1995 and Berggren and Pearson, 2005). For calcareous nannofossils, the base of the Thanetian Stage could be referred to the uppermost part of Zone NP6 or the lower most part of Zone NP6/ NP7 (Berggren et al., 1995).

In the present study, the Selandian/Thanetian boundary is located within the lower part of the Esna Formation and is tentatively drawn at the conformable contact between the calcareous nannofossil Zones NP6 and NP7/8. This level is correlated to the upper part of the planktonic foraminifera P4 Subzone.

5- Paleocene/Eocene boundary

The Paleocene/Eocene boundary in the studied area is placed at the base of the planktonic foraminiferal Zone E1. It is correlative with the base of the Calcareous nannofossil Subzone NP9b.

Summery and conclusions

The Upper Maastrichtian-Lower Eocene successions in Gebel Duwi and Gabel Atshan are differentiated into four rock units arranged from base to top: Dakhla, Tarawan, Esna and Thebes Formations. Twelve planktonic foraminiferal biozones and subzones were recognized, they are: CF4, CF3and CF2subzones (Late Maastrichtian); P1(P1a,P1b), P2, P3(P3a,P3b),P4, P5 zones (Paleocene) and E1, E2, E3,E4 zones (Early Eocene). For calcareous nannofossils, ten biozones and subzones were identified, they are: CC25c, CC26b (latest Maastrichtian); NP2, NP4, NP5, NP6, NP7/8, NP9a (Paleocene), NP9b NP10, NP11(Early Eocene).

The Cretaceous/Paleogene (K/Pg) boundary is marked by the absence of the earliest Paleocene nannofossil biozones NP1. It is also marked by the absence of the earlist Paleocene planktonic zones P0 and P1, and is tracedat the top of CC26b, in the lower part of the Dakhla Formation. The Danian/Selandian boundary lies at the uppermost part of Zone NP4and nearly at the top of P3a Subzone. It is located lithologically in the middle part of the Dakhla Formation. The Selandian/ Thanetian boundary corresponds to the contact between the calcareous nannofossil Zones NP6 and NP7/8 and the upper part of the planktonic foraminifera P4 Subzone within the Esna Formation. The Paleocene/Eocene boundary is approximately defined at the base of the planktonic foraminiferal Zone E1 and the base of the calcareous nannofossil NP9b in the lower part of Esna shale.

Acknowledgements

Thanks to Prof. Dr. M. Faris for assistance in the investigations of calcareous nannofossils, critical reading and valiable suggestions.

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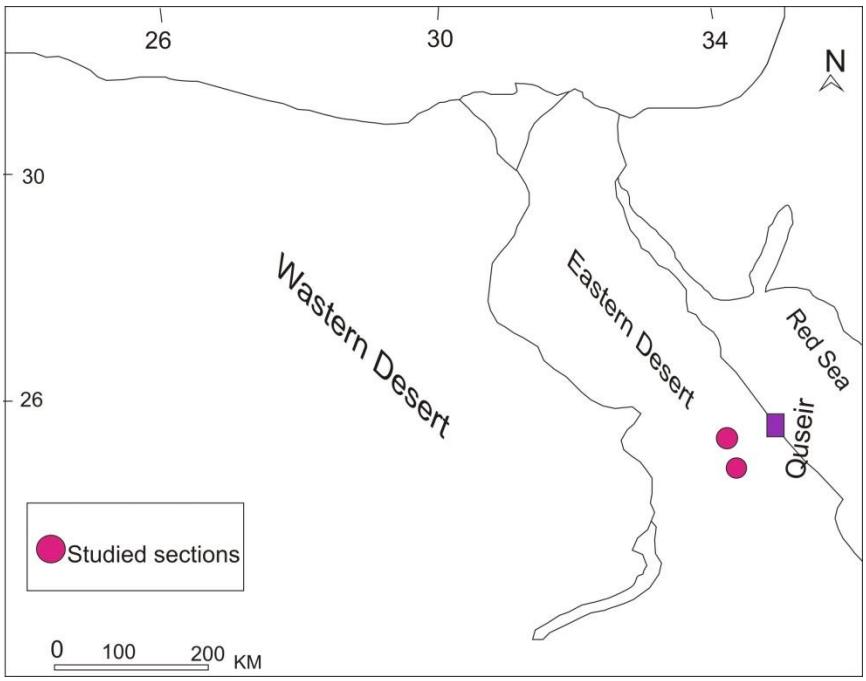


Fig 1.Location map of the studied sections(Gebel El Duwi &Gebel Atshan).

