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YPRESIAN TO PRIABONIAN NANNOFOSSIL BIOSTRATIGRAPHY AND PALAEOECOLOGY, GULF OF SUEZ, EGYPT

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ABSTRACT

The studied succession of the Gulf of Suez consists of three formations: Thebes, Darat and Khaboba from base to top respectively. The examination of the studied samples resulted in identification of 42 calcareous nannoplankton species of NP11 to Np18 zones of Martini (1971). The calcareous nannoplankton taxa used herein to subdivide the studied succession into six nannoplankton biozones which are described in ascending order as *Discoaster binodosus, Tribrachiatus orthostylus, Discoaster lodoensis, Reticulofenestra umbilica, Discoaster saipanensis* and *Chiasmolithus oamaruensis*. Based on the palaeoecological indicator species, the palaeoenvironment of the early-late Eocene succession was distinguished. An oligotrophic palaeoenvironment is inferred for this low to mid latitude early to late Eocene succession.

Keywords: Eocene, lithostratigraphy, biostratigraphy, paleoecology, calcareous nannofossil, Gulf of Suez

INTRODUCTION

The Eocene Epoch is a critical transition period from the global greenhouse conditions of the Late Cretaceous and early Palaeogene to the icehouse state of the late Cenozoic. The lower boundary is marked by a distinct pulse of global warming, the PETM, and the upper boundary by cooling associated with the onset of Antarctic glaciations, with a significant proportion of search focussed on the conditions governing its lower and upper boundaries with the Palaeocene and Oligocene, respectively (Shamrock and Watkins, 2012).

Calcareous nannoplanktons, are strongly influenced by climatic and hydrological conditions. Temperature is the most important factor affecting the distribution of calcareous nannoplankton, but trophic resources also play an important role in the distribution and abundance of calcareous nannoplankton in the past and modern oceans, (Aubry, 1992, 1998; Chepstow-Lusty and Chapman, 1995; Eshet and Almogi-Labin, 1996).

Several recent studies have been conducted on Eocene calcareous nannofossil biostratigraphy and/or palaeoenvironmetnal assemblage trends, producing a wealth of new nannofossil data; however, many of these studies focus on high resolution analyses (Kahn and Aubry, 2004; Egger *et al*., 2005; García-Cordero and Carreño, 2009; Savian *et al*., 2011; Dedert *et al*., 2012; Shamrock and Watkins, 2012; Oszczypko-Clowes and Żydek, 2012).

The aim of this paper is to present a detailed biostratigraphy, based primarily on calcareous nannoplankton of the Eocene age sediments penetrated in the Gulf of Suez, Egypt. The present study indicates the palaeoenvironmental conditions of the studied succession, depending on the quantitative stratigraphic distribution of the calcareous nannoplankton taxa.

GEOLOGICAL SETTING

The Gulf of Suez came into being as a result of tensional movement and subsidence along NW-SE trending normal faults, probably prior to Devonian time (Said, 1963). The Gulf of Suez in Egypt has a north-northwest–south-southeast orientation and is located at the junction of the African and Arabian plates where it separates the northeast African continent from the Sinai Peninsula. The Gulf of Suez is bounded by longitude 32° 10` and 34° E and latitude 27° and 30° N (Fig. 1) and is known as Clysmic Gulf. The length of the Gulf of Suez from the southern tip of the Sinai Peninsula to Suez is about 350 Km. The graben, however, most likely extends from Suez further north to the Mediterranean Sea. This extension is masked by the alluvial and deltaic deposits of Nile, along which the Suez Canal was eventually built. The Gulf is rather shallow and narrow body of water, the average depth is not exceeding 55 m. The overall water covered surface amounts to about 25,000 sq. km. It is bounded by two major sets of marginal faults. Palaeozoic–Tertiary strata and huge Precambrian basement blocks are exposed on both sides of the Gulf of Suez.

MATERIALS AND METHODS

GG 83 -1 borehole of the Gulf of Suez, is located at latitude 28° 47' N and Longitude 32° 55' E (Fig. 1).

This study has been carried out on 23 ditch samples collected from the succession.

These samples were treated to separate the calcareous nannofossils to get an idea about the widespread assemblage in the GG 83 -1 borehole of the Gulf of Suez. The samples were processed as follows: 0.5 gram of sediments was gently disaggregated in a mortar with 10 ml of distilled water. The obtained suspension was agitated several times in a tube and left to settle down for 2 minutes. After this time, permanent slides were prepared using canada balsam by heating on a hot plate. At least three traverses of the slides, corresponding to 450 fields of view, were examined in order to document species richness encountered during the analysis of one slide (Gardin and Monechi, 1998). Smear slides were examined using a light microscope with magnification X 2500 (X 100 oil objective with a X 2.5 additional lens). Relative abundance of each nannofossil species and overall preservation of the nannofossil assemblage, were recorded for each sample. Individual species abundance is represented by the following abbreviations: A = abundant; 11–100 specimens per 10 fields of view (FOV); C = common; 6–10 specimens per 10 FOV; F = few; 1–5 specimens per 10

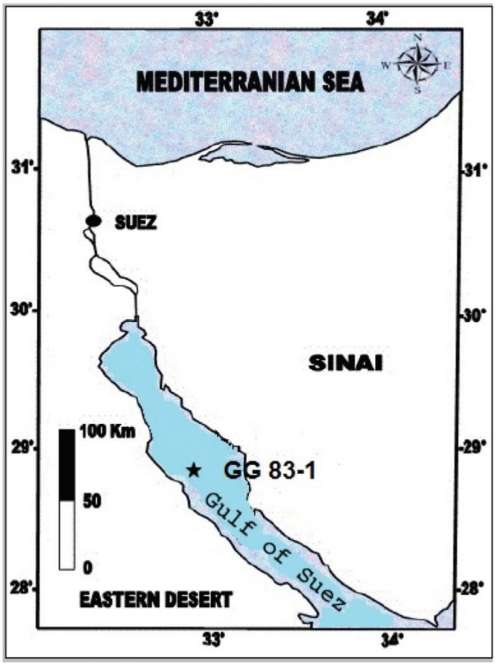

Fig. 1. Location map of the studied borehole.

FOV; and R = rare; 1 specimen per >10 FOV. Preservation of the calcareous nannofossil assemblage was determined as follows: G = good; individual specimens exhibit little or no dissolution or overgrowth; diagnostic characteristics are preserved and nearly all the specimens can be identified; M = moderate; individual specimens show evidence of dissolution or overgrowth; some specimens cannot be identified to the species level; and P = poor; individual specimens exhibit considerable dissolution or overgrowth; many specimens cannot be identified to the species level.

LITHOSTRATIGRAPHY

The studied area was subject to several studies (E.G.P.C, 1964; Mandur and Baioumi , 2013).

