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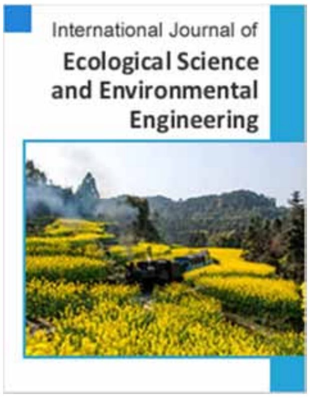

Impact of the African/Arabian and Eurasian Plates Collision on the Evolution of the Upper Cretaceous-Lower Paleogene Sedimentary Basin, Eastern Desert, Egypt

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Citation

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Abstract

Detail field, litho- and bio-stratigraphic studies on the Upper Cretaceous-Lower Paleogene rocks exposed in the Eastern Desert of Egypt have provided an opportunity to evaluate the stratigraphy and the geological evolution of the sedimentary basin. Lithostratigraphically, seven rock units; Quseir, Duwi, Sudr, Dakhla, Tarawan, Esna and Thebes formations, are considered after amending and dropping various used rock units names. Rakhiyat Formation in the north is changed and amended into Quseir Formation which has been used and consolidated in all sectors. Duwi Formation in the south is time-equivalent to the lower part of Sudr Formation in the north. Sharawna Member at Gabal Oweina and Hamama Member at Gabal Qreiya in the south (previously related to Dakhla Formation) are changed and amended into Sudr Formation which extends laterally as a tongue toward the south due to the marine transgression during the Late Campanian-Early Maastrichtian age. Similarly, Owaina Member at Gabal Oweina and Beida Member at Gabal Qreiya in the south are changed and amended into Dakhla Formation. Upward Tarawan, Esna and Thebes formations are resting on the Dakhla Formation all over the study area. Biostratigraphically, the studied successions are subdivided into 23 planktonic foraminiferal zones covering the interval from Campanian to Ypresian age. Sedimentation processes of the studied sections are interrupted by several synsedimentary tectonic episodes related to the collision between African/Arabian and Eurasia plates during the closure of Tethys Ocean. The relative sea-level in the study area and global eustatic one together with the synsedimentary tectonic episodes is associated together.

1. Introduction

The Arabian and the African plates were one part during the geological age of much of the Phanerozoic Eon of the earth. At the end of Oligocene Epoch [1, 2, 3] the Red Sea rifting began and the separation of Africa and Arabia occurred. Accordingly, the Arabian

Plate has been slowly moved toward the Eurasian Plate [4]. Egypt is located in the southeastern part of the Mediterranean Sea and represents a subordinate part of the Eastern Mediterranean region. The Eastern Mediterranean Sea is a small ocean basin known by Neo- Tethys Ocean [5, 6] and includes a short segment of the convergence boundary between Africa and Eurasia (Figure 1). Due to the complexity of the tectonics and deep structures of the Eastern Mediterranean area, the development of Mediterranean area seems to be the result of crustal shortening due to the north ward movement of the African Plate relative to the Eurasian Plate [8, 9, 10, 11, 12]. [13] suggested that the Syrian Arc structure is closely related to the compression stresses between the Afro/Arabian and Eurasian plates, which led to the closure of Tethys Ocean.

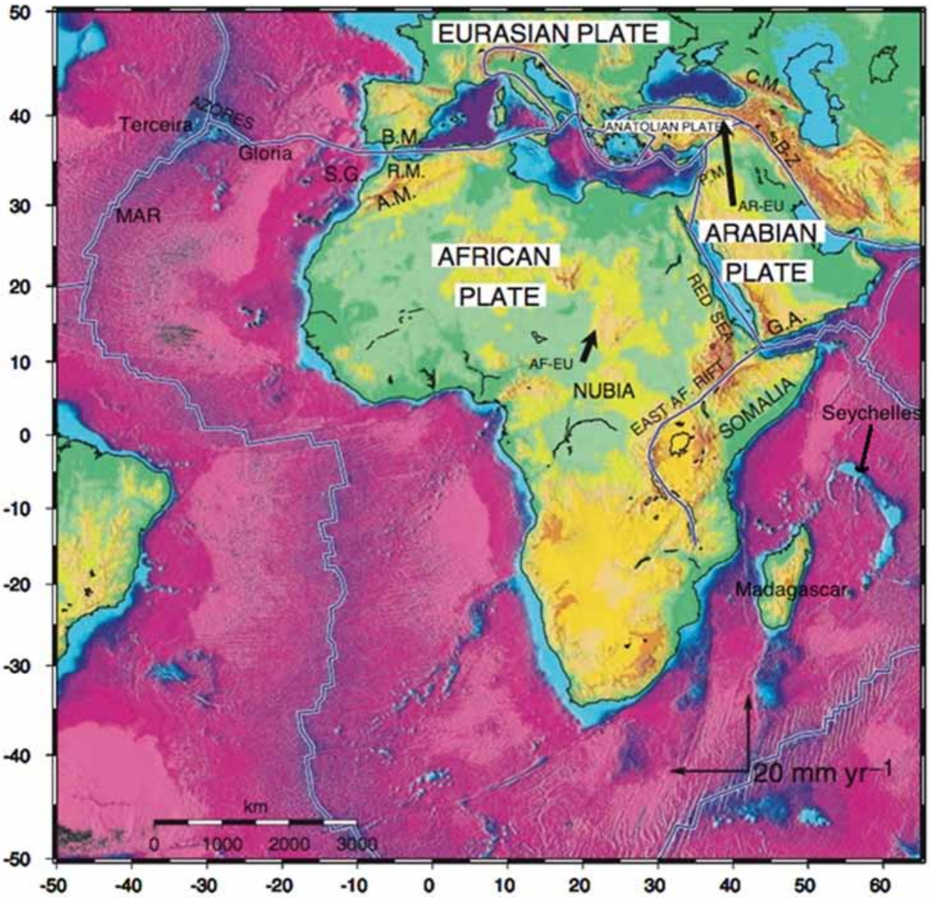

Figure 1. *Overview of the African/Arabian and Eurasian tectonic plates region (Modified after [7].*

The Upper Cretaceous-Lower Paleogene successions are well represented in the different provinces of Egypt. The sediments of these successions are characterized by pronounced facies variations, distinct depositional changes and noticeable sedimentation gaps due to both the synsedimentary tectonic events and the relative sea-level changes. The present work is carried out on the area extends between Sibaiya City in the south (Upper Egypt) and Wadi Tarfa in the north (facing the Ras Gharib City), in the Eastern Desert of Egypt. In the present study, four Upper Cretaceous-Lower Paleogene stratigraphic sections were measured and analyzed. These sections are Gabal Oweina (Latitude 25°15ˉ N, Longitude 32°45ˉE) at the eastern side of the Upper Nile Valley, Gabal Qreiya (Latitude 26°21ˉN, Longitude 33°01ˉE) at 50km northeast of Qena City, Timimit el Shifa (Latitude 27°22.N, Longitude 32°21.E) at the central of Wadi Qena and Wadi Tarfa (Latitude 28°17.N, Longitude 32°10.E) at the north of Wadi Qena (Figure 2).

The Upper Cretaceous-Lower Paleogene rock units in the Eastern Desert were interpreted in different ways by various authors [15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36]. The studies of these authors were focused on the general geology, stratigraphy, paleontology and sedimentology. The lithostratigraphic classifications of them showed considerable conflict and disagreement for the Upper Cretaceous-Lower Paleogene rock units (Figure 3).

The aims of the current work are to: i) reduce the numerous lithostratigraphic names through high-resolution field, litho-and bio-stratigraphic studies, ii) interpret the evolution of the sedimentary basin in the study area to recognize, clarify and understand the vertical and lateral relationships of the Upper Cretaceous-Lower Paleogene rock units, and iii) shed light on the relative sea-level fluctuations and compared them with the global sea-level curve of [37].

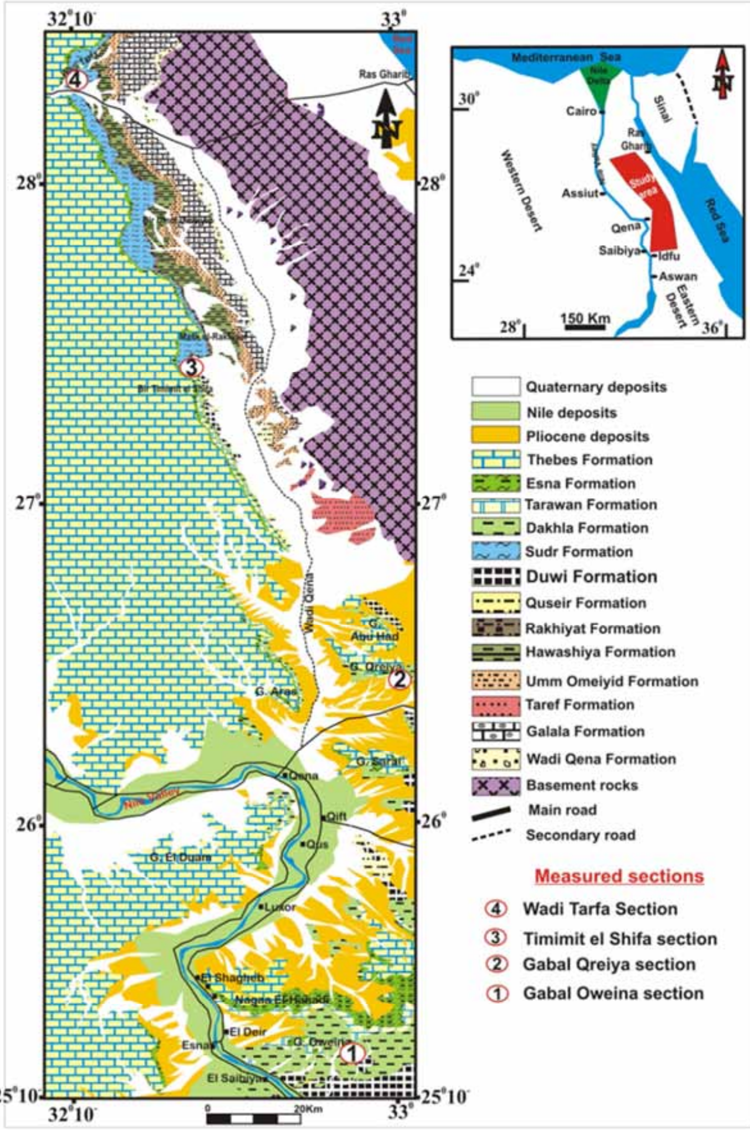

Figure 2. *Geological map of the study area (After [14], Luxor, Assiut and Beni Suef sheets).*

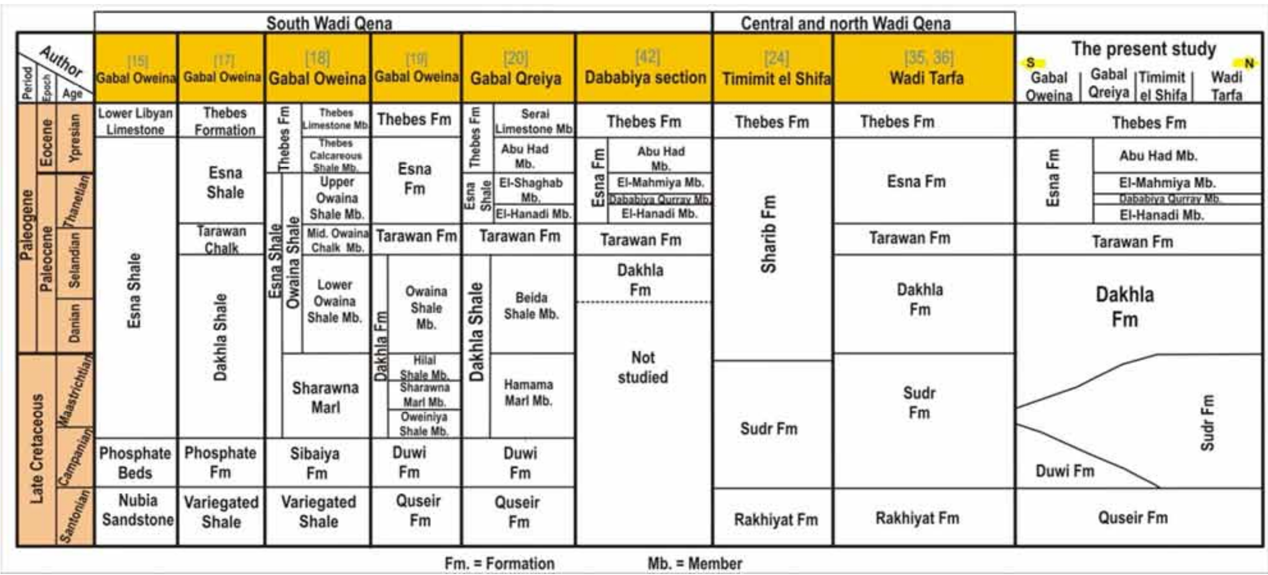

Figure 3. *Lithostratigraphic correlation of the different proposed rock units of the Upper Cretaceous-Lower Paleogene successions at the study area.*

