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Calcareous nannofossil bioevents at the Palaeocene/Eocene boundary in the Kharga Oasis, Western Desert of Egypt

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Abstract

Two upper Palaeocene – lower Eocene stratigraphic sequences at the Kharga Oasis (Umm El Ghanayim and Naqb Assiut sections) were studied biostratigraphically on the basis of their calcareous nannofossil content. The investigated interval includes the upper part of the Tarawan Formation, the Tarawan Chalk, and the Esna formations. A total number of sixty-seven different taxa have been identified. The lowest occurrence (LO) of *Discoaster araneus* was used to place the base of the NP9b Subzone (base of Eocene) at the Gabal Umm El Ghanayim section. The lowest occurrences (LOs) of *Rhomboaster bitrifida, Discoaster araneus* and *D. anartios* are used to define the NP9a/NP9b subzonal boundary at the Gabal Naqb Assiut section. In this section, the P/E boundary is marked by a minor lithologic hiatus as indicated by the absence of the basal part of the Dababiya Member.

At the studied two sections, a major turnover in calcareous nannofossil assemblages across the P/E transition was documented. The abundance of warm water *Ericsonia subpertusa*, *Fasculithus* spp., *Coccolithus eopelagicus, Discoaster* spp., *Rhomboaster bitrifida* and *Tribrachiatus bramlettei* characterize the Palaeocene-Eocene transition and suggest global warming and the Palaeocene – Eocene Thermal Maximum (PETM).

Keywords: Calcareous nannofossils, Palaeocene/Eocene boundary, Kharga Oasis, Western Desert, Egypt

1. INTRODUCTION

The late Palaeocene to early Eocene interval is considered to be one of the warmest time periods (THOMAS, 1998) known as the Palaeocene – Eocene Thermal Maximum (PETM) (KENNETT & STOTT, 1991) during which numerous events occurred. The remarkable climate change during that time can be explained by the release of a massive amount of methane from gas hydrates (DICKENS et al., 1995; KATZ et al., 1999).

Major changes in the terrestrial and marine biota occurred at the PETM. This interval is marked by the mass extinction of benthic foraminifera, with a global decrease in their diversity, which ranges from 30 to 50% (KENNETT & STOTT, 1991), being known as the Benthic Foraminiferal Extinction Event (BFEE) (THOMAS & SHACKLETON, 1996). The time interval is characterized by the presence of short-ranging taxa such as „malformed discoasters“ and „rhomboasters“. The extreme environmental changes at the PETM caused those malformations of coccoliths (JIANG & WISE, 2006). The global Palaeocene/Eocene boundary was defined at the Dababiya Quarry section, south of Luxor, in the Upper Nile Valley (DUPUIS et al., 2003).

The aims of the present study are to identify the calcareous nannofossil assemblages of the PETM interval, to assign the studied sections to several nannofossil biozones and to provide some light on the palaeoecology for the late Palaeocene-early Eocene interval based on the presence of the most abundant calcareous nannofossil taxa.

2. GEOLOGIC SETTING AND LITHOSTRATIGRAPHY

The Kharga Oasis is one of the depressions of the Western Desert, lying between latitudes 24° and 26° north, about 200 km to the west of the Nile Valley. The two sections at Kharga Oasis are the Naqb Assiut and Gabal Umm El Ghanayim sections were investigated (Fig. 1).

The upper Palaeocene to lower Eocene sedimentary succession in the Kharga Oasis includes from the base to the top: the upper part of the Dakhla Shale, the Tarawan Chalk, the Esna Shale and the Thebes formations. The lithostratigraphic correlation for the P/E rock units in different sections from the western and eastern Desert and the present study, are illustrated in Table 1.

In the following paragraphs a brief description of the measured and sampled formations is given.

2.1. Tarawan Formation

The Tarawan Formation was first termed by AWAD & GHOBRIAL (1965) to describe the limestone; chalky limestone and the marly limestone succession which overlie the Dakhla Shale and underlie the Esna Formation. This unit is about 11 m thick, and is represented by samples 1 to 8 in the Gabal Umm El Ghanayim section.