Generally, the sequence of the studied succession was subdivided into three formations; these are arranged chronologically as follows:

Thebes Formation : The term Thebes Formation was introduced for the limestone succession that overlies the Esna Formation and underlies the Darat Formation (Said, 1960). In the present study, the Thebes Formation is about 515 feet thick and consists of white to grey limestone, pyrite, chalk, with interbedded sandy limestone and chert. The age of this formation is early Eocene (Ypresian) based on calcareous nannofossils (Fig. 2).

Darat Formation : The Darat Formation is the succession that unconformably overlies the Thebes Formation and underlies the Khaboba Formation (Viotti and Demerdash, 1969). The average thickness of this Formation in the studied area is about 260 feet, which consists of light brown limestone interbedded with brown shales and chert. According to the calcareous nannofossil taxa, it is assigned to middle Eocene (Lutetian–Bartonian) age, (Fig. 2).

Khaboba Formation : The term of Khaboba Formation was introduced by Viotti and Demerdash (1969) for the succession that overlies the Darat Formation and underlies the Tanka

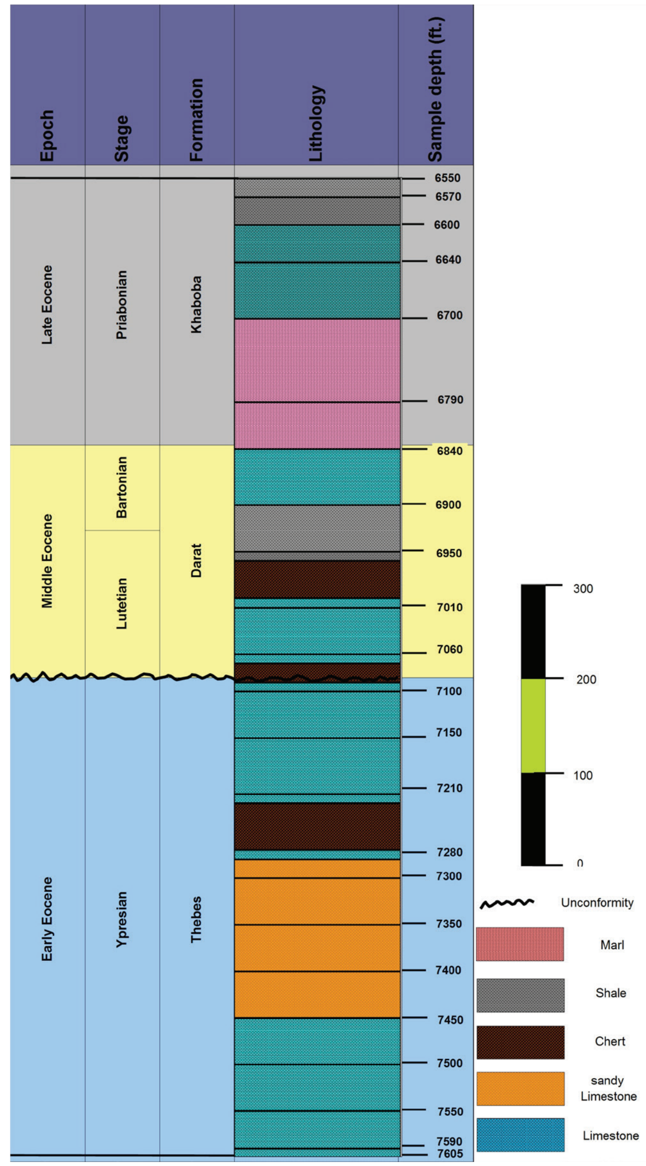

Fig. 2. Lithostratigraphic correlation chart of the studied boreholes.

Formation. The average thickness of this formation in the studied section is about 290 feet. This formation essentially consists of grey marl, green shale and brown limestone. It is assigned to late Eocene (Priabonian) age based on its contents of calcareous nannofossil (Fig.2).

BIOSTRATIGRAPHY

The examination of the Eocene succession has led to the identification of forty-two calcareous nannoplankton species (Fig. 3). Some selected representative index calcareous nannoplankton species are illustrated (Fig.4).

In this study, the nannofossil zonation of Martini (1971), Okada and Bukry (1980) and Varol (1998) is followed. The calcareous nannofossil assemblages from the borehole typically were sufficient in number of specimens, diversity of taxa, and preservation state to allow dating of all the samples.

The following calcareous nannofossil zones were recognized in the studied material from base to top:

