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Integrated Foraminiferal Biostratigraphy and Paleoenvironmental Analysis of the Selandian- Ypresian Time Interval at Bir El-Markha Section, West-central Sinai Region, Egypt

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THIS STUDY examines the foraminiferal content of the late Selandian-Ypresian succession exposed at the Bir El-Markha section in the west-central Sinai region to evaluate the prevailing depositional conditions and sea-level behaviour throughout this time span. From base to top, this succession is made up of the Tarawan Formation, the Esna Formation (comprising four members: El-Hanadi, El-Dababiya Quarry, El-Mahmiya, and Abu Had), and the Thebes Formation. Seven planktonic foraminiferal biozones have been detected, including the P4 Zone (late Selandian–early Thanetian age, which is split into three further subzones P4a, P4b, and P4c); P5 Zone (latest Thanetian age); and E1–E5 zones (Ypresian age). The Selandian/Thanetian boundary is located within the P4b partial range subzone at the upper part of the Tarawan Formation, and it matches with the Maximum Flooding Surface (MFS1) of the depositional sequence 1 (DS1). The Paleocene/Eocene boundary is located at the base of the E1 partial range zone, which matches with the basal portion of the Dababiya Quarry Member (QDM) of the Esna Formation, and it is distinguished by the presence of interzonal hiatuses since the DQM's lowest portion (beds 1-3) is absent. The investigation of the depositional environments and sea-level behaviour prevailed during the examined succession's deposition is primarily based on the examination of paleoecological parameters related to its foraminiferal content, such as species diversity, P/B%, Agglutinated/Calcareous ratio (Aggl./Calc%), infaunal/epifaunal ratio, and total number of foraminiferal species, as well as their abundance patterns. Four third-order transgressive-regressive depositional sequences (DS) separated by four type-one sequence boundaries (SB) have been recognized within the studied succession, indicating a correlation with cyclic sea level changes and tectonic movements.

Keywords: Bir El-Markha, West-central Sinai, Lithostratigraphy, Planktonic foraminiferal biostratigraphy, Paleoenvironmental Analysis.

1. Introduction

Numerous research works have been released regarding the foraminiferal contents and their significance in identifying the paleoenvironments that prevailed in Egypt during the Paleocene to Eocene transition. The most significant ones include (Abdel Razik,1972; Thomas & Varenkamp, 1992; Speijer & Van der Zwaan, 1994; Speijer et al., 1996a, b; Luning, 1997; Speijer & Schmitz, 1998; Perch-Nielsen et al.,1998; Aubry et al., 1999; Bolle et al., 2000; Tantawy et al., 2000, 2001; El Dawoody, 2001; Zachos et al. 2001; Speijer & Morsi, 2002; Aubry et al., 2002; Tantawy, 2003; Zachos et al., 2003; Berggren & Ouda, 2003; Knox et al., 2003;Youssef, 2003a, b; Tripati & Elderfield, 2004; Aubry et al., 2007; Thomas, 2007; Alegret et al. 2009; Sprong et al., 2009, 2011,2012; Berggren et al., 2012; Orabi & Hassan, 2015 and Hewaidy et al., 2020). The current study focuses on the upper Selandian-Ypresian sequence's depositional conditions and paleobathymetric relative sea-level development as it is exposed in the Bir El-Markha area, which is located in the west-central Sinai at latitude 28° 56' 35" N and longitude 33° 20' 55" E **(Fig. 1)**. This work is thought to be a great occasion to learn about how global events affected foraminiferal assemblages, the evolution of the depositional environment, and the development of paleobathymetric relative sea level during the late Selandian- Ypresian time span. This is achieved by combining the results of paleoecological parameters for its foraminiferal content, lithofacies analysis, planktonic foraminiferal biostratigraphic examinations, and a comprehensive field investigation for the stratigraphic surfaces.

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2. Materials and Methods

The material on which this study is carried out includes field and laboratory works. The field work includes measuring and sampling 30 rock samples from upper Paleocene (Selandian) - lower Eocene (Ypresian) succession, exposed at the Bir El-Markha section in the west-central Sinai region. On the other hand, the laboratory work includes preparation and processing of the collected rock samples for foraminiferal studies following the normal techniques. All the foraminiferal species were picked, identified, and the stratigraphically important species were scanning photographed and shown on 4 plates, and a high resolution foraminiferal biostratigraphic classification for the studied succession was attempted.

The paleoecological parameter analyses of the five grams of foraminiferal contents from all of the rock samples that were collected such as (species diversity, Planktonic / Benthonic%, Agglutinated /Calcareous ratio (Aggl. /Calc %), infaunal/epifaunal ratio, and total number of foraminiferal species, as well as their abundance patterns) are used to investigate the depositional environments and paleobathymetric relative sea-level development prevailed during the examined succession's deposition.

The studied succession is classified into transgressive-regressive depositional sequences based mainly on the integration between the results of these paleoecological parameter analyses with those of the planktonic foraminiferal biostratigraphic investigations, lithofacies analysis, and deep field examination for the stratigraphic surfaces. Finally, the documented depositional sequences and their comparability with those from previous regional and local studies are attempted.

3. Results

3.1. Lithostratigraphy

The upper Selandian-Ypresian sequence exposed at the Bir El-Markha section is composed of three rock units that have been lithostratigraphically analyzed **(Fig. 2).** The comprehensive description of these rock units, arranged in chronological order from older to younger, is as follows:

3.1.1. Tarawan Formation (Awad & Ghobrial, 1965): This rock unit is widely spread over the Red Sea region, the Upper Nile Valley, the Sinai, and the south and central Western Deserts. Its thickness reaches around 3.5 meters at the Bir El-Markha section (samples Mk50-Mk56), with yellowish white chalky limestone making up the majority of its bottom portion, grading upward to argillaceous limestone and marl. It lies beneath the Esna Formation and unconformably overlies the Dakhla Formation with a prolonged gap (Barthel & Herrmann-Degen, 1981; Hermina, 1990; El-Azabi &El-Araby, 2000; El-Azabi & Farouk, 2011; King, 2012; Farouk, 2016 and Hewaidy et al., 2017). According to its content of foraminifera, which spans the P4a and P4b planktonic foraminiferal subzones of Berggren & Pearson, 2005 and Wade et al., 2011, it is dated to the late Selandian–early Thanetian age.

In the studied area, the Tarawan Formation may be equivalent to the Chalk in the Western Desert (Said, 1962); the Middle Oweina Chalk Member in the Nile Valley (El-Naggar, 1966); the Tarawan Chalk at Red Sea Coast, Nile Valley and Western Desert (Abdel-Razik, 1972); the upper part of the Kukur and the lowermost part of Garra formations at south Kharga Oasis (Hermina, 1990) and the Tarawan Limestone at El Dababiya Quarry section (Dupuis et al., 2003). It is also equated to the Tarawan Formation at north Kharga (Hermina, 1990) and El Dababiya Quarry section (Aubry et al., 2007).

3.1.2. Esna Formation (Beadnell, 1905 emended by Said, 1962): This formation is extensively dispersed along the Red Sea Coast, Sinai, Eastern Desert, Nile Valley, and South and Central Western Deserts. At Bir El-Markha section, it reaches approximately 23.5 meters thick (samples Mk57-Mk76) and it mostly composed of grey to green shales intercalated with calcareous shale in its lower part and grades upwardly to thinnly bedded of argillaceous limestone. It sits beneath the Thebes Formation and unconformably above the Tarawan Formation. Based on its foraminiferal composition, it is dated from the latest Paleocene (Thanetian) to the early Eocene (Ypresian); as it spans the (P4c) Subzone to the lower part of the (E5) Zone of Berggren & Pearson, 2005 and Wade et al., 2011. The Esna Formation in the current study is classified into four members, which are organized as follows, from base to top, in accordance with Aubry et al. (2007):

3.1.2.A. El-Hanadi Member (Abd El-Razik, 1972 and emended by Aubry et al., 2007): This member, which is roughly 5.5 meters thick at the Bir El-Markha section (samples Mk57–Mk62), is composed of dark gray calcareous shale that grades upward to green fissile shale. Based on its foraminiferal content, it is dated to the latest Paleocene (Thanetian) age, covering the (P5) zone and (P4c) subzone of Berggren & Pearson, 2005, and Wade et al., 2011.

This member is comparable to the El-Hanadi Member of Abdel-Razik (1972) in the Red Sea Coast, Nile

Valley, and Western Desert; Aubry et al. (2007) in the El Dababiya Quarry section; and Hewaidy et al. (2020) in the Kharga Oasis. It might correspond to the lower portion of the Esna Formation of Ghorab (1961) in the Sinai and Gulf of Suez; El-Shazly et al. (1979) in the west side of Wadi Araba; Abu Khadrah et al. (1987) in the Southern Galala plateau; Hermina (1990) in the north Kharga; Shahin & Kora (1991) and Ziko et al. (1993) in the east-central Sinai; Eweda & El-Sorogy (1999) in the west Sinai; Khalil & Mashaly (2004) in the south-west Sinai and Ismail (2012) in the south-west Gulf of Suez. It is also equated to the upper lower portion of Garra Formation of Hermina (1990) in south Kharga, and the Esna Unit -1 of Dupuis et al. (2003) at the Dababiya Quarry area.

3.1.2. B. El-Dababiya Quarry Member (DQM) (Dupuis et al., 2003 and emended by Aubry et al., 2007): Aubry et al. (2007) state that this member is composed of a series of the following five separate beds and reaches a thickness of approximately 3.86 m at the global standard stratotype section and point (GSSP): Beds 1 is 0.63 m thick of dark grey, non-calcareous laminated shale with sporadic cylindrical phosphatic coprolites; Bed 2 is 0.50 m thick of phosphatic brown laminated shale with numerous cylindrical coprolites; Bed 3 is 0.84 m thick of cream-colored, laminated phosphatic shale with coprolites and phosphatic inclusions; Bed 4 is 0.71 m thick of grey calcareous shale and Bed 5 is 1 m thick of marly calcarenitic limestone. At Bir El-Markha section, this member reaches approximately 2 meters thick (samples Mk63-Mk64). Based on its foraminiferal content, it is dated to the earliest Eocene (earliest Ypresian) because it encompasses the E1 planktonic foraminiferal biozone of Berggren & Pearson, 2005, and Wade et al., 2011. Lithostratigraphically, the DQM in the area under study is represented by two distinctive beds: Bed 1 is 140 cm thick of light grey calcareous shale, and Bed 2 is 60 cm thick of marly limestone. these two recorded beds are equivalent to beds (4 and 5) at the (DQM) in GSSP of the P/E boundary, showing the existence of an unconformity surface between El-Dababiya Quarry Member and El-Hanadi Member **(Fig. 3)**; due to the absence of the counterparts of the lowest three beds (1, 2 and 3).

This member in the current study is comparable to the DQM of Abdel-Razik (1972) in the Western Desert, Red Sea Coast, and Nile Valley; Aubry et al. (2007) at the El Dababiya Quarry area; and Hewaidy et al. (2020) at Kharga Oasis. It may equivalent to the middle part of Esna Formation of Ghorab (1961) at Sinai and Gulf of Suez; El-Shazly et al. (1979) at west side of Wadi Araba ; Abu Khadrah et al.(1987) at the Southern Galala plateau; Hermina (1990) at north Kharga; Shahin & Kora (1991) and Ziko et al. (1993) at east-central Sinai; Eweda & El-Sorogy (1999) at west Sinai; Khalil & Mashaly (2004) at south-west Sinai; and Ismail (2012) at south-west Gulf of Suez. It is also equated to the middle part of Garra Formation of Hermina (1990) at south Kharga and the lower part of Esna Unit -2 of Dupuis et al. (2003) at the Dababiya Quarry section.

3.1.2. C. El-Mahmiya Member (Aubry et al., 2007): At Bir El-Markha section, this member attains about 9 meters thick (samples Mk65-Mk70) and it consists of light green fissile shale in its lower part grades upwardly to dark grey calcareous shale. Based on its foraminiferal content, which covers the E2 and E3 planktonic foraminiferal biozones of Berggren & Pearson, 2005 and Wade et al., 2011, it is dated to the early Eocene (early Ypresian) age.

In the present study, this member is equivalents to the lower upper part of Esna Fm. of Ghorab (1961) at Sinai & Gulf of Suez; El-Shazly et al. (1979) at west side of Wadi Araba; Abu Khadrah et al. (1987) at Southern Galala; Hermina (1990) at North Kharga; Shahin & Kora (1991) and Ziko et al. (1993) at east-central Sinai; Eweda & El-Sorogy, 1999 at west Sinai; Khalil & Mashaly (2004) at south-west Sinai and Ismail (2012) at south-west Gulf of Suez. It may be match to the lower upper part of Garra Formation of Hermina (1990) at south Kharga and the El-Sheghab Member of Abdel-Razik (1972) at Red Sea Coast, Nile Valley and Western Desert. It is also equivalent to the upper part of Esna Unit- 2 of Dupuis et al. (2003) and El-Mahmiya Member of Aubry et al. (2007) at El Dababiya Quarry section and Hewaidy et al. (2020) at Kharga Oasis.

3.1.2. D. Abu Had Member (Abdel-Razik, 1972 and emended by Aubry et al., 2007): This member, which is roughly 7 meters thick, represents the uppermost portion of the Esna Formation at the Bir El-Markha section (Samples Mk71-Mk76), it is made up of thinly bedded, argillaceous limestones. Based on its foraminiferal content, it is dated to the early Eocene (early Ypresian); as it encompasses the lower portion of the E5 and E4 planktonic foraminiferal biozones of Berggren & Pearson, 2005; Wade et al., 2011.

The Abu Had Member of Abdel-Razik (1972) in the Red Sea Coast, Nile Valley, and Western Desert; Aubry et al. (2007) at the El Dababiya Quarry section; and Hewaidy et al. (2020) at Kharga Oasis may be comparable to this member in the current study.

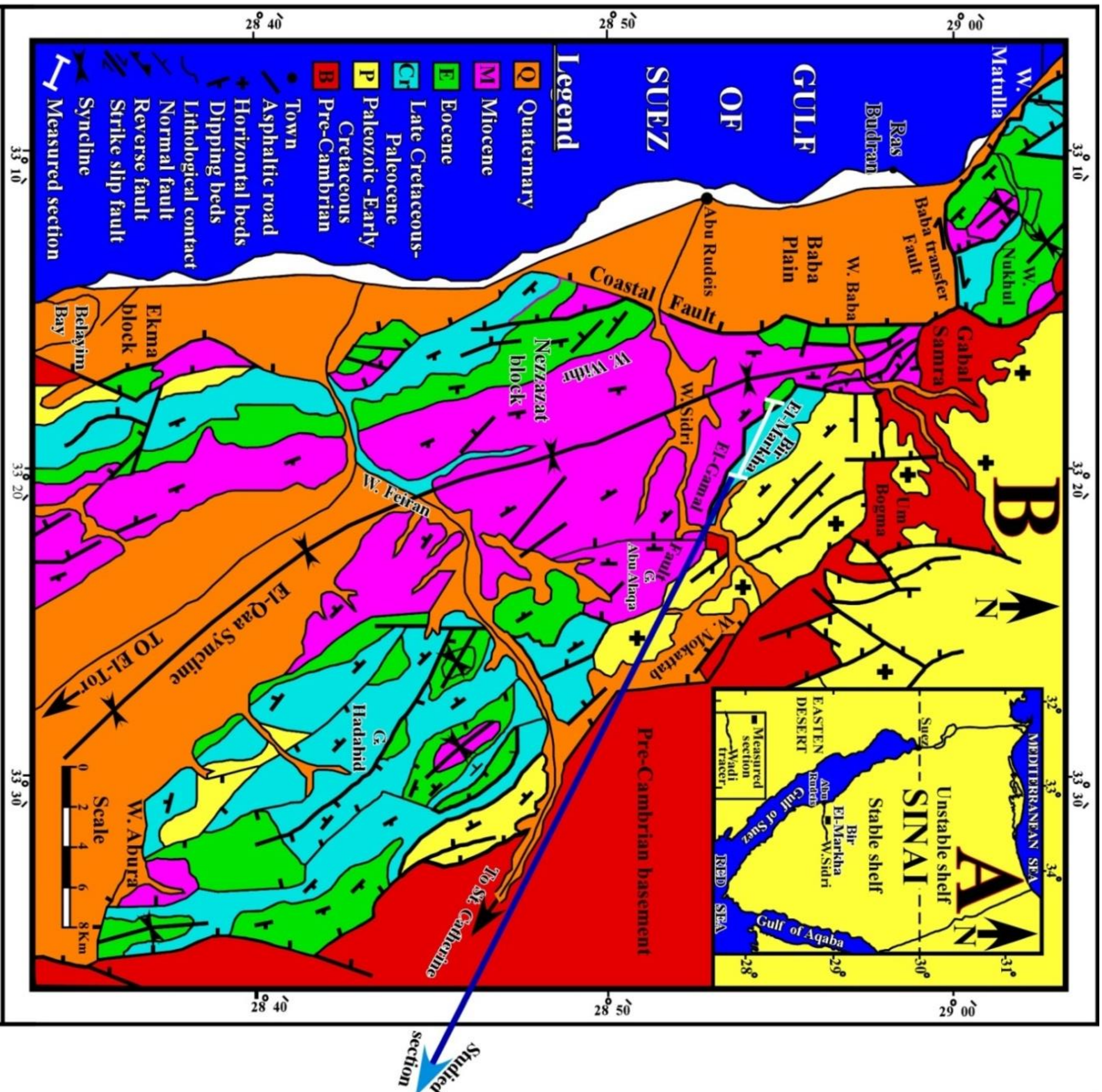


Fig. 1: Location (A) and Geologic (B) maps of the eastern coast of the Gulf of Suez area showing Bir El-Markha and surrounding areas (modified after McClay *et al*., 1998).