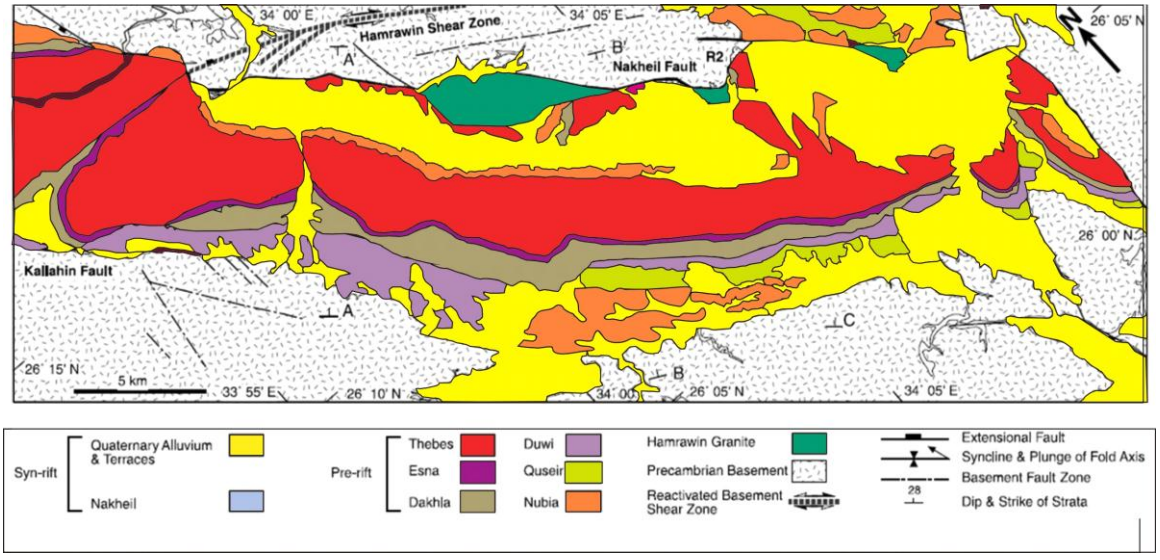


Fig . 2. Geologic map of the studied area, modified after Khalil& Meclay (2002).