Epoch	Stage	Formation	Sample depth	Abundance	Preservation	Total	NP Zones (Martini 1971)	*Neococcolithes dubius*	*Neococcolithus minutus*	*Cribrocentrum reticulatum*	*Transversopontis pulcher*	*Helicosphaera salebrosa*	*Rhabdolithus sp*	*Cruciplacolithus vanhecka*	*Discoaster saipanensis*	*Pontosphaera multipora*	*Ericsonia fenestrata*	*Braarudosphaera alta*	*Helicosphaera salebrosa*	*Lanternithus minutus*	*Dictyococcites scrippsae*	*Braarudosphaera bigelowii*	*Chiasmolithus grandis*	*Micrantholithus altus*	*Sphenolithus furcatolithoides*	*Chiasmolithus nitidus*	*Reticulofenestra umbilica*	*Dictyococcites bisectus*
Late Eocene	Priabonian	Khaboba	6550	F	P	249	NP18	0	0	9	0	8	18	9	12	0	0	0	0	27	8	21	0	0	0	0	22	0
			6570	C	M	295		18	10	50	8	0	26	9	8	21	20	0	0	9	3	0	0	0	0	0	21	8
			6600	F	M	179		0	0	10	0	13	0	0	0	9	0	0	0	0	9	0	0	0	0	0	13	0
			6640	F	P	268		0	0	37	0	0	0	0	1	0	0	40	0	11	12	34	0	0	0	0	9	0
			6700	F	P	231		0	0	13	0	0	10	0	0	0	0	9	0	39	35	32	0	0	0	0	8	12
			6790	C	M	273		0	0	51	12	9	42	0	1	0	0	0	18	34	0	0	0	0	0	0	19	15
Middle Eocene	Bartonian	Darat	6840	C	M	433	NP17	0	0	71	0	9	31	0	0	0	0	38	16	45	9	0	12	18	0	0	7	0
			6900	C	M	342		0	0	0	0	0	13	8	0	0	13	52	9	36	21	16	15	1	0	0	0	0
	Lutetian		6950	C	M	385	NP16	0	0	0	0	0	0	0	0	0	0	0	15	34	9	15	17	18	0	15	33	0
			7010	C	M	462		0	0	0	0	0	24	8	15	9	47	12	12	31	7	36	0	0	9	0	24	0
			7060	C	M	333		0	0	0	0	0	0	0	0	0	0	0	0	0	9	47	0	0	11	8	13	6
Early Eocene	Ypresian	Thebes	7100	R	P	162	NP13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0
			7150	R	P	193		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			7210	R	P	218		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			7280	R	P	224		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			7300	R	P	103	NP12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			7350	R	P	77		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			7400	R	P	174		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			7450	F	P	194		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			7500	R	P	123		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			7550	R	P	236		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			7590	R	P	59	NP11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			7605	C	P	172		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Sample depth	*Micrantholithus spp.*	*Reticulofenestra dictyoda*	*Helicosphaera seminulum*	*Helicosphaera lophota*	*Discoaster spp.*	*Zygrhablithus bijugatus*	*Discoaster barbadiensis*	*Chiasmolithus solitus*	*Toweius crassus*	*Lophodolithus nascens*	*Pontosphaera spp.*	*Discoaster kuepperi*	*Discoaster lodoensis*	*Ericsonia ovalis*	*Sphenolithus moriformis*	*Thoracosphaera spp.*	*Discoaster binodosus*	*Sphenolithus radians*	*Tribrachiatus orthostylus*	*Chiasmolithus consuetus*	*Sphenolithus primus*
6550	0	0	0	0	23	31	18	0	0	0	8	0	0	17	18	0	0	0	0	0	0
6570	9	0	0	0	9	25	0	0	0	0	0	0	0	33	0	8	0	0	0	0	0
6600	0	0	0	0	11	25	0	0	0	0	11	0	0	36	33	9	0	0	0	0	0
6640	34	0	0	0	0	44	0	0	0	0	0	0	0	37	0	9	0	0	0	0	0
6700	0	0	0	0	0	42	0	0	0	0	0	0	0	31	0	0	0	0	0	0	0
6790	0	0	0	0	0	49	9	0	0	0	43	0	0	37	34	0	0	0	0	0	0
6840	12	0	0	24	0	43	0	0	0	0	8	0	0	41	47	2	0	0	0	0	0
6900	9	0	0	9	0	32	18	0	0	0	9	0	0	36	32	13	0	0	0	0	0
6950	9	36	14	0	0	48	0	11	0	0	13	0	0	46	43	9	0	0	0	0	0
7010	0	39	0	0	29	39	10	49	0	0	0	0	0	30	32	0	0	0	0	0	0
7060	51	45	9	23	0	4	0	12	0	0	47	0	0	39	0	9	0	0	0	0	0
7100	0	0	0	0	0	30	9	13	0	0	0	0	0	38	34	17	0	0	0	9	0
7150	0	0	0	0	9	0	8	0	11	0	13	6	12	40	42	37	15	0	0	0	0
7210	0	0	0	0	6	48	8	11	24	0	0	0	0	29	28	8	0	39	0	17	0
7280	0	0	0	0	13	25	9	15	12	8	0	7	5	30	19	14	9	49	0	9	0
7300	0	0	0	0	0	0	0	0	0	0	13	18	0	21	14	0	15	9	13	0	0
7350	0	0	0	0	0	0	0	0	0	0	21	16	9	13	11	0	0	0	7	0	0
7400	0	0	0	0	0	0	0	0	0	0	19	17	13	0	36	13	39	0	37	0	0
7450	0	0	0	0	0	0	0	0	0	0	36	14	48	35	11	15	9	16	10	0	0
7500	0	0	0	0	0	0	0	0	0	0	9	18	15	19	19	0	7	15	21	0	0
7550	0	0	0	0	0	0	0	0	0	0	9	13	38	16	45	15	23	46	31	0	0
7590	0	0	0	0	0	0	0	0	0	0	0	0	0	9	13	0	0	0	18	0	19
7605	0	0	0	0	0	0	0	0	0	0	0	0	0	46	40	9	8	31	13	7	18

Fig. 3. Calcareous nannofossil assemblage abundance, preservation and species richness data from the studied succession.

***Discoaster binodosus* zone (NP11)**

Definition: Interval from the last occurrence (LO) of *Tribrachiatus contortus* to the first occurrence (FO) of *Discoaster lodoensis*.

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

Age: Early Eocene (Ypresian)

Nannofloral association: The calcareous nannofossil assemblages are poorly preserved and rare to abundant. The characteristic nannofossils of this zone include: *Tribrachiatus orthostylus, Discoaster binodosus, Sphenolithus moriformis, S. radians, S. primus, Ericsonia ovalis, Dictyococcites scrippsae, Thoracosphaera sp* and *Chiasmolithus consuetus.*

Occurrence: The *Discoaster binodosus* zone (NP11) is recorded from the studied borholes in the Thebes Formation and it attains a thickness of about 15 feet (Fig. 3).

Remarks: The lower boundary of *Discoaster binodosus* zone (NP11) was represented by the occurrence of *Tribrachiatus orthostylus* and last occurrence of *Tribrachiatus contortus* and its upper boundary is marked by the first occurrence *Discoaster lodoensis* . Shamrock and Watkins (2012) and Agnini *et al.* (2007) have proposed the FO of *Sphenolithus radians* as an alternate marker for the base of NP11. The *S. radians* was observed in the same sample depth 7605 as the occurrence of *T. orthostylus*. This zone is correlated with the standard *Discoaster binodosus* zone (Martini,1971; Okada and Bukry,1980; Tantawy, 2006; Faris and Abu Shama, 2007; Mandur, 2010; Stassen *et al*., 2012; Faris *et al.*, 2014) and *Sphenolithus radians* Zone NNTe1 Zone of Varol (1998) (Fig. 5).

***Tribrachiatus orthostylus* Zone (NP12)**

Definition: Interval from the FO of *Discoaster lodoensis* to the LO of *Tribrachiatus orthostylus*

Authors: (Brönnimann and Stradner, 1960; Bukry, 1973)

Age: Early Eocene (Ypresian)

Nannofloral association: Poor preservation and rare calcareous nannofossil assemblages were recorded in this zonal interval.The most common coccolith assemblage encountered in this zone includes: *Tribrachiatus orthostylus, Discoaster binodosus, D. lodoensis, D. kuepperi* , *Thoracosphaera* spp., *Sphenolithus moriformis, S. radians, Pontosphaera* spp. *and Ericsonia ovalis.*

Occurrence: This zone is recorded within the Thebes Formation with thickness of about 290 feet (Fig. 3)

Remarks: The lower boundary of the *Tribrachiatus orthostylus* Zone (NP12) is marked by the first appearance of *Discoaster lodoensis* and its upper boundary marked by the last occurrence of the *Tribrachiatus orthostylus*. Perch Nielsen (1985) defined this zone by the occurrence of *Discoaster kuepperi* which is concurrent with the *Discoaster lodoensis*. Bukry (1973) defined the top of NP12 by the First occurrence of *Toweius crassus*. He mentioned that the stratigraphic range of *T. orthostylus* is high in the middle Eocene *Nannotetrina fulgens* Zone, but Aubry (1996) considered the occurrence of *Tribrachiatus orthostylus* as reworked species. This zone equates with that of Martini (1971) and Okada and Bukry (1980) and NNTe2- NNTe5 (Varol, 1998) (Fig. 5). It corresponds to that of Stassen *et al.* (2012) and Shamrock and Watkins (2012).