2.2. Esna Formation

The term Esna Shale was first introduced by BEADNELL (1905), to describe the shale succession that overlies the Tarawan Formation and underlies the Thebes Formation at Gabal Oweina, Esna-Idfu area, Upper Nile Valley. ABDEL-RAZIK (1972) separated this formation into two members, the El Hanadi Member at the base and the El Shaghab Member at the top. DUPUIS et al. (2003) classified the Esna Formation from the base to the top, into three units (Esna Unit 1, Esna Unit 2 and Esna Unit 3) (Table 1).

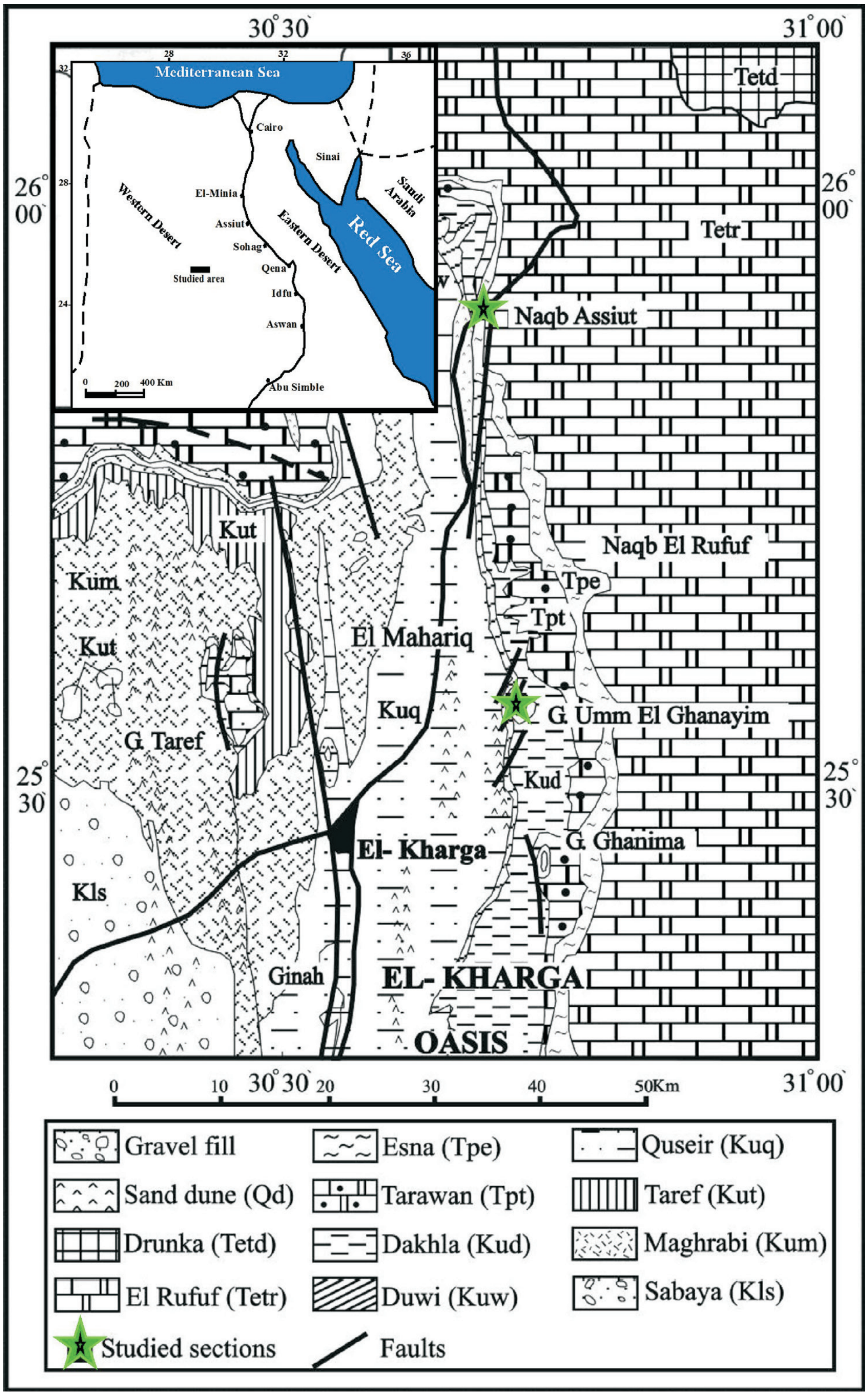


Figure 1. Geological map of the Kharga area (Western Desert, Egypt) with the location of the studied sections (modified after SAID, 1990).