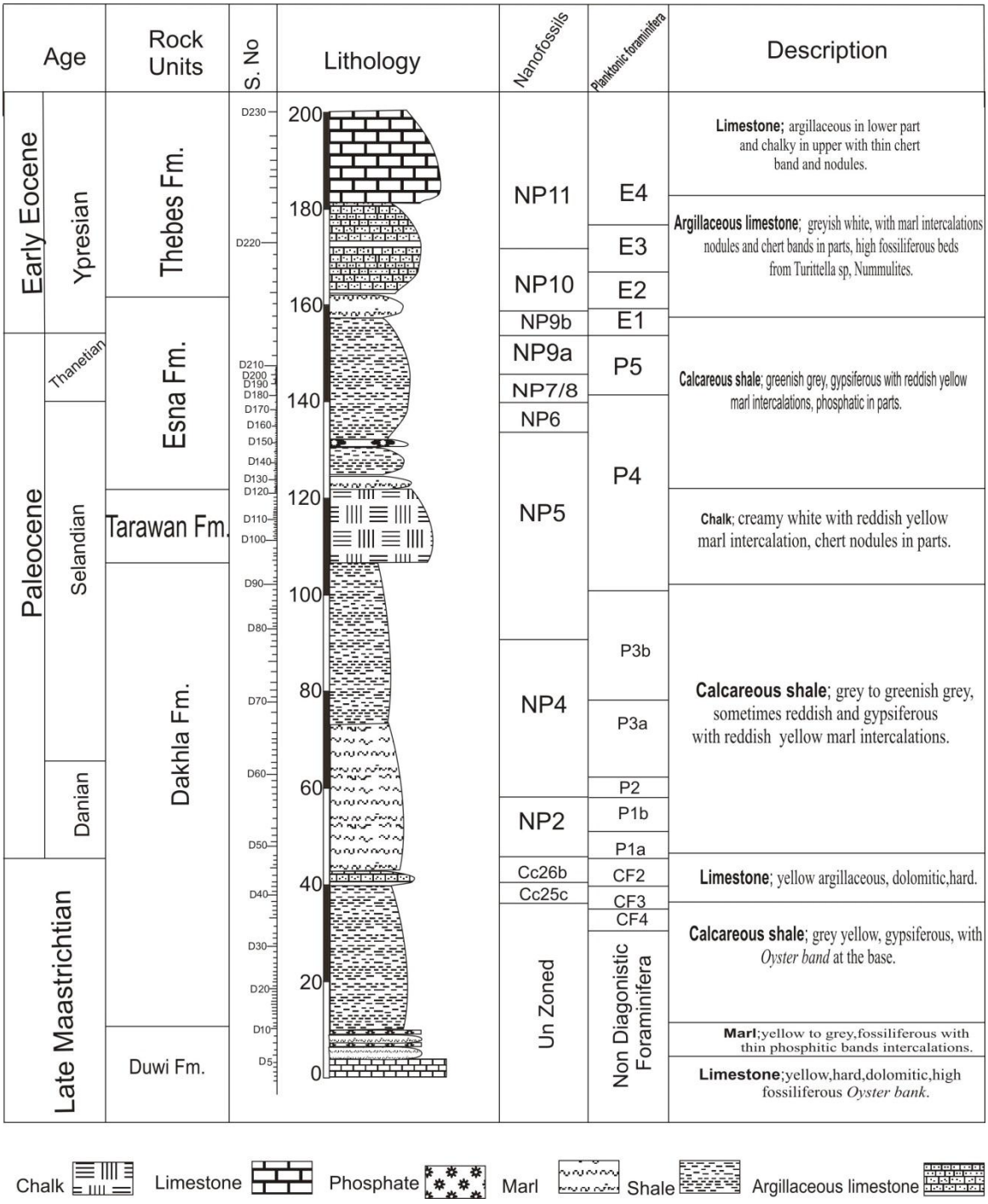


Fig. 3. Lithologic units, planktonic and calcareous nannofossil biozones of Upper Maastrichtian-Lower Eocene rocks of Gabel El Duwi.

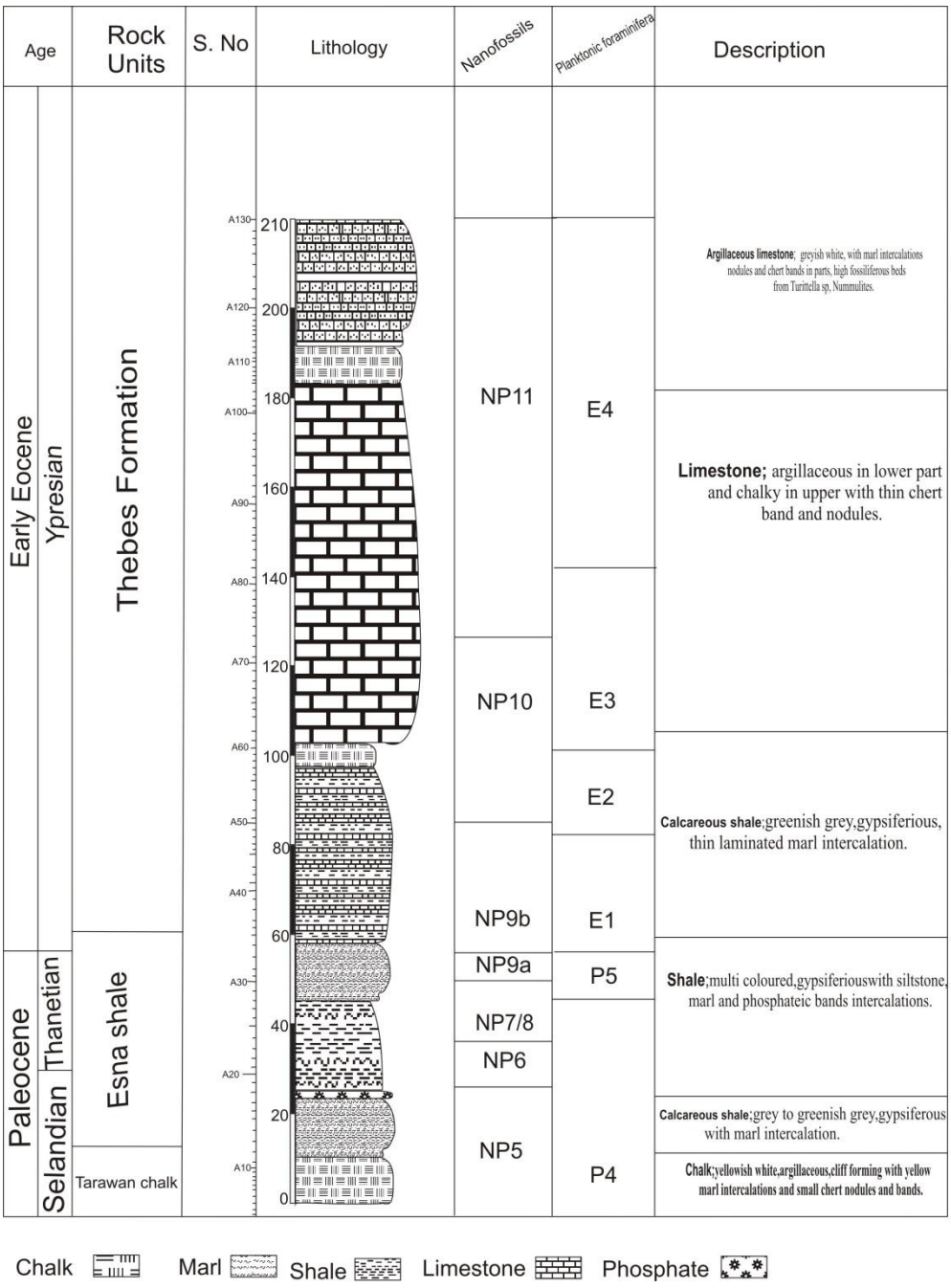


Fig. 4. Lithologic units, planktonic and calcareous nannofossil biozones of Upper Maastrichtian -Lower Eocene rocks of Gabel Atshan.