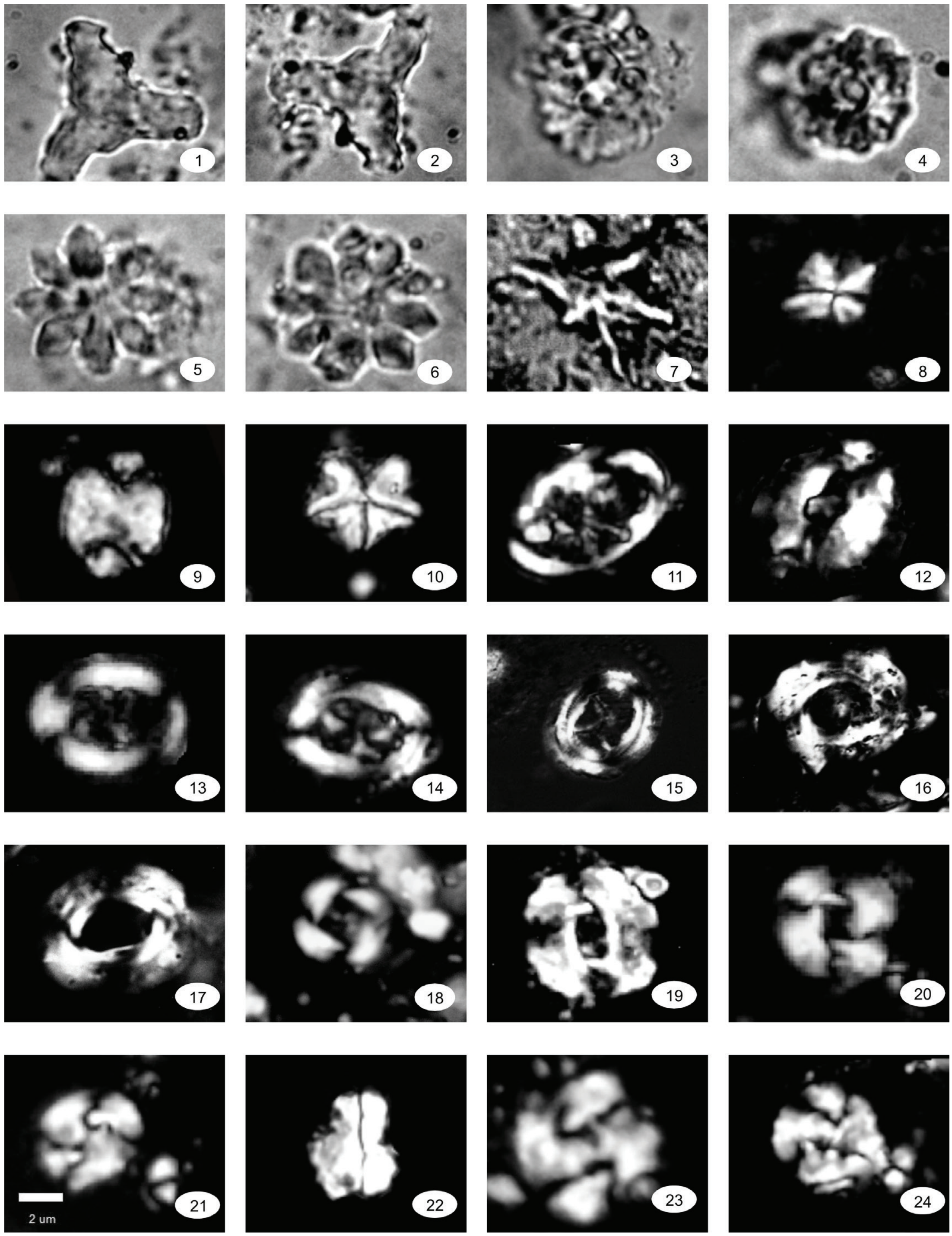

Fig. 4. Some Calcareous nannofossil Eocene species in the studied succession. 1,2 : *Tribrachiatus orthostylus* (Shamrai, 1963).Sample 7590, *Discoaster binodosus* zone (NP11). 3, 4: *Discoaster barbadiensis* (Tan, 1927). Sample 6550 *, Chiasmolithus oamaruensis zone* (NP18). 5, 6 :*Discoaster saipanensis* (Bramlette and Riedel, 1954). Sample 6640 *, Chiasmolithus oamaruensis zone* (NP18). 7: *Discoaster lodoensis* (Bramlette and Riedel, 1954). Sample 7550, *Tribrachiatus orthostylus zone* (NP12). 8: *Sphenolithus moriformis* (Perch-Nielsen, 1971). Sample 7605, *Discoaster binodosus* zone (NP11). 9: *Pontosphaera multipora* (Roth, 1970). Sample 7010, *Discoaster tanii nodifer* zone (NP16). 10: *Micrantholithus altus* (Bybell and Gartner, 1972). Sample 6950, *Discoaster tanii nodifer* zone (NP16). 11: *Lophodolithus nascens* (Bramlette and Sullivan, 1961) .Sample 7450, *Discoaster lodoensis* zone (NP13). 12: *Helicosphaera seminulum* (Bramlette and Sullivan, 1961). Sample 6950, *Discoaster tanii nodifer* zone (NP16). 13: *Chiasmolithus consuetus* (Hay and Mohler, 1967). Sample 7605, *Discoaster binodosus* zone (NP11). 14: *Chiasmolithus solitus* (Locker, 1968). Sample 7010 , *Discoaster tanii nodifer* zone (NP16). 15 : *Chiasmolithus grandis* (Bramlette and Riedel, 1954).Sample 6900, *Discoaster saipanensis* zone (NP17). 16, 17: *Reticulofenestra umbilica* (Martini and Ritzkowski, 1968).Sample 7060, *Discoaster tanii nodifer* zone (NP16). 18 : *Cribrocentrum reticulatum* (Perch- Nielsen, 1971). Sample 6840, *Discoaster saipanensis* zone (NP17). 19, 20: *Reticulofenestra dictyoda* (Stradner and Edwards, 1986). Sample 7060, *Discoaster tanii nodifer* zone (NP16). 21: *Dictyococcites bisectus* (Bukry and Percival, 1971).Sample 6570 , *, Chiasmolithus oamaruensis zone* (NP18). 22: *Zygrhablithus bijugatus* (Deflandre, 1959).Sample 7500 , *Discoaster lodoensis* zone (NP13). 23, 24: *Dictyococcites scrippsae* (Bukry and Percival, 1971).Sample 6950 , *Discoaster tanii nodifer* zone (NP16).