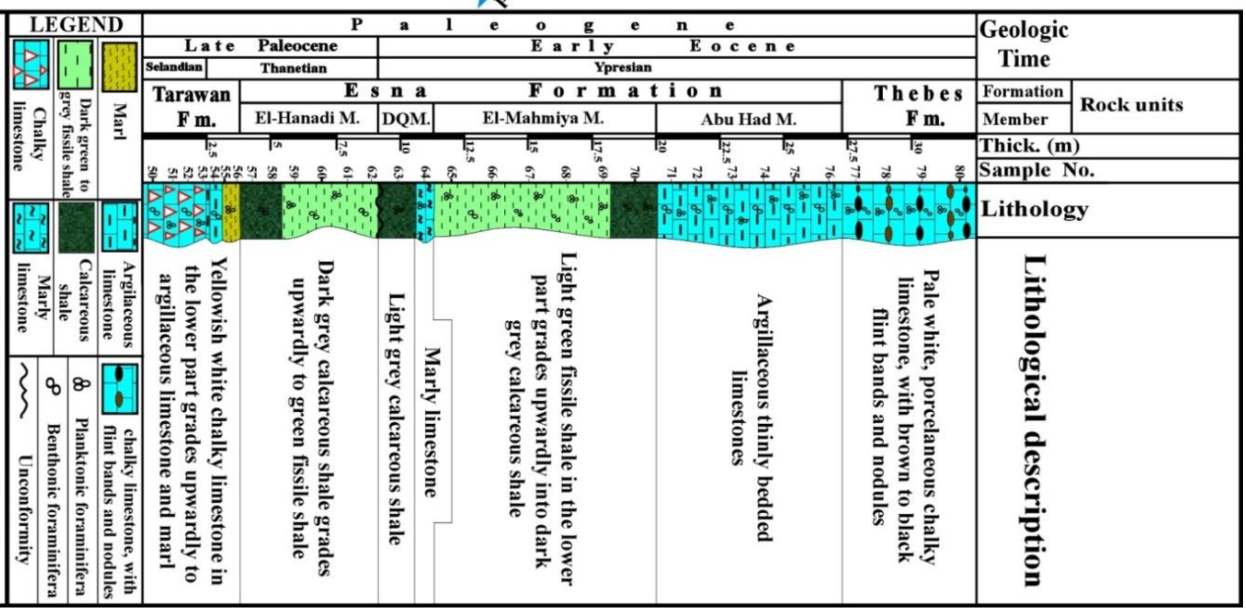


Fig. 2: Lithostratigraphic columnar section of Bir El-Markha area, west-central Sinai, Egypt.

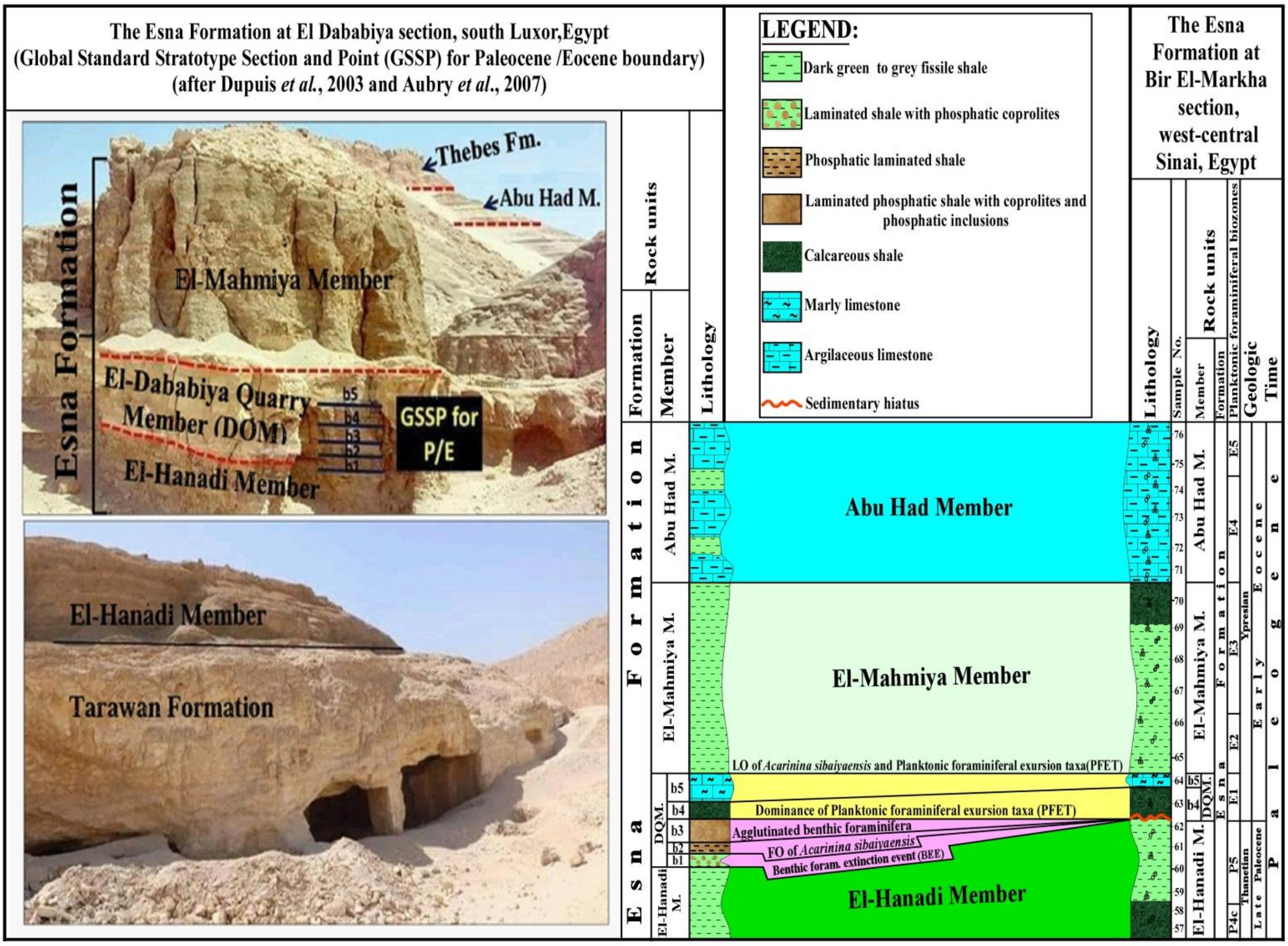


Fig. 3: Correlation between Esna Formation at GGSP (El Dababiya section, south Luxor) and Bir El-Markha section, west-central Sinai, Egypt.

This could correspond to the uppermost portion of the Esna Formation of Ghorab (1961) in the Sinai and Gulf of Suez; El-Shazly et al. (1979) on the western side of Wadi Araba; Abu Khadrah et al. (1987) in the Southern Galala; Hermina (1990) in the north Kharga; Shahin & Kora (1991) and Ziko et al. (1993) in the east-central Sinai; Eweda & El-Sorogy (1999) in the west Sinai; Khalil & Mashaly (2004) in the south-west Sinai; and Ismail (2012) in the south-west Gulf of Suez. It is also equivalents to the uppermost part of Garra Formation of Hermina (1990) at south Kharga and the Esna Unit- 3 of Dupuis et al. (2003) at El Dababiya Quarry section.

The correlation between the Esna Formation at Bir El-Markha section, west-central Sinai) and GGSP (El Dababiya section, south Luxor) is illustrated on **(Fig. 3)**.

3.1.3. Thebes Formation (Said, 1960): This formation is well developed to the east of the Red Sea range in the Quseir-Safaga Reach, the Sinai Peninsula, and also in the west of the Nile Valley. It stands for the apex of the investigated succession at Bir El-Markha section and has a conforming relationship with the Esna Formation. The lowermost portion of the Thebes Formation, which is only examined in this study, is roughly 5.5 meters thick and is composed of pale white, porcellaneous chalky limestone with brown to black flint bands and nodules (samples Mk77– Mk80). Given that it spans the upper interval of the (E5) planktonic foraminiferal biozone of Berggren & Pearson, 2005 and Wade et al., 2011, it is attributed to the early Eocene (early Ypresian) age. The lower contact of the Thebes Formation with the underlying Esna Formation can be clearly identified in the field by their abrupt facies transition from argillaceous limestones with thin bedded layers below to porcellaneous chalky limestone with bands of brown to black flint and nodules above.

The portion of this Formation under investigation in this study may be comparable to the Serai Member of Abdel-Razik (1972) in the Western Desert, Nile Valley, and Red Sea Coast. It might correspond to the lower part of Thebes Formation of Hermina (1990) at north Kharga; Ziko et al. (1993) at east-central Sinai;

Khalil & Mashaly (2004) at south-west Sinai; Aubry et al. (2007) at El Dababiya Quarry section and Ismail (2012) at south-west Gulf of Suez. It is also similarly comparable to the lower part of Dungul Formation of Hermina (1990) at south Kharga; the Cherty Chalky limestone Member of Thebes Formation of Eweda & El-Sorogy (1999) at west Sinai and the Thebes Limestone of Dupuis et al. (2003) at El Dababiya Quarry section.

3.2. Planktonic foraminiferal biostratigraphy

Extremely rich foraminiferal assemblages have been found in the upper Paleocene–lower Eocene sequence exposed in the Bir El-Markha area. Of the 160 species of foraminifera that are identified, 61 are planktonic and 99 are benthonic. The most dominant benthonic foraminiferal species in addition to the distinctive planktonic foraminiferal species in the succession under research are imaged using scanning electron microscopy (SEM) and are shown on **(Plates 1-4)**. Biostratigrapically, the vertical distribution of the identified foraminiferal species **(Figs. 4& 5)** leads to classify the studied succession into seven planktonic foraminiferal biozones based on the zonal schemes of Berggren & Pearson 2005 and Wade et al., 2011 **(Table 1).** These biozones are P4 Zone (late Selandian - early Thanetian age), which is divided into three subzones (P4a, P4b, and P4c); P5 Zone (latest Thanetian age); and E1 - E5 zones (Ypresian age). In order of oldest to youngest, the following is a brief summary of these biozones at the examined section:

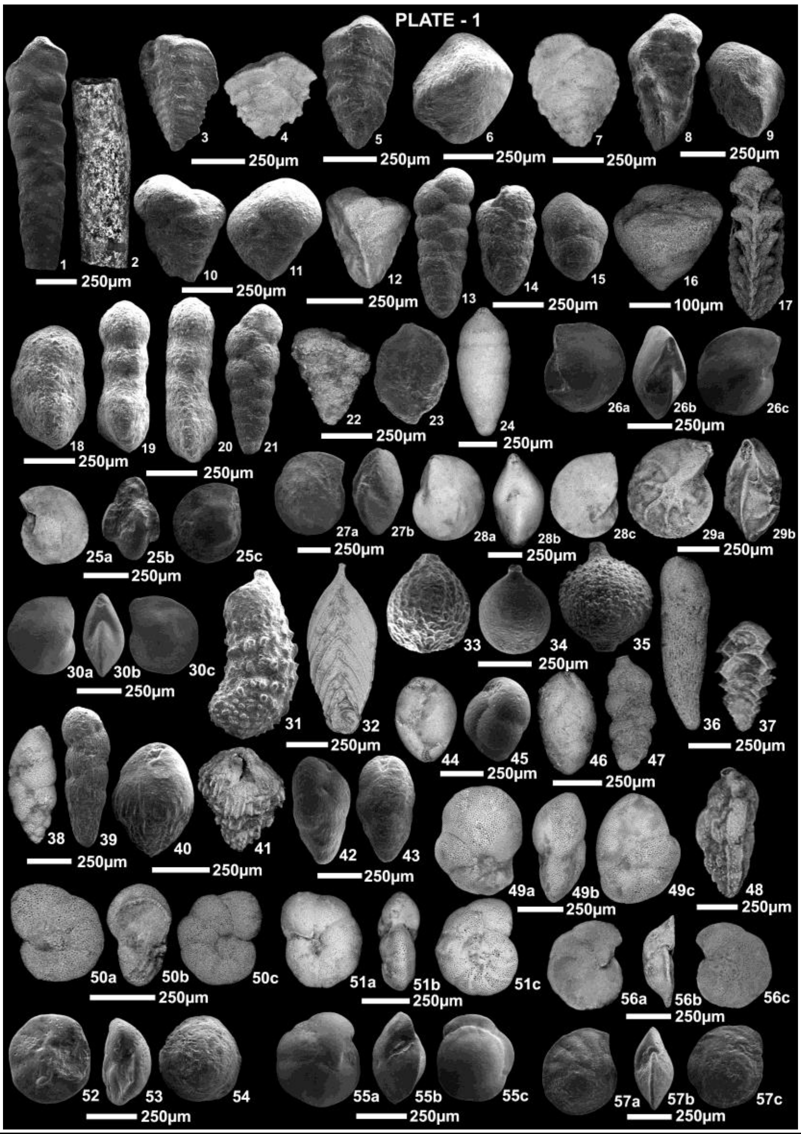
3.2.1: P4 Zone (Total Range Zone) (Bolli, 1957 and emended by Berrgren et al., 1995 and Berrgren & Pearson, 2005) is a biostratigraphic interval designated by the entire range of the zonal marker *Globanomalina Pseudomenardii* (Bolli), and it is considered to be the earliest planktonic foraminiferal biozone at Bir El-Markha section. It reaches a thickness of roughly 5 meters and is represented by the entire thickness of the Tarawan Formation in addition to the lowest portion of the Esna Formation (lower portion of the El-Hanadi Member) (samples MK50-MK58). It is dated to early Thanetian and Selandian age. This biozone is separated into three subzones in the current study as follow:

3.2.1. A: P4a Subzone (Concurrent Range Subzone) (Berggren & Pearson, 2005) is documented from the lowest portion of Tarawan Formation (samples MK50-MK51) and spans from the first occurrence (FO) of *Globanomalina pseudomenardii* (Bolli) at the base to the last occurrence (LO) of *Parasubbotina variospira* (Belford) at the top. It is attributed to Selandian age and reaches a thickness of roughly 1.5 meters. The elimination of all *Praemurica* species and the dominance of *Morozovellied*s and *Acarininides* define the bottom boundary of this subzone.

3.2.1. B: P4b Subzone (Partial Range Subzone) (Berggren et al., 1995 and emended by Berggren et al., 2000 and Berggren & Pearson, 2005) is recorded from the upper Tarawan Formation (samples MK52-MK56) and extends from the LO of *Parasubbotina variospira* (Belford) at the base to the FO of *Acarinina soldadoensis* (Bronnimann) at the top. It is dated to the latest Selandian–early Thanetian age and reaches a thickness of roughly 2 meters.

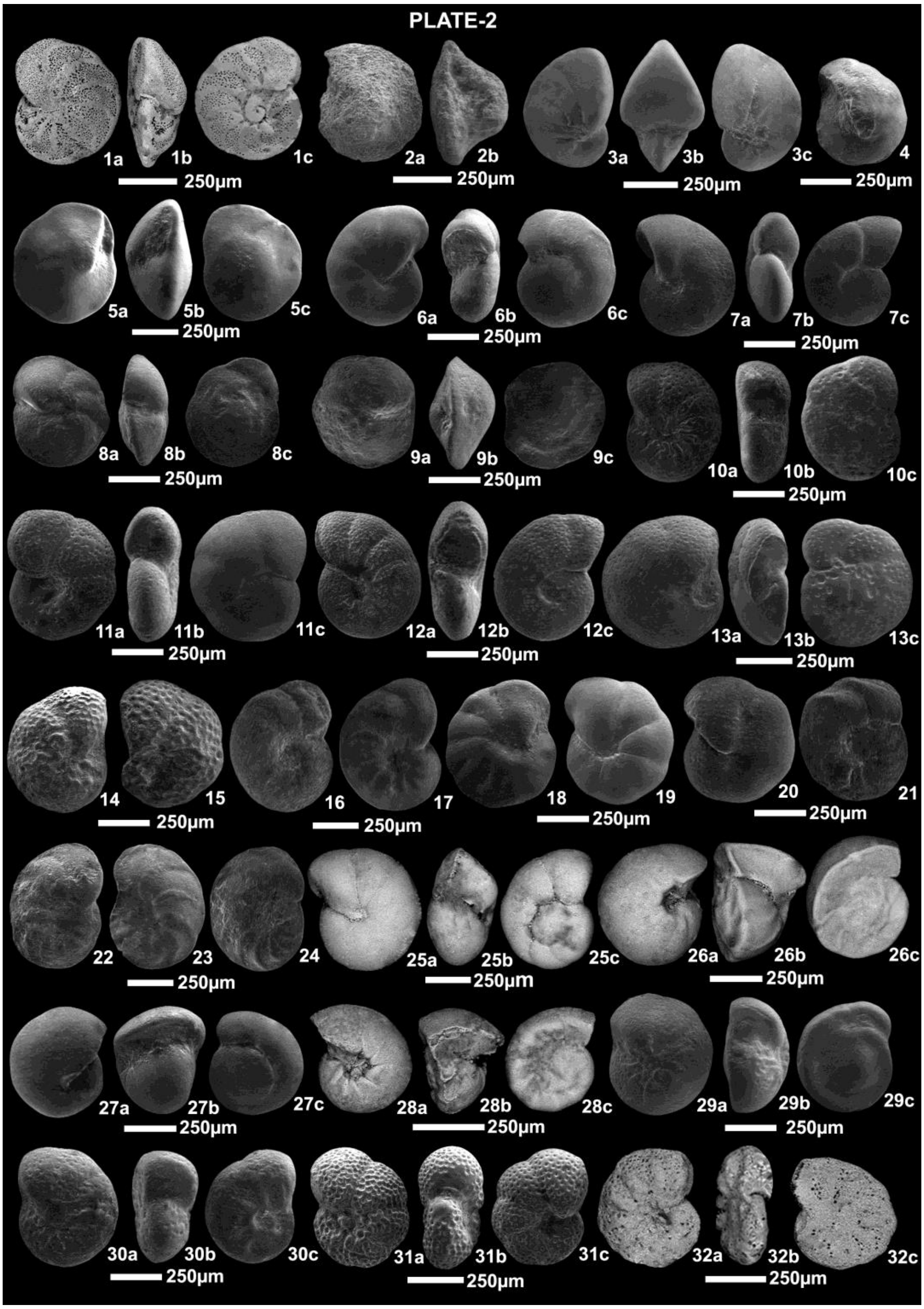
According to some Egyptian authors (e.g., Speijer and Schmitz, 1998; Faris & Farouk, 2012; Farouk, 2016; Farouk et al., 2016), the Selandian/Thanetian stage boundary is represented by a sequence boundary (SB) and is situated at the Dakhla/Tarawan formational boundary, with a noticeable hiatus, supported by the facies change from the argillaceous to the carbonate and the decreased thickness of the calcareous nannofossils from the NP6 Zone. This boundary has been delineated by several authors (e.g. Tantawy et al., 2000; Khalil & Al-Sawy, 2014) inside the Tarawan Formation with a conformable relation at the NP6/NP7 zonal boundary or within the lower portion of the calcareous nannofossils NP6 Zone. However, Berggren et al. (2012) identified this boundary as being inside the Tarawan Formation and connected it to a hiatus that was shown by the existence of burrowed surfaces at the P4 and NP5 zones. This boundary agrees well with a major Maximum Flooding Surface (MFS) of the Se/Th-1 depositional sequence on the global sea-level chart of Hardenbol et al. (1998), which divides the Thanetian regression phases from the Selandian transgression.

The Selandian/Thanetian (Sel / Th) boundary at the present research region corresponds to the Maximum Flooding Surface (MFS-1) of the depositional sequence-1 (DS-1) and is situated in the upper portion of the Tarawan Formation within the P4b Subzone. It is characterized by the maximum transgression based on the highest percentages of TNF (about 16500 individuals), P/B% (about 91%) and infaunal taxa (about 82%) which indicate the maximum transgression**.** It may be correlated with the MFS of the sequence Th-1 Hardenbol et al., 1998, which roughly correspond to the base of magnetochron C26n and, consequently, the base of the Thanetian stage (Vandenberghe et al., 2012; Al- Husseini, 2016).