AUBRY et al. (2007) subdivided the Esna Formation into four members, from the base to the top as follows, the El Hanadi, El Dababiya Quarry, El Mahmiya and Abu Had members.

In the present study, the Esna Formation was sampled and described. The total thickness is about 17.5 m at the Gabal Umm El Ghanayim section and about 10 m at the Naqb Assiut section. This rock unit represents the El-Hanadi, El Dababiya Quarry and the lower part of El-Mahmiya Member (Figs. 2 and 3). These members will be discussed briefly below.

2.2.1. El Hanadi Member

The El Hanadi Member was originally introduced by ABDEL-RAZIK (1972) to describe the lower part of the Esna Formation (5 m of shale succession) which overlies the Tarawan Formation and underlies the El Shaghab Member at Gabal El Shaghab, east of El Hanadi Village, near Esna City. According to AUBRY et al. (2007), the El Hanadi Member equates to the Esna Unit 1 of DUPUIS et al. (2003). At the Gabal Umm El Ghanayim section, the El Hanadi Member is composed of a calcareous shale about 1 m thick at the base (sample 9 to 11), and another shale of about 8 m thick (samples 12 to 26) at its top (Fig. 2). At the Naqb Assiut section, the lower part of the El Hanadi Member is composed of about 6 m of shale deposits (samples 1 to 17) and varies gradually into massive marls of about 0.95 m thick (samples 18 and 19) in its upper part.

2.2.2. Dababiya Quarry Member

At the type locality, the El Dababiya Quarry Member consists of five characteristic beds (1-5) of about 3.68 m thickness: Bed no. 1 is an organic rich clay layer (~0.63 m thick); bed no. 2 is a phosphate brown shale (~0.50 m thick); and bed no. 3 is a creamy phosphatic shale (~0.84 m thick); bed no. 4 is a grey calcareous shale (~07.1 m thick) and bed no. 5 is a calcarenitic marly limestone (~1.00 m thick) (AUBRY et al., 2007).

In the current study, the Dababiya Quarry Member is about 1.2 m thick at Gabal Umm El Ghanayim and 0.9 m thick at the Naqb Assiut section. This Member consists of three beds as described from the base to the top: Bed 1 is an organic rich clay layer, which contains scattered coprolites at Gabal Umm El Ghanayim (sample 27, about 15 cm), but it is absent at the Naqb Assiut section; Bed 2 is brown-coloured fish debris and coprolite-rich laminated shale at Gabal Umm El Ghanayim (samples 28 to 35, about 90 cm). At the Naqb Assiut section it consists of massive phosphatic marls rich with collophane grains at the base, and 70 cm of marly limestone at the top (samples 20 and 21, about 20 cm). Bed 3 consists of marls at Gabal Umm El-Ghanayim (sample 36, about 15 cm), while at the Naqb Assiut section (Fig. 3) it is mainly composed of chalky limestone (samples 22 to 25, about 70 cm).

2.2.3. El Mahmiya Member

This Member was defined by AUBRY et al. (2007), to cover the Esna 2 Unit of DUPUIS et al. (2003) at the Village of El Dababiya (35 km south of Luxor). At the Gabal Umm El Ghanayim section, the El Mahmiya Member is essentially composed of about 6 m of shale (samples 37 to 48), while at the Naqb Assiut section, the El Mahmiya Member consists mainly of 2.25 m of calcareous shale (samples 26 to 30).

3. MATERIAL AND METHODS

A total number of 78 samples were collected for calcareous nannofossils investigations, from which 48 belong to the Gabal Umm El Ghanayim section and 30 to Naqb Assiut. The samples have been closely collected from the upper Palaeocene-lower Eocene interval in the study sections and reach about 5 cm near the P/E boundary. The calcareous nannofossil assemblages were observed using a polarized light microscope at a magnification of 1250X and their identification was based on the standard taxonomy of PERCH-NIELSEN (1985).

Calcareous nannofossil abundances were determined by counting 200-300 specimens/slide (BACKMAN & SHAKLETON, 1983). Additionally, one random traverse of the slide was scanned for rarer species. The nannofossil relative abundance was considered as follows: A = abundant (>10 specimens/field of view), C = common (1-10 specimens/field of view), F = few (1 specimen/1-10 fields of view), R = rare (1 specimen/> 10 fields of view) VR= very rare (1 specimen/more than100 field of view). The species richness is given as the total number of species recorded in each sample.