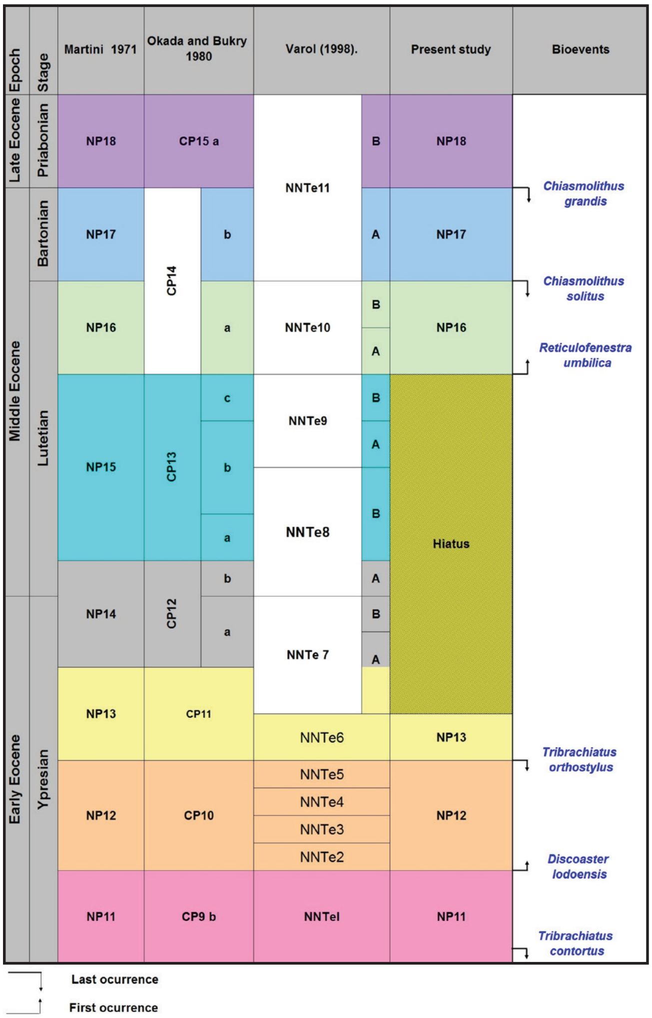

Fig. 5. Standard calcareous nannofossil biostratigraphy and calcareous nannofossil bioevents in this study.

***Discoaster lodoensis* zone (NP13)**

Definition: Interval from the LO of *Tribrachiatus orthostylus* or FO of *Toweius crassus* to the FO of *Discoaster sublodoensis*.

Authors: (Brönnimann and Stradner, 1960; Bukry, 1973)

Age: Early Eocene (Ypresian)

Nannofloral association: Poorly preserved and rare. Diversified assemblage are recorded in the *Discoaster lodoensis* zone (NP13). It is characterized by: *Ericsonia ovalis, Discoaster* spp., *D. lodoensis, D. binodosus, D. barbadiensis, D. kuepperi, Zygrhablithus bijugatus, Pontosphaera* spp., *Sphenolithus moriformis, S. radians, Thoracosphaera spp., Chiasmolithus solitus, Chiasmolithus consuetus, Toweius crassus and Lophodolithus nascens.*

Occurrence: This zone is recorded in the studied borehole within the Thebes Formation and it attains thickness of about 200 feet (Fig. 3).

Remarks: The lower boundary of this zone is drawn by LO of *Tribrachiatus orthostylus* and FO of *Toweius crassus* The upper boundary of this zone is not delineated owing to the absence of the marker species *Discoaster sublodoensis*. This zone correlates with the lower part of the NP13 Zone (Martini, 1971) and the lower part of the Zone CP11 (Okada and Bukry,1980) and *Imperiaster obscurus* Zone NNTe6 of Varol (1998) (Fig. 5). The *Discoaster lodoensis* zone is equivalent to that of (Faris and Abu Shama, 2007; Stassen *et al*., 2012; Shamrock and Watkins, 2012).

***Reticulofenestra umbilica* Zone (NP16)**

Definition: Interval from LO of *Rhabdolithus gladius* to LO of *Chiasmolithus solitus*.

Authors: (Perch-Nielsen, 1972).

Age: Middle Eocene (Lutetian)

Nannofloral association: The most common and moderate coccolith species encountered in this zone include: *Chiasmolithus solitus, Ch. nitidus, Ch. grandis, Sphenolithus furcatolithoides, S. moriformis, Micrantholithus* spp., *M. altus, Helicosphaera lophota, H. salebrosa, H. seminulum, Braarudosphaera alta, B. bigelowii, Reticulofenestra dictyoda, R. umbilica, Thoracosphaera* spp., *Dictyococcites bisectus, D. scrippsae, Pontosphaera* spp., *P. multipora, Discoaster* spp., *D. barbadiensis, D. saipanensis, Calcidiscus protoannulus, Rhabdolithus* spp., *Lanternithus minutus, Ericsonia ovalis, E. fenestrata* and *Zygrhablithus bijugatus.*

Occurrence: Within the Darat Formation in the studied borehole with thickness of about 150 feet (Fig. 3), *Reticulofenestra umbilica* Zone (NP16) unconformably overlies the early Eocene *Discoaster lodoensis* zone (NP13). The *Reticulofenestra umbilica* zone (NP16) is located at the base of the Darat Formation, so the hiatus occurs in the Thebes Formation in the studied borehole where the two nannofossil zones *Discoaster sublodoensis* zone (NP14) and *Nannotetrina fulgens* zone (NP15) are missing. This hiatus corresponds with the global hiatus (Poag *et al*., 1985; Olsson *et al*., 1988).

Remarks: The lower boundary of the *Reticulofenestra umbilica* zone (NP16) is indicated by the FO *Reticulofenestra umbilica* and the upper boundary of the zone is delineated by the LO of *Chiasmolithus sollitus.* This zone is equivalent to the *Sphenolithus furcatolithoides* Zone (Gartner, 1971), NP13 Zone (Martini, 1971), the Zone CP14a (Okada and Bukry, 1980) and *Chiasmolithus solitus* Zone (NNTe10 of Varol,1998) (Fig. 5). This zone corresponds to that of Wei and Wise (1989); Xu and Wise (1992); Jovane *et al*. (2007); Fornaciari *et al*. (2010); Shamrock and Watkins (2012) and Ozdinova (2013).

***Discoaster saipanensis* zone (NP17)**

Definition: The interval from LO of *Chiasmolithus solitus* to the FO of *C. oamaruensis*.

Authors: (Martini, 1970)

Age: Middle Eocene (Bartonian)

Nannofloral association: The calcareous nannofossil assemblages are moderately preserved and common to abundant in the *Discoaster saipanensis* Zone. The characteristic nannofossils of this zone include: *Micrantholithus altus, Chiasmolithus grandis, Helicosphaera lophota, Helicosphaera salebrosa, Braarudosphaera alta, Ericsonia fenestrata, Micrantholithus* spp., *Discoaster barbadiensis, Reticulofenestra umbilica, Helicosphaera salebrosa, Braarudosphaera bigelowii, Rhabdolithus* spp., *Dictyococcites scrippsae, Sphenolithus moriformis, Lanternithus minutus, Pontosphaera* spp., *Thoracosphaera* spp., *Cribrocentrum reticulatum, Zygrhablithus bijugatus and Ericsonia ovalis.*

Occurrence: This *Discoaster saipanensis* zone (NP17) is recorded in the studied borehole within the Darat Formation with thickness of about 110 feet (Fig. 3).