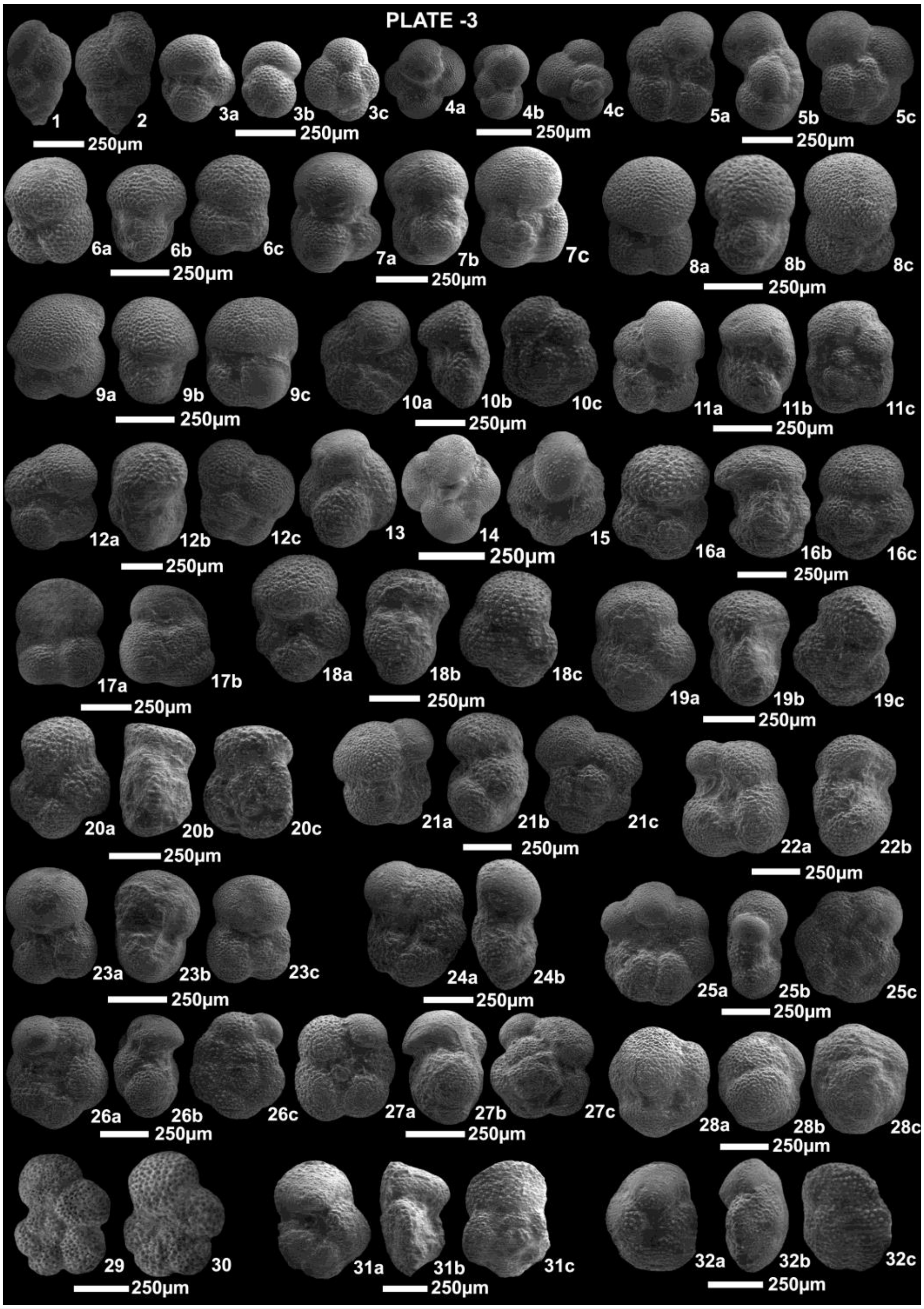
(Explanation of PLATE – 1)

1- *Bolivinopsis clotho* (Grzybowski, 1901), sample 60, El-Hanadi M.**; 2- *Bathysiphon eocenicus* Cushman & Hanna, 1927,** sample 72, Abu Had M.**; 3- *Spiroplectinella dentata* (Alth, 1850),** sample 66, El-Mahmiya M.**; 4- *Spiroplectinella esnaensis* (Le Roy, 1953),** sample 52, Tarawan Fm**.; 5- *Spiroplectinella henryi* (LeRoy, 1953),** sample 60, El-Hanadi M.**; 6- *Spiroplectinella knebeli* (Le Roy, 1953),** sample 55, Tarawan Fm.**; 7- *Vulvulina colei* Cushman, 1932,** sample 58, El-Hanadi M.**; 8- *Gaudryina africana* Le Roy, 1953,** sample 63, Dababiya Quarry M.**; 9- *Gaudryina cf. ellisorae* Cushman, 1936,** sample 55, Tarawan Fm.**; 10- *Gaudryina inflata* Israelsky, 1951,** sample 61, El-Hanadi M.**; 11- *Gaudryina laevigata* Franke, 1914,** sample 59, El-Hanadi M.**; 12- *Gaudryina pyramidata* Cushman, 1926,** sample 54, Tarawan Fm.**; 13- *Dorothia sinaensis* Said and Kenawy, 1956,** sample 54, Tarawan Fm.; **14- *Dorothia bulletta* (Carsey, 1926),** sample 60, El-Hanadi M.**; 15- *Dorothia pupa* (Reuss, 1860),** sample 53, Tarawan Fm.**; 16- *Marssonella oxycona* (Reuss, 1860),** sample 57, El-Hanadi M.**; 17- *Clavulinoides trilaterus* (Cushman, 1926),** sample 52, Tarawan Fm.**; 18- *Pseudoclavulina amorpha* (Cushman, 1926),** sample 59, El-Hanadi M.**; 19- *Pseudoclavulina farafraensis* Le Roy, 1953,** sample 60, El-Hanadi M.**; 20- *Pseudoclavulina maqfiensis* Le Roy, 1953,** sample 58, El-Hanadi M.**; 21- *Textularia farafraensis* LeRoy, 1953,** sample 55, Tarawan Fm.**; 22- *Textularia schwageri* LeRoy, 1953,** sample 59, El-Hanadi M.**; 23- *Spiroloculina esnaensis* (Le Roy, 1953),** sample 68, El-Mahmiya M**.; 24- *Pseudonodosaria manifesta* (Reuss, 1851),** sample 75, Abu Had M.**; 25a-c: *Lenticulina cultrata* (Montfort, 1808),** sample 78, Thebes Fm.**; 26a-c: *Lenticulina insulsus* (Cushman, 1947),** sample 60, El-Hanadi M.**; 27a&b: *Lenticulina isidis* (Schwager, 1883),** sample 55, Tarawan Fm.**; 28a-c: *Lenticulina macrodisca* (Reuss, 1862),** sample 67, El-Mahmiya M.**; 29a&b: *Lenticulina midwayensis* (Plummer, 1926),** sample 64, Dababiya Quarry M.**; 30a-c: *Lenticulina muensteri* (Roemer, 1839),** sample 72, Abu Had M**; 31: *Marginulinopsis tuberculata* (Plummer, 1926),** sample 54, Tarawan Fm.**; 32- *Neoflabellina jarvisi* (Cushman, 1935),** sample 61, El-Hanadi M.**; 33- *Lagena sulcata* (Walker and Jacob, 1798),** sample 51, Tarawan Fm.**; 34: *Pygmaeoseistron globosa (*Montagu, 1803),** sample 55, Tarawan Fm.**; 35: *Pygmaeoseistron hispida* (Reuss, 1862),** sample 50, Tarawan Fm.; **36: *Loxostomoides applinae* (Plummer, 1926),** sample 67, El-Mahmiya M.**; 37: *Tappanina selmensis* (Cushman, 1933),** sample 60, El-Hanadi M.**; 38: *Stainforthia farafraensis* (LeRoy, 1953),** sample 64, Dababiya Quarry M..; **39: *Siphogenerinoides eleganta* (Plummer, 1926),** sample 55, Tarawan Fm.**; 40: *Bulimina farafraensis* LeRoy, 1953,** sample 77, Thebes Fm.; **41: *Bulimina midwayensis* Cushman and Parker, 1936,** sample 66, El-Mahmiya M.**; 42&43: *Bulimina thanetensis* Cushman and Parker, 1947,** sample 60, El-Hanadi M.**; 44&45: *Praeglobobulimina ovata* (D' Orbigny, 1846),** sample 72, Abu Had M.**; 46: *Praeglobobulimina quadrata* (Plummer, 1926),** sample 53, Tarawan Fm.**; 47- *Uvigerina maqfiensis* Le Roy, 1953,** sample 64, Dababiya Quarry M.**; 48: *Trifarina esnaensis* LeRoy, 1953,** sample 58, El-Hanadi M.**; 49a-c: *Cancris auriculus* (Fichtel and Moll, 1798)** sample 73, Abu Had M; **50a-c: *Valvulineria scorbiculata* (Schwager, 1883),** sample 69, El-Mahmiya M.**; 51a-c: *Discorbis pseudoscopos* Nakkady, 1950,** sample 75, Abu Had M**; 52-54: *Neoeponides elevatus* (Plummer, 1926),** sample 74, Abu Had M**; 55a-c: *Neoeponides lotus* (Schwager, 1883),** sample 67, El-Mahmiya M.; **56a-c: *Cibicidoides pharaonis* Le Roy, 1953, sample** 78, Thebes Fm.**; 57a-c: *Cibicidoides alleni* (Plummer, 1926),** sample 55, Tarawan Fm.



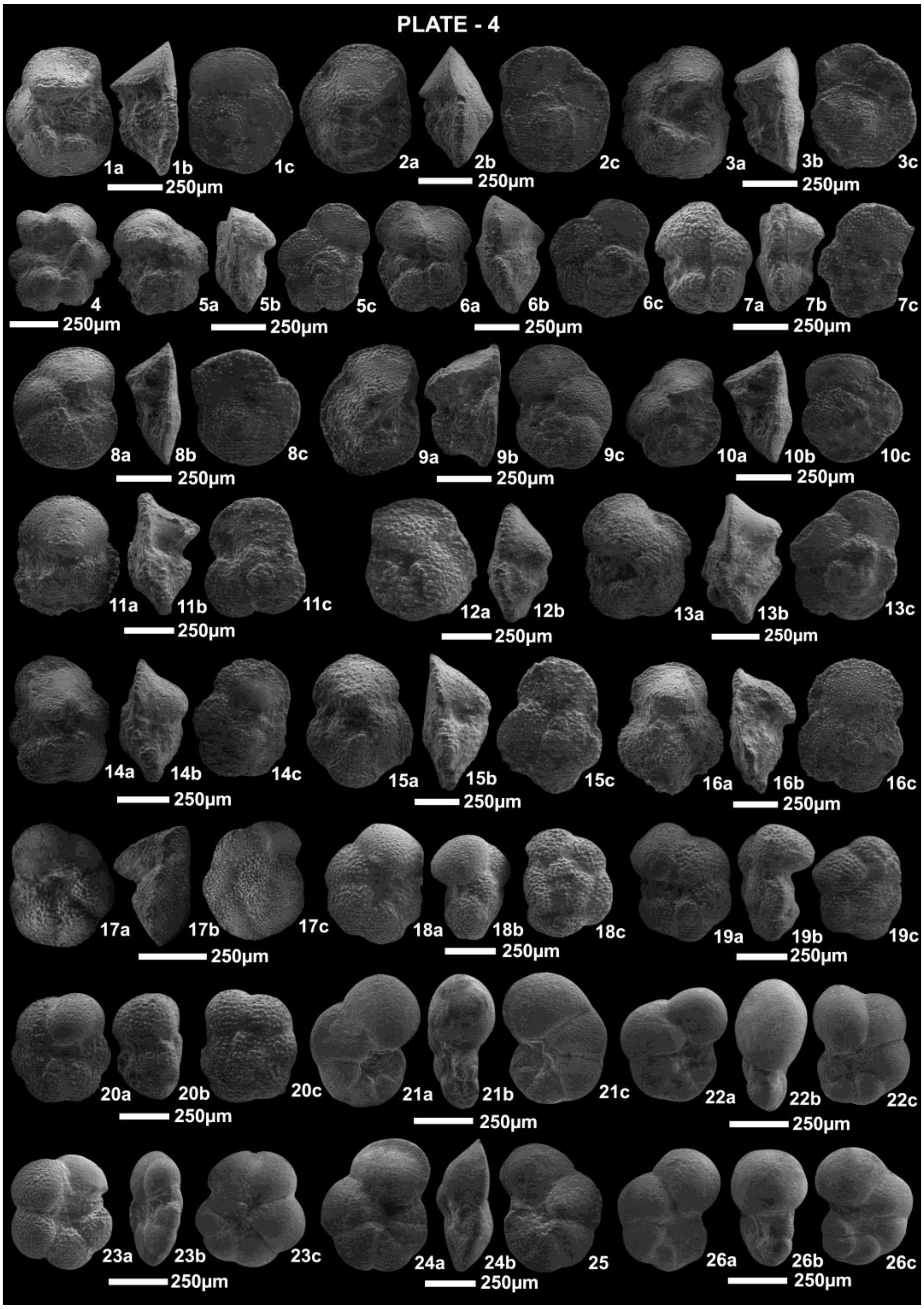
(Explanation of PLATE – 2)

1a-c: ***Cibicides farafraensis*** **(Le Roy, 1953),** sample 63, Dababiya Quarry M..**; 2a&b:** ***Nuttallinella florealis*** **(White, 1928),** sample 61, El-Hanadi M.**; 3a-c:** ***Nonionella africana*** **LeRoy, 1953,** sample 66, El-Mahmiya M.**; 4-** ***Pullenia coryelli*** **White, 1929,** sample 53, Tarawan Fm.**; 5a-c:** ***Alabamina midwayensis*** **Brotzen, 1948,** sample 51, Tarawan Fm.**; 6a-c:** ***Valvalabamina depressa*** **(Alth, 1850),** sample 72, Abu Had M.**; 7a-c:** ***Valvalabamina planulata*** **(Cushman and Renz, 1941),** sample 58, El-Hanadi M.**; 8a-c:** ***Osangularia plummerae*** **Brotzen, 19405a,** sample 64, Dababiya Quarry M.**; 9a-c:** ***Oridorsalis plummerae*** **(Cushman, 1948),** sample 66, El-Mahmiya M.**; 10a-c:** ***Anomalinoides aegyptiaca*** **(Le Roy, 1953),** sample 75, Abu Had M**; 11&12:** ***Anomalinoides affinis*** **(Hantken, 1875),** sample 57, El-Hanadi M.**; 13a-c-** ***Anomalinoides praeacutus*** **(Vasilenko, 1950),** sample 78, Thebes Fm.**; 14&15:** ***Anomalinoides rubiginosus*** **(Cushman, 1926),** sample 54, Tarawan Fm.**; 16&17:** ***Anomalinoides susanaensis*** **(Browning, 1959),** sample 61, El-Hanadi M.**; 18-21:** ***Anomalinoides umbonifera*** **(Schwager, 1883),** sample 63, Dababiya Quarry M.**; 22-24:** ***Anomalinoides zitteli*** **(Le Roy, 1953),** sample 52, Tarawan Fm.**; 25a-c:** ***Gyroidinoides beisseli*** **(White, 1928),** sample 69, El-Mahmiya M.**; 26a-c:** ***Gyroidinoides girardana*** **(Reuss, 1851),** sample 73, Abu Had M.**; 27a-c:** ***Gyroidinoides globosus*** **(Hagenow, 1842),** sample 53, Tarawan Fm.**; 28a-c:** ***Gyroidinoides subangulatus*** **(Plummer, 1926),** sample 60, El-Hanadi M.**; 29a-c:** ***Angulogavelinella avnimelechi*** **Reiss, 1952,** sample 55, Tarawan Fm.**; 30a-c:** ***Gavelinella beccariiformis*** **(White, 1928),** sample 58, El-Hanadi M.**; 31a-c:** ***Gavelinella danica*** **(Brotzen, 1940),** sample 53, Tarawan Fm.**; 32a-c:** ***Gavelinella lellingensis*** **Brotzen, 1948,** sample 61, El-Hanadi M.



(Explanation of PLATE –3)

1: ***Chiloguembelina midwayensis*** **(Cushman, 1940),** sample 52, Tarawan Fm.**; 2:** ***Chiloguembelina wilcoxensis*** **(Cushman and Ponton, 1932),** sample 58, El-Hanadi M.**; 3a-c*:*** ***Globorotaloides quadrocameratus*** **Olsson *et al*., 2006b,** sample 72, Abu Had M.**; 4a-c:** ***Globoturborotalita bassriverensis*** **Olsson and Hemleben, 2006,** sample 69, El-Mahmiya M.**; 5a-c:** ***Parasubbotina variospira*** **(Belford, 1984),** sample 50, Tarawan Fm.**; 6a-c:** ***Subbotina hornibrooki*** **(Brönnimann, 1952a),** sample 78, Thebes Fm.**; 7a-c:** ***Subbotina inaequispira*** **Subbotina, 1953,** sample 60, El-Hanadi M.**; 8a-c:** ***Subbotina triloculinoides*** **(Plummer, 1926),** sample 55, Tarawan Fm.**; 9a-c:** ***Subbotina velascoensis*** **(Cushman, 1925),** sample 66, El-Mahmiya M.**; 10a-c:** ***Acarinina alticonica*** **Fleisher, 1974,** sample 79, Thebes Fm.**; 11&12:** ***Acarinina angulosa*** **(Bolli, 1957),** sample 63, Dababiya Quarry M.**; 13-15:** ***Acarinina nitida*** **(Martin, 1943),** sample 54, Tarawan Fm.**; 16a-c:** ***Acarinina soldadoensis soldadoensis*** **(Bronnimann, 1952),** sample 67, El-Mahmiya M.**; 17a&b:** ***Acarinina quetra (*****Bolli, 1957),** sample 75, Abu Had M.**; 18a-c:** ***Acarinina esnaensis*** **(LeRoy, 1953),** sample 64, Dababiya Quarry M.**; 19&20:** ***Acarinina wilcoxensis*** **(Cushman and Ponton, 1932),** sample 69, El-Mahmiya M.**; 21&22:** ***Acarinina interposita*** **Subbotina, 1953,** sample 74, Abu Had M.**; 23a-c:** ***Acarinina pseudotopilensis*** **Subbotina, 1953,** sample 63, Dababiya Quarry M.**; 24a&b:** ***Acarinina pentacamerata*** **(Subbotina, 1947),** sample 77, Thebes Fm.**; 25&26:** ***Acarinina multicamerata*** **Guasti and Speijer, 2008,** sample 64 Dababiya Quarry M.**; 27a-c:** ***Acarinina esnehensis*** **(Nakkady, 1950),** sample 61, El-Hanadi M.**; 28a-c:** ***Acarinina subsphaerica*** **(Subbotina, 1947),** sample 55, Tarawan Fm.**; 29&30:** ***Acarinina sibaiyaensis*** **(El-Naggar, 1966),** sample 63, Dababiya Quarry M.**; 31a-c:** ***Morozovella aequa*** **(Cushman & Renz, 1942),** sample 72, Abu Had M.**; 32a-c*:*** ***Morozovella allisonensis*** **Kelly *et al*., 1998,** sample 64, Dababiya Quarry M.