Nannofossil preservation was classified as: G = good (little or no evidence of dissolution and/or overgrowth; specimens can be easily identified to species level) and M = moderate (specimens exhibit some etching and/or overgrowth; most specimens are identifiable to the species level).

Table 1. Lithostratigraphic correlation for the P/E transition interval, between different works from the western and eastern Desert and the present study.

Epoch	Stage	Khalifa (1970)	Abdel Razik (1972)	Hermina (1990)	Dupius *et al* (2003)	Aubry *et al* (2007)	Khozyem *et al.* (2014)	Youssef (2015)	Ouda *et al.* (2016a)	El-Dawy *et al.* (2016)	Ouda *et al.* (2016b)	Present study
		G. El Shaghab area	Western Desert	North Kharga	Dababiya section	Dababiya section	Dababiya section	Nag El Quda	G. El Aguz	Naqb Asuit section	Darb Gaga section	
Eocene, Early	Ypresian	Esna Shale	Thebes Fm.; Hamidat Mb.	Esna Formation	Esna Shale; Esna Unit 3	Esna Shale; Abu Had Mb.	Not studied (LSS) (RSS)		Thebes Fm.	Not studied	Not studied	
			Esna Formation; El-Shaghab Mb.		Esna Unit 2	El Mahmiya Mb.	Esna 2; LSS: 5, 4; RSS: 5, 4	El Mahmiya Mb.	Esna Formation; Abu Had Mb.	El Mahmiya Mb.		El Mahmiya Mb.
					Dababiya Quarry Beds: Bed 5, Bed 4, Bed 3, Bed 2, Bed 1	Dababiya Quarry Mn.: Bed 5, Bed 4, Bed 3, Bed 2, Bed 1	LSS: 3, 2, 1; RSS: 3, 2	Dababiya Quarry Mb.: Bed 5, Bed 4, Bed 3, Bed 2, Bed 1	El Mahmiya Mb.; El Aguz Limestone	Esna Shale; Dababiya Quarry Mb.: Bed 5, Bed 4, Hiatus	Esna Shale; Dababiya Quarry Mm.: Bed 5, Bed 4, Bed 3, Bed 2, Bed 1	Esna Shale; Dababiya Quarry Mb.: Bed 3, Bed 2, Hiatus (NAS); Bed 3, Bed 2, Bed 1 (UGS)
Palocene, Late	Thanetian		El Hanadi Mb.		Esna Unit 1	El Hanadi Mb.	Esna 1	El Hanadi Mb.	El Hanadi Mb.	El Hanadi Mb.	El Hanadi Mb.	NAS / UGS; El Hanadi Mb.
		Tarawan Chalk	Tarawan Chalk	Tarawan Fm.	Tarawan Limestone	Tarawan Fm.	Not studied		Tarawan Fm.	Not studied	Not studied	Tarawan Fm.

Mb.: Member, Fm.: Formation, NAS: Naqb Assiut section, UGS: Umm El Ghanayim section