Remarks: The last occurrence *Chiasmolithus solitus* marks the base of both CP14b and NP17 and the upper boundary of the Zone is delineated by the last occurrence of *Chiasmolithus*

Epoch	Stage	Formation	Sample depth (feet)	NP Zones (Martini 1971)	Cold water							Warm water																		Temprate water				*Helicosphaera* spp.				*Sphenolithus* spp.					*Reticulofenestra* spp.			
					Chiasmolithus grandis	*Chiasmolithus nitidus*	*Chiasmolithus solitus*	*Chiasmolithus consuetus*	*Ericsonia fenestrata*	*Lanternithus minutus*	Total	*Discoaster* spp.	*Discoaster saipanensis*	*Discoaster barbadiensis*	*Discoaster binodosus*	*Discoaster kuepperi*	*Discoaster lodoensis*	*Helicosphaera lophota*	*Helicosphaera salebrosa*	*Helicosphaera seminulum*	*Sphenolithus moriformis*	*Sphenolithus furcatolithoides*	*Sphenolithus primus*	*Sphenolithus radians*	*Pontosphaera multipora*	*Pontosphaera* spp.	*Thoracosphaera* spp.	*Zygrhablithus bijugatus*	Total	*Dictyococcites scrippsae*	*Reticulofenestra umbilica*	*Dictyococcites bisectus*	Total	*Helicosphaera lophota*	*Helicosphaera salebrosa*	*Helicosphaera seminulum*	Total	*Sphenolithus moriformis*	*Sphenolithus furcatolithoides*	*Sphenolithus radians*	*Sphenolithus primus*	Total	*Reticulofenestra dictyoda*	*Reticulofenestra umbilica*	Total	*Dictyococcites bisectus*
Late Eocene	Priabonian	Khaboba	6550	NP18	0	0	0	0	0	27	27	23	12	18	0	0	0	0	8	0	18	0	0	0	0	8	0	31	118	8	22	0	30	0	8	0	8	18	0	0	0	18	0	22	22	0
			6570		0	0	0	0	20	9	29	9	8	0	0	0	0	0	0	0	0	0	0	0	21	0	8	25	71	3	21	8	32	0	0	0	0	0	0	0	0	0	0	21	21	8
			6600		0	0	0	0	0	0	0	11	0	0	0	0	0	0	13	0	33	0	0	0	9	11	9	25	111	9	13	0	22	0	13	0	13	33	0	0	0	33	0	13	13	0
			6640		0	0	0	0	0	11	11	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	9	44	54	12	9	0	21	0	0	0	0	0	0	0	0	0	0	9	9	0
			6700		0	0	0	0	0	39	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	42	35	8	12	55	0	0	0	0	0	0	0	0	0	0	8	8	12
			6790		0	0	0	0	0	34	34	0	1	9	0	0	0	0	9	0	34	0	0	0	0	43	0	49	145	0	19	15	34	0	9	0	9	34	0	0	0	34	0	19	19	15
Middle Eocene	Bartonian	Darat	6840	NP17	12	0	0	0	0	45	57	0	0	0	0	0	0	24	9	0	47	0	0	0	0	8	2	43	133	9	7	0	16	24	9	0	33	47	0	0	0	47	0	7	7	0
			6900		15	0	0	0	13	36	64	0	0	18	0	0	0	9	0	0	32	0	0	0	0	9	13	32	113	21	0	0	21	9	0	0	9	32	0	0	0	32	0	0	0	0
	Lutetian		6950	NP16	17	15	11	0	0	34	77	0	0	0	0	0	0	0	0	14	43	0	0	0	0	13	9	48	127	9	33	0	42	0	0	14	14	43	0	0	0	43	36	33	69	0
			7010		0	0	49	0	47	31	127	29	15	10	0	0	0	0	0	0	32	9	0	0	9	0	0	39	143	7	24	0	31	0	0	0	0	32	9	0	0	41	39	24	63	0
			7060		0	8	12	0	0	0	20	0	0	0	0	0	0	23	0	9	0	11	0	0	0	47	9	4	103	9	13	6	28	23	0	9	32	0	11	0	0	11	45	13	58	6
Early Eocene	Ypresian	Thebes	7100	NP13	0	0	13	9	0	0	22	0	0	9	0	0	0	0	0	0	34	12	0	0	0	0	17	30	102	0	0	0	0	0	0	0	0	34	12	0	0	46	0	0	0	0
			7150		0	0	0	0	0	0	0	9	0	8	15	6	12	0	0	0	42	0	0	0	0	13	37	0	142	0	0	0	0	0	0	0	0	42	0	0	0	42	0	0	0	0
			7210		0	0	11	17	0	0	28	6	0	8	0	0	0	0	0	0	28	0	0	39	0	0	8	48	137	0	0	0	0	0	0	0	0	28	0	39	0	67	0	0	0	0
			7280		0	0	15	9	0	0	24	13	0	9	9	7	5	0	0	0	19	0	0	49	0	0	14	25	150	0	0	0	0	0	0	0	0	19	0	49	0	68	0	0	0	0
			7300	NP12	0	0	0	0	0	0	0	0	0	0	15	18	0	0	0	0	14	0	0	9	0	13	0	0	69	0	0	0	0	0	0	0	0	14	0	9	0	23	0	0	0	0
			7350		0	0	0	0	0	0	0	0	0	0	0	16	9	0	0	0	11	0	0	0	0	21	0	0	57	0	0	0	0	0	0	0	0	11	0	0	0	11	0	0	0	0
			7400		0	0	0	0	0	0	0	0	0	0	39	17	13	0	0	0	36	0	0	0	0	19	13	0	137	0	0	0	0	0	0	0	0	36	0	0	0	36	0	0	0	0
			7450		0	0	0	0	0	0	0	0	0	0	9	14	48	0	0	0	11	0	0	16	0	36	15	0	149	0	0	0	0	0	0	0	0	11	0	16	0	27	0	0	0	0
			7500		0	0	0	0	0	0	0	0	0	0	7	18	15	0	0	0	19	0	0	15	0	9	0	0	83	0	0	0	0	0	0	0	0	19	0	15	0	34	0	0	0	0
			7550		0	0	0	0	0	0	0	0	0	0	23	13	38	0	0	0	45	0	0	46	0	9	15	0	189	0	0	0	0	0	0	0	1	45	0	46	0	91	0	0	0	0
			7590	NP11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	19	0	0	0	0	0	32	0	0	0	0	0	0	0	0	13	0	0	19	32	0	0	0	0
			7605		0	0	0	7	0	0	7	0	0	0	8	0	0	0	0	0	40	0	18	31	0	0	9	0	106	0	0	0	0	0	0	0	0	40	0	31	18	89	0	0	0	0

Fig. 6. Calcareous nannofossil cold water, warm water, temperate water, *Helicosphaera* spp., *Sphenolithus* spp., *Reticulofenestra* spp. and *Dictyococcites bisectus* species richness data from the studied borehole.

grandis (Martini, 1971; Okada and Bukry, 1980) and the *Chiasmolithus grandis* Zone NNTe11A of Varol (1998) (Fig 5). This zone is equivalent to the *Discoaster saipanensis* zone (Xu and Wise, 1992; Fornaciari *et al*., 2010; Shamrock and Watkins, 2012; Ozdinova, 2013; Pérez Panera, 2013). Tremolada and Bralower (2004) suggested that the occurrence of *C. solitus* was common in high latitudes but rare and sporadic in lower latitudes. The LO of *Discoaster bifax* (Bukry and Percival, 1971) has also been used to mark the base of CP14b.