(Explanation of PLATE – 4)

1a-c: ***Morozovella acuta*** **(Toulmin, 1941),** sample 60, El-Hanadi M.**; 2a-c:** ***Morozovella acutispira*** **(Bolli and Cita, 1960),** sample 55, Tarawan Fm.**; 3a-c:** ***Morozovella velascoensis*** **(Cushman, 1925a),** sample 58, El-Hanadi M**; 4:** ***Morozovella conicotruncata*** **(Subbotina, 1947),** sample 53, Tarawan Fm.**; 5a-c:** ***Morozovella angulata*** **(White, 1928),** sample 60, El-Hanadi M**; 6a-c:** ***Morozovella formosa formos*****a Bolli, 1957,** sample 75, Abu Had M**.;7a-c:** ***Morozovella apanthesma*** **(Loeblich and Tappan, 1957a),** sample 54, Tarawan Fm.**; 8a-c:** ***Morozovella occlusa*** **(Loeblich and Tappan, 1957a),** sample 60, El-Hanadi M.; **9a-c:** ***Morozovella crater*** **(Finlay, 1939),** sample 78, Thebes Fm.**; 10a-c*: Morozovella edgari*** **(Premoli Silva & Bolli, 1973),** sample 67, El-Mahmiya M.**; 11a-c:** ***Morozovella subbotinae*** **(Morozova, 1939),** sample 64, Dababiya Quarry M.**; 12a-c:** ***Morozovella lensiformis*** **(Subbotina, 1953),** sample 74, Abu Had M**.; 13&14:** ***Morozovella formosa gracilis*** **Bolli, 1957,** sample 66, El-Mahmiya M.**; 15&16:** ***Morozovella marginodentata*** **Subbotina, 1953,** sample 61, El-Hanadi M.**; 17a-c:** ***Morozovella aragonensis*** **(Nuttall, 1930),** sample 78, Thebes Fm.**; 18a-c:** ***Igorina broedermanni*** **(Cushman and Bermudez, 1949),** sample 66, El-Mahmiya M.**; 19a-c:** ***Igorina convexa*** **(Subbotina, 1953),** sample 60, El-Hanadi M**; 20a-c:** ***Igorina lodoensis*** **(Mallory, 1959),** sample 63, Dababiya Quarry M.**; 21a-c:** ***Globanomalina chapmani*** **(Parr, 1938),** sample 55, Tarawan Fm.**; 22a-c:** ***Globanomalina luxorensis*** **(Nakkady, 1950),** sample 75, Abu Had M**.; 23a-c:*Globanomalina planoconica*** **(Subbotina, 1953),** sample 60, El-Hanadi M.**; 24&25:** ***Globanomalina pseudomenardii*** **(Bolli, 1957),** sample 54, Tarawan Fm.**; 26a-c:** ***Pseudohastigerina wilcoxensis*** **(Cushman & Ponton, 1932),** sample 78, Thebes Fm.

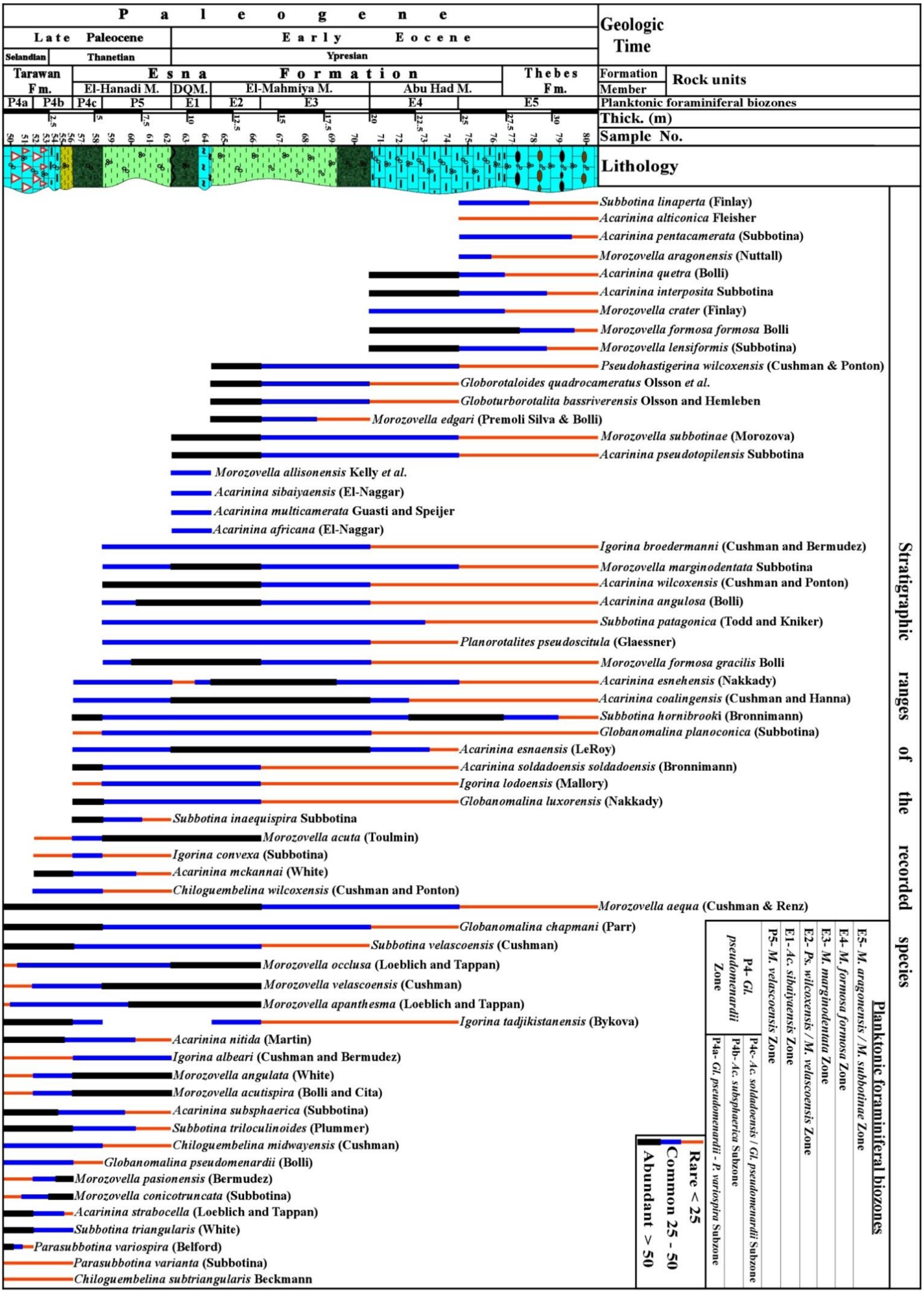


Fig. 4: Distribution chart of the identified planktonic foraminiferal species at Bir El-Markha section.

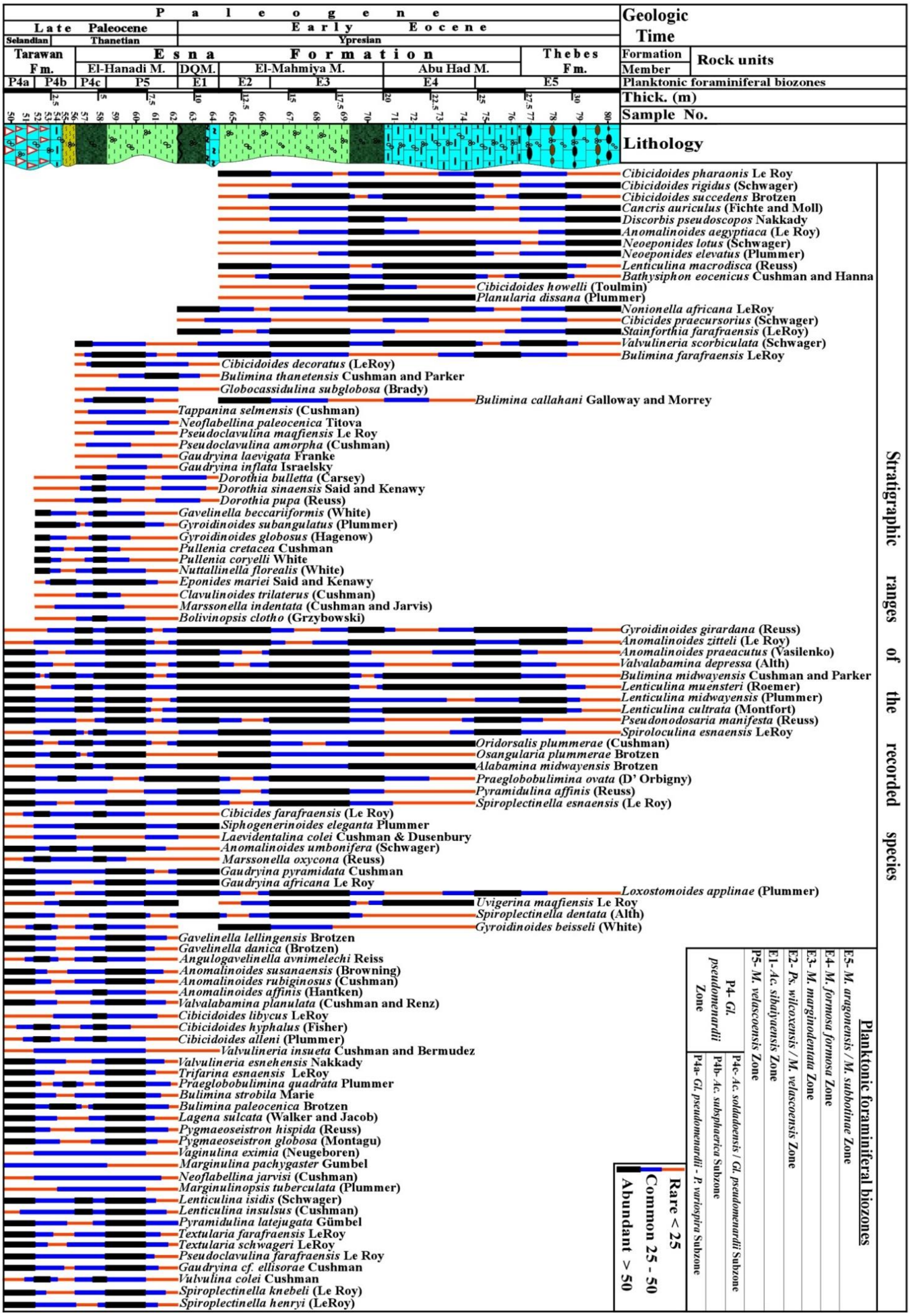


Fig. 5: Distribution chart of the identified benthonic foraminiferal species at Bir El-Markha section.

Table 1: Summary of the used planktonic foraminiferal zonal schemes for Upper Paleocene-Lower Eocene, age estimated and their coeval at Bir El-Markha area. (The estimated ages and datum events are based on (Berggren and Pearson, 2005 &Berggren *et al.*,1995 and correlation with Toumarkine &Luterbacher, 1985).

Time (Ma)	Stage	Planktonic Foraminiferal datum events (┬ Last Ocurrence (LO); ┴ First Ocurrence (FO))	Age (Ma)	Berggren & Pearson (2005) and Wade et al. (2011)		Berggren et al. (1995)		Toumarkine & Luterbacher (1985)	Stage	Present study: Bir El-Markha area west-central Sinai	
50.5											
	Early Paleogene, Eocene, Early, Ypresian	*M. subbotinae* ┬	50.80								
51–52	Early Paleogene, Eocene, Early, Ypresian			E5	*M. aragonensi s/ M. subbotinae*	P7	*M. aragonensis / M. formosa*	*M. formosa formosa*	Early Eocene	E5	*M. aragonensis / M. subbotinae*
		M. aragonensis ┴	52.30								
53–54	Early Paleogene, Eocene, Early, Ypresian			E4	*M. formosa*	*M. subbotinae* (P6) P6b	*M. formosa / M.lensiformis - M. aragonensis*	*M. subbotinae*	Early Eocene	E4	*M. formosa formosa*
		M. formosa ┴	54.00								
54	Early Paleogene, Eocene, Early, Ypresian			E3	*M. marginodentata*	*M. subbotinae* (P6) P6a	*M. velascoensis - M. formosa / M.lensiformis*	*M. edgari*	Early Eocene	E3	*M. marginodentata*
		M. velascoensis ┬	54.50								
55	Early Paleogene, Eocene, Early, Ypresian			E2	*P. wilcoxensis - M. velascoensis*	P5	*M. velascoensis*	*M. velascoensis*	Late	E2	*P. wilcoxensis - M. velascoensis*
		P. wilcoxensis ┴	55.35								
				E1	*Ac. sibaiyaensis*	P5	*M. velascoensis*	*M. velascoensis*	Late	E1	*Ac. sibaiyaensis*
		Ac. sibaiyaensis ┴	55.50								
56	Early Paleogene, Paleocene, Late, Thanetian			P5	*M. velascoensis*	P5	*M. velascoensis*	*M. velascoensis*	Late	P5	*Morozovella velascoensis*
		Gl. pseudomenardii ┬	55.90								
	Early Paleogene, Paleocene, Late, Thanetian			*Gl. pseudomenardii* (P4) P4c	*Ac. soldadoensis - Gl. pseudomenardii*	*Gl. pseudomenardii* (P4) P4c	*Ac. soldadoensis- Gl. pseudomenardii*	*Planorotalites pseudomenardii*	Late	*Gl. pseudomenardii* (P4) P4c	*Ac. soldadoensis - Gl. pseudomenardii*
		Ac. soldadoensis ┴	56.50								
57–58	Early Paleogene, Paleocene, Late, Thanetian			P4b	*Ac. subsphaerica*	P4b	*Ac. subsphaerica – Ac. soldadoensis*	*Planorotalites pseudomenardii*	Late	P4b	*Ac. subsphaerica*
59	Early Paleogene, Paleocene, Late, Thanetian / Selandian			P4a	*Gl. pseudomenardii – P. variospira*	P4a	*Gl. pseudomenardii – Ac. subsphaerica*	*Planorotalites pseudomenardii*	Middle	P4a	*Gl. pseudomenardii– P. variospira*
		P. variospira ┬	59.20								
59.40	Selandian	*Gl. pseudomenardii* ┴	59.40								

Additionally, it corresponds to the maximum transgression within the planktonic foraminiferal P4b Subzone as reported by a number of authors (e.g. Lunning et al., 1998; Spijer and Schmitz, 1998; Guasti et al., 2005; Alegret & Ortiz, 2012; King, 2012; Hollis et al., 2014; Farouk et al., 2016) as well as the eustatic sea-level charts (e.g., Haq et al., 1987; Hardenbol et al., 1998; Vandenberghe et al., 2012).

3.2.1. C: P4c Subzone (Concurrent Range Subzone) (Berggren et al., 1995) is reported from the lowest portion of the Esna Formation (lower part of El-Hanadi Member), and it extends from the FO of the *Acarinina soldadoensis* (Bronnimann) at the base to the LO of *Globanomalina pseudomenardii* (Bolli) at the top (sample MK57-MK58). It is dated to the early Thanetian age and reaches a thickness of roughly 1.5 meters.

3.2.2: P5 Zone (Partial Range Zone) (Bolli, 1957 and emended by Berggren et al., 2003 and Berggren & Pearson, 2005) is reported from the upper lower portion of Esna Formation (upper part of El-Hanadi Member), and it extends from the LO of *Globanomalina pseudomenardii* (Bolli) at the base to the FO of *Acarinina sibaiyaensis* (El Naggar) at the top (sample MK59-MK62). It is dated to the latest Thanetian age and attains about 4 meters.

3.2.3. E1 Zone (Partial Range Zone) (Pardo et al., 1999 and emended by Molina et al., 1999 and Berggren & Pearson, 2005) is reported from the middle part of Esna Formation (El-Dababiya Quarry Member) (samples MK63-MK64), and it extends between the FO of *Acarinina sibai*yaensis (El-Naggar) at the base to the FO of *Pseudohastigerina wilcoxensis* (Cushman & Ponton) at the top. It reaches a thickness of approximately 2 meters. It is attributed to the early Eocene (earliest Ypresian age) and represents the earliest biozone of the Eocene period.

The Paleocene/Eocene (P/E) boundary in the study area is defined by the base of the planktonic foraminiferal partial range biozone of *Acarinina sibaiyaensis* (E1). Notably, the GSSP of the P/E boundary is defined at the base of clay (Bed-1) of the Dababiya Quarry Member (QDM) within the Esna Formation at a level that coincides with the Paleocene/Eocene thermal Maximum (PETM) and the carbon isotope excursion (CIE) in the Dababiya section at Dababiya village, south Luxor (Aubry, et al., 2007). In contrast to the GSSP, the DQM in the study area is represented by only the upper two beds (coeval with beds 4 and 5 at GSSP). As a result, the P/E boundary at Bir El-Markha section is characterized by the occurrence of inter-zonal hiatus due to the absence of the lower part (beds 1-3) of the DQM. The P/E boundary at Markha section is recorded at the base of the Dababiya Quarry Member (QDM) of the Esna Formation. The sequence boundaries Th6 of Hardenbol et al., 1998, and ThGal2 of Kuss et al., 2000, may be correlated with this gap.

Table 2: Correlation between the planktonic foraminiferal biozones of Late Paleocene -Early Eocene as proposed by different authors out-side (A) and inside (B) of Egypt and their equivalents at Bir El-Markha area, west-central Sinai.