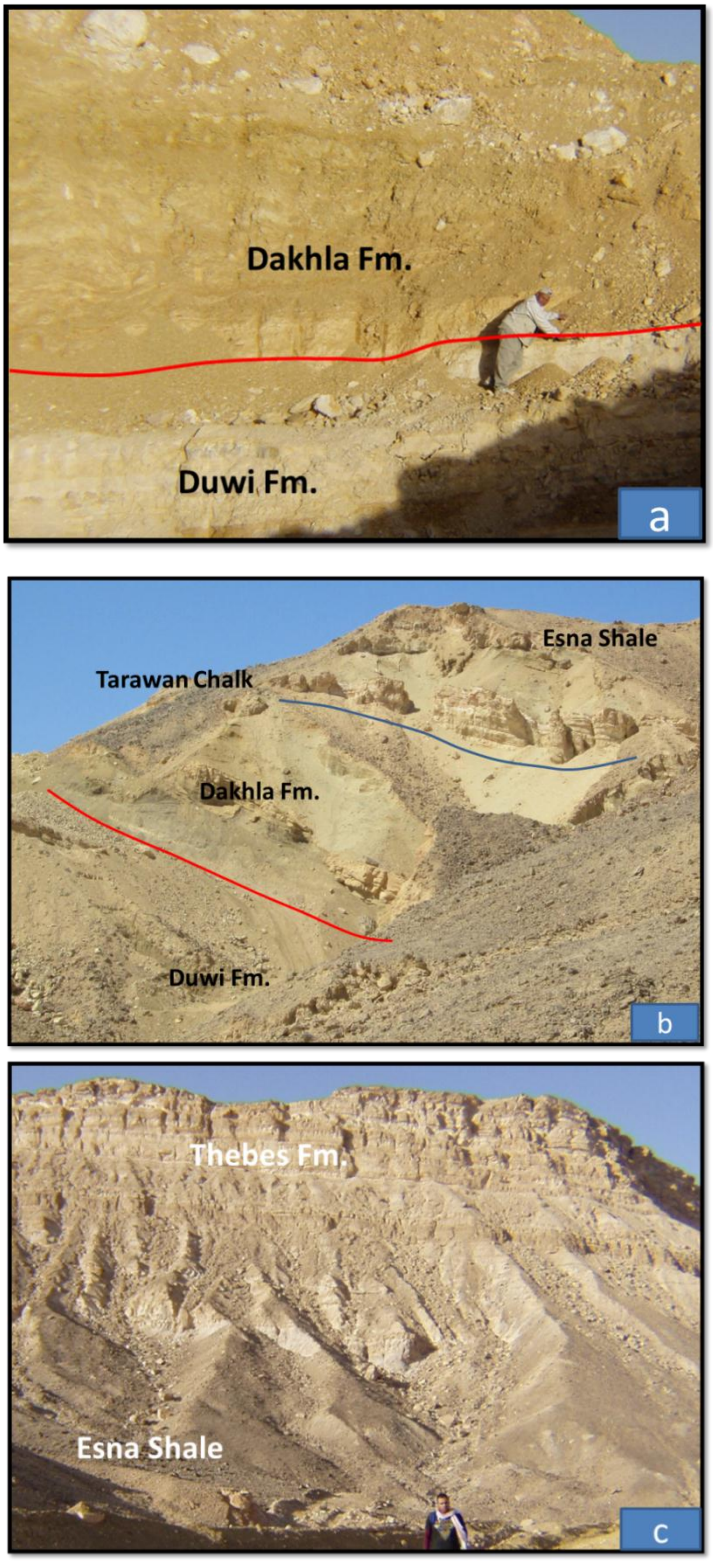


Fig. 5. a- Contact between Duwi Formation and Dakhla Shale at Gebel Duwi, b- Upper Cretaceous-Paleocene rock units in Gebel Duwi, c- Esna Shale and Thebes Formation at Gebel Duwi.