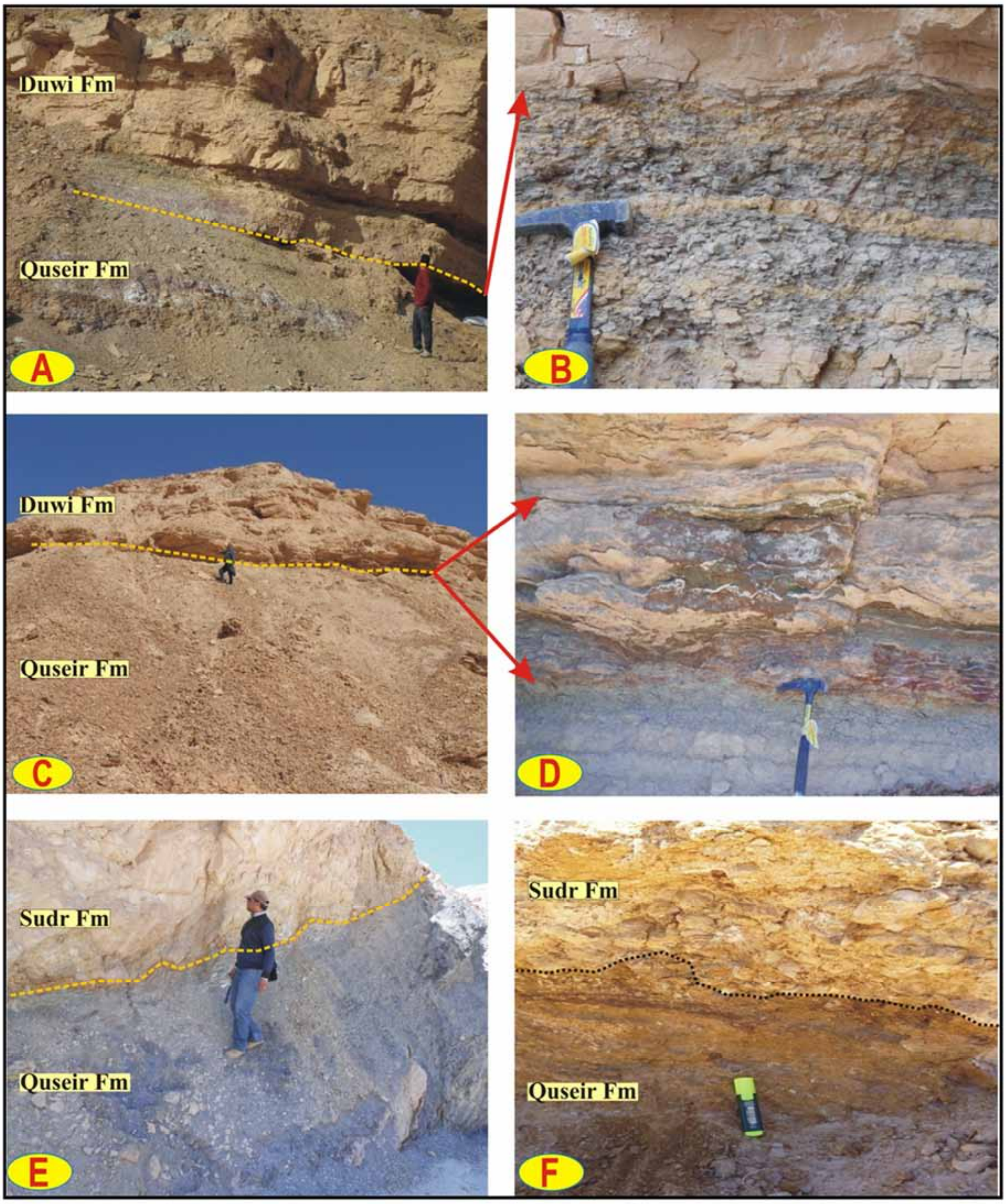

Figure 4. *(A, B): Field photographs showing the contact between the clastic facies of Quseir Formation below and the phosphatic facies of Duwi Formation above that characterized by an irregular surface, Gabal Oweina section. (C, D): Field photographs showing the contact between the clastic facies of Quseir Formation below and the phosphatic facies of Duwi Formation above that characterized by an occurrence of a glauconitic bed, Gabal Qreiya section. (E): A field photograph showing the contact between Quseir and the overlying Sudr formations with the existence of an erosive and irregular surface, Timimit el Shifa section. (F): A field photograph showing the contact between Quseir and the overlying Sudr formations with the existence of an irregular surface and paleosol bed, Wadi Tarfa section.*

2. Lithostratigraphy

Lithostratigraphic classifications of the Upper Cretaceous-Lower Paleogene sequences in the Eastern Desert of Egypt show a great controversy (Figure 3) which needs to be revised and revision in the used nomenclature of the rock units. In the present study seven rock units for the Upper Cretaceous-Lower Paleogene successions are defined. These rock units are stratigraphically arranged as: Quseir, Duwi, Sudr, Dakhla, Tarawan, Esna and Thebes formations (Figure 3). The studied successions offer an excellent chance to amendment the recognizable rock units with its vertical and lateral facies changes as follow:

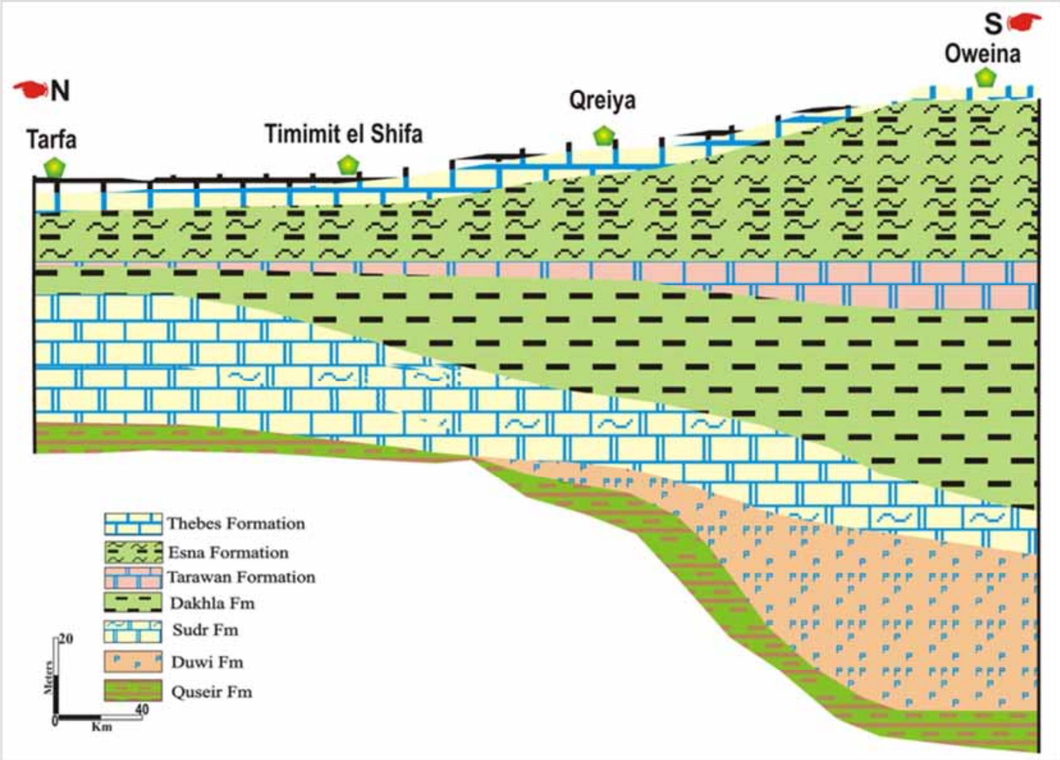

Figure 5. *Lithostratigraphic classifications at the study area.*

2.1. Quseir Formation

This formation was termed by [38] to describe a series of non-fossiliferous variegated shales and clays at Gabal Atshan, Quseir area, Red Sea. In the present study, toward the south at Gabal Oweina and Gabal Qreiya sections, the Quseir Formation represents the clastic unit at the base of the low-lying plateaus unconformably overlain by the Duwi Formation with sharp and irregular surface contact as well as the presence of about 10-20cm thick of a glauconitic bed (Figures 4 A-D, 5, 8, 9).

At Gabal Oweina section, it represented only by about 5m thick (its upper most part) whereas at Gabal Qreiya section it reaches about 57m thick. Toward the north, it represented by clastic unit mainly of greenish grey, reddish and black claystones alternating with sandstone and siltstone beds at both Timimit el Shifa (~20m thick) and Wadi Tarfa (~5m thick) sections (Figures 10, 11). At these areas, this unit is unconformably overlain by the carbonate facies of Sudr Formation with an erosive surface contact as well as the presence of paleosol (Figure 4 E, F). [24] described these sediments at Timimit el Shifa-Masak El-Rakhiyat area, in the central part of Wadi Qena, Eastern Desert and defined them as Rakhiyat Formation. Therefore, according to the priority of the stratigraphic nomenclature and the similarity in the lithology, facies composition and sedimentary environment, the Rakhiyat Formation is changed and amended to the Quseir Formation.

2.2. Duwi Formation

It was suggested by [38] for the phosphate-bearing succession of the Gabal Duwi, Quseir District. In the present work, it consists of a succession of phosphorites interbedded with sandstones, shales and marls, ranging in thickness between about 60m at Gabal Oweina and about 18m at Gabal Qreiya sections (Figures 8, 9). It also capped by black shale varies in thickness from ~25m at Gabal Oweina and ~2m at Gabal Qreiya. A prominent decrease in the thickness of the Duwi Formation is noticed toward the north that is pinched out to the north of Gabal Qreiya whereas it is disappeared at Timimit el Shifa (Figure 5). The Duwi Formation is unconformably overlain by a carbonate unit with a sharp contact and ferruginous band at Gabal Oweina and about 15-30cm thick of a conglomeratic bed at Gabal Qreiya sections (Figure 6 A, D). This unit was named by [18] as Sharawna Marl Member at Gabal Oweina and as Hamama Marl Member by [20] at Gabal Qreiya. They were considered these members as a part of the Dakhla Formation. In the present investigation the carbonate unit is considered as lateral extended tongue for the Sudr Formation toward the south of Egypt due to the presence of a clear similarity in the lithology, facies and sedimentary environment of these units (Figure 6 A, C, E, F). Consequently, by using the priority of the stratigraphic nomenclature Sharawna Member at Gabal Oweina and Hamama Member at Gabal Qreiya are here changed and amended into the Sudr Formation of Ghorab.