***Chiasmolithus oamaruensis* Zone (NP18)**

Definition: Interval from FO of *Chiasmolithus oamaruensis* to the FO of *Isthmolithus recurvus*.

Authors: (Matini ,1970)

Age: Late Eocene (Priabonian)

Nannofloral association: Moderate to poor preservation and common to few calcareous nannofossil taxa were recorded in this zonal interval. The *Chiasmolithus oamaruensis* Zone is characterized by the occurrence of assemblage of the previous zone in addition to the taxa listed herein: *Transversopontis pulcher, Neococcolithus minutus, Dictyococcites bisectus, Pontosphaera multipora, Neococcolithes dubius, Discoaster saipanensis* and *Calcidiscus protoannulus.*

Occurrence: The *Chiasmolithus oamaruensis* Zone (NP18) is recorded in the studied borehole within the Khaboba Formation and it attains thickness of about 290 feet (Fig. 3).

Remarks: The base of the *Chiasmolithus oamaruensis* Zone (NP18) is marked by the LO *Chiasmolithus grandis* and the absence of *Isthmolithus recurvus*. Perch-Nielsen (1971) and Okada and Bukry (1980) defined the base of this zone by the LO of *Chiasmolithus grandis*, while Martini (1971) and Varol (1998) defined the base of this zone by FO of *Chiasmolithus oamaruensis* (Fig 5). This zone is correlated with zonal indices described by Wei and Wise (1989); Jovane *et al*. (2007); Fornaciari *et al*. (2010); Shamrock and Watkins (2012) and Ozdinova (2013).

PALAEOECOLOGY

Calcareous nannoplankton are largely controlled by temperature and water mass conditions (Winter and Sisser, 1994; Persico and Villa, 2004) therefore they react to climate fluctuations as well as variation in surface water conditions. Haq and Lohman (1976) showed a relationship between calcareous nannofossil assemblages and latitude. So calcareous nannofossils have been used as proxies for palaeoenvironmental reconstruction and palaeoceanography.

Calcareous nannoplankton were subdivided into four groups according to the characterization of palaeoecological

Epoch	Stage	Formation	Sample depth (feet)	NP Zones (Martini 1971)	Cold water%	Temeprate water %	Warm water %	*Helicosphaera* spp. %	*Sphenolithus* spp.%	*Reticulofenestra* spp.%	*Dictyococcites bisectus* %
Late Eocene	Priabonian	Khaboba	6550	NP18	0.11	0.12	0.46	0.03	0.07	0.09	0
			6570		0.1	0.11	0.23	0	0	0.07	0.03
			6600		0	0.12	0.59	0.07	0.18	0.07	0
			6640		0.04	0.09	0.2	0	0	0.05	0
			6700		0.16	0.18	0.19	0	0	0.03	0.05
			6790		0.11	0.37	0.39	0.02	0.12	0.04	0.04
Middle Eocene	Bartonian	Darat	6840	NP17	0.13	0.04	0.3	0.08	0.1	0.02	0
			6900		0.18	0.06	0.33	0.03	0.09	0	0
	Lutetian		6950	NP16	0.2	0.11	0.33	0.04	0.11	0.18	0
			7010		0.26	0.06	0.3	0	0.08	0.13	0
			7060		0.06	0.08	0.31	0.1	0.03	0.17	0.03
Early Eocene	Ypresian	Thebes	7100	NP13	0.13	0	0.62	0	0.3	0	0
			7150		0	0	0.73	0	0.22	0	0
			7210		0.13	0	0.62	0	0.31	0	0
			7280		0.1	0	0.66	0	0.3	0	0
			7300	NP12	0	0	0.67	0	0.25	0	0
			7350		0	0	0.74	0	0.22	0	0
			7400		0	0	0.78	0	0.21	0	0
			7450		0	0	0.77	0	0.14	0	0
			7500		0	0	0.67	0	0.27	0	0
			7550		0	0	0.66	0	0.39	0	0
			7590	NP11	0	0	0.54	0	0.54	0	0
			7605		0.04	0	0.61	0	0.51	0	0

Fig. 7. Percentage distribution of palaeocological indicator of the studied succession.

preferences:

1. Cool water taxa, (abundant in eutrophic, high-latitude environments), included *Chiasmolithus* spp. group, *Ericsonia fenestrata* and *Lanternithus minutus* (Persico and Villa, 2004; Oszcypko-Clowes and Zydek, 2012) (Fig. 6).
2. Warm water taxa comprise *Discoaster* spp. group, *Helicosphaera* spp. group, *Sphenolithus* spp. group, *Pontosphaera* spp. group, *Thoracosphaera* spp. group and *Zygrhablithus bijugatus*. This group appears to have tolerated warm and oligotrophic conditions (Wei and Wise, 1990; Villa *et al*., 2008; Oszcypko-Clowes and Zydek, 2012) (Fig. 6).
3. Temperate water taxa include the *Dictyococcites scrippsae*, *Reticulofenestra umbilica* and *Dictyococcites bisectus.* The higher warming response is suggested by higher percentage of temperate–water taxa and by the presence of warm water taxa (Wei *et al*., 1992; Monechi *et al*., 2000) (Fig. 6).
4. No temperate – water taxa which included all the species not included in the previous groups (Wei and Wise, 1990).

Helicosphaera group appears to thrive in shallow eutrophic environments, with enhanced abundances in hemipelagic, near continental environment (Perch-Nielsen, 1985), upwelling regions and gyre margin waters with high fertility (Girandeau ,1992). Reticulofenestrids were documented to dominate the nannoflora along continental margins (Haq, 1980) representing eutrophic environments due to continental run off and/ or river in put.

Sphenolithus spp. are thought to be dissolution-resistant taxa (Kahn and Aubry, 2004; Aubry and Bord, 2009) and generally show common to abundant presence in low to middle latitudes. This biogeographic distribution suggests that *Sphenolithus* spp. are a warm-water indicator (Wei and Wise, 1990). A dominance of *Sphenolithus* group is usually noticed in warm water, oligotrophic stable environments (Aubry, 1992; Agnini *et al*., 2007; Fornaciari *et al*., 2010). The abundance of *Zygrhablithus bijugatus* is interpreted as an indication of oligotrophic conditions (Agnini *et al*., 2007; Gibbs *et al*., 2006). This taxon has been interpreted as a warm water taxon (Kahn and Aubry, 2004).