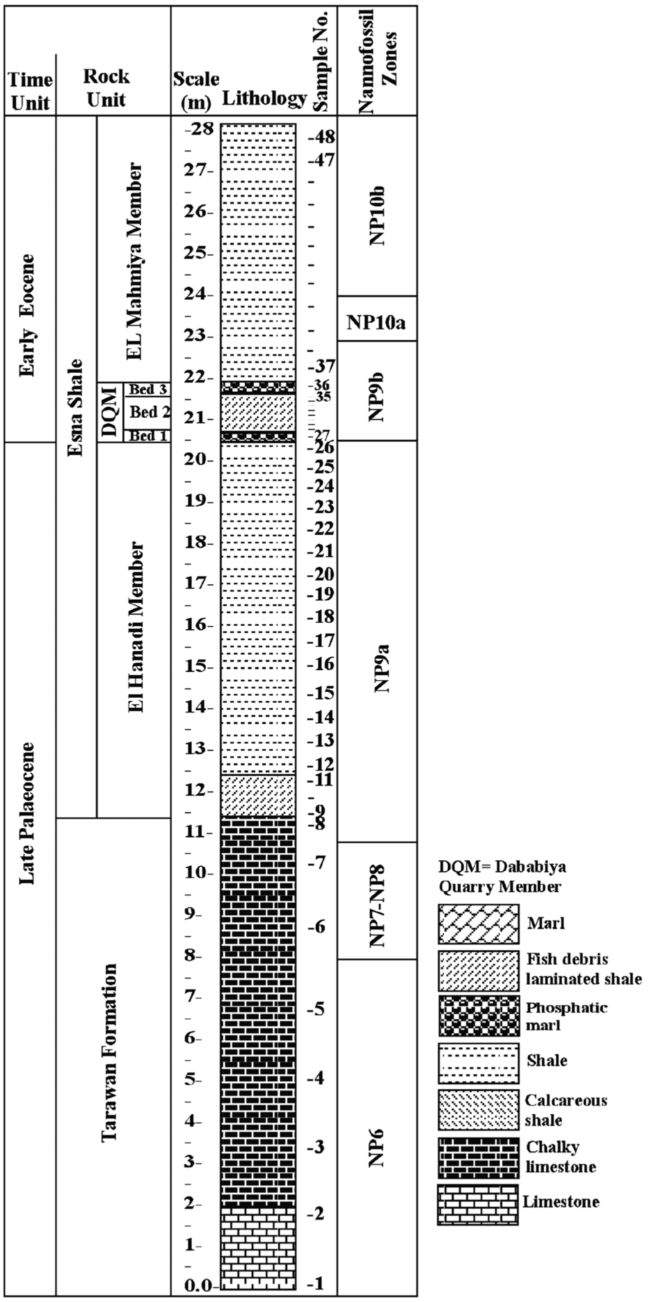


Figure 2. Lithostratigraphy and biostratigraphy of Umm El Ghanayim section (Kharga Oasis, Western Desert, Egypt), samples position and correlation to the standard zonation of MARTINI (1971).

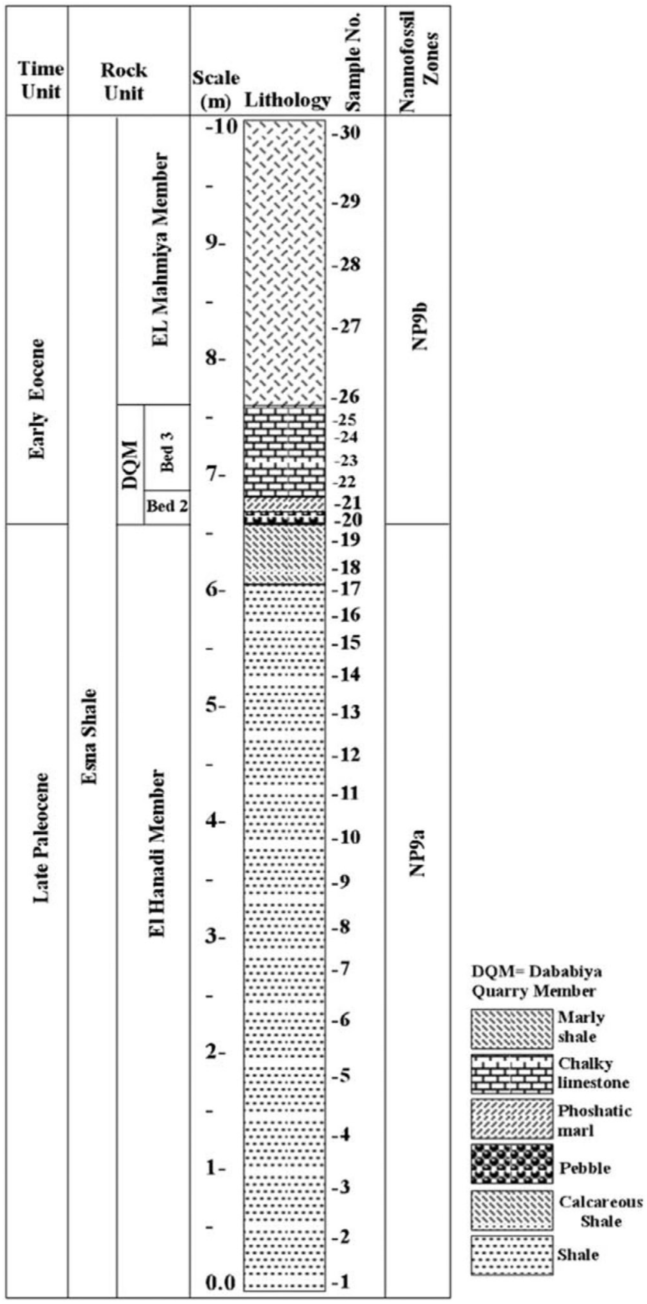


Figure 3. Lithostratigraphy and biostratigraphy of Naqb Assiut section (Kharga Oasis, Western Desert, Egypt), samples position and correlation to the standard zonation of MARTINI (1971).