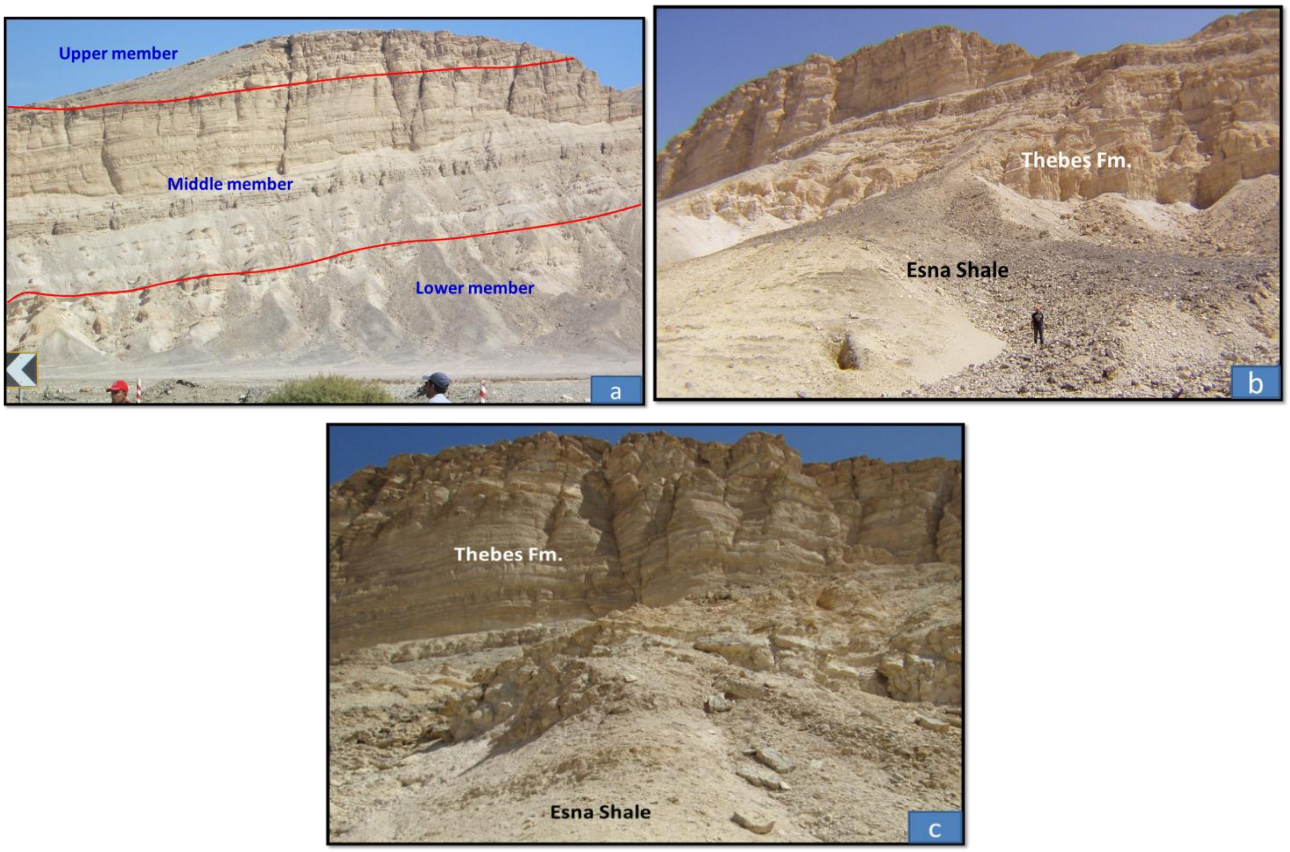
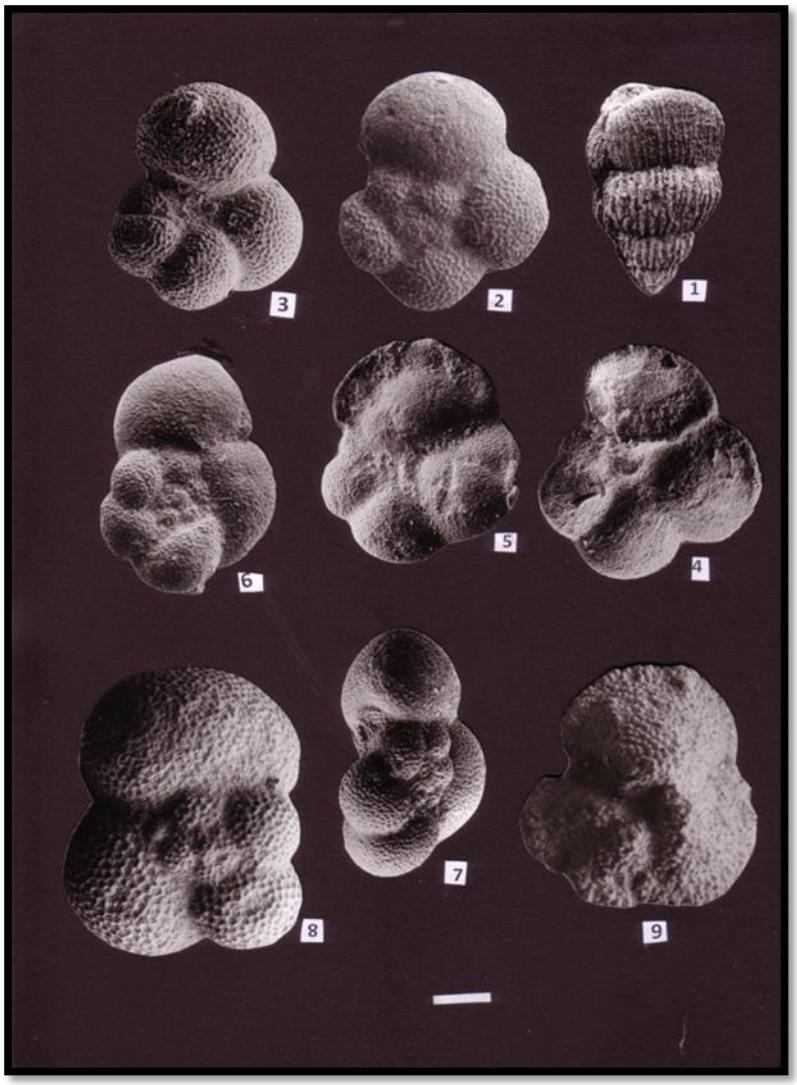