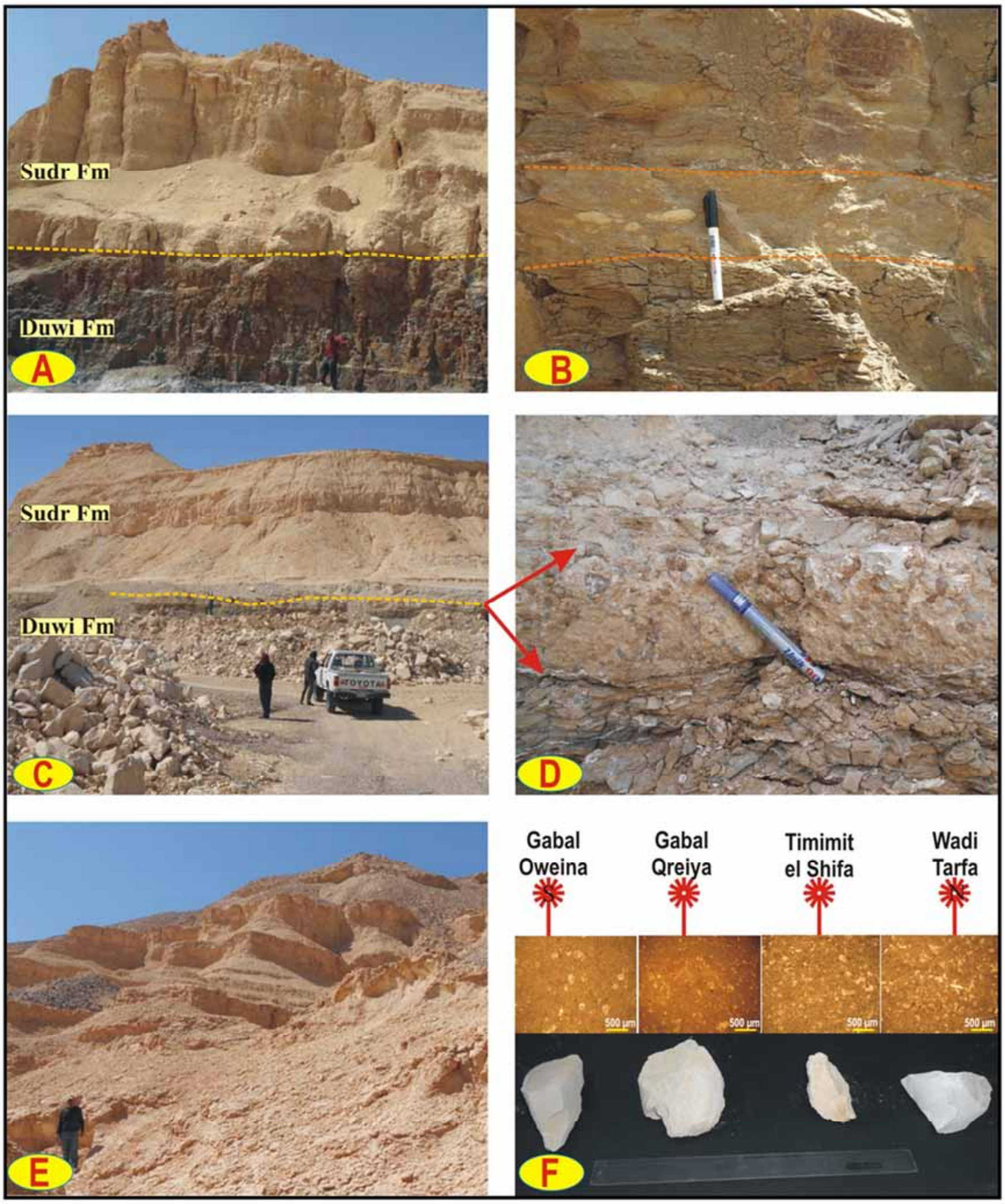

Figure 6. *(A): A field photograph showing an abrupt facies changes marked by intensive ferruginous band between Duwi Formation below and Sudr Formation above, Gabal Oweina section. (B): A field photograph showing a conglomeratic bed at the middle part of Dakhla Formation, Gabal Oweina section. (C, D): Field photographs showing the contact between Duwi Formation below and Sudr Formation above that characterized by an occurrence of a conglomeratic bed, Gabal Qreiya section. (E): A field photograph showing Sudr Formation, Timimit el Shifa section. (F): Photographs showing hand specimens and their microfacies of Sudr Formation at the study area, note the presence of a clear similarity in their color and composition.*

2.3. Sudr Formation

This formation was introduced by [39] to describe a thick chalk and chalky limestone at Wadi Sudr in west-central Sinai, Egypt. [40] re-defined the Sudr Formation as a succession of massive white and cream chalk and chalky limestone beds with thin interbeds of light gray calcareous shale and argillaceous crystalline limestone. Sudr Formation that exposed in all the studied sections displays pinched out and decreasing in thickness towards the south (~54.5m thick at Wadi Tarfa, ~35m thick at Timimit el Shifa section, ~28m thick at Gabal Qreiya section and ~16m thick at Gabal Oweina section). It shows significant and marked changes in the lithofacies from south to north in the same time. It is mainly composed of chalk and chalky limestone with a basal oyster bed yielding *Pycnodonta vesicularis* (Lamarck) that grades upwards into phosphatic marl with horizontal and inclined bioturbations at Wadi Tarfa section in the north whereas it is of marl and marly limestone in the extreme south at Gabal Oweina section (Figures 6A, 6C, 6E, 8, 9, 10, 11).

2.4. Dakhla Formation

It was named by [17] to define the siliciclastics facies which overlain the phosphate deposits of Duwi Formation and underlain the carbonate facies of Tarawan Formation. The studied Dakhla Formation rests on the Sudr Formation at all the study sections and consists of a succession of light olive gray, dark greenish gray, dark yellowish brown compact shales, calcareous shales and claystones. The thickness of this unit in the study area increases toward the south. It measures about 20.5m at Wadi Tarfa, ~55m at Gabal Qreiya and ~94m at Gabal Oweina sections (Figures 7A, 7C, 7F 5, 8, 9, 11). [18, 20] proposed two rock units (siliciclastic sediments) such as Owaina Member at Gabal Oweina and Beida Member at Gabal Qreiya respectively and they considered them as parts of the Dakhla Formation. In the present study, these two units are changed and amended as the originally known Dakhla Formation. An observable glauconitic phosphatic conglomeratic bed of about 15-20cm thick is detected at the middle part of Dakhla Formation at Gabal Oweina (Figure 6B). This bed marks the Cretaceous/Paleocene (K/P) boundary (Figure 5). Moreover, four distinctive organic-rich brown and gray shale beds occur toward the top of Dakhla Formation at Gabal Qreiya and Wadi Tarfa (Figures 7D, 9, 11). They characterize the Danian/Selandian (D/S) boundary and named Qreiya beds by [34].

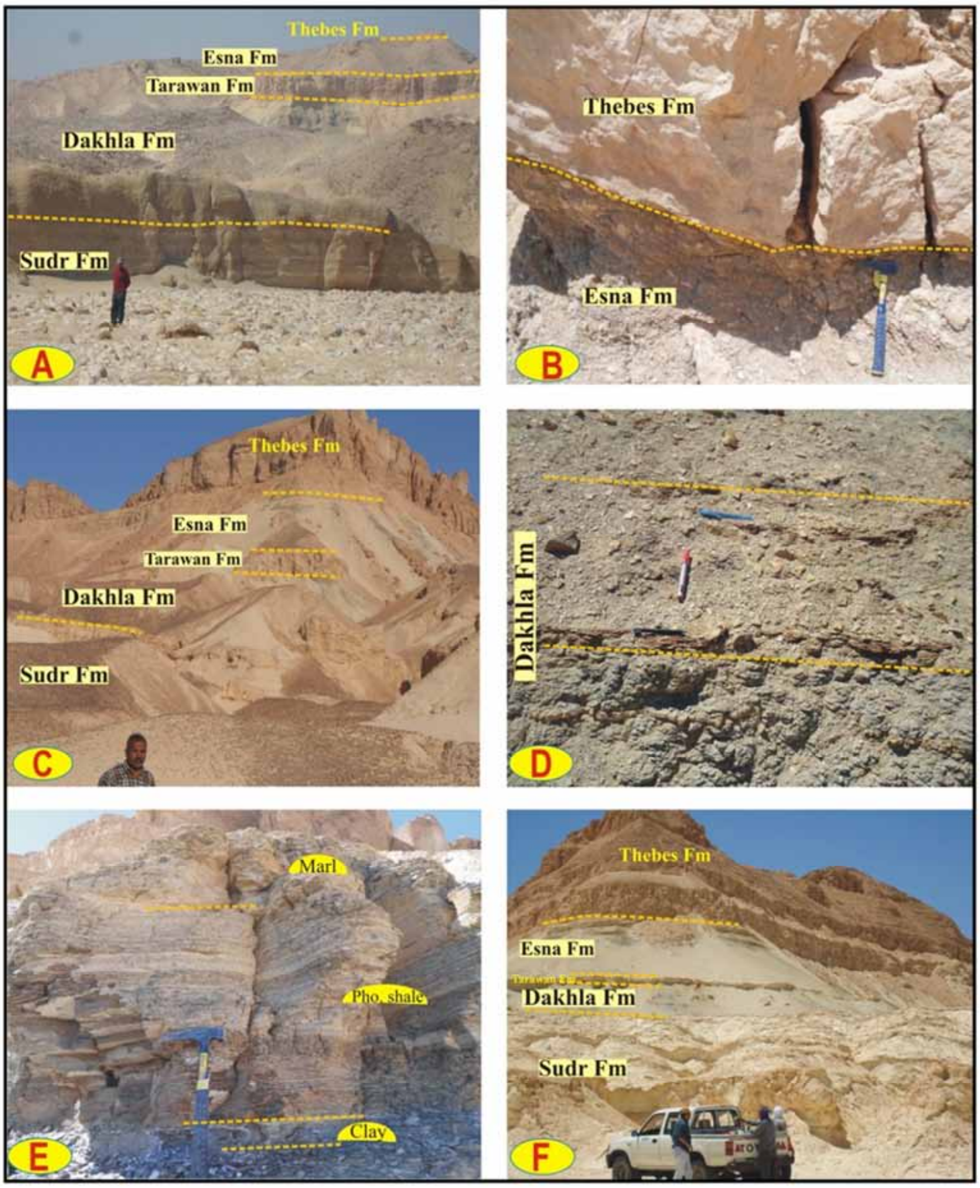

Figure 7. *(A): General view showing Sudr, Dakhla, Tarawan, Esna and Thebes formations at the top, Gabal Oweina section. (B): A field photograph showing the contact between the Esna Formation below and the residual Eocene Thebes Formation above, Gabal Oweina section. (C): General view showing Sudr, Dakhla, Tarawan, Esna and Thebes formations at the top, Gabal Qreiya section. (D): A field photograph showing distinctive beds of brown and gray shales at the top of Dakhla Formation, Gabal Qreiya section. (E): Close field photograph showing the Dababiya Quarry Member of dark clay bed at the base, brown friable phosphatic shale bed at the middle and marl bed at the top within Esna Formation, Gabal Qreiya section. (F): General view showing Sudr, Dakhla, Tarawan, Esna and Thebes formations at the top, Wadi Tarfa section.*