(A)

Stage	Bolli (1966) Trinidad	Berggren (1969) Libya	Postuma (1971) Europ and America	Blow (1979) General	Berggren & Van Couvering (1974) (General)	Benjamini (1980) (Palestine)	Berggren and Miller (1988) General	Berggren and Norris (1997) General	Present study: Bir El-Markha area, west-central Sinai	Stage
Eocene / Early	*Gr. aragonensis* *Gr. formosa*	*Globorotalia formosa*	Not studied	P8: *Morozovella aragonensis* (P8b)	*Globorotalia formosa*	*Morozovella formosa formosa*	(P7) *M. aragonensis / M. formosa*	(P7) *Morozovella formosa formosa*	E5 *M. aragonensis/M. subbotinae*	Ypresian / Early / Eocene
	Gr. subbotina	*Gl. subbotinae*: *Gr. subbotinae/ Ps. wilcoxensis*	*Globorotalia rex*	P8: *Morozovella formosa* (P8a)	*Gr. subbotina / Gr. wilcoxensis*	*Morozovella subbotinae*	*M. subbotinae* (P6): P6c *M. formosa / M. lensiformis*	*M. subbotinae*(P6): P6b *M. formosa formosa/ M. lensiformis- M. aragonensis*	E4 *M. formosa formosa*	
	Gr. edgari	*Gl. velascoensis/ Gl. subbotinae*		*Gr. wilcoxensis berggreni* (P7)	*Gr. velascoensis / Gr. subbotinae*		P6b *M. subbotina / Ps. wilcoxensis*	P6a *M. formosa formosa/ M. lensiformis*	E3 *M. marginodentata*	
	Globorotalia velascoensis	*Globorotalia velascoensis*	*Globorotalia velascoensis*	*Gr. subbotina* (P6)	*Globorotalia velascoensis*	*Morozovella velascoensis*	P6a+P5 *Morozovella subbotina/ Morozovella velascoensis*	P5 *Morozovella velascoensis*	E2 *P. wilcoxensis -M. velascoensis*	
									E1 *Ac. sibaiyaensis*	
Paleocene / Late				*Gr. soldadoensis* (P5)					P5 *Morozovella velascoensis*	Tha. / Late / Paleocene
	Globorotalia pseudomenardii	*Globorotalia pseudomenardii*	*Globorotalia pseudomenardii*	*Globorotalia pseudomenardii* (P4)	*Globorotalia pseudomenardii*	*Morozovella pseudomenardii*	P4 *Planorotalites pseudomenardii*	P4: P4c *Ac. soldadoensis-Gl. pseudomenardii*	P4: P4c *Ac. soldadoensis – Gl. pseudomenardii*	
								P4b *Ac. subsphaerica- Ac. soldadoensis*	P4b *Ac. subsphaerica*	
								P4a *Gl. pseudomenardii/ Ac. subsphaerica*	P4a *Gl. pseudomenardii – P. variospira*	Sel.

(B)

Stage	EL-Naggar, 1966 (Nile Valley)	Fahmy *et al.*, 1969 (General) Egypt	Hewaidy, 1987 (North East Sinai)	Luger, 1985 (Kharga Oasis)	Shahin, 1988 (Southwest Sinai)	Cherif & Ismail, 1991 (South-west Gulf of Suez)	Shahin, 1992 (West Central Sinai)	El-Nady, 1995 (North East Sinai)	Luning *et al.*, 1998a (Central Sinai)	Shahin& El-Nady, 2001 (North East Sinai)	Samir, 2002 (South west Sinai)	Aubry *et al.*, 2007 and Ouda *et al.*, 2012 (Dababiya)	Hewaidy *et al.*, 2020 (Kharga Oasis)	Present study: Bir El-Markha area, west-central Sinai	Stage
Eocene / Early	Not studied	*Globorotalia subbotinae*: *Gr. formosa - Gr. marginodentata*	Not studied	Not studied	Not studied	*Morozovella subbotinae*	*Morozovella formosa formosa*	*Morozovella formosa formosa*	*Morozovella formosa formosa*	*Morozovella formosa formosa*	*Morozovella subbotinae* P6: P6b *M. formosa formosa / M. lensiformis - M. aragonensis*	P7	*M. aragonensis/ M. subbotinae* (E5)	E5 *M. aragonensis / M. subbotinae*	Ypresian / Early / Eocene
	Globorotalia wilcoxensis	*Globorotalia subbotinae*	*Morozovella subbotinae*	*Morozovella subbotinae*	*Acarinina wilcoxensis*		*Morozovella subbotinae*	*Morozovella subbotinae*	*Morozovella subbotinae*	*Morozovella subbotinae*		P6b	*M. formosa* (E4)	E4 *M. formosa formosa*	
				Morozovella edgari		*Morozovella edgari*		*Morozovella edgari*	*Morozovella edgari*	*Morozovella edgari*	P6a *M. formosa formosa / M. lensiformis*	P6a	*Morozovella marginodentata* (E3)	E3 *Morozovella marginodentata*	
	Globorotalia velascoensis: *Gl. aequa/ Gl. esnaensis* (Sz)	*Globorotalia velascoensis*: *Globorotalia velascoensis* (Sz)	*Morozovella velascoensis*	*Morozovella velascoensis*	*Morozovella velascoensis*	*Morozovella velascoensis*	*Morozovella velascoensis*	*Morozovella velascoensis*	*Morozovella velascoensis*	*Morozovella velascoensis*	P5 *Morozovella velascoensis*	*P. wilcoxensis - M. velascoensis*	*P. wilcoxensis - M. velascoensis*(E2)	E2 *P. wilcoxensis - M. velascoensis*	
												Ac. sibaiyaensis	*Ac. sibaiyaensis* (E1)	E1 *Ac. sibaiyaensis*	
Paleocene / Late												*M. velascoensis*	*M. velascoensis* (P5)	P5 *Morozovella velascoensis*	Thanetian / Late / Paleocene
	Gl. pseudomenardii (Sz)	*Globorotalia pseudomenardii* (Sz)	*Planorotalites pseudomenardii*	*Globorotalia pseudomenardii*	*Planorotalites pseudomenardii*	Hiatus-2	*Planorotalites pseudomenardii*	*Planorotalites pseudomenardii*	*Globanomalina pseudomenardii*	*Globanomalina pseudomenardii*	P4: P4c *Ac. soldadoensis- Gl. pseudomenardii*	*Ac. soldadoensis - Gl. pseudomenardii*	*Ac. soldadoensis- Gl. pseudomenardii* (P4c)	P4: P4c *Ac. soldadoensis- Gl. pseudomenardii*	
											P4b *Ac. subsphaerica - Ac. soldadoensis*	*Ac. subsphaerica*	Not studied	P4b *Ac. subsphaerica*	
											P4a *Gl. pseudomenardii / Ac. subsphaerica*	*Gl. pseudomenardii– P. variospira*		P4a *Gl. pseudomenardii/ Ac. subsphaerica*	Sel.

Furthermore, because of the existence of an incised erosion surface, it coincided with the combined sequence boundary and transgression surface interpreted at the base of the DQM in GSSP (Dupuis et al., 2003; King, 2012). Conversely, the P/E boundary has a significant impact on the variety and richness of both planktonic and benthonic foraminiferal assemblages in the study area.

3**.2.4: E2 Zone (Concurrent Range Zone) (Molina et al., 1999 and emended by Berggren & Pearson, 2005)** is reported from the middle part of Esna Formation (lower part of El-Mahmiya Member), and it extends from the FO of *Pseudohastigerina wilcoxensis* (Cushman & Ponton) at the base to the LO of *Morozovella velascoensis* (Cushman) at the top (samples MK65-MK66). It is dated to the earliest Eocene (earliest Ypresian) age, and reaches a thickness of roughly 3 meters.

3.2.5: E3 Zone (Partial Range Zone) (Berggren & Miller, 1988 and emended by Berggren et al., 1995 and Berggren & Pearson, 2005) is reported from the lower upper portion of Esna Formation (upper part of El-Mahmiya Member), and it extends from the LO of *Morozovella velascoensis* (Cushman) at the base to the FO of *Morozovella formosa* Bolli at the top (samples MK67– MK70). It is dated to the early Eocene (Ypresian) age, and reaches a thickness of roughly 6 meters.

3.2.6. E4 Zone (Partial Range Zone) (Blow, 1979 and emended by Berggren & Pearson, 2005) is reported from the upper portion of Esna Formation (lower part of Abu Had member), and it extends from the FO of *Morozovella formosa* Bolli at the base to the FO of *Morozovella aragonensis* (Nuttall) at the top (samples MK71-MK74). It is dated to the early Eocene (Ypresian) age, and reaches a thickness of roughly 4.5 meters.

3.2.7: E5 Zone (Concurrent Range Zone) (Berggren and Miller, 1988 and emended by Berggren & Pearson, 2005) is measured from the top-most portion of the Esna Formation (upper part of Abu Had Member) and continues throughout the measured part of the Thebes Formation (samples MK75–MK80). It is extended between the FO of *Morozovella aragonensis* (Nuttall) at the base to the LO of *Morozovella subbotinae* (Morozova) at the top. It belongs to the early Eocene (Ypresian age), and reaches a thickness of roughly 8 meters.

These established planktonic foraminiferal biozonations in the research area are compared to their counterparts at other locations within and outside of Egypt in **(Table 2).**

4. Discussion

4.1. Paleoenvironmental Analysis sea-level behaviour

The stratigraphic surfaces, lithofacies distribution, and the most significant paleoecological parameters of the five grams of foraminiferal contents from all of the rock samples that were collected were examined in detail, in order to study the depositional environments and paleobathymetric relative sea-level development that predominated during the deposition of the upper Selandian-Ypresian succession exposed at Bir El-Markha area. These parameters include the total number of foraminiferal individuals (TNF), species diversity, planktonic/benthonic ratio (P/B %), statistical analysis of benthonic forams (the Aggl/Calc ratio and the Infaunal/Epifaunal ratio), and statistical analysis of the dominating planktonic foraminiferal genera e.g. (*Subbotina*, *Morozovella*, *Acarinina*, *Igorina*, *Globanomalina*, and *Pseudohastigerina*).

Based on the results of these studies, four third-order depositional sequences (DS1-DS4) bounded by four type 1 sequence boundaries (SB.1–SB.4) representing four depositional cycles of rising and falling relative sea level change during the Selandian-Ypresian time interval have been identified in the studied succession **(Figs 6 & 7).**

These four depositional sequences are categorized into their systems tracts based on their depositional tendencies and the behavior of the sea level throughout each depositional cycle. A package of conformable sedimentary succession, denoted by transgressive systems tracts (TST) and highstand systems tracts (HST), and enclosed by two sequence borders makes up each depositional sequence.

These established depositional sequences are described in detail below, with their sequence boundaries listed in chronological order from older to younger:

4.1.1. DS1: This (DS1), which includes the entire Tarawan Formation, is considered to be the oldest in the examined timeframe. Its base is delimited by SB.1, which also happens to be the Dakhla/Tarawan formational boundary, and it can be clearly recognized in the field by its sudden transition from the uppermost section of Dakhla Formation's argillaceous facies to the lowermost part of Tarawan Formation's carbonate facies. In Hardenbol et al.'s (1998) world sea level chart, this (SB.1) corresponds to the Se12/Th sequence boundary. It might possibly match the regional unconformity surface that other researchers have previously reported in various parts of the world. (e.g.: Hermina, 1990; Spijer & Schmitz, 1998; Luning et al., 1998a; El-Azabi & El-Araby, 2000; Spijer, 2003b; Clemmensen & Thomsen, 2005; Guasti et al., 2005; El-Azabi &Farouk, 2011; Schmitz et al., 2011; King, 2012; Sprong et al., 2012; Farouk & El-Sorogy, 2015; Farouk, 2016, Farouk et al., 2016 and Hewaidy et al., 2017). Conversely, the (SB.2) surpasses this (DS1). Within the current study region, this (DS1) reaches approximately 3.5 meters in thickness (samples Mk50-Mk56) and is mostly composed of chalky limestone with a yellowish white color that grades higher to argillaceous limestone and marl. Given that it spans the planktonic foraminiferal subzones (P4a and P4b); it is dated as Selandian–early Thanetian age. It is categorized as follows, with (TST1) at the bottom and (HST1) at the top:

TST1: This (TST1), at Bir El-Markha section, is situated directly above the (SB.1) and reaches a thickness of approximately 2.5 meters (samples Mk50-Mk53). It is represented by the lower and middle parts of Tarawan Formation. It spans the interval of the latest Selandian (P4a and the lower part of P4b) palnktonic foraminiferal subzones. There is a significant variation in the paleoecological parameters employed for the statistical analysis of the foraminiferal content from lower to upper within this interval. The bottom portion of (TST1) spans the interval of the (P4a) Subzone of late Selandian age and comprises the lower part of the Tarawan Formation. It reaches a thickness of approximately 1.5 meters (samples Mk50-Mk51), and it is distinguished by a high TNF of 10650 individuals on average; a relatively high diversity of 80 species on average; a medium P/B ratio of 55% on average; and a high planktonic foraminiferal number of 5858 individuals on average; roughly 10% of these planktonics belong to the genus *Subbotina*, 43% to the genus *Morozovella*, 25% to the genus *Acarinina*, 5% to the genus *Igorina*, and 17% to *Globanomalina*. It is also characterized by a relatively low benthonic foraminiferal ratio of an average of 45% (4792 individuals); a low Aggl. / Calc. ratio of an average of 26% and a high infaunal taxa ratio of an average of 76%. Additionally, this interval's benthonic foraminiferal fauna is marked by the prevalence of *Spiroplectinella henryi* (LeRoy), *Spiroplectinella knebeli* (Le Roy), *Anomalinoides umbonifera* (Schwager), *Anomalinoides praeacutus* (Vasilenko), *Valvalabamina depressa* (Alth), *Gavelinella danica* (Brotzen), *Valvalabamina planulata* (Cushman & Renz), *Valvulineria esnehensis* Nakkady), *Anomalinoides susanaensis* (Browning), *Gavelinella lellingensis* Brotzen, *Anomalinoides rubiginosus* (Cushman), *Spiroplectinella dentata* (Alth), *Spiroplectinella esnaensis* (Le Roy), *Gaudryina africana* Le Roy, *Gaudryina cf. ellisorae* Cushman, *Gaudryina pyramidata* Cushman, *Pseudoclavulina farafraensis* Le Roy, *Textularia schwageri* LeRoy, *Textularia farafraensis* LeRoy, *Pygmaeoseistron globosa* (Montagu), *Pygmaeoseistron hispida* (Reuss), *Bulimina midwayensis* Cushman & Parker, *Pyramidulina latejugata* Gümbel, *Lenticulina isidis* (Schwager), *Lagena sulcata* (Walker & Jacob), *Bulimina paleocenica* Brotzen, *Bulimina strobila* Marie, *Praeglobobulimina quadrata* Plummer, *Trifarina esnaensis* LeRoy, *Loxostomoides applinae* (Plummer), *Pyramidulina affinis* (Reuss), *Praeglobobulimina ovata* (D' Orbigny), *Osangularia plummerae* Brotzen, *Oridorsalis plummerae* (Cushman), *Pseudonodosaria manifesta* (Reuss), *Lenticulina muensteri* (Roemer), *Lenticulina midwayensis* (Plummer), *Lenticulina cultrata* (Montfort). It is believed that these species are shallow outer neritic (Le Roy, 1953; Berggren & Aubert, 1975; Hewaidy, 1994; Speijer, 1994, Speijer & Schmitz, 1998 and El-Dawy & Hewaidy, 2003).

Conversely, the upper portion of this (TST1) spans the interval of the bottom part of the latest Selandian age (P4b) Subzone and constitutes the middle part of the Tarawan Formation. About 1 meters of thickness is reached (samples Mk52-Mk53). It is distinguished by a very high TNF range of approximately 14500 to 16500 individuals; a high diversity range of 82 to 95 species; a very high P/B ratio range of 75% to 91%; and a very high number of planktonic foraminiferals ranging from 10875 to 15015 individuals. Of these planktonics, approximately 6-8% belong to the genus *Subbotina*, 48-50% to the genus *Morozovella*, 31-23% to the genus *Acarinina*, 7–10% to the genus *Igorina*, and 8–9% to *Globanomalina*. It is also distinguished by a very low benthonic foraminiferal ratio ranging from 25–9% (3625 to 1485 individuals), a very low Aggl / Calc. ratio of 20–15%, and a very high infaunal taxa ratio of 79–82%. Additionally, the benthonic foraminiferal fauna of this part of (TST-1) is dominated by *Nuttallinella florealis* (White), *Pullenia coryelli* White, *Pullenia cretacea* Cushman, *Gyroidinoides globosus* (Hagenow), *Gyroidinoides subangulatus* (Plummer), *Gavelinella beccariiformis* (White), *Anomalinoides affinis* (Hantken), *Cibicidoides alleni* (Plummer), *Cibicidoides hyphalus* (Fisher), *Cibicides farafraensis* (Le Roy), *Angulogavelinella avnimelechi* Reiss, *Gyroidinoides beisseli* (White), *Marssonella oxycona* (Reuss) and *Vulvulina colei* Cushman. These species have been suggested to inhabit deeper outer bathyal to upper neritic environments (Le Roy, 1953; Van Morkhoven et al., 1986; Speijer, 1994, Speijer & Schmitz, 1998; El-Dawy & Hewaidy, 2003; Stassen et al., 2012 and Holbourn et al., 2013).

Based on these data, a transgressive phase during the deposition of this (TST1) is represented by retrogradational parasequence sets of shallow outer neritic in the lower part that grades upward to deep outer neritic - upper bathyal yellowish white chalky limestone. These sets demonstrate an increase in the relative sea level and the maximum flooding surface (MFS1) in this (DS1) is located within the (P4b) Subzone between the middle and upper parts of Tarawan Formation and coincides with the Selandian/Thanetian (Se/Th) stages boundary; due to the highest percentages of TNF (about 16500 individuals), P/B% (about 91%) and infaunal taxa (about 82%) indicate the maximum transgression,

HST1: This (HST1) spans the interval of the middle and upper parts of the (P4b) Subzone of the early Thanetian era and is represented at Bir El-Markha section by the upper portion of Tarawan Formation. It thickens to around 2 meters (samples Mk54-Mk56). According to the statistical analysis of the used paleoecological parameters for the foraminiferal contents, the lower part (interval that includes the middle portion of P4b Subzone) of this (HST1) (sample Mk54) is marked by a very high TNF about 13600 individuals; a high diversity about 90 species; a high P/B ratio about 68%; and a high number of planktonic foraminiferals about 9248 individuals; of these planktonics, about 8% belong to the genus *Subbotina*, 45% to the genus *Morozovella*, 26% to the genus *Acarinina*, 9% to the genus *Igorina*, and 12% to *Globanomalina*. It is further distinguished by a low Aggl. / Calc. ratio of around 22%, a high infaunal taxonomic ratio of about 77%, and a comparatively low benthonic foraminiferal ratio of about 32% (4352 individuals). Furthermore, this bottom portion of (HST1)'s benthonic foraminiferal fauna is primarily dominated by *Osangularia plummerae* Brotzen, *Gyroidinoides subangulatus* (Plummer), *Anomalinoides umbonifera* (Schwager), *Bulimina midwayensis* Cushman, *Bulimina paleocenica* Brotzen, *Spiroloculina esnaensis* LeRoy and *Eponides mariei* Said & Kenawy. These species are believed to exist in a deep, neritic outer environment (Le Roy, 1953; Berggren & Aubert, 1975; Hewaidy, 1994; Speijer, 1994, Speijer & Schmitz, 1998 and El-Dawy & Hewaidy, 2003).