Palaeotemperatures from calcareous nannofossil proxies were calculated using the Microsoft Excel program in accordance with the mentioned authors in the palaeoecologysection and our research data.

The biostratigraphic zonation proposed by MARTINI (1971) and OKADA & BUKRY (1980) was adopted. In addition, other bioevents for lower latitudes were also used (AGNINI et al., 2014).

4. RESULTS

4.1. Calcareous Nannofossils Biostratigraphy

The present manuscript concerns the biostratigraphy of calcareous nannofossils from the upper part of the Tarawan Chalk and Esna formations (upper Palaeocene – lower Eocene interval) at the Umm El Ghanayim and Naqb Assiut sections.

The calcareous nannofossil assemblages are rich (72 species) and very diverse (22 genera) throughout the studied interval (late Palaeocene to early Eocene), while the preservation varies from moderate to good.

The stratigraphic distribution charts of calcareous nannofossil species are shown in Figs. 4 and 5. Some index calcareous nannofossil species are illustrated in Pls. 1 and 2.

Abbreviations used in the present study are: NP = Palaeogene nannofossil zone of MARTINI (1971), CP = Palaeogene nannofossil zone of OKADA & BUKRY (1980), CNP (Palaeocene calcareous nannofossil zone) and CNE (Eocene calcareous nannofossil zone) of AGNINI et al. (2014). Their correlation is shown in Table 2 with four nannofossil zones identified in the present study, covering the time interval from the late Palaeocene to early

Eocene and occupying the top of the Tarawan Chalk and the Esna Shale formations. These biozones are briefly discussed below.

4.1.1. *Heliolithus kleinpellii* Zone (NP6)

Definition: This zone comprises the interval from the LO of *Heliolithus kleinpellii* to the LO of *Discoaster mohleri*.

Authors: MOHLER & HAY in HAY et al. (1967)

Age: Late Palaeocene

Correlation: *H. kleinpellii* Zone (CP5) of OKADA & BUKRY (1980). It is equivalent to the upper part of the *H. cantabriae* BZ (CNP8) of AGNINI et al. (2014) (Table 2).

Occurrence: This zone is represented by 1-5 samples, from the Gabal Umm El Ghanayim section. It is not recorded at some localities in Egypt (FARIS et al., 1999; FARIS & ZAHRAN, 2002). The *H. kleinpellii* Zone is well represented in many other areas in Egypt (STROUGO & FARIS, 1993; FARIS et al., 2000, 2005; AYYAD et al., 2003; FARIS & ABU SHAMA, 2007a; FARIS & FAROUK, 2015a).

Remarks on assemblages: Beside the marker species *Heliolithus kleinpellii* (Fig. 4), this zone includes *Coccolithus eopelagicus*, *Ericsonia subpertusa*, *E. universa*, *Toweius eminens* and *T. tovae*.

4.1.2. *Discoaster mohleri- Heliolithus riedelii* Zone (NP7-NP8)

Definition: This zone is defined as the interval from the LO of *Discoaster mohleri* to the LO of *Discoaster multiradiatus*.

Author: HAY (1964); emended by ROMEIN (1979).

Age: Late Palaeocene

Correlation: It is equivalent to the *D. mohleri – D. nobilis* (CP6-CP7) Zones of OKADA & BUKRY (1980), to the *Discoaster mohleri* (CNP9) and *Discoaster backmanii* (CNP10) Zones of AGNINI et al. (2014) (Table 2).