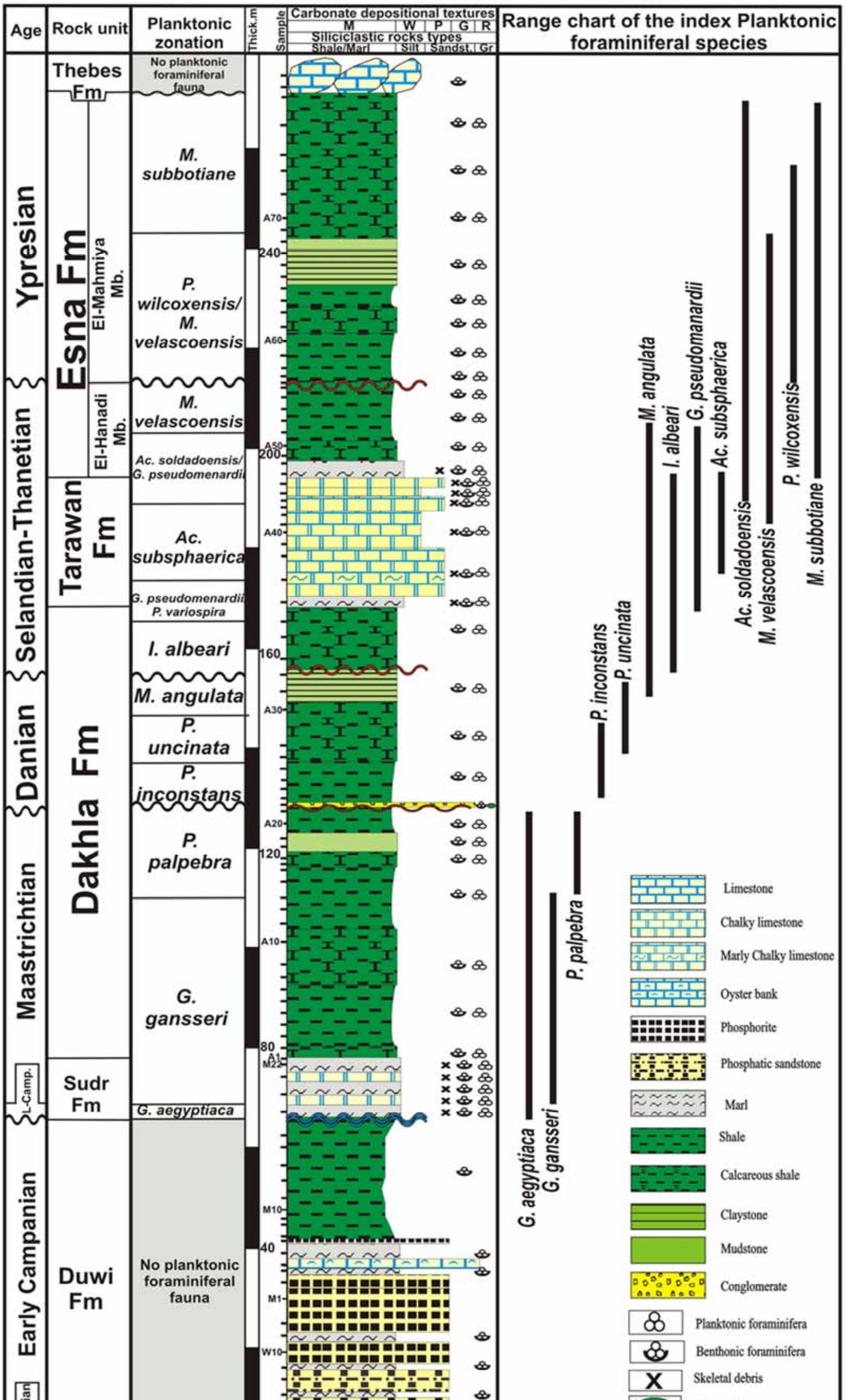

Figure 8. *Litho-, and bio-stratigraphy, range chart of the index planktonic foraminiferal species in the Upper Cretaceous-Lower Paleogene succession at Gabal Oweina section.*

2.5. Tarawan Formation

The term Tarawan Formation was introduced by [41] to define the carbonate sediments at Gebel Teir/Tarawan, Kharga Oasis, Western Desert. In the present work, Tarawan Formation is made up of snow white and moderately hard chalky limestone or massive marly limestone and conformably rests on Dakhla Formation. It shows a distinct lateral variation in thickness from north to south where it measures ~2m thick at Wadi Tarfa; ~8m thick at Gabal Qreiya and ~23m thick at Gabal Oweina sections in the extreme south (Figures 7A, 7C, 7F, 5, 8, 9, 11).

2.6. Esna Formation

The Esna Shale was termed by [15] and reviewed by [17] to describe the siliciclastic facies at Gabal Oweina, east of Sibaiya City, Upper Nile Valley. Esna Formation conformably rests on Tarawan Formation all over the study area and its thickness increases toward the south which varies between about 22.5m thick at Wadi Tarfa, ~42m thick at Gabal Qreiya and ~72m thick at Gabal Oweina sections (Figures 7A, 7C, 7F, 5, 8, 9, 11). [42] subdivided Esna Formation at Dababiya section into four members arranged in stratigraphic order as follow; El-Hanadi, Dababiya Quarry, El-Mahmiya and Abu Had. In the present work, this subdivision is applied. El-Hanadi Member composes of marl and calcareous shale with a thickness of about 5m Wadi Tarfa, ~8m thick at Gabal Qreiya and ~20m thick at Gabal Oweina sections at the basal part of the Esna Formation. Dababiya Quarry Member consists of three distinctive beds at Wadi Tarfa and Gabal Qreiya sections and not detected at Gabal Oweina section. These are organic-rich clay bed (~5cm thick) at the base, thin laminated brown phosphatic shale bed (~20-50cm thick) at the middle and marl bed (~25-70cm thick) at the top (Figure 7E). El-Mahmiya Member is mainly composed of greenish gray, dark gray claystones and shales attaining a thickness of about 13m thick at Wadi Tarfa, ~26.75m thick at Gabal Qreiya and ~52m thick at Gabal Oweina sections. Abu Had Member is composed of intercalation of calcareous shale and marl with thickness of about 4m thick at Wadi Tarfa and ~6 m thick at Gabal Qreiya sections. It represents the gradational change from the shales of Esna Formation to the carbonates of Thebes Formation.

2.7. Thebes Formation

The term Thebes Formation was applied by [43] to describe a thick sequence of limestone with chert interbeds at Gabal Gurnah, near Luxor, Nile Valley forming the uppermost part of the studied sections. In the present work, Thebes Formation conformably rests on Esna Formation with a gradational contact and consists of thin to medium laminated limestone with chert interbeds in the studied lowermost parts about 10m thick (Figures 7A-C, 7F, 5, 8, 9, 11).

3. Biostratigraphy

The measured stratigraphic sections yield rich and well diversified planktonic foraminiferal fauna of very good preservation (Figures 18, 19). Generally, the studied Upper Cretaceous-Lower Paleogene successions are subdivided into 23 planktonic foraminiferal zones based on the stratigraphic ranges of the index planktonic foraminiferal species (Figures 8, 9, 10, 11). These zones are correlated with the standard zonation of [44] and the Tunisia zonation of [45] for the Late Cretaceous and of [46] for the Early Paleogene (Figure 12). The proposed planktonic foraminiferal zones are arranged stratigraphically as follow:

3.1. Globotruncana Ventricosa Zone

This zone is defined to cover the interval from the Lowest Occurrence (LO) of the nominate taxon to the LO of *Globotruncanita calcarata* (Cushman). In the present study, the lower boundary of *G. ventricosa* Zone is tentatively placed at a paleosol bed, approximately is correlated with the Quseir/Sudr formational contact in the north at Wadi Tarfa and Timimit el Shifa sections (Figures 10, 11). On the other hand, this zone is not recorded in the south at Gabal Oweina and Gabal Qreiya sections due to the change in the depositional conditions, whereas the sediments are barren of planktonic foraminiferal fauna (Figure 12).

3.2. Globotruncana Aegyptiaca Zone

It is defined to cover the interval from the LO of the nominate taxon to the LO of *Gansserina gansseri* (Bolli). The lower boundary of this zone is tentatively correlated with the lithostratigraphic boundary of the Duwi/Sudr formations toward the south at Gabal Oweina and Gabal Qreiya sections (Figures 8, 9). Toward the north at Wadi Tarfa and Timimit el Shifa sections, it is traced at the middle part of the Sudr Formation (Figures 10, 11). The *G. aegyptiaca* Zone is conformably overlain by the *Gansserina gansseri* Zone of the Early-Middle Maastrichtian age in all sections (Figure 12).

3.3. Gansserina Gansseri Zone

This zone is defined as a total-range zone of the nominate taxon to cover the interval of the Early-Middle Maastrichtian age (Figures 8, 9, 10, 11). It is conformably overlain by the *Pseudoguemblina palpebra* Zone of the Late Maastrichtian age in the area (Figure 12).

3.4. Pseudoguemblina Palpebra Zone

The *P. palpebra* Zone is defined to cover the interval from the HO of *G. gansseri* (Bolli) to LO of *Plummerita hantknenoides* (Brönnimann). It is conformably overlain by *P. hantknenoides* Zone of the Latest Maastrichtian age at two sections Wadi Tarfa and Gabal Qreiya, that doesn't exist at Gabal Oweina and Timimit el Shifa sections (Figure 12). This is due to an occurrence of a hiatus in the area. The upper boundary of the *P. palpebra* Zone is characterized by the presence of a glauconitic phosphatic conglomeratic bed at Gabal Oweina section (Figure 5).

3.5. Plummerita Hantknenoides Zone

The *P. hantknenoides* Zone is defined to cover the total interval of the nominate taxon of the Latest Maastrichtian age. It occurs at Wadi Tarfa and Gabal Qreiya sections indicating a continuous sedimentation for the Maastrichtian sediments at these two sections in comparative to Timimit el Shifa and Gabal Oweina sections where this zone disappears indicating a hiatus at this time (Figure 12).

3.6. Guembelitria Cretacea (P0) Zone

This zone is defined to cover the interval from the Cretaceous/Paleogene (K/Pg) boundary to the LO of *Parvularugoglobigerina eugubina* (Luterbacher, Premoli Silva). The *G. cretacea* Zone occurs only at Gabal Qreiya section covering the lowermost part of Dakhla Formation (Figure 6). It is conformably overlain by the *Parvularugoglobigerin aeugubina* (Pα) Zone (Figure 12).

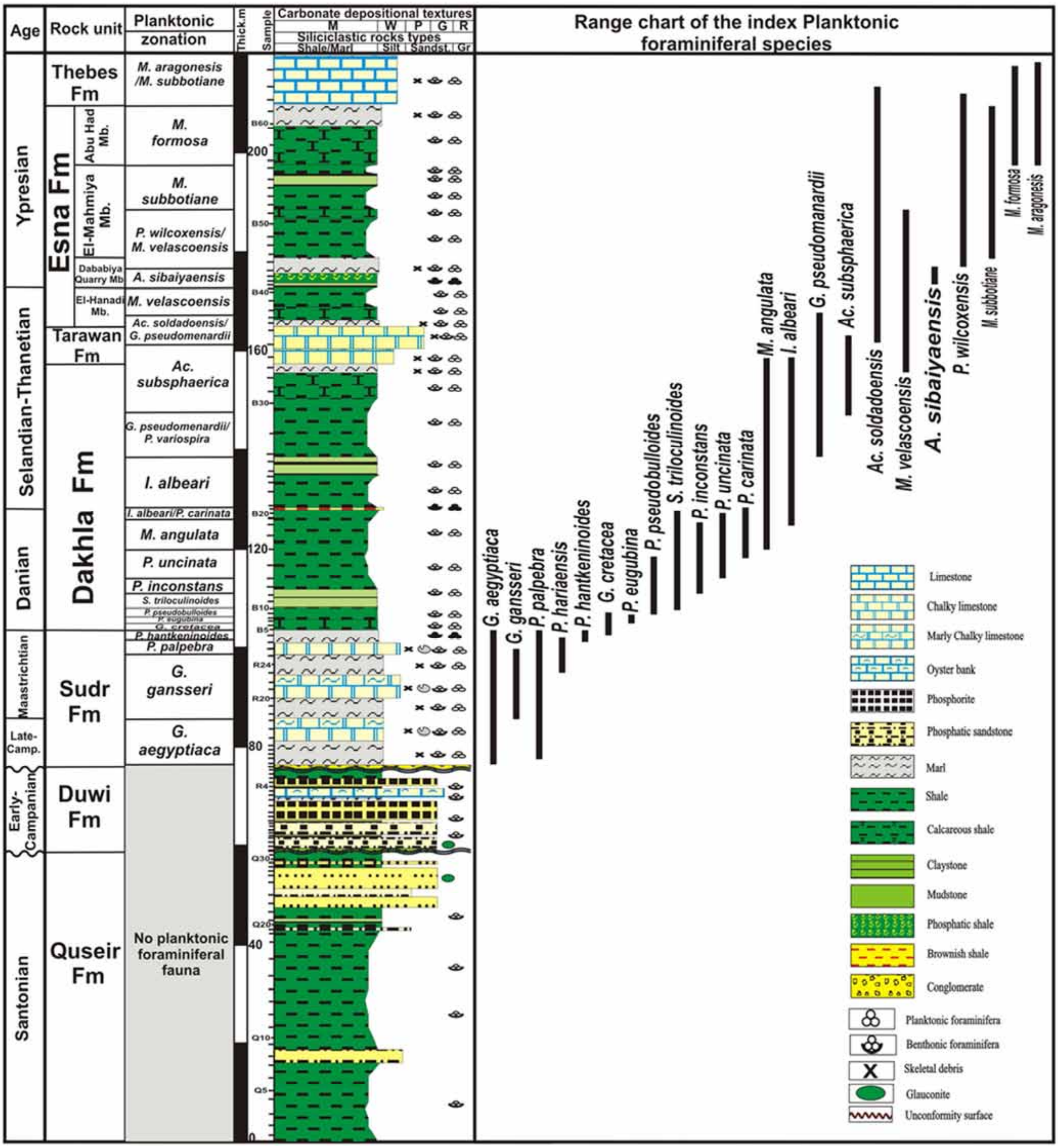

Figure 9. *Litho-, and bio-stratigraphy, range chart of the index planktonic foraminiferal species in the Upper Cretaceous-Lower Paleogene succession at Gabal Qreiya section.*