Conversely, the upper part (interval that includes the top portion of P4b Subzone) of this (HST1) (samples Mk55-Mk56) is characterized by a medium to very low TNF range of 4000 to 1500 individuals; a relatively medium diversity range of 86 to 80 species; a very low P/B ratio range of 28% to 7%; and a medium to very low planktonic foraminiferal number range of 1120 to 105 individuals; of these planktonics, about 19-20% belonged to the genus *Subbotina*, 25–10% to the genus *Morozovella*, 42–51% to the genus *Acarinina*, 8–7% to the genus *Igorina*, and 6-12% to *Globanomalina*. It is also marked by a very high benthonic foraminiferal ratio ranging from 72-93% (2880 to 1395 individuals), a medium to relatively high Aggl / Calc ratio ranging from 41-60%, and a middle infaunal taxa ratio ranging from 64-59%. Additionally, the benthonic foraminiferal fauna of this interval is dominated by *Uvigerina maqfiensis* Le Roy and *Praeglobobulimina ovata* (D' Orbigny). It is believed that these species exist in inner-middle neritic habitats (Le Roy, 1953; Speijer, 1994; Speijer & Schmitz, 1998; Saint-Marc, 1992 and Ernst et al., 2006).

Based on these results, the foraminiferal content data show a drop in the relative sea level, which is supported by pro-gradational parasequence sets of deep outer neritic argillaceous limestone that, in their lower part, grade upward to middle-to-inner neritic marl. These conditions indicate a regressive phase during the deposition of this (HST1).

4.1.2. DS2: This (DS2) is represented in Bir El-Markha section by the lowest portion of the Esna Formation (El-Hanadi Member), reaching a thickness of approximately 5.5 meters (samples Mk57-Mk62). It is composed of dark grey calcareous shale grading upwardly to green fissile shale. It is assigned to latest Paleocene (Thanetian) age depending on its foraminiferal content as it spans (P4c and P5) planktonic foraminiferal biozones. This (DS2) is bounded at the base by the (SB.2), which is coincided with the Tarawan/Esna formational contact and it is located at the (P4b) / (P4c) planktonic foraminiferal subzonal boundary. The distinctive feature of this (SB.2) is a rapid transition in facies from the carbonate facies of the uppermost Tarawan Formation to the argillaceous facies of the lowermost Esna Formation. This makes it easy to identify in the field. In the study area, This (SB2) conformed to eustatic sea-level fall within the basal part of the (P4c) planktonic foraminiferal biozone (Haq et al., 1987; Hardenbol et al., 1998) and the Velascoensis Event might be connected to it (Strougo, 1986 and Farouk et al., 2016). Additionally, it might match the sequence boundary (ThSin-5) recorded by Lunning et al., 1998a in central east Sinai; (ThGal1) of Kuss et al., 2000 at Galala plateaux; (SB-5) of Hewaidy et al., 2006 in the Farafra Oasis; (SB-DB9) of King, 2012 in the Dababiya Quarry Corehole; (Eg.Th - 9) of Farouk, 2016 in Egypt and SB-1of Hewaidy et al., 2020 at the Kharga Oasis. On the other hand, this (DS2) is topped by the (SB3). This (DS2) is exclusively represented in the current study region by (TST2) at the base and (HST2) at the top, as shown below:

TST2: This (TST2) lies directly above the (SB.2) at the Bir El-Markha section, and it reaches a thickness of roughly 1.5 meters (samples Mk57-Mk58). It is represented by El-Hanadi Member's lowest portion. It spans the interval of the latest Paleocene (late Thanetian) (P4c) planktonic foraminiferal subzone. The lower part (interval that includes the lower part of P4c Zone) of this (TST2) (sample Mk57) is characterized by a high TNF of approximately 5560 individuals, a high diversity of approximately 130 species, a low P/B ratio of approximately 30%, and a high number of planktonic foraminifera of approximately 1668 individuals; of these planktonics, approximately 18% belong to the genus *Subbotina*, 23% to the genus *Morozovella*, 42% to the genus *Acarinina*, 8% to the genus *Igorina*, and 9% to *Globanomalina*. In addition, it has a high benthonic foraminiferal ratio about 70% (3892 individuals), a medium Aggl. / Calc. ratio (about 41%), and a moderate infaunal taxa ratio (about 63%). Furthermore, this interval's benthonic foraminiferal fauna is marked by a high proportion of *Alabamina midwayensis* Brotzen, *Gyroidinoides girardana* (Reuss), *Oridorsalis plummerae* (Cushman), *Anomalinoides zitteli* (Le Roy), *Siphogenerinoides eleganta* Plummer *Valvulineria scorbiculata* (Schwager), *Uvigerina maqfiensis* Le Roy, *Lenticulina insulsus* (Cushman), *Lenticulina isidis* (Schwager), *Lenticulina muensteri* (Roemer), *Lenticulina midwayensis* (Plummer), and *Lenticulina cultrata* (Montfort). These species are believed to inhabit a middle-neritic environment (Le Roy, 1953; Berggren & Aubert, 1975; Hewaidy, 1994; Speijer, 1994; Speijer & Schmitz, 1998 and Speijer & Schmitz, 1998).

On the other hand, the upper portion of this (TST2) (sample Mk58) (interval that includes the upper part of P4c Zone) is distinguished by a very high TNF (about 12750 individuals), a very high diversity (about 141 species), a high P/B ratio (about 65%), and a very high planktonic foraminiferal number (about 8288 individuals); of these planktonics, roughly 6% belong to the genus *Subbotina*, 46% to the genus *Morozovella*, 28% to the genus *Acarinina*, 9% to the genus *Igorina*, and 11% to *Globanomalina*. Also, it is characterized by a low benthonic foraminiferal ratio of around 35% (4462 individuals), a low Aggl. / Calc. ratio of approximately 23%,and a very high infaunal taxa ratio of about 78%, Additionally, this interval's benthonic foraminiferal fauna was characterized by the dominance of *Anomalinoides affinis* (Hantken), *Cibicidoides alleni* (Plummer), *Cibicidoides hyphalus* (Fisher), *Cibicidoides libycus* LeRoy, *Cibicides farafraensis* (Le Roy), *Angulogavelinella avnimelechi* Reiss, *Gyroidinoides beisseli* (White), *Marssonella oxycona* (Reuss), *Vulvulina colei* Cushman, *Dorothia bulletta* (Carsey), *Dorothia pupa* (Reuss), *Bolivinopsis clotho* (Grzybowski), *Clavulinoides trilaterus* (Cushman), *Cibicidoides decoratus* (LeRoy), *Osangularia plummerae* Brotzen, *Gyroidinoides subangulatus* (Plummer), *Anomalinoides umbonifera* (Schwager), *Bulimina farafraensis* LeRoy, *Bulimina midwayensis* Cushman, *Bulimina paleocenica* Brotzen, *Bulimina callahani* Galloway & Morrey, *Spiroloculina esnaensis* LeRoy, *Eponides mariei* Said & Kenawy, *Nuttallinella florealis* (White), *Pullenia coryelli* White, *Pullenia cretacea* Cushman, *Gyroidinoides globosus* (Hagenow), *Gyroidinoides subangulatus* (Plummer) and *Gavelinella beccariiformis* (White). These species are thought to exist in a deep, neritic outer environment (Le Roy, 1953; Berggren & Aubert, 1975; Van Morkhoven et al., 1986; Hewaidy, 1994; Speijer, 1994, Speijer & Schmitz, 1998; El-Dawy & Hewaidy, 2003; Stassen et al., 2012, Holbourn et al., 2013 and Hewaidy et al., 2020).

According to these data, there has been an increase in the relative sea level, which is demonstrated by retrogradational parasequence sets of deep middle neritic calcareous shale that, in its lower part, grades upward to deep outer neritic dark grey shale. This indicates deeper-up conditions and indicates a transgressive phase during the deposition of this (TST2). The (MFS2) in this (DS2) marks the P4/P5 planktonic foraminiferal zonal boundary and it coincides with the LO of *G. pseudomenardii* (Bolli).it indicated by the highest percentages of TNF (approximately 12750 individuals), P/B% (approximately 65%), and infaunal taxa (approximately 63%), representing the acme interval of this transgressive phase within the (DS2).

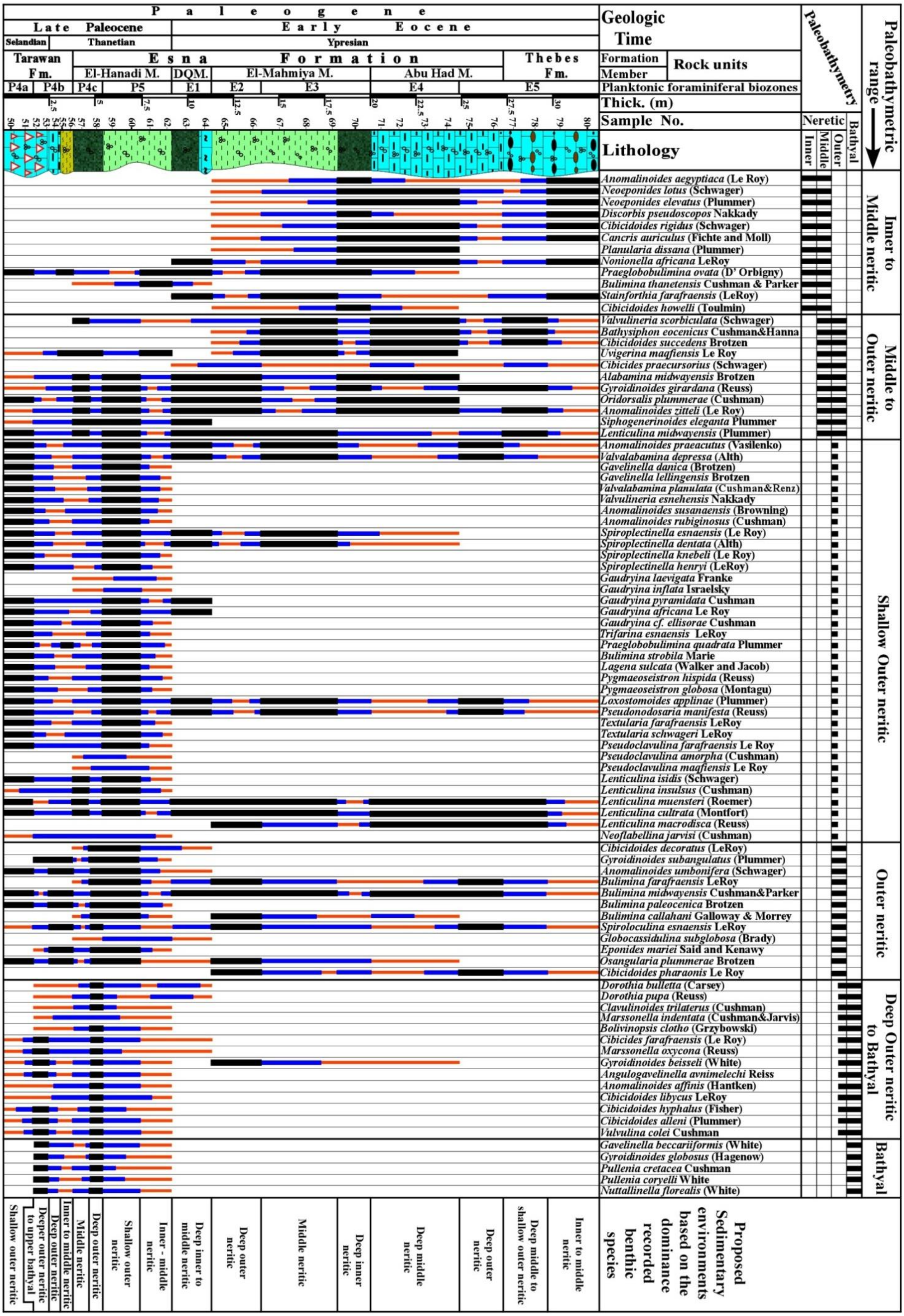


Fig. 6: Paleobathymetric ranges of the most dominated recorded benthic foraminiferal species and Proposed Sedimentary environments for the studied Upper Paleocene - Early Eocene (Ypresian) rock units at Bir El-Markha section, west- central Sinai. The paleobathymetric interpretations is based on (Le Roy, 1953; Berggren, 1974; Berggren & Aubert, 1975; Luger, 1985; Corliss, 1985; Cherif & Hewaidy, 1986; Van Morkhoven *et al.*, 1986; Hewaidy, 1990; Saint-Marc, 1992; Hewaidy, 1994; Speijer, 1994; Jorissen *et al.*, 1995; Hewaidy, 1996 &1997; Speijer & Schmitz, 1998; Van Der Zwaan *et al.*, 1999; El-Dawy & Hewaidy, 2003; Ernst *et al.*, 2006; Stassen *et al.*, 2012; Sprong *et al.*, 2012; Holbourn *et al.*, 2013 and Hewaidy *et al.*, 2017).

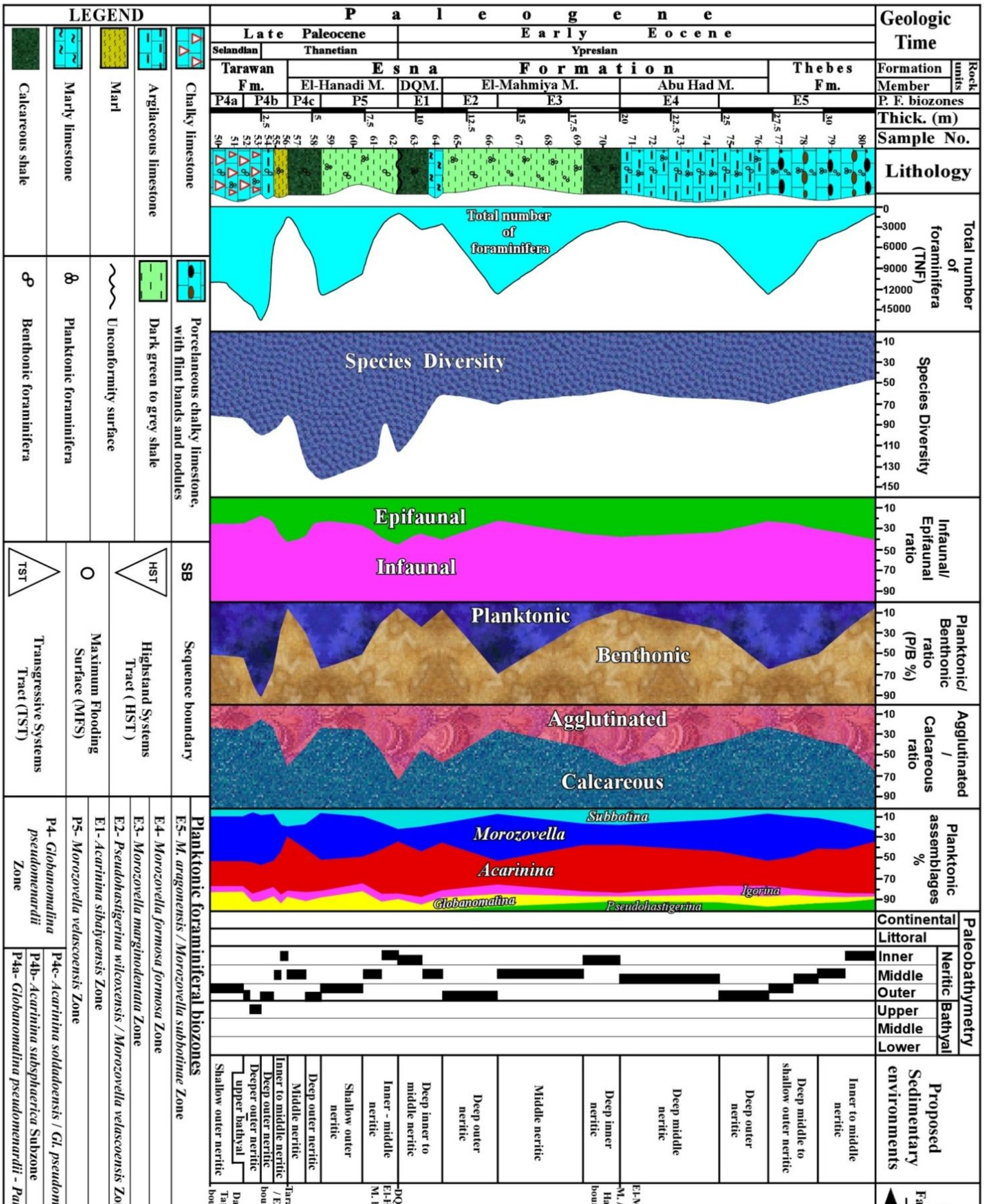


Fig. 7: The Integration between planktonic foraminiferal zonation, paleoecological parameters and depositional sequences at Bir El-Markha section, west- central Sinai.