Occurrence: At Gabal Umm El Ghanayim, this zone is restricted to within the top part of the Tarawan Formation (samples 6 and 7). *Discoaster mohleri/Heliolithus riedelii* Zone was recorded in different areas in Egypt (FARIS 1988a, b; STROUGO & FARIS, 1993; FARIS et al., 1999; AYYAD et al., 2003; GHANDOUR et al,. 2004; FARIS & ABU SHAMA, 2007a; FARIS & SALEM, 2007b).

Remarks on assemblages: The base of this zone is defined by the LO of *D. mohleri* whilst its top is defined by the LO of *D. multiradiatus* (ABU SHAMA et al., 2007; FARIS & ABU SHAMA, 2007a). The calcareous nannofossil assemblages are similar to those of the underlying NP6 Zone, with the additional presence of marker species *D. mohleri* (Fig. 4).

4.1.3. *Discoaster multiradiatus* Zone (NP9)

Definition: This zone defines the interval from the LO of *Discoaster multiradiatus* to the LO of *Tribrachiatus bramlettei*.

Authors: BRAMLETTE & SULLIVAN (1961); amended by MARTINI (1971)

Age: Late Palaeocene

Correlation: *Chiasmolithus bidens* Subzone (CP8a) of OKADA & BUKRY (1980). It is equivalent to the *Discoaster multiradiatus/Fasciculithus richardii* gr. CRZ (CNP11) of AGNINI et al. (2014) (Table 2).

Occurrence: The NP9 Zone covers the topmost part of the Tarawan Formation (sample 8), as well as most of the Esna Formation (samples 9 to 38) at the Gabal Umm El Ghanayim section, and occupies the whole Esna Formation at the Gabal Naqb Assiut section (samples 1 to 30).

Remarks on assemblages: The calcareous nannofossil assemblages are highly diverse and abundant in the NP9 Zone and this agrees well with the statement of PERCH-NIELSEN (1985) that the Palaeocene diversity reached a maximum value in the

Table 2. Late Palaeocene to Early Eocene biozones and bioevents, according to the standard biozonations of MARTINI, 1971 (NP), OKADA & BUKRY, 1980 (CN), AGNINI et al., 2014 (CNP to CNE) and the zonal scheme of the present study.

Epoch		Stage	Calcareous nannofossil biozones							
			Martini (1971) NP	Nannofossil bioevents	Okada and Bukry (1980) CP	Nannofossil bioevents	Agnini *et al* (2014) CNE CNP	Nannofossil bioevents	This study	Zonal scheme
Eocene	Early	Ypresian	*T. contortus* Zone (NP10)		*T. contortus* Subzone (CP9a)		*T. eminens* PRZ (CNE2)	T *F. tympaniformis*	NP10b	*T. digitalis*
							F. tympaniformis TZ (CNE1)	T *F. richadii* gr.	NP10a	*T. bramlettei*
									NP9b	*D. araneus* *Rhomboaster* spp.
Palocene	Late	Thanetian	*D. multiradiatus* Zone (NP9)	*T. bramlettei*	*D. multiradiatus* Zone (CP8): *Ca. eodela* Subzone (CP8b)	*T. bramlettei*	*D. multiradiatusl F. richadii* gr. CRZ (CNP11)		NP9a	
					D. multiradiatus Zone (CP8): *Ch. bidens* Subzone (CP8a)	*Ca. eodela*				
			H. riedellii Zone (NP8)	*D. multiradiatus*	*D. nobilis* Zone (CP7)	*D. multiradiatus*	*D. backmanii* BZ (CNP10)	B *D. multiradiatus*	NP7/8	*D. multiradiatus*
			D. mohleri Zone (NP7)	*H. riedellii*	*D. mohleri* Zone (CP6)	*D. nobilis*	*D. moheri* BZ (CNP9)	B *D. backmanii*		
		Selan.	*H. kleinpellii* Zone (NP6)	*D. mohleri*	*H. kleinpellii* Zone (CP5)	*D. mohleri*	*H. cantabriae* BZ (CNP8)	B *D. moheri*	NP6	*D. mohleri*

Selan.: Selandian
TZ= Top Zone
BZ= Base Zone
CRZ= Concurrent Range Zone
PRZ= Partial Range Zone
T= Top
B= Base
Highest Occurrence
Lowest Occurrence

NP9 Zone. The identification of NP9 is mainly based on the presence of *D. multiradiatus*. The marker species *D. multiradiatus* is continuously present from sample 8 upwards in G. Umm El Ghanayim and appears in all samples in the Nabq Assiut section. The genus *Fasciculithus* suffered decreasing diversity at the onset of the P/E boundary, and disappeared completely shortly above the base of the NP10 Zone.