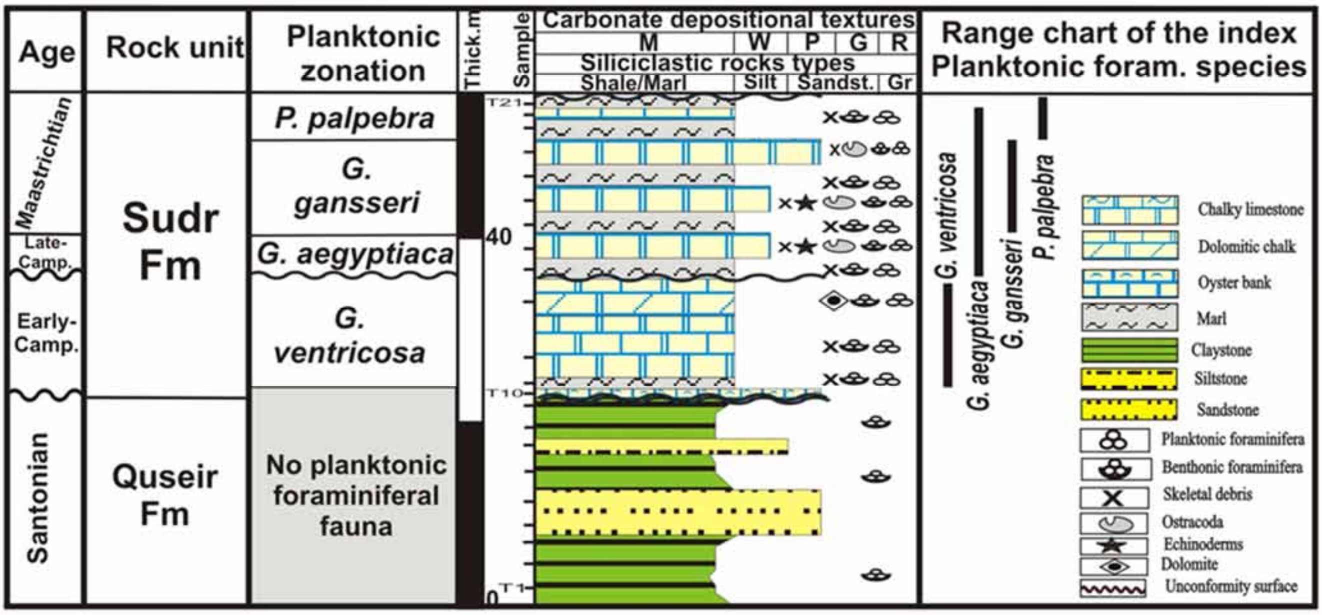

Figure 10. *Litho-, and bio-stratigraphy, range chart of the index planktonic foraminiferal species in the Upper Cretaceous succession at Timimit elShifa section.*

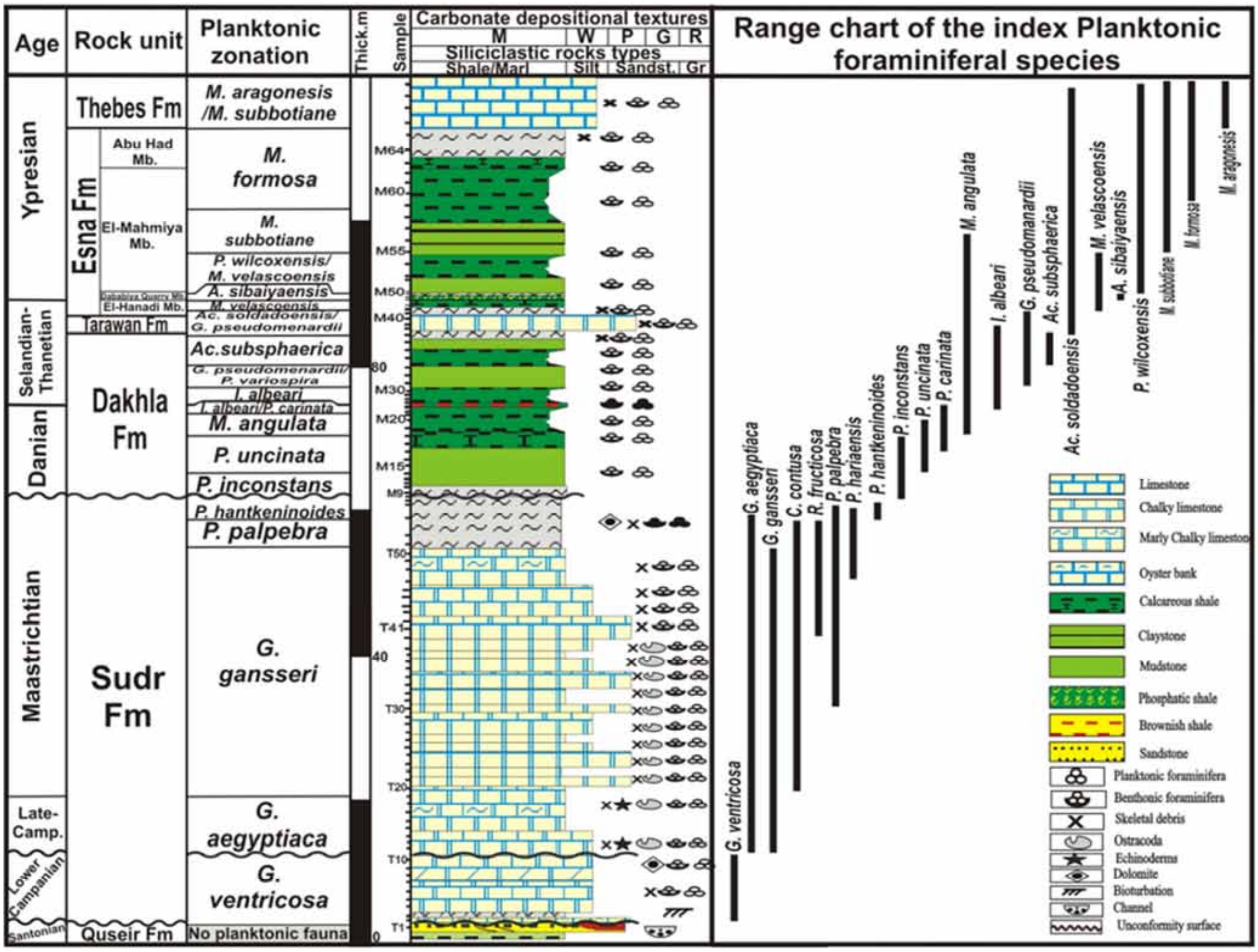

Figure 11. *Litho-, and bio-stratigraphy, range chart of the index planktonic foraminiferal species in the Upper Cretaceous-Lower Paleogene succession at Wadi Tarfa section.*

3.7. Parvularugoglobigerina Eugubina (Pα) Zone

This zone is defined to cover the total interval of the nominate taxon of the Earliest Danian age. The *P. eugubina* Zone is only recorded at Gabal Qreiya section (Figure 6). It is conformably overlain by the *Parasubbotina pseudobulloides* (P1a) Zone (Figure 12).

3.8. Parasubbotina Pseudobulloides (P1a) Zone

This zone is defined to mark the interval from the HO of *P. eugubina* (Luterbacher, PremoliSilva) to the LO of *Subbotina triloculinoides* (Plummer). The *P. pseudobulloides* Zone is only recorded at Gabal Qreiya section (Figure 6). It is conformably overlain by the *Subbotina triloculinoides* (P1b) Zone (Figure 12).

3.9. Subbotina Triloculinoides (P1b) Zone

It is defined to cover the interval from the LO of the nominate taxon to the LO of *Praemurica inconstans* (Subbotina). The *S. triloculinoides* Zone is only recorded at Gabal Qreiya section (Figure 6). It is conformably overlain by the *Praemurica inconstans* (P1c) Zone. These zones **(**P0, Pα, P1a and P1b**)** are not recorded at both Wadi Tarfa, and Gabal Oweina sections (Figure 12).

3.10. Praemurica Inconstans (P1c) Zone

It is defined to cover the interval from LO of *Praemurica inconstans* (Subbotina) to the LO of *Praemurica uncinata* (Bolli). The *P. inconstans* Zone is documented at Wadi Tarfa, Gabal Qreiya and Gabal Oweina sections (Figures 8, 9, 11). It is conformably overlain by the *Praemurica uncinata* (P2) Zone (Figure 12).

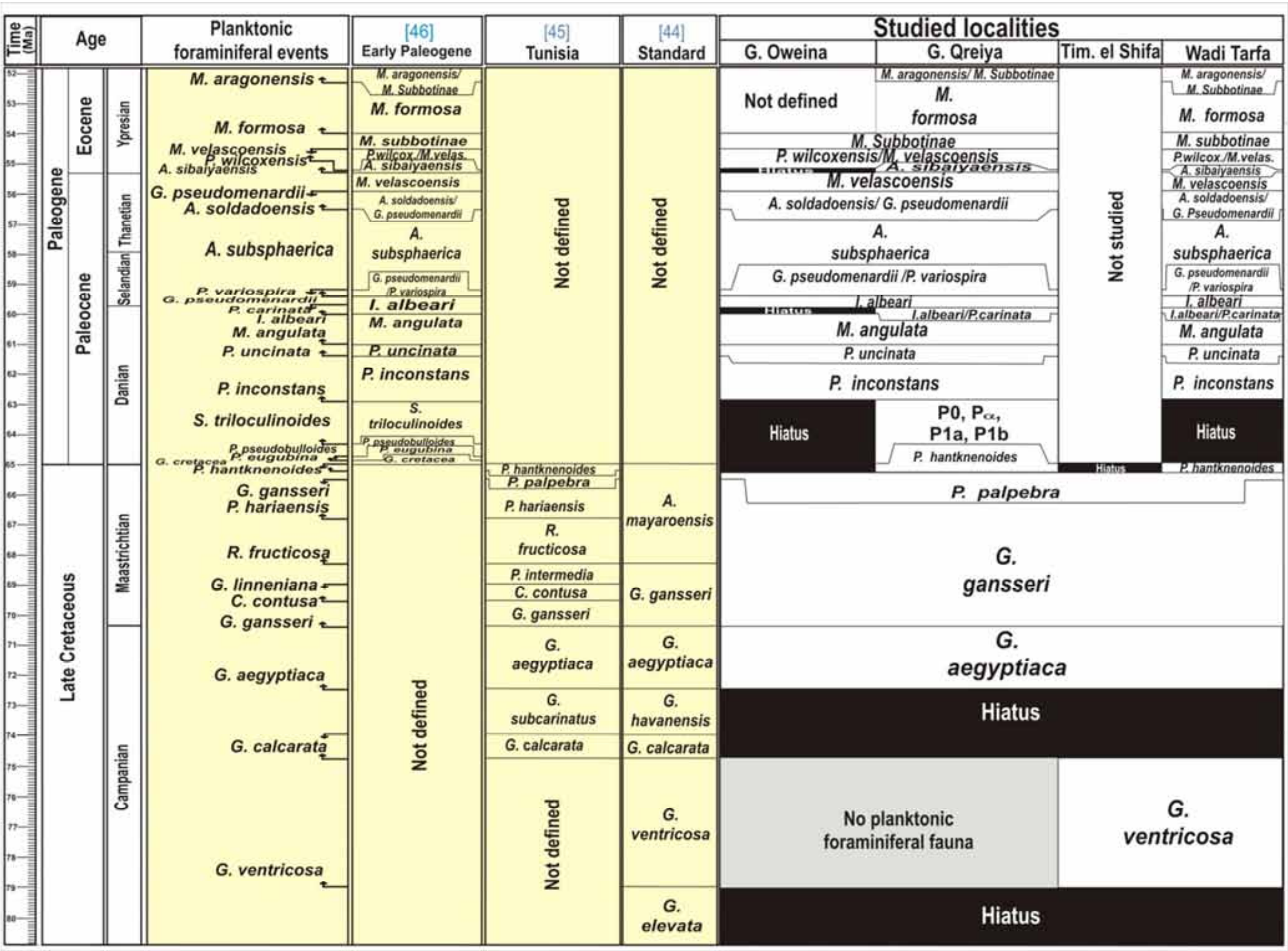

Figure 12. Comparison between the planktonic foraminiferal biozones of the present work with international global schemes (Age assignment based on [47] for Late Cretaceous and [46] for Early Paleogene).