HST2: El-Hanadi Member's upper portion in Bir El-Markha section represents this (HST2), which covers the interval of the latest Paleocene (latest Thanetian) planktonic foraminiferal biozone (P5). It reaches a thickness of roughly 4 meters (Samples Mk59-MK62). The results of the statistical analysis of the paleoecological parameters used for the foraminiferal contents indicate that the lower part (interval that includes the lower part of P5 Zone) of this (HST2) (samples Mk59-Mk60) is characterized by a TNF of an average of 9750 individuals; a high diversity of an average of 129 species; a medium P/B ratio of an average of 51%; and a medium number of planktonic foraminiferal numbers of 4973 individuals on average; roughly 10% of these planktonics belong to the genus *Subbotina*, 40% to the genus *Morozovella*, 25% to the genus *Acarinina*, 7% to the genus *Igorina*, and 18% to *Globanomalina*. Additionally, it is distinguished by a relatively medium average benthonic foraminiferal ratio of 49% (4777 individuals), a low average Aggl / Calc ratio of 25%, and a high average infaunal taxa ratio of 72%. Furthermore, this interval's benthonic foraminiferal fauna is marked by an abundance of *Valvalabamina depressa* (Alth), *Gavelinella danica* (Brotzen), *Valvalabamina planulata* (Cushman & Renz), *Anomalinoides praeacutus* (Vasilenko), *Valvulineria esnehensis* Nakkady), *Anomalinoides susanaensis* (Browning), *Gavelinella lellingensis* Brotzen, *Anomalinoides rubiginosus* (Cushman), *Spiroplectinella dentata* (Alth), *Spiroplectinella esnaensis* (Le Roy), *Spiroplectinella henryi* (LeRoy), *Spiroplectinella knebeli* (Le Roy), *Gaudryina africana* Le Roy, *Gaudryina cf. ellisorae Cushman*, *Gaudryina pyramidata* Cushman, *Pseudoclavulina farafraensis* Le Roy, *Textularia schwageri* LeRoy, *Textularia farafraensis* LeRoy, *Pygmaeoseistron globosa* (Montagu), *Pygmaeoseistron hispida* (Reuss), *Bulimina midwayensis* Cushman & Parker, *Bulimina paleocenica* Brotzen, *Bulimina strobila* Marie, *Praeglobobulimina quadrata* Plummer, *Loxostomoides applinae* (Plummer), *Trifarina esnaensis* LeRoy, *Pseudonodosaria manifesta* (Reuss), *Lagena sulcata* (Walker & Jacob), *Pyramidulina affinis* (Reuss), *Pyramidulina latejugata* Gümbel, *Lenticulina cultrata* (Montfort), *Lenticulina insulsus* (Cushman), *Lenticulina isidis* (Schwager), *Lenticulina midwayensis* (Plummer), *Lenticulina muensteri* (Roemer), *Cibicidoides decoratus* (LeRoy), *Osangularia plummerae* Brotzen, *Gyroidinoides subangulatus* (Plummer), *Anomalinoides umbonifera* (Schwager), *Bulimina farafraensis* LeRoy, *Bulimina callahani* Galloway & Morrey, *Eponides mariei* Said & Kenawy, *Alabamina midwayensis* Brotzen, *Gyroidinoides girardana* (Reuss), *Oridorsalis plummerae* (Cushman), *Anomalinoides zitteli* (Le Roy) and *Siphogenerinoides eleganta* Plummer. These species are interpreted as shallow outer neritic environment (Le Roy, 1953; Berggren & Aubert, 1975; Hewaidy, 1994; Speijer, 1994, Speijer & Schmitz, 1998 and El-Dawy &Hewaidy, 2003). Conversely, the upper portion (interval that encompasses the upper P5 Zone) of this (HST2) (samples Mk61-Mk62) is characterized by a low to low TNF range of 3800 to 1450 individuals; a high to medium diversity range of 115 to 90 species; a very low P/B ratio range of 20 to 7%; and a low planktonic foraminiferal number range of 760 to 102 individuals. Of these planktonics, roughly 17–22% belong to the genus *Subbotina*, 25–13% to the genus *Morozovella*, 43-50% to the genus *Acarinina*, 7–5% to the genus *Igorina*, and 8–10% to *Globanomalina*. It is furthermore distinguished by a very high benthonic foraminiferal ratio ranging from 80-93% (3040 to 1348 individuals), a medium to high Aggl / Calc ratio of 46-72%, and a medium infaunal taxa ratio of 62-57%. Additionally, the topmost of this (HST1) is characterized by the predominance of *Bulimina thanetensis* Cushman & Parker, *Uvigerina maqfiensis* Le Roy, and *Praeglobobulimina ovata* (D' Orbigny). These species are interpreted as inner to middle neritic environments (Saint-Marc, 1992; Speijer, 1994 and Ernst et al., 2006).

The foraminiferal content data indicates a decline in the relative sea level, which is supported by pro-gradational parasequence sets of shallow outer neritic grades that ascend to inner-middle neritic green fissile shale. These sets of grades indicate shallower-upward conditions and signify a regressive phase during the deposition of this (HST2).

4.1.3. DS3: This (DS3) is represented in Bir El-Markha section by the middle portion of the Esna Formation (El-Dababiya Quarry and El-Mahmiya members), which reaches a thickness of roughly 11 meters (samples Mk63-Mk70). It is composed of marly limestone and light grey calcareous shale at the bottom, grading upward to light green fissile shale and dark grey shale. Based on its foraminiferal composition, which spans (E1- E3) planktonic foraminiferal biozones, it is dated to the early Eocene (earliest Ypresian). The base of this (DS3) is bounded at its base by the (SB3), which is situated between the El-Hanadi Member and the El-Dababiya Quarry Member in the middle of the Esna Formation and matches with the Paleocene/Eocene (P/E) boundary. This (SB-3) is distinguished by the Benthic Foraminiferal Extinction Event (BFE), which is the extinction of deep-sea benthic foraminifera (Thomas, 1990; Spijer, 1994 and Katz et al., 1999), and by the interzonal hiatus caused by the disappearance of the lowermost part of Dababiya Quarry Member (Beds 1-3). Because of the incised erosion surface, this (SB3) in the study region may be connected with the combined transgression surface and sequence boundary that was recorded at the base of the (DQM) in GSSP (Dupuis et al., 2003 and King, 2012); the sequence boundary (Th6) of Hardenbol et al., 1998; (Th Ga12) of Kuss et al., 2000 at the Galala plateaux; (SB) at the top of (DB9) sequence of King, 2012 in the Dababiya Quarry Corehole; the (Eg.Th.-10) of Farouk, 2016 in Egypt and also (SB-II) of Hewaidy et al., 2020 at the Kharga Oasis. On the other hand, this (DS3) is topped by the (SB4). This (DS3) is categorized as (TST3) at the base and a (HST3) at the top in the currently investigated area:

TST3: This (TST3), which is 5 meters thick (Samples Mk63 – Mk66), comprises the El-Dababiya Quarry Member (DQM) and the lower portion of El-Mahmiya Member at the current examined section. It spans the (E1 and E2) planktonic foraminiferal biozones of earliest Eocene (earliest Ypresian) age. The lower part (interval that includes the E1 Zone) of this (TST3) (samples Mk63-Mk64) is characterized by low to relatively medium TNF ranges from 2450 to 3150 individuals; a relatively medium diversity ranges from 60 to 88 species; a very low P/B ratio ranges from 9% to 25%; and a low planktonic foraminiferal number ranges from 221 to 788 individuals. Of these planktonics, roughly 18–20% belong to the genus *Subbotina*, 18–25% to the genus *Morozovella*, 45–44% to the genus *Acarinina*, 8–6% to the genus *Igorina*, and 11–5% to genus *Globanomalina*. In addition, it has a very high benthonic foraminiferal ratio (91–75%) ranging from 2229 to 2362 individuals; a medium–low Aggl /Calc. ratio (58–44%); and a medium infaunal taxa ratio (60–65%). Furthermore, this interval's benthonic foraminiferal fauna is distinguished by *Valvalabamina depressa* (Alth), *Spiroplectinella dentata* (Alth), *Spiroplectinella esnaensis* (Le Roy), *Gaudryina africana* Le Roy, *Gaudryina pyramidata* Cushman, *Anomalinoides praeacutus* (Vasilenko), *Bulimina midwayensis* Cushman & Parker, *Praeglobobulimina ovata* (D' Orbigny), *Loxostomoides applinae* (Plummer), *Pseudonodosaria manifesta* (Reuss), *Pyramidulina* affinis (Reuss), *Lenticulina cultrata* (Montfort), *Lenticulina midwayensis* (Plummer), *Lenticulina muensteri* (Roemer), *Nonionella africana* LeRoy, *Alabamina midwayensis* Brotzen, *Gyroidinoides girardana* (Reuss), *Oridorsalis plummerae* (Cushman), *Anomalinoides zitteli* (Le Roy) and *Siphogenerinoides eleganta* Plummer. It is believed that these species exist in deep inner to middle neritic environments (Le Roy, 1953; Berggren & Aubert, 1975; Hewaidy, 1994; Speijer, 1994, Speijer & Schmitz, 1998; El-Dawy & Hewaidy, 2003; Stassen et al., 2012 and Hewaidy et al., 2017). However, the upper portion of this (TST3) (samples Mk65-Mk66) shows a very high TNF of an average of 12700 individuals; a relatively high diversity of an average of 70 species; a very high P/B ratio of an average of 70%; and a very high number of planktonic foraminifera, with an average of 8890 individuals. Of these planktonics, roughly 9% belong to the genus *Subbotina*, 44% to the genus *Morozovella*, 23% to the genus *Acarinina*, 9% to the genus *Igorina*, 12% to *Globanomalina*, and 3% to the genus *Pseudohastigerina*. It is also marked by a low benthonic foraminiferal ratio of an average of 30% (3810 individuals); a very low Aggl. / Calc. ratio of an average of 24% and a very high infaunal taxa ratio of an average of 78%. Additionally, this interval's benthonic foraminiferal fauna is distinguished by the predominance of *Stainforthia farafraensis* (LeRoy), *Cibicidoides pharaonis* Le Roy, *Osangularia plummerae* Brotzen, *Lenticulina muensteri* (Roemer), *Bulimina farafraensis* LeRoy, *Bulimina midwayensis* Cushman, *Bulimina callahani* Galloway & Morrey, *Spiroloculina esnaensis* LeRoy, *Oridorsalis plummerae* (Cushman), *Lenticulina midwayensis* (Plummer), *Anomalinoides zitteli* (Le Roy), *Lenticulina cultrata* (Montfort), *Gyroidinoides beisseli* (White), *Alabamina midwayensis* Brotzen, *Lenticulina macrodisca* (Reuss), and *Gyroidinoides girardana* (Reuss). These species are interpreted as deep outer neritic environment (Le Roy, 1953; Berggren & Aubert, 1975; Hewaidy, 1994; Speijer, 1994, Van Morkhoven et al., 1986; Speijer & Schmitz, 1998; El-Dawy & Hewaidy, 2003; Stassen et al., 2012 and Holbourn et al., 2013).

These results indicate an increase in the relative sea level, which is demonstrated by the retrogradational parasequence of deep inner to middle neritic light grey calcareous shale and marly limestone, which grades upward to deep outer neritic light green fissile shale and dark grey shale, which represents a transgressive phase during the deposition of this (TST3). The (MFS3) in this (DS3) is located within the middle part of El-Mahmiya Member. It marks the E2/E3 planktonic foraminiferal zonal boundary as it acts the acme point of this transgressive phase within this (DS3) based on the highest percentages of TNF (about 12700 individuals), P/B% (about 70%) and infaunal taxa (about 78 %) which indicate the maximum transgression.

HST3: This (HST-3) at Bir El-Markha section spans the interval of (E3) planktonic foraminiferal biozone of earliest Eocene (earliest Ypresian) age and is represented by the top portion of El-Mahmiya Member. It thickens to roughly 6 meters (Mk67-MK70 samples). The lower part (interval that includes the lower part of E3 Zone) of this (HST3) (samples Mk67-Mk69) is characterized by a relatively medium TNF of an average of 4000 individuals; a medium diversity of an average of 61 species; a very low P/B ratio of an average of 20%; and a medium number of planktonic foraminiferal content of an average of 800 individuals. Of these planktonics, roughly 17% belong to the genus *Subbotina*, 22% to the genus *Morozovella*, 43% to the genus *Acarinina*, 5% to the genus *Igorina*, 6% to *Globanomalina*, and 7% to the genus *Pseudohastigerina*. Additionally, it is distinguished by a medium Aggl. / Calc. ratio of 42%, a very high benthonic foraminiferal ratio of 80% (3200 individuals), and a medium infaunal taxa of 63%. Furthermore, the dominance of in this interval's benthonic foraminiferal fauna are *Valvulineria scorbiculata* (Schwager), *Bathysiphon eocenicus* Cushman & Hanna, *Cibicidoides succedens* Brotzen, *Uvigerina maqfiensis* Le Roy, *Stainforthia farafraensis* (LeRoy), *Anomalinoides praeacutus* (Vasilenko), *Valvalabamina depressa* (Alth), *Spiroplectinella dentata* (Alth), *Spiroplectinella esnaensis* (Le Roy), *Bulimina midwayensis* Cushman & Parker, *Praeglobobulimina ovata* (D' Orbigny), *Loxostomoides applinae* (Plummer), *Pseudonodosaria manifesta* (Reuss), *Pyramidulina affinis* (Reuss), *Lenticulina cultrata* (Montfort), *Lenticulina midwayensis* (Plummer) and *Lenticulina muensteri* (Roemer). These species are interpreted as middle neritic environment (Le Roy, 1953; Berggren & Aubert, 1975; Hewaidy, 1994; Speijer, 1994, Speijer & Schmitz, 1998 and El-Dawy & Hewaidy, 2003). On the other hand, the upper portion of this (HST3) (sample Mk70) (interval that includes the upper part of E3 Zone) is characterized by a very low TNF of about 2250 individuals; a relatively low diversity of about 55 species; a very low P/B ratio of about 8%; and a very low number of planktonic foraminiferal content of about 180 individuals; of these planktonics, about 19% belonged to the genus *Subbotina*, 20% to the genus *Morozovella*, 45% to the genus *Acarinina*, 4% to the genus *Igorina*, 3% to *Globanomalina*, and 9% to the genus *Subbotina*. Also, it has a very high benthonic foraminiferal ratio of around 92% (2070 individuals); a medium Aggl. / Calc. ratio of approximately 60%; and medium infaunal taxa of approximately 62%. Furthermore, the dominance of in this interval's benthonic foraminiferal fauna are *Praeglobobulimina ovata* (D' Orbigny), *Nonionella africana* LeRoy, *Cibicidoides howelli* (Toulmin), *Alabamina midwayensis* Brotzen, *Neoeponides lotus* (Schwager), *Neoeponides elevatus* (Plummer), *Cancris auriculus* (Fichte & Moll), *Cibicidoides rigidus* (Schwager), *Planularia dissana* (Plummer), *Anomalinoides aegyptiaca* (Le Roy), *Discorbis pseudoscopos* Nakkady, *Gyroidinoides girardana* (Reuss), *Oridorsalis plummerae* (Cushman), and *Anomalinoides zitteli* (Le Roy). These species are thought to represent a deep inner environment (Le Roy, 1953; Berggren & Aubert, 1975; Hewaidy, 1994; El-Dawy & Hewaidy, 2003; Saint-Marc, 1992; Speijer, 1994, Speijer & Schmitz, 1998; Ernst et al., 2006; Stassen et al., 2012 and Hewaidy et al., 2017).

The foraminiferal content data reveals a decline in the relative sea level, which is demonstrated by pro-gradational parasequence sets of middle neritic grades that ascend to deep inner dark grey shale, which represents a regressive phase during the deposition of (HST3).

4.1.4. DS4: The youngest depositional sequence in the study region is taken into consideration in this (DS4). The combined uppermost portion of the Esna Formation (Abu Had Member) and the measured portion of the Thebes Formation serve as its representation. The thickness reaches approximately 12.5 meters (Samples Mk71-Mk80). It was composed of thinly bedded, argillaceous limestones that graded higher to a chalky, pale white limestone with nodules and bands of brown to black flint. Depending on its foraminiferal composition, which spans the E4 and E5 planktonic foraminiferal biozones, it is dated to the early Eocene (early Ypresian). This (DS4) coincides with the (E3) / (E4) planktonic foraminiferal biozonal boundary and is situated immediately above the (SB.4), which is situated inside the upper portion of the Esna Formation (between El-Mahmiya and Abu Had members). It is distinguished by a sudden shift in facies from the argillaceous El-Mahmiya Member facies to the carbonate Abu Had Member facies, as well as by a break in sedimentation shown by reworked glauconite. This (SB-4) may be correlated with (SB-6) of Hewaidy et al., 2006 in the Farafra Oasis; (Yp/Kh7) of El-Azabi & Farouk, 2011 and (SB-2) of El-Dawy et al., 2016 at the Kharga Oasis. It may also correspond with short-term eustatic sea-level fall recorded by Haq et al., 1987 and Hardenbol et al., 1998 close to the base of E4 foraminiferal biozone. This (DS4) is categorized as (TST4) at the base and a (HST4) at the top in the currently investigated area:

TST4: This (TST4), which includes the Abu Had Member at Bir El-Markha section, reaches a thickness of roughly 7 meters (Samples Mk71 – Mk76). The E4 and lower E5 planktonic foraminiferal biozones of early Eocene (early Ypresian) age are encompassed by it. The statistical analysis of the foraminiferal contents revealed that the lower part (interval that includes E4 Zone) of this (TST4) (samples Mk71-Mk74) is characterized by a relatively medium TNF of an average of 5100 individuals; a medium diversity of an average of 65 species; a low P/B ratio of an average of 29%; and a medium number of planktonic foraminiferal individuals of an average of 1479; of these planktonics, roughly 12% belong to the genus *Subbotina*, 32% to the genus *Morozovella*, 34% to the genus *Acarinina*, 8% to the genus *Igorina*, 6% to *Globanomalina*, and 8% to the genus *Pseudohastigerina*. Additionally, it is distinguished by a very low average Aggl. / Calc. ratio of 38%, a comparatively high average infaunal taxa ratio of 67%, and a very high average benthonic foraminiferal ratio of 71% (3621 individuals). Furthermore, the dominance of in this interval's benthonic foraminiferal fauna include *Bathysiphon eocenicus* Cushman & Hanna, *Cibicidoides succedens* Brotzen, *Uvigerina maqfiensis* Le Roy, *Valvulineria scorbiculata* (Schwager), *Neoeponides lotus* (Schwager), *Neoeponides elevatus* (Plummer), *Cancris auriculus* (Fichte & Moll), *Lenticulina cultrata* (Montfort), *Lenticulina muensteri* (Roemer), *Bulimina midwayensis* Cushman & Parker, *Lenticulina macrodisca* (Reuss), *Cibicidoides rigidus* (Schwager), *Planularia dissana* (Plummer), *Nonionella africana* LeRoy, *Alabamina midwayensis* Brotzen, *Gyroidinoides girardana* (Reuss), *Oridorsalis plummerae* (Cushman) and *Anomalinoides zitteli* (Le Roy). These species are thought to exist in a deep middle neritic environment (Le Roy, 1953; Berggren & Aubert, 1975; Hewaidy, 1994; Speijer, 1994; Speijer & Schmitz, 1998; El-Dawy & Hewaidy, 2003 and Stassen et al., 2012). On the other hand, the upper part (interval encompassing the lower part of E5 Zone) of (TST4) (samples Mk75-Mk76) is characterized by a very high TNF of 12600 individuals on average; a relatively high diversity of 69 species on average; a high P/B ratio of an average of 65%; and a very high number of planktonic foraminiferal individuals of 8190 individuals on average; of these planktonics, roughly 8% belonged to the genus *Subbotina*, 45% to the genus *Morozovella*, 25% to the genus *Acarinina*, 10% to the genus *Igorina*, 10% to *Globanomalina*, and 2% to the genus *Pseudohastigerina*. Additionally, it is characterized by a low average benthonic foraminiferal ratio of 35% (4410 individuals), a low average Aggl / Calc ratio of 22%, and an exceptionally high average infaunal taxa ratio of roughly 79%. Furthermore, this interval's benthonic foraminiferal fauna is distinguished by the predominance of *Bulimina farafraensis* LeRoy, *Valvalabamina depressa* (Alth), *Anomalinoides praeacutus* (Vasilenko), *Bulimina midwayensis* Cushman & Parker, *Loxostomoides applinae* (Plummer), *Pseudonodosaria manifesta* (Reuss), *Lenticulina muensteri* (Roemer), *Lenticulina macrodisca* (Reuss), *Lenticulina cultrata* (Montfort), *Cibicidoides pharaonis* Le Roy, *Spiroloculina esnaensis* LeRoy, and *Gyroidinoides girardana* (Reuss). These species are interpreted as outer neritic environment (Le Roy, 1953; Berggren & Aubert, 1975; Van Morkhoven et al., 1986; Hewaidy, 1994; Speijer, 1994: Speijer & Schmitz, 1998; El-Dawy & Hewaidy, 2003; Stassen et al., 2012 and Holbourn et al., 2013).These results suggest an increase in the relative sea level, which is evidenced by the deep middle neritic retrogradational parasequence grades upwardly to the deep outer neritic argillaceous thinly bedded limestones. This indicates a transgression phase during the deposition of these systems tracts.