Fig. 6. a- Three informal members of the Thebes formation at Gebel Atshan Section, b- Esna Shale and Thebes Formations at Gebel Atshan, c, Gradational contact between Esna and Thebes formations at Gebel Atshan Section.

Plate 1



Scale bar is 100 µm.

Plate 1: 1- *Pseudotextularia deformis* (Kikoine), sample D3, Duwi Formation. 2, 3- *Parasubbotina pseudbulloides* (Plummer), sample D25, Dakhla Formation. 4, 5- *Globanomalina pseudominardii* (Bolli), sample D60, Dakhla Formation. 6, 7- *Globanomalina compressa* (Plummer), sample D70, Dakhla Formation. 8- *Subbotina triloculinoides* (Plummer), sample D50, Esna Formation. 9- *Morozovella subbotinae* (Morozova), sample D140, Esna Formation.

Plate 2

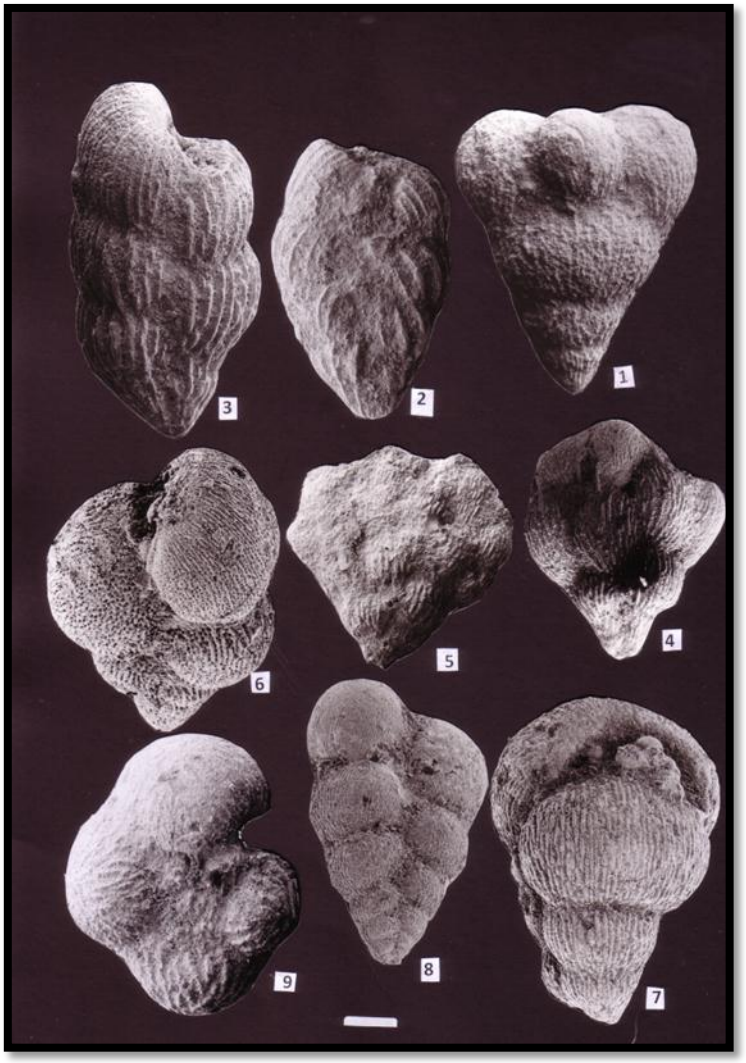


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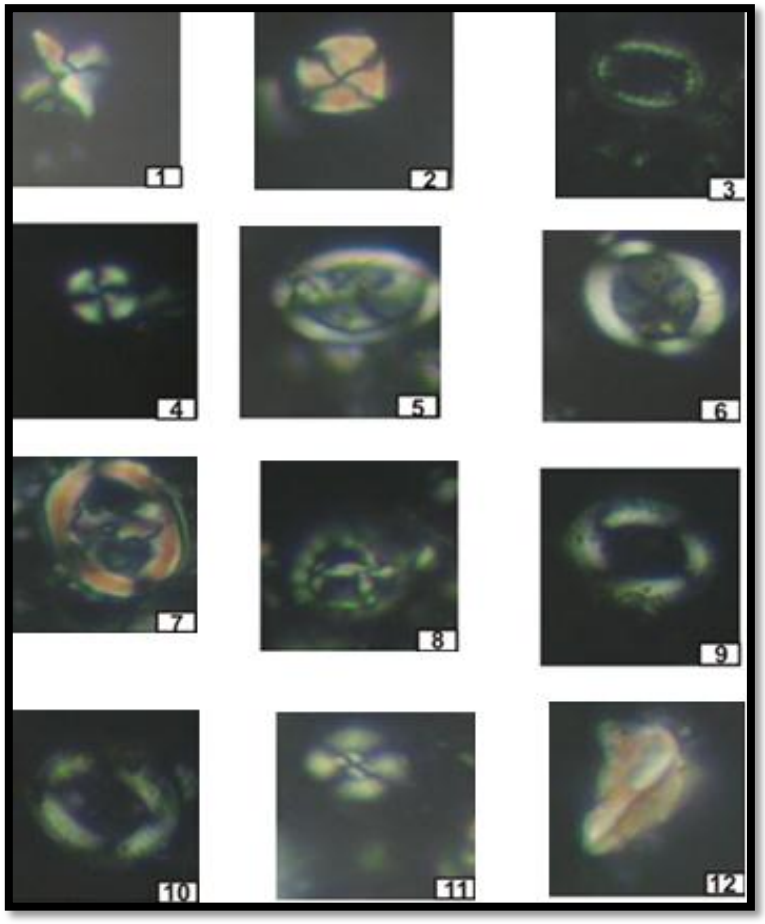
Plate 2. 1- *Racemiguembelina fructicosa* (Egger), sample D9, Duwi Formation. 2, 3- *Pseudoguembelina costulata* (Cushman), sample D5, Duwi Formation. 4- *Pseudoguembelina hariaensis* Nederbragt, sample D32, Dakhla Formation. 5- *Pseudoguembelina* sp., sample D20, Dakhla Formation 6,7- *Pseudoguembelina palpebral* Bronnimann, sample D8, Duwi Formation. 8- *Heterohelix globulasa* Ehrenberg, sample D10, Duwi Formation. 9- *Rugoglobigerina rugosa* Plummer, sample D72, Dakhla Formation.

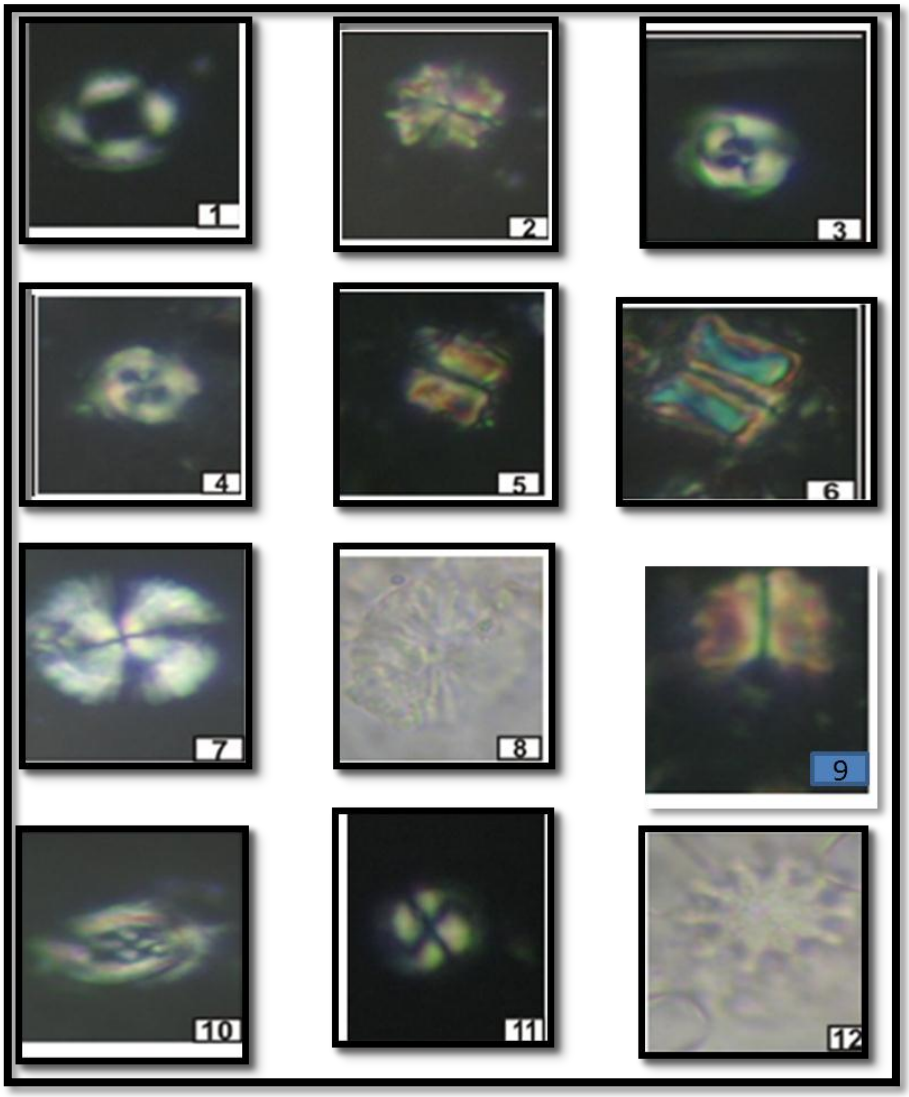
Plate 3



Scale bar is 10 µm.