3.11. Praemurica Uncinata (P2) Zone

It is defined this zone to cover the interval from the LO of the nominate taxon to the LO of *Morozovella angulata* (White). The *P. uncinata* Zone is recognized at Wadi Tarfa, Gabal Qreiya and Gabal Oweina sections (Figures 8, 9, 11). It is conformably overlain by the *Morozovella angulata* (P3a) Zone (Figure 12).

3.12. Morozovella Angulata (P3a) Zone

This zone is defined to cover the interval from the LO of the nominate taxon to the LO of *Igorina albeari* (Cushman and Bermŭdez). The *M. angulata* Zone is documented at Wadi Tarfa, Gabal Qreiya and Gabal Oweina sections (Figure 12).

3.13. Igorina Albeari/Praemurica Carinata (Lowermost Part of P3b) Zone

This zone is defined to cover the interval from the LO of *I. albeari* (Cushman and Bermŭdez) to the HO of *P. carinata* (El-Naggar). The *I. albeari*/*P. carinata* Zone is only traced at Wadi Tarfa and Gabal Qreiya sections (Figures 9, 11) representing the uppermost Danian sediments, before reaching to the distinctive lithologic beds of the Danian/Selandian (D/S) boundary (Figure 11D). Whereas, this zone is not recorded at Gabal Oweina indicating a hiatus at this time (Figure 12).

3.14. Igorina Albeari (P3b, Main Part) Zone

This Zone is defined to cover the interval from the HO of *P. carinata* to the LO of *Globanomalina pseudomenardii* (Bolli). The *I. albeari* Zone is recorded at Wadi Tarfa, Gabal Qreiya and Gabal Oweina sections (Figures 8, 9, 11). It is conformably overlain by *Globanomalina pseudomenardii/Parasubbotina variospira* (P4a) Zone (Figure 12).

3.15. Globanomalina Pseudomenardii/ Parasubbotina Variospira (P4a) Zone

The present zone is defined to cover the interval between the LO of *G. pseudomenardii* (Bolli) and the HO of *P. variospira* (Belford). It is documented at Wadi Tarfa, Gabal Qreiya and Gabal Oweina sections (Figures 8, 9, 11). It is conformably overlain by the *Acarinina subsphaerica* (P4b) Zone (Figure 12).

3.16. Acarinina Subsphaerica (P4b) Zone

This Zone is defined to cover the interval from the HO of *P. variospira* (Belford) to the LO of *Acarinina soldadoensis* (Brönnimann). The *A. subsphaerica* Zone is recorded at Wadi Tarfa, Gabal Qreiya and Gabal Oweina sections (Figures 8, 9, 11). It is conformably overlain by the *Acarinina soldadoensis/Globanomalina pseudomenardii* (P4c) Zone (Figure 12).

3.17. Acarinina Soldadoensis/Globanomalina Pseudomenardii (P4c) Zone

This zone is defined to cover the interval from the LO of *A. soldadoensis* (Brönnimann) to the HO of the *G. pseudomenardii* (Bolli). The *A. soldadoensis/G. pseudomenardii* Zone occurs at Wadi Tarfa, Gabal Qreiya and Gabal Oweina sections (Figures 8, 9, 11). It is conformably overlain by the *Morozovella velascoensis* (P5) Zone (Figure 12).

3.18. Morozovella Velascoensis (P5) Zone

The present Zone is defined to cover the interval from the HO of *G. pseudomenardii* (Bolli) to the LO of *Acarinina sibaiyaensis* (El-Naggar) to mark the Latest Paleocene interval before the Paleocene/Eocene Thermal Maximum (PETM). The *M. velascoensis* Zone occurs in Wadi Tarfa, Gabal Qreiya and Gabal Oweina sections (Figures 8, 9, 11). This zone is conformably overlain by the *Acarinina sibaiyaensis* (E1) Zone in Wadi Tarfa and Gabal Qreiya sections. Whereas, it unconformably overlain by the *Pseudohastigerina wilcoxensis/Morozvella velascoensis* (E2) Zone at Gabal Oweina section (Figure 12).

3.19. Acarinina Sibaiyaensis (E1) Zone

This zone is defined to cover the interval from the LO of the nominate taxon to the LO of *Pseudohastigerina wilcoxensis* (Cushman and Ponton). The *A. sibaiyaensis* Zone is traced at Wadi Tarfa and Gabal Qreiya sections indicating a continuous sedimentation for the interval of the Paleocene/Eocene (P/E). Whereas, this zone is not recorded at Gabal Oweina indicating a hiatus at this time (Figures 8, 9, 11). It is conformably overlain by the *Pseudohastigerina wilcoxensis/Morozvella velascoensis* (E2) Zone (Figure 12).

3.20. Pseudohastigerina Wilcoxensis/ Morozvella Velascoensis (E2) Zone

It is defined to cover the interval from the LO of *P. wilcoxensis* (Cushman and Ponton) to the HO of *M. velascoensis* (Cushman). The *P. wilcoxensis/M. velascoensis* Zone is recognized at Wadi Tarfa, Gabal Qreiya and Gabal Oweina sections (Figures 8, 9, 11). It is conformably overlain by the *Morozovella subbotinae* (E3) Zone (Figure 12).

3.21. Morozovella Subbotinae (E3) Zone

It is defined to cover the interval from the HO of *M. velascoensis* (Cushman) to the LO of *M. Formosa* (Bolli). The *M. subbotinae* Zone is recognized at Wadi Tarfa, Gabal Qreiya and Gabal Oweina sections (Figures 8, 9, 11). It is conformably overlain by the *Morozovella Formosa* (E4) Zone at Wadi Tarfa and Gabal Qreiya sections. Whereas, at Gabal Oweina section, it represents the exposed uppermost part of Esna Formation that covered by the residual blocks of Thebes Formation (Figure 12).

3.22. Morozovella Formosa (E4) Zone

It is defined to cover the interval from the LO of the nominate taxon to the LO of *M. aragonensis* (Nuttall). The *M. formosa* is recorded at Wadi Tarfa and Gabal Qreiya sections (Figures 9, 11). It is conformably overlain by the *Morozovella aragonensis/Morozovella subbotinae* (E5) Zone (Figure 12).

3.23. Morozovella Aragonensis/Morozovella Subbotinae (E5) Zone

The present zone is defined to cover the interval from the LO *M. aragonensis* (Nuttall) and the HO of *M. subbotinae* (Morozova). It is recognized at Wadi Tarfa and Gabal Qreiya sections (Figures 9, 11). It represents the studied uppermost part of sections (the base of Thebes Formation) (Figure 12).

4. Synsedimentary Tectonic Episodes and Relative Sea-Level Changes

The Upper Cretaceous-Lower Paleogene times in the Egyptian sequences are characterized by the influence of repeated synsedimentary tectonic episodes and sea-level fluctuations. The events are thought to have played a significant role in controlling the distribution and development of the lithofacies and biofacies [26, 35, 48, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54].

The integrated field observations and detailed litho-and bio-stratigraphic investigations of the studied sections revealed a noticeable vertical and lateral variation in the thickness of the rock unit from one locality to another together with the absence of planktonic foraminiferal zones as well as the occurrence of unconformity features at different stratigraphic levels. The phenomenon that enabled to divide the studied sequences into set of successive sedimentological events.

During the Santonian time, the clastic Quseir Formation sequence was deposited, with variable thickness at the study sections, in a marginal to shallow marine environment [24, 36]. It is overlain by the Duwi Formation toward the south (Gabal Oweina and Gabal Qreiya sections) with sharp and irregular surface contact as well as a glauconitic bed. Whereas, toward the north it is overlain by the Sudr Formation (Timimit el Shifa and Wadi Tarfa) with an erosive surface contact as well as the presence of paleosol, correlated with the extinction of the Earliest Campanian *G. elevate* Zone (Figures 13, 14).

By the advent of the Early Campanian time, a slight transgression took place during the deposition of the shallow phosphate sediments of Duwi Formation with benthonic fauna in the south besides open marine carbonate sediments of the lower part of the Sudr Formation with planktonic foraminifera (*G. ventricosa* Zone) in the north. These observations clearly reveal the instability of the sedimentary basin floor causing uplifting and subsiding local synsedimentary movement. Accordingly, a major uplift, approximately north of Gabal Qreiya section, is recorded, which represents the northern periphery of the restricted shallow marine phosphate basin (Duwi Formation) and the southern periphery of the pelagic (open marine) carbonate basin of the lower part of Sudr Formation (Figure 13).

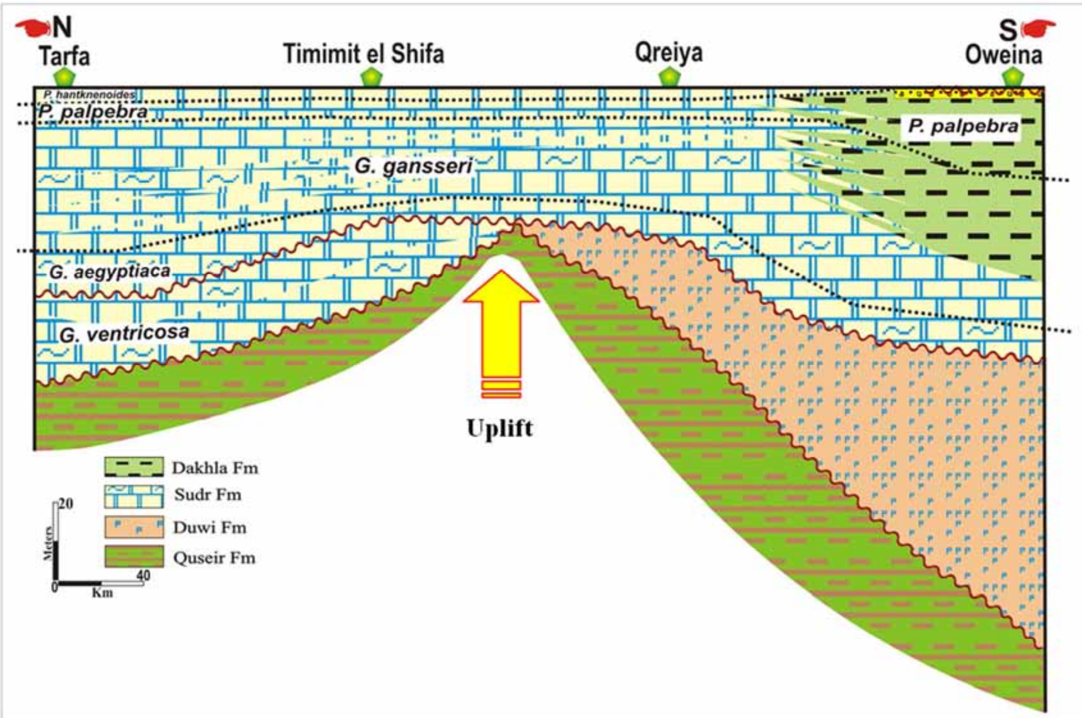

Figure 13. Sedimentary basin evolution of the Campanian–Maastrichtian sediments (Interval of G. ventricosa, G. aegyptiaca, G. gansseri, P. palpebra and P. hantknenoides zones).