The (MFS4) in this (DS4) is located within the (E5) planktonic foraminiferal biozone and coincides with the Esna/Thebes formational contact based on the highest percentages of TNF (approximately 12600 individuals), P/B% (about 65%), and infaunal taxa (about 79%) representing the maximum transgression. Moreover, this (MFS4) is distinguished by an abrupt facies transition between the argillaceous, thinly bedded limestones of the uppermost portion of the Abu Had Member and the pale white, porcellaneous chalky limestone that covers it, adorned with brown to black flint bands and nodules from the lowermost portion of the Thebes Formation.

HST4: At Bir El-Markha section, this (HST-4) is the highest interval in (DS4) and it is represented by the measured part of Thebes Formation. It spans the interval of upper part of (E5) planktonic foraminiferal biozone of early Eocene (early Ypresian) age.

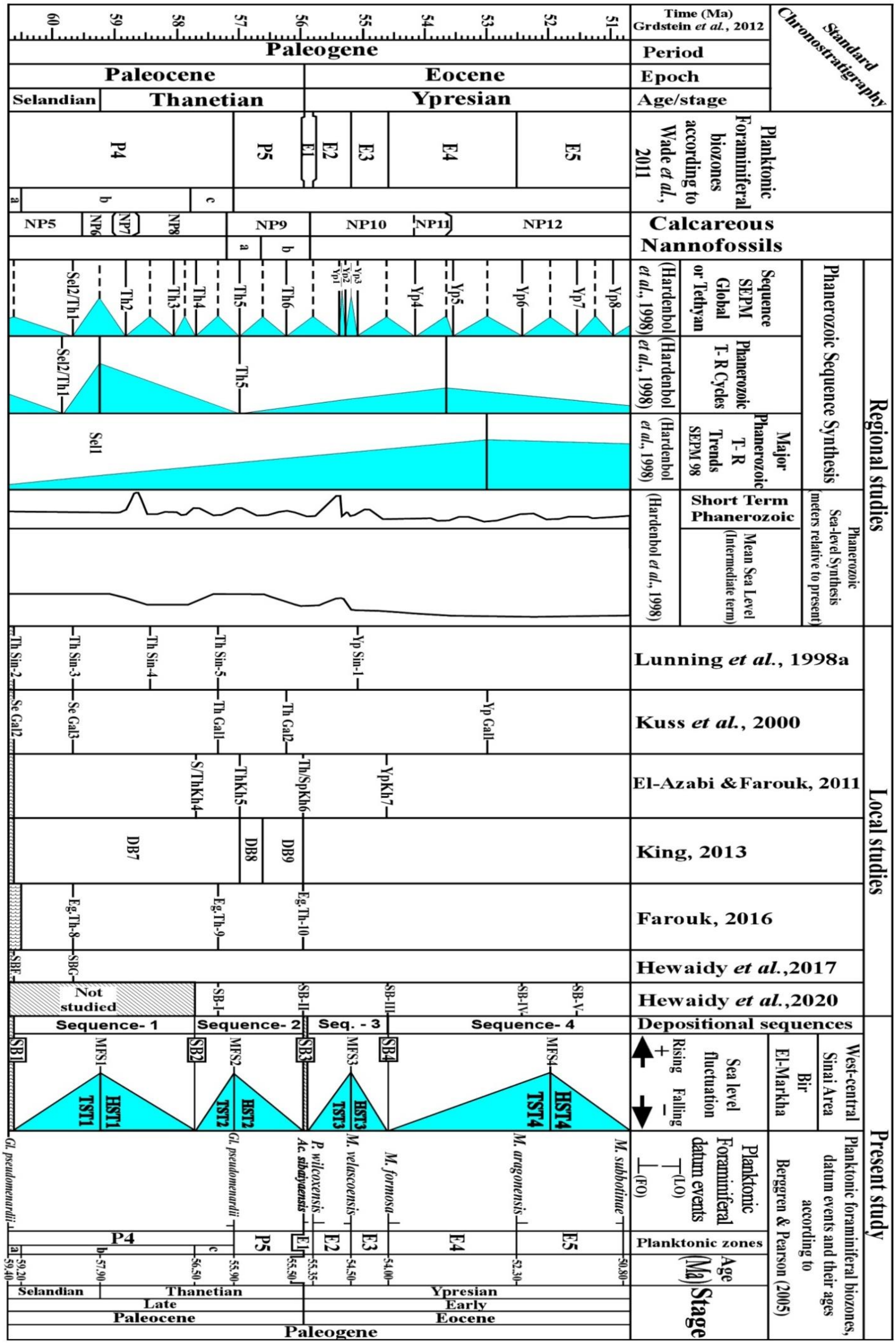


Fig. 8: Correlation of the recorded depositional sequences and their sequence boundaries at Bir El-Markha section during the Upper Paleocene - Lower Eocene (Ypresian) time interval with those of the previous local and regional studies.

This (HST-4) attains about 5.5 meters thick (Samples Mk77-MK80). The lower part (interval that includes the lower upper part of E5 Zone) of this (HST4) (samples Mk77-Mk78) is characterized by a medium to low TNF ranges from 8750 to 4750 individuals; a medium to medium diversity ranges from 62 to 58 species; a medium to low P/B ratio ranges from 51% to 28%; and a medium to low planktonic foraminiferal number ranges from 4462 to 1330 individuals; of these planktonics, roughly 10-11% belong to the genus *Subbotina*, 40–30% to the genus *Morozovella*, 30–40% to the genus *Acarinina*, 6-7% to the genus *Igorina*, 9-5% to *Globanomalina*, and 5-7% to the genus *Pseudohastigerina*. It is also distinguished by a low Aggl. / Calc. ratio of 28-35%, a high infaunal taxa ratio of an average of 75-70%, and a medium to high benthonic foraminiferal ratio ranging from 49-72% (about 4288 - 3420 individuals). Additionally, the bottom portion of this (HST4) is distinguished by the predominance of *Valvulineria scorbiculata* (Schwager), *Bathysiphon eocenicus* Cushman & Hanna, *Cibicidoides succedens* Brotzen, *Gyroidinoides girardana* (Reuss), *Anomalinoides zitteli* (Le Roy), *Lenticulina cultrata* (Montfort), *Lenticulina midwayensis* (Plummer), *Lenticulina muensteri* (Roemer) and *Lenticulina macrodisca* (Reuss). It is believed that these species are found in deep middle to shallow outer neritic environments (Le Roy, 1953; Berggren & Aubert, 1975; Hewaidy, 1994; Speijer, 1994 and Speijer & Schmitz, 1998). However, the upper part (interval that includes the uppermost part of E5 Zone) of this (HST4) (samples Mk79-Mk80) is characterized by a medium to very low TNF range of 3100-1050 individuals; a relatively low diversity range of 52 to 48 species; a very low P/B ratio range of 18% to 6%; and a medium to very low planktonic foraminiferal number range of 558 to 63 individuals; of these planktonics, approximately 18–25% belong to the genus *Subbotina*, 24–10% to the genus *Morozovella*, 42–50% to the genus *Acarinina*, 4-3% to the genus *Igorina*, 4-2% to *Globanomalina*, and 8–10% to the genus *Pseudohastigerina*. It is additionally distinguished by a medium to high Aggl. / Calc. ratio of 40-65%, a medium infaunal taxa ratio of 65-60%, and a very high benthonic foraminiferal ratio ranging from 82-94% (about 2542 - 987 individuals). Moreover, the upper portion of this (HST4) is characterized by the predominance of *Stainforthia farafraensis* (LeRoy), *Neoeponides lotus* (Schwager), *Neoeponides elevatus* (Plummer), *Cancris auriculus* (Fichte & Moll), *Cibicidoides rigidus* (Schwager), *Nonionella africana* LeRoy, *Anomalinoides aegyptiaca* (Le Roy) and *Discorbis pseudoscopos* Nakkady. It is believed that these species are found in inner to middle neritic environments (Le Roy, 1953; Hewaidy, 1994; El-Dawy & Hewaidy, 2003; Stassen et al., 2012 and Hewaidy et al., 2017).

These results demonstrate a drop in the relative sea level, which is indicated by pro-gradational parasequence sets of deep middle – shallow outer neritic in the lower part and grades upwardly to inner-middle neritic pale white, porcellaneous chalky limestone, with brown to black flint bands and nodules that represent regressive phase during the deposition of this interval of (HST4).

In the Bir El-Markha region, the boundaries of these four documented depositional sequences and their comparability with those from previous regional and local studies are displayed on **(Fig. 8).**

5. Conclusions

This study's primary contribution is the integration of extensive fieldwork and foraminiferal content analysis to provide paleoenvironmental interpretations and paleobathymetric relative sea-level development that correspond to the upper Selandian-Ypresian succession exposed in the Bir El-Markha section, west-central Sinai region.

The sequence under study consists of the Tarawan, Esna, and Thebes formations, arranged base to top. The Esna Formation is composed of El-Hanadi, El-Dababiya Quarry, El-Mahmiya, and Abu Had members. Compared to the GSSP, only the top two beds (coeval with beds 4 and 5 at GSSP) in the study region reflect the El-Dababiya Quarry Member.

Based on the vertical distribution of the identified planktonic foraminiferal species, seven planktonic foraminiferal biozones have been identified: P4 Zone (late Selandian - early Thanetian age), divided into three subzones (P4a, P4b, and P4c); P5 Zone (latest Thanetian age); and E1 - E5 zones (Ypresian age).

The Selandian/Thanetian (Sel / Th) border in the Bir El-Markha region is located inside the (P4b) partial range Subzone at the lower upper portion of the Tarawan Formation, at the (MFS1) of the (DS1). This is characterized by the highest percentages of TNF (about 16500 individuals), P/B% (nearly 91%), and infaunal taxa (approximate 82%), which indicate a significant transgression. Conversely, the study area's Paleocene/Eocene (P/E) boundary is situated close to the base of the Dababiya Quarry Member (QDM) of the Esna Formation. It is located on the P5 / E1 zonal boundary and is identified by the inter-zonal hiatus that results from the nonexistence of the bottom portion of the DQM (beds 1-3).

Through the integration of lithologic, planktonic foraminiferal biostratigraphic studies, results of paleoecological parameters, and in-depth field investigation for the stratigraphic surfaces, four third-order transgressive-regressive depositional sequences (DSS) are identified within this studied succession, bounded by four type-one sequence boundaries (SBS). All of these recorded depositional sequences are only reflected in transgressive systems tracts (TST) and highstand systems tracts (HST). When compared to other regional and local depositional sequences, the established sequences and their boundaries in the studied area show that the formation of these sequences is typically associated with the cyclical rise and fall of relative sea level change, though it can also occasionally be linked to tectonic movements.

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الطباقية الحيوية المتكاملة للفورامنيفرا والتحليل البيئي القديم خلال الفترة الزمنية السيلاندية- الإيبريسية في قطاع بئر مارخة، منطقة غرب وسط سيناء ، مصر

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يقوم هذا البحث على دراسة محتوى الفورامينيفرا بنوعيها الطافي والقاعي في صخور الباليوسين العلوى (السيلاندى) - الإيوسين السفلى (الإيبريسى) المكشوفة فى منطقة بئر مارخة الواقعة في غرب وسط سيناء - مصر. وقد تم تقسيم التتابع المدروس إلى ثلاثة تكاوين صخرية من أسفل إلى أعلى: متكون الطروان الذى يتبع عصر (الباليوسين العلوى) والذى يعلو متكون الدخلة الذي يتبع عصر (الباليوسين السفلى) بعلاقة عدم توافق، ثم متكون الإسنا الذى يتبع عصر (الباليوسين العلوى - الإيوسين السفلى) والذي أمكن تقسيمه فى منطقة الدراسة الى أربعة أعضاء وهم من أسفل الى أعلى (الهنادى، محجر الدبابية، المحمية وأبو حاد)، ثم متكون طيبة الذى يتبع عصر (الإيوسين السفلى). وقد تم دراسة هذه الوحدات الصخرية بالتفصيل وتم وصفها وصفا دقيقا. وقد إتضح من الدراسة التفصيلية لعضو محجر الدبابية المميز أنه يتكون من طبقتان فقط فى منطقة الدراسة وهاتان الطبقتان تضاهى الطبقتان العلويتان (٤ و٥) في القطاع المرجعى بمنطقة الدبابية فى وادي النيل مما يدل على وجود علاقة عدم توافق لغياب الجزء السفلى المكافئ للطبقات (١-٣) من عضو محجر الدبابية.

وقد أوضحت دراسة محتوى الفورامنيفرا إلى أن هذا التتابع الصخرى غني جدا بمحتواه من الفورامنيفرا، حيث تم تعريف (١٦٠) نوعا، منهم (٦١) نوعا من الطافيات بالأضافة إلى (٩٩) نوعا من القاعيات. وقد تم تصوير كلا من الأنواع المميزة والمرشدة من الطافيات والأنواع المهمة والتي لها دلالة بيئية من القاعيات باستخدام الميكروسكوب الإلكتروني الماسح ووضحت على (٤) لوحات. وقد أدت دراسة التوزيع الرأسى الدقيق لكل أنواع الفورامنيفرا الطافية المعرفة إلى تقسيم التتابعات الطبقية التابعة للباليوسين العلوى وحتى الأيوسين السفلى في منطقة بئر مارخة إلى سبعة نطاقات حيوية طافية، وهى مرتبة من الأقدم إلى الأحدث: P4 Zone والذي يتبع (الباليوسين المتأخر"السيلاندى - الثانيتى السفلى)، والذى تم تقسيه إلى تحت نطاقات حيوية ثلاث، وهم من الأقدم إلى الأحدث: P4a Subzone والذي يتبع زمن (السيلاندي "Selandian")، P4b Subzone والذى يتبع زمن (السيلاندي - الثانيتي المبكر"Selandian-early Thanetian"), وP4c Subzone والذي يتبع زمن (الثانيتى المبكر"early Thanetian"). ثم P5 Zone: والذي يتبع زمن (الثانيتى المتأخر"late Thanetian"). ثم E1-E5 Zones: والتي تتبع الأيوسين المبكر (الإيبريسي "Ypresian"). وقد نوقشت هذة النطاقات وقورنت بمثيلاتها داخل وخارج مصر.

وقد تم دراسة الحدود الفاصلة بين المراحل العمرية المختلفة بالتفصيل وما تحويه من فجوات زمنية خلال ترسيب التتابعات المدروسة، وقد سجل الحد الفاصل بين السيلاندى والثانيتى فى الجزء العلوى من متكون الطروان داخل تحت النطاق الحيوي (P4b) وهذا الحد يتمشى مع السطح الأقصى للغمر (MFS-1) فى التتابع الطبقى الأول (DS1). أما الحد الفاصل بين الباليوسين والإيوسين فيقع داخل متكون الإسنا عند الحد السفلى من عضو محجر الدبابية والذى ينطبق على الحد الفاصل بين النطاقين الحيويين P5/E1 وهذا الحد يتميز بوفرة الأنواع التى تميز النطاقات ذات درجات الحرارة العالية وأيضا يتميز بوجود علاقة عدم توافق لغياب الجزء السفلى المكافئ للطبقات (١-٣) في عضو محجر الدبابية فى القطاع المرجعى بمنطقة الدبابية.

وقد أمكننا إستنتاج بيئات الترسيب للتتابع الصخري المدروس وتفسيرها من خلال دراسة المحتوى الصخري والتحليلات المختلفة لمحتوى الفورامنيفرا مثل (دراسة الأنواع السائدة من الفورامنيفر القاعية و العدد الكلى لأنواع الفورامنيفرا "TFN" ونسب الطافيات الى القاعيات (P/B ratio) والتنوع (species diversity) وأيضا نسب الفورامنيفرا القاعية ذات الجدار الرملى الى الفورامنيفرا القاعية ذات الجدار الكلسى.% .Calc. /Aggl)). وقد أوضحت النتائج أن متكون الطروان ربما قد ترسب في بيئة (inner neritic to upper bathyal environments) وأن العضو السفلى من متكون الإسنا (عضو الهنادي) ربما قد ترسب في بيئة (inner to deep outer neritic environments) وعضو محجر الدبابية ربما قد ترسب في بيئة (inner to middle neritic environments) وعضو المحمية ربما قد ترسب فى بيئة (deep inner to deep outer neritic environments) وأما عضو ابو حاد ربما قد ترسب فى بيئة (deep middle to deep outer neritic environments) بينما الجزء المدروس من متكون طيبة ربما قد ترسب فى بيئة (inner to shallow outer neritic environments). وبناء على التكامل بين دراسات الخواص الصخرية, الطباقية الحيوية, والدراسات الحقلية للأسطح الطباقية لتتابع الباليوسين العلوى وحتى الأيوسين السفلى فى منطقة بئر مارخة أمكننا تقسيم هذا التتابع المدروس الى أربعة تتابعات طباقية ترسيبية (Four depositional sequences (DS) من الرتبة الثالثة (third order sequences) يفصل بينهم أربعة أسطح تمثل فواصل بين هذة التتابعات من النوع الأول (type 1 sequence boundaries (SB)) وذلك فى محاولة منا لتوضيح مدى تغير منسوب سطح البحر فوق منطقة الدراسة خلال الفترة الزمنية المدروسة. إثنان من هذة التتابعات شملتهما رواسب الباليوسين العلوى بينما الإثنين الأخرين فشملتهما رواسب الإيوسين السفلى .وقد تم مناقشة كل الخصائص المميزة لكل تتابع حيث أمكن تقسيم كلا منها بناء على سلوك مستوى سطح البحر النسبى من الإرتفاع والإنخفاض الى فترات من ال (Transgressive systems tracts "TST" وHighstand systems tracts "HST"). وقد تمت مضاهاة هذة التتابعات الطباقية الأربعة المسجلة والربط بين حدودها الفاصلة خلال الفترة الزمنية المدروسة فى منطقة بئر مارخة محليا وعالميا لتوضيح مدى تأثير التذبذب فى مستوى سطح البحر العالمى خلال تكوين هذه التتابعات وحدودها والتى ثبت أن أغلبها مرتبطا بحركة مستوى سطحه.