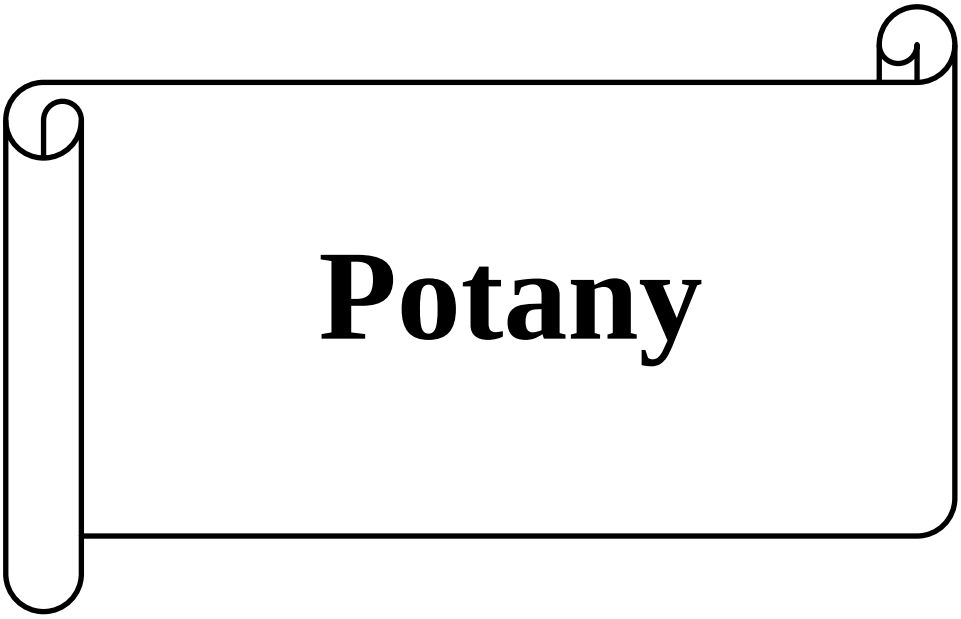
Plate 3. 1- *Micula decussata*Vekshina (1959). Sample D4, Duwi Formation. *2- Micula murus* (Martini, 1961) Samples D6 ,Duwi Formation.3- *Cribrosphaerella ehrenbergii* (Arkhangelsky, 1912) Sample D5, Duwi Formation. 4,11- *Watznaueria barnesae* (Black *in* Black & Barnes, 1959), Sample D6, Duwi Formation. 5,*6- Arkhangelskiella cymbiformis* Vekshina (1959), Samples D7, Duwi Formation.7- *Zeugrhabdotus embergeri* (Noel, 1959), Sample D9, Duwi Formation. 8- *Prediscosphaera grandis* Perch-Nielsen (1979) Samples D6, Duwi Formation. 9, 10- *Manivitella pemmatoidea* (Deflandre *in* Manivit, 1965) Samples D8, Duwi Formation. 12- *Lucianorhabdus cayeuxii* Deflandre (1959), Sample D6, Duwi Formation.

Plate 4



Scale bar is 10 µm.

Plate: 4.1- *Ericsonia* cf*universa* Wind and Wise (1977), Sample 40, Dakhla Formation. 2- *Sphenolithus primus* (Bramlette & Sullivan, 1961), Sample D70, Dakhla Formation. 3,4- *Toweiuse minens* (Bramlette & Sullivan, 1961) Sample D99, Esna Formation. 5, 9- *Fasciculithus tympaniforms* Hay & Mohler in Hay et al. (1967) Sample D44, Dakhla Formation. 6- *Fasciculithus involutus* Bramlette & Sullivan (1961) Sample 31, Dakhla Formation. 7- *Heliolithus cantabriae* Perch-Nielsen (1971) Sample 72, Esna Formation. .8-*Discoasterm ultiradiatus* Bramlette & Reidel (1954) D140-D171,Esna Formation.10-*Cruciplacolithus tenuis* (Stradner, 1961) Hay & Mohler in Hay *et al.* (1967), Sample D124, Esna Formation. 11- *Ericsonia subpertusa* (1967) Sample D158, Esna Formation. 2- *Discoaster binodosus* (Martini,1958) Sample D173, Esna Formation.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