The deposits of the Middle Campanian time are not represented all over the area as the activation of this synsedimentary movement as continued during this time. This is documented by the occurrence of an irregular surface and a conglomeratic bed at Duwi/Sudr formational boundary at Gabal Oweina and Gabal Qreiya sections respectively in the south. Whereas, toward the north at Timimit el Shifa and Wadi Tarfa sections, it is recognized within the Sudr Formation marked hiatus due to the extinction of the Middle Campanian *G. calcarata* and *G. havanensis* zones within the Sudr Formation (Figures 13, 14).

During the Late Campanian-Early Maastrichtian time, a major transgression took place all over the study area causing the deposition of the open marine environment carbonate (marl and chalky limestone) sediments of the Sudr Formation enriched with foraminiferal fauna especially the planktonic foraminifera (*G. aegyptiaca* and *G. gansseri* zones) as a tongue toward the south until Gabal Oweina section, where it is equivalent to the lower parts of the Dakhla Formation at this time (Figure 13). This transgressive phase coincides with the eustatic rise in the global sea-level curve [37].

At the end of Maastrichtian-Earliest Danian time, the study area was subjected to differential synsedimentary tectonic events reaching its great intensity and maximum high in the south at Gabal Oweina section than the northern part at Timimit el Shifa and Wadi Tarfa sections representing a local tectonic event. While at Gabal Qreiya section is still subsidence. Consequently, at Gabal Oweina section in the extreme south, an observable glauconitic phosphatic conglomeratic bed is detected at the middle part of the Dakhla Formation. This is indicating the occurrence of a hiatus marked by the absence of the Latest Maastrichtian *P. hantknenoides* Zone and the Earliest Danian *G. cretacea* (P0), *P. eugubina* (Pα), *P. pseudobulloides* (P1a) and *S. triloculinoides* (P1b) zones. Whereas, at Timimit el Shifa section, this event is relatively of low intensity and is documented biostratigraphically by the absence of the Latest Maastrichtian *P. hantknenoides* Zone. Also, at Wadi Tarfa section in the extreme north, a noticeable irregular erosional surface and reworked globular clayey intraclasts are present between the Maastrichtian and Danian indicates the occurrence of a hiatus, which marked by the absence of the lowermost part of the Danian sediments, comprising the *G. cretacea* (P0), *P. eugubina* (Pα), *P. pseudobulloides* (P1a) and *S. triloculinoides* (P1b) zones. At Gabal Qreiya the sea-level curve is conformable within the global sea-level curve (Figure 14).

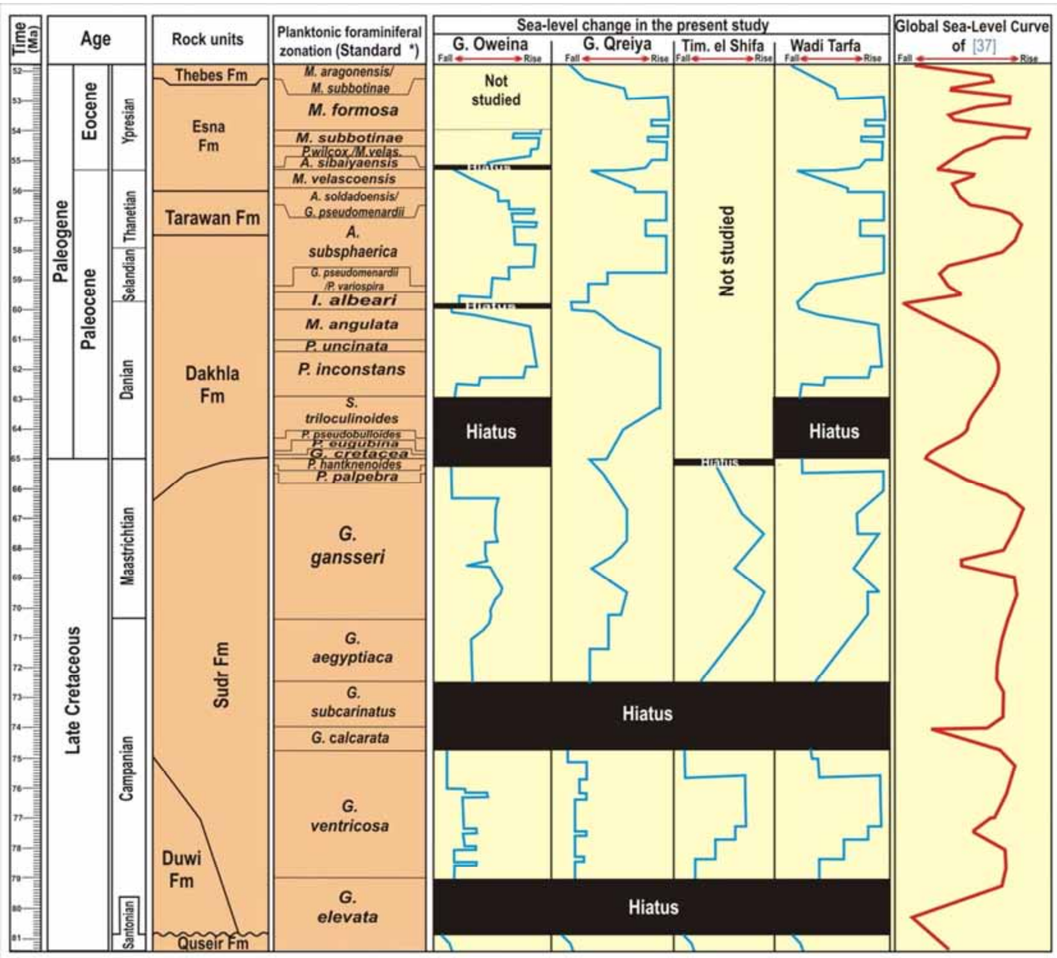

*Figure 14. Relative sea-level changes of the Upper Cretaceous-Lower Paleogene successions at the study area compared with the global sea-level curve of [37] (*For Standard zonation, See Figure 14).*

During the Danian time, a major marine invasion flooded the study area and the basin was gradually filled with thick succession of open marine shales of Dakhla Formation enriched with the planktonic foraminifera (*G. cretacea, P. eugubina*, *P. pseudobulloides*, *S. triloculinoides, P. inconstans*, *P. uncinata, M. angulata* and *I. albeari*/*P. carinata* zones) all over the study area, with a marked increases in the thickness toward the south at Gabal Oweina section (Figure 15). At Gabal Oweina, Gabal Qreiya and Wadi Tarfa sections the sea-level curve is conformable within the global sea-level fall (Figure 14). Yet, a local tectonic event is recorded toward the top of Dakhla Formation at Gabal Oweina section marked by the absence of the uppermost part of the Danian (*I. albeari*/*P. carinata* Zone) characterizing the Danian/Selandian (D/S) boundary.

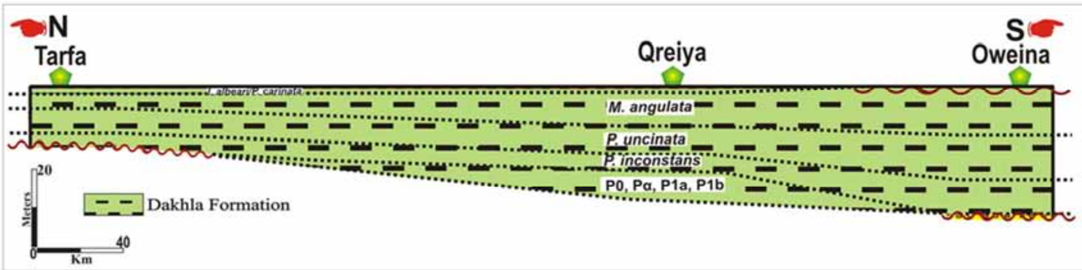

Figure 15. *Sedimentary basin evolution of the Danian sediments (Interval of G. cretacea, P. eugubina, P. pseudobulloides, S. triloculinoides, P. inconstans, P. uncinata, M. angulata and I. albeari/ P. carinata zones).*

During the Selandian-Thanetian time, the sea invasion has continued in thea rearesulting in the deposition of open marine clastic sediments of the upper part of the Dakhla Formation, carbonate sediments of Tarawan Formation and the lower part of the Esna Formation enriched with the planktonic foraminifera (*I. albeari, G. pseudomenardii/P. variospira, A. subsphaerica, A. soldadoensis/G. pseudomenardii* and *M. velascoensis* zones) (Figure 16). At Gabal Oweina, Gabal Qreiya and Wadi Tarfa sections, the sea-level curve is conformable within the global sea-level fall (Figure 14). Yet, a local tectonic event is recorded toward the middle of the Esna Formation at Gabal Oweina section marked by the absence of the *A. sibaiyaensis* (E1) characterizing the Paleocene/Eocene (P/E) boundary.

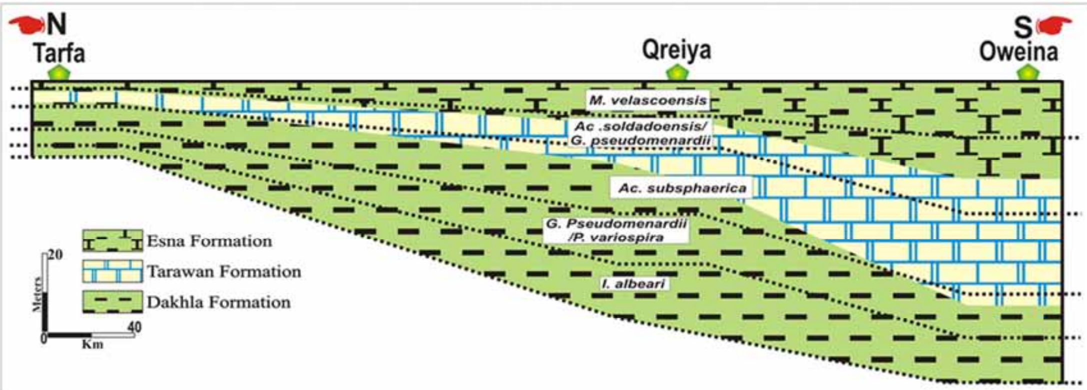

Figure 16. *Sedimentary basin evolution of the Selandian-Thanetian sediments (Interval of I. albeari, G. pseudomenardii/ P. variospira, A. subsphaerica, A. soldadoensis/ G. pseudomenardii and M. velascoensis zones).*

During the Ypresian time, the sea invasion still continued in the area resulting in the deposition of the clastic sediments of the Esna Formation which are marked by abundant, highly diversified and well-preserved planktonic foraminifera (*A. sibaiyaensis*, *P. wilcoxensis/M. velascoensis*, *M. subbotinae* and *M. formosa* zones) conformable within the global sea-level rise (Figure 14). After that the Late Ypresian Sea retreated northwards almost continuously, leaving the study area to shallow marine conditions and the deposition of the Thebes Formation (Figure 17).

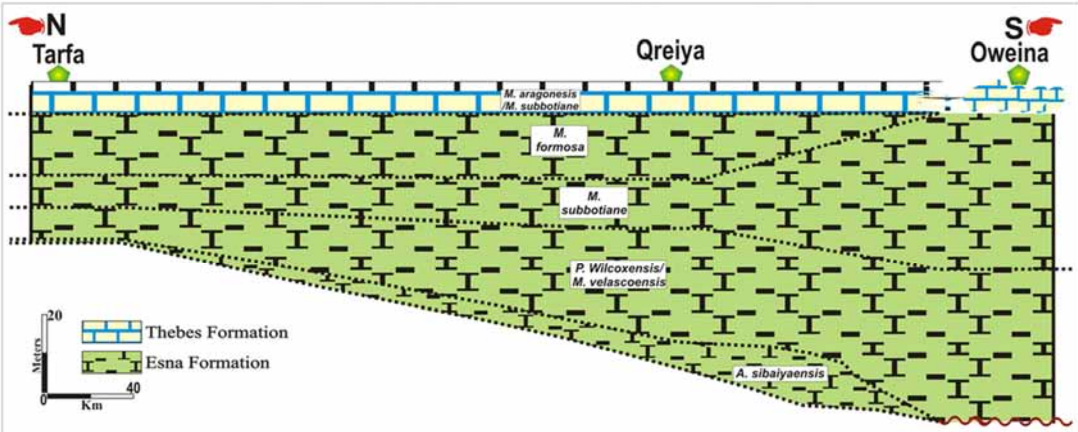

Figure 17. *Sedimentary basin evolution of the Ypresian sediments (Interval of A. sibaiyaensis, P. wilcoxensis/ M. velascoensis, M. subbotinae, M. formosa and M. aragonensis/ M. subbotinae zones).*

[55] stated that the changes in situation of the plate boundaries between Africa and Europe as they develop in successive times in Late Cretaceous and Early Tertiary is principal cause in control the sedimentation during these times. [53] stated that the regional tilt blocks with the isolated areas rich in economic phosphorites during the Upper Cretaceous and Lower Paleogene times in N. Africa and the Middle East are the direct result of successive northward tilt of the margin of the African plate related to the interplay between Africa and Europe in these times.