DISCUSSION

In the time interval examined here, several palaeoclimatic events have been highlighted by means of the alternating dominance of the palaeoecological indicator groups delineated above.

1. Early Eocene phase

During early Eocene, the studied succession is characterized by high percentage of warm water (64%), cold water species (3%), *Sphenolithus* spp. (35%) (Figs 7, 8). Accordingly, high percentage of warm water species and *Sphenolithus* spp. in the early Eocene was interpreted for oligotrophic stable environment (Aubry, 1992) and low latitude with deeper marine conditions (Wei *et al.*, 1992), (Figs 4,5).

2. Middle Eocene phase

The Middle Eocene is characterized by high diversity of warm water species (31%), cold water (17%), temperate water (7%), *Helicosphaera* spp. (5%), *Sphenolithus* spp. (8%), *Reticulofenestra* spp. (8%) and *Dictyococcites bisectus 0.6%* (Figs. 7, 8). The assemblages of the Middle Eocene reflected oligotrophic environments and mid to low latitude.

3. Late Eocene phase

The assemblage of the Late Eocene NP 18 was characterized by high abundance of warm water species (34%), temperate water species (17%), cold water species (9%), *Helicosphaera* spp. (2%), *Sphenolithus* spp. 6%, *Reticulofenestra* spp. 6% and *Dictyococcites bisectus* 2% (Figs. 7, 8). The higher percentage of warm water taxa and temperate water taxa reflected the greater warming responses, oligotrophic environment and low latitude.

Similar to this study, several authors recorded warming events and oligotrophic conditions of the early - middle Eocene

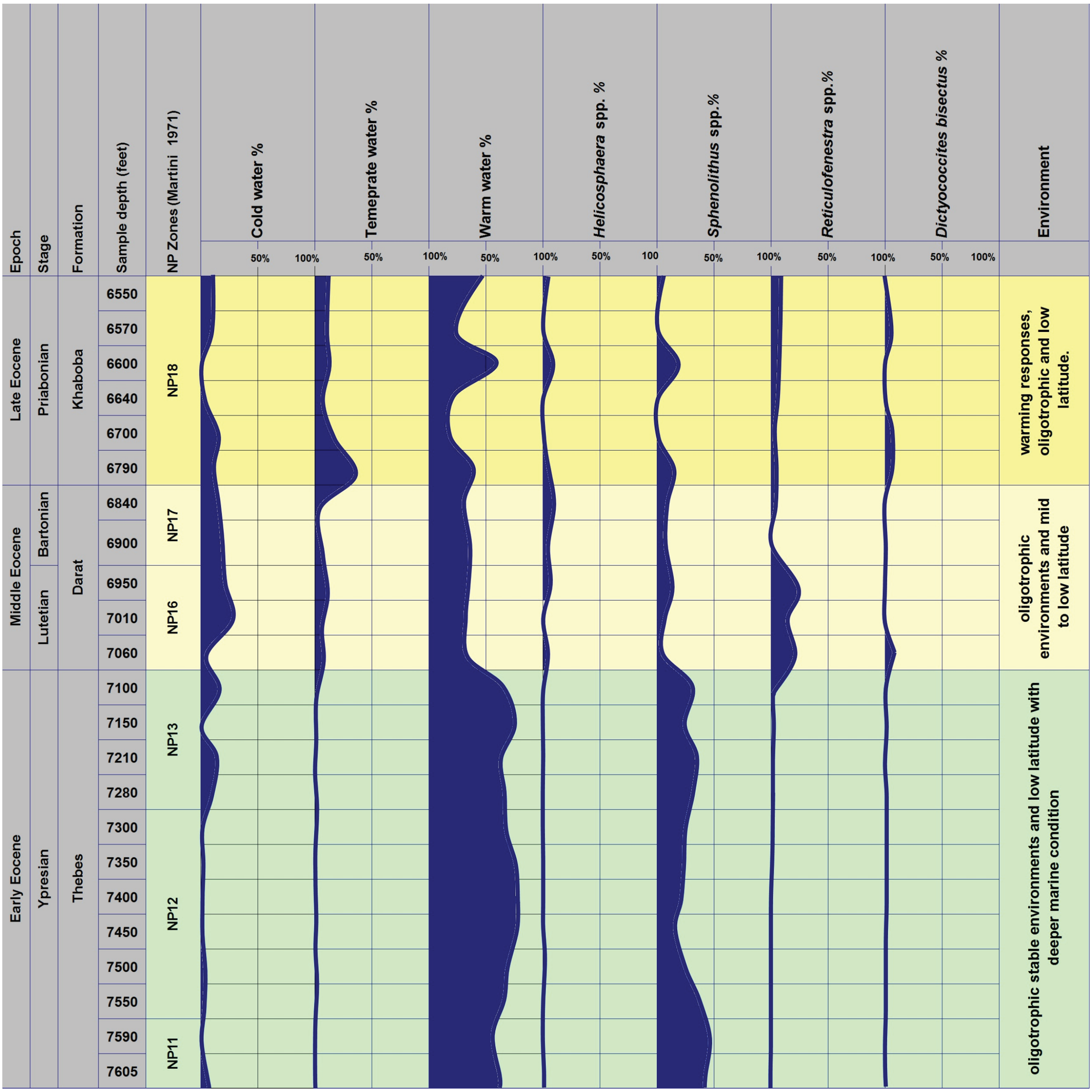

Fig. 8. Percentage distribution pattern of palaeocological indicator of the studied succession.

phases (Perch-Nielsen,1985; Jiang and Wise, 2009; Dedert et al., 2012).The largest event was the Palaeocene –Eocene Thermal Maximum (PETM) (Egger *et al*., 2005; Westerhold *et al*., 2009). Alternating dominances of cool water taxa occurred in the latest Eocene, indicating a cooling trend before the main cooling event of the earliest Oligocene (Persico and Villa, 2004).

CONCLUSTIONS

The early–late Eocene succession of GG 83 -1 borehole in the Gulf of Suez includes three formations, from top to base, these are: Thebes, Darat and Khaboba. 42 calcareous nannoplankton species from the studied succession allow to subdivide the succession into six calcareous nannoplankton biozones, these are described in ascending order as: *Discoaster binodosus* zone NP11, *Tribrachiatus orthostylus* zone NP12, *Discoaster lodoensis* zone NP13, *Discoaster tanii nodifer* zone NP16, *Discoaster saipanensis* zone NP17 and *Chiasmolithus oamaruensis zone* NP18. According to statistical data on the constitution of the identified calcareous nannoplankton, the palaeoecologic conditions of the studied succession were deduced. The palaeoecologic indicators (cool, warm and temperate water species) were investigated and discussed for the studied succession; and the environment deduced as follows: Early Eocene was oligotrophic with stable environments and low latitude with deeper marine conditions, Middle Eocene environment was oligotrophic and mid to low latitude and Late Eocene oligotrophic, with low latitude and deeper marine environments.

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