In the present study, the Egyptian Upper Cretaceous-Lower Paleogene in the Eastern Desert is obviously distributed with significant and marked vertical and lateral lithofacies changes influenced by repeated synsedimentary tectonic episodes and relative sea-level fluctuations. Consequently, it can be stated that the stratigraphic evolution of the studied Upper Cretaceous-Lower Paleogene sedimentary basin in the Eastern Desert of Egypt was controlled by the collision of African/Arabian and Eurasian plates at these times. This collision led to the closure of the Tethys Ocean and formation the Syrian Arc System in north Egypt [35, 56, 57, 58, 59].

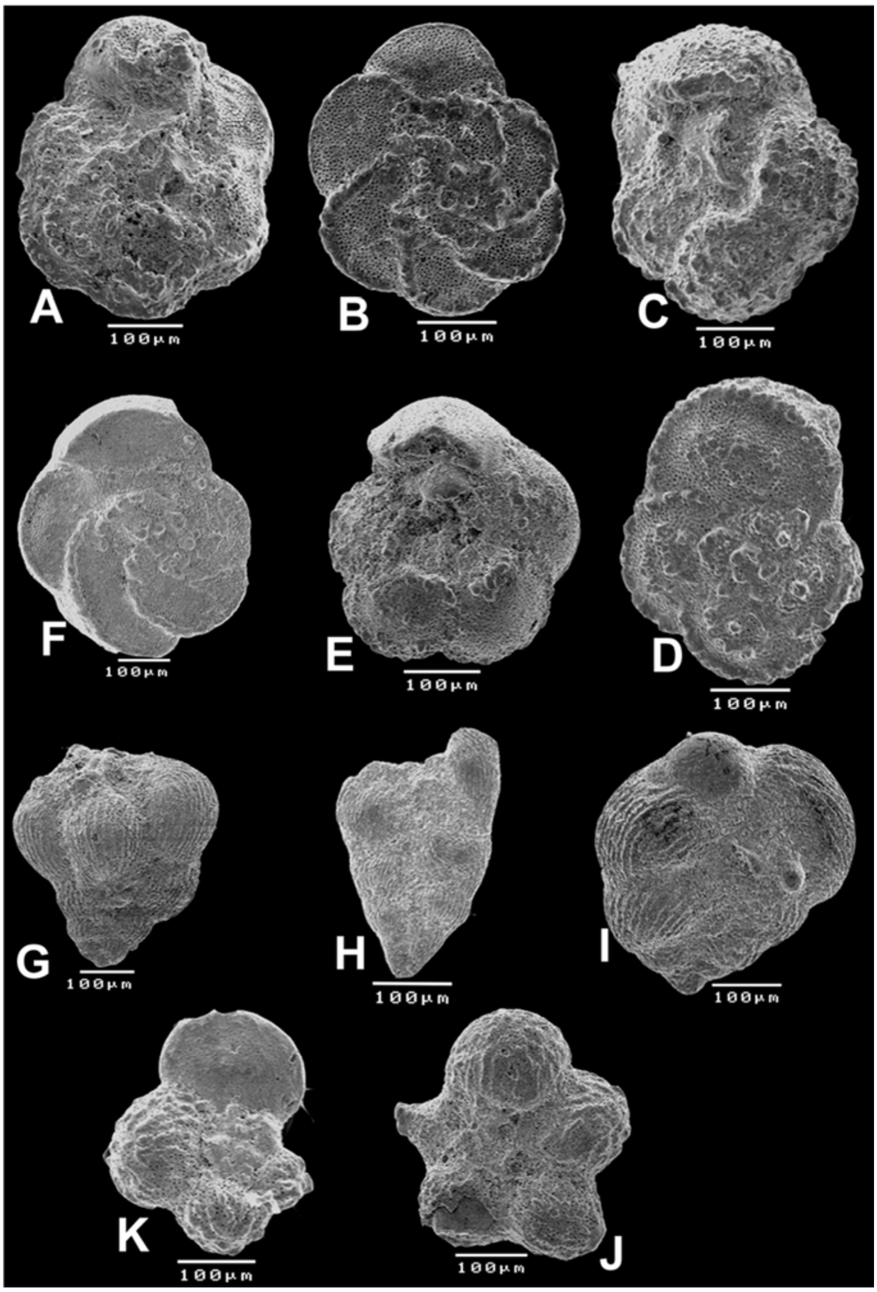

Figure 18. *(A, B): Globotruncana ventricosa (White), Sudr Formation at Timimit el Shifa section. (C, D): Globotruncana aegyptiaca (Nakkady), Sudr Formation at Timimit el Shifa section. (E, F): Gansserina gansseri (Bolli), Sudr Formation at Gabal Oweina section. (G): Racemiguembelina fructicosa (Egger), Sudr Formation at Gabal Qreiya section. (H): Pseudoguemblina hariaensis (Nederbragt), Sudr Formation at Gabal Qreiya section. (I): Pseudoguemblina palpebra (Brönnimann, Brown), Dakhla Formation at Gabal Oweina section. (J, K): Plummerita hantknenoides (Brönnimann), Sudr Formation at Gabal Qreiya section.*

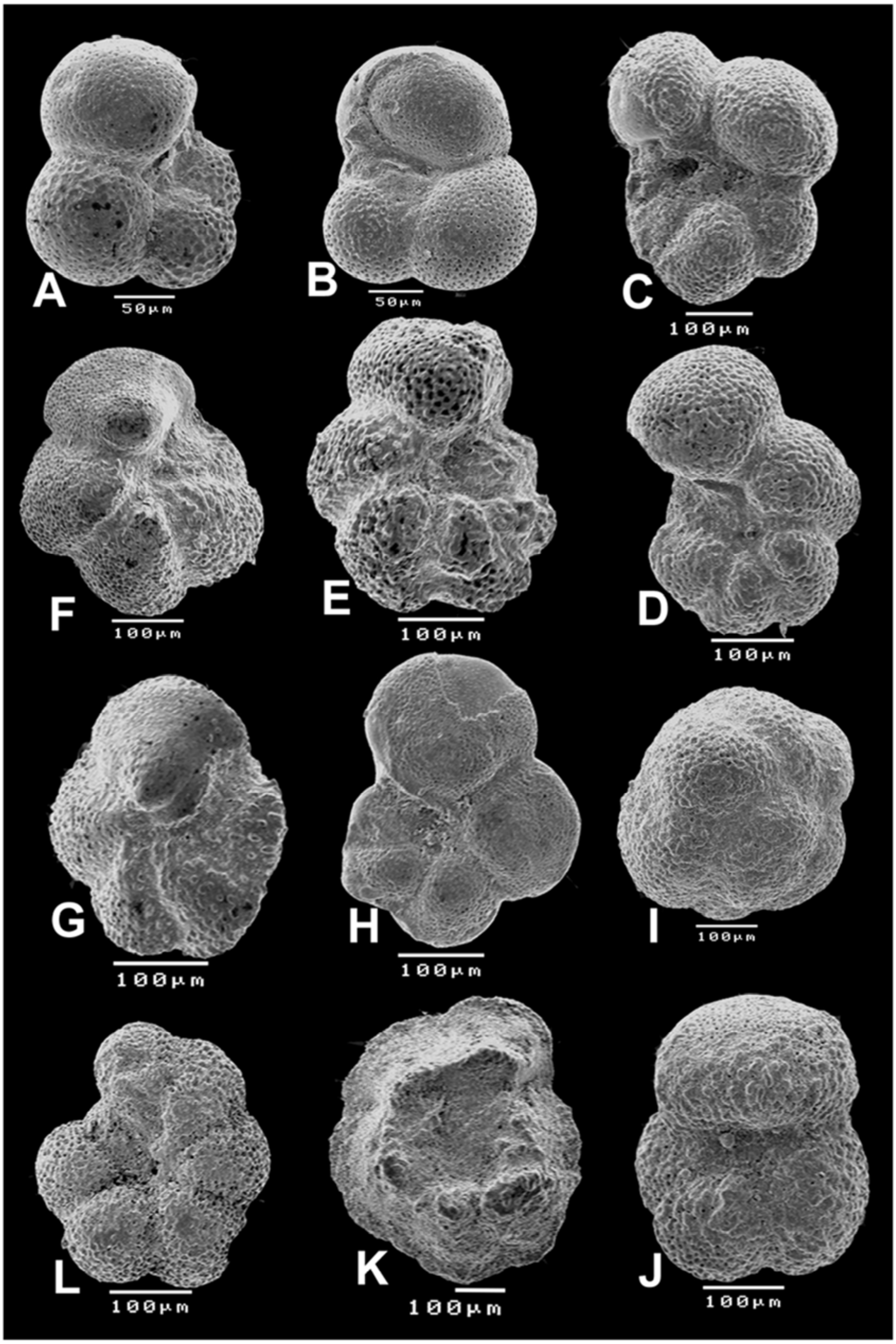

Figure 19. *(A): Parasubbotina pseudobulloides (Plummer), Dakhla Formation at Gabal Qreiya section. (B): Subbotina triloculinoides (Plummer), Dakhla Formation at Gabal Qreiya section. (C): Praemurica inconstans (Subbotina), Dakhla Formation at Gabal Oweina section. (D): Praemurica uncinata (Bolli), Dakhla Formation at Gabal Qreiya section. (E): Praemurica carinata (El-Naggar), Dakhla Formation at Gabal Qreiya section. (F): Morozovella angulata (White), Dakhla Formation at Gabal Oweina section. (G): Igorina albeari (Cushman, Bermŭdez), Dakhla Formation at Wadi Tarfa section. (H): Globanomalina psendomenardii (Bolli), Dakhla Formation at Wadi Tarfa section. (I): Acarinina subsphaerica (Subbotina), Dakhla Formation at Gabal Qreiya section. (J): Acarinina soldadoensis (Brönnimann), Tarawan Formation at Wadi Tarfa section. (K): Morozovella velascoensis (Cushman), Esna Formation at Gabal Oweina section. (L): Acarinina sibaiyaensis (ElNaggar), Esna Formation at Wadi Tarfa section.*

5. Conclusion

Depending on the similarities in lithofacies, biofacies, depositional conditions and the priority in the stratigraphic nomenclature code, the numerous lithostratigraphic names of the upper Cretaceous-Lower Paleogene stratigraphic sections in the Eastern Desert of Egypt are revised and amended. This was done by measuring four stratigraphic sections at Gabal Oweina, Gabal Qreiya, Timimit el Shifa and Wadi Tarfa. Rakhiyat Formation that recognized in the north at Timimit el Shifa and Wadi Tarfa by [24] is here changed and amended into Quseir Formation of Youssef which has been used and consolidated in all sectors. Also, Sharawna Member that recognized at Gabal Oweina by [18] and Hamama Member at Gabal Qreiya by [20] in the south are here changed and amended into the Sudr Formation of Ghorab. Moreover, Owaina Member which proposed at Gabal Oweina by [18] and Beida Member at Gabal Qreiya by [20] in the south are changed and amended into Dakhla Formation of Said. Biostratigraphically, 23 planktonic foraminiferal zones are defined covering the interval from Late Cretaceous (Campanian) to Eocene (Ypresian) age.

Synsedimentary tectonics accompanied by pronounced relative sea-level changes are thought to have played a substantial role in controlling the distribution of the significant and marked vertical and lateral lithofacies changes of the studied sequences. These events were related to the collision of African/Arabian and Eurasia plates at these times.

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