AUBRY (1999) divided the NP9 Zone into two subzones (NP9a and NP9b) based on the lowest appearance of *Rhomboaster* spp. and/or *Discoaster araneus*.

Late Paleocene																										Early Eocene																						Age
Esna Shale																																																Formation
Tarawan								EL Hamdi																		Dababiya Quarry Member										EL Mahmiya Member												
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	Sample No.
F	F	F	F	F	R	C	A	A	A	A	A	C	C	C	A	A	A	C	A	A	A	A	C	C	C	F	F	F	F	C	C	A	A	C	A	F	F	C	C	A	F	F	F	F	F	F	F	Abundance
M	M	M	M	M	M	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	M	M	M	M	M	M	M	M	M	M	G	G	G	G	G	G	G	M	M	G	G	G	M	M	Preservation
NP6					NP7-NP8		NP9a																			NP9b												NP10a		NP10b								Nannofossil Zone (NP)
F	F	C	F	F	F	F	F	R	R	F	F	R	F	C	F	F	F	F	F	F	F	F	F	F	C	C	C	C	F	F	F	F	F	R	R	R	F	R	R	R	C	C	C	C		C	C	*Coccolithus pelagicus*
R	VR			R	R	R		VR			F		R			VR			R		R			F	F	F	F	F		R		F			R			F	R		R		R					*Coccolithus eopelagicus*
F	F	F	F	F	F	F	F	F	F	F	F	F	F		F	F	F	R	F	F	F	F	F	F	F	C	F	F	C	C	C	A	A	F	F	R		R	R	F	F	F	F	F	F	F	R	*Ericsonia subpertusa*
F	F	F	F	F	F	F	F	F	F	F	F		F	F	F	F	F	F	R	F	F	F	F	F	F		F	R	F	F		R	VR	F	R	VR	R	R	R	R			VR			F		*Sphenolithus primus*
R	R	F	VR	R	R	R	VR	R	R	R	VR	R	VR	R		R	VR	VR	R	R	VR	VR	R												VR	VR	VR	VR	R	R	R	F		VR	F		F	*Thoracosphaera operculata*
R	R	R	R	R	VR	VR	VR	VR	R	VR		VR	VR	VR	R	R		R	R				R																					VR				*Toweius tovae*
VR	R		R	R		R	R	R		VR		VR		VR		R							R	R										R	VR			VR										*Toweius eminens*
VR	VR			R		R		R	R	R	F							R																	F													*Ericsonia universa*
R		R		R	VR																R	VR	R	R	R	R	R	R		R	R	VR	VR		R	F	F	F	F	R	R	R	R	VR	R		VR	*Neochiastozygus junctus*
R	R	R	R	R		VR			VR	VR	VR																																					*Heliolithus kleinpellii**
					VR	VR																																										*Discoaster mohleri**
					VR		R	VR	VR	VR	R		VR	VR	VR	R	R	R	R	R	R	R	R																									*Fasciculithus clinatus*
					R	F	F	F	F	F	F	F	R	F	F	F		R	R	R	R		R					R		R	R					VR	VR	VR	VR									*Fasciculithus tympaniformis**
					VR	R																																										*Chiasmolithus danicus*
					VR	R	R	R	F	F	F	F	R	R	R	F		R	R	R	R	R	R	R											R	VR		VR	VR									*Fasciculithus involutus*
					R	VR	VR	VR	VR	VR			VR		VR		VR			R		VR		R																								*Ellipsolithus macellus**
						R	VR	VR	R		R	VR						VR																														*Neochiastozygus perfectus*
						VR	VR	R	R	F	F	F	F	R	R	R	R	R	F	F	F	F	R	R	F	F	R	R	R	R	R	R	VR		R	F	F											*Zygodiscus plectopons*
							R	R	R		VR	R	VR			VR	R	R		R	VR	R		R		VR		R			R			VR		R												*Zygodiscus adamas*
							R	R	F	F	R	R	R		R		R	R				R	R				R			R	R																	*Discoaster lenticularis*
							VR					VR										VR	R			VR																						*Chiasmolithus californicus*
							VR	R			R				VR	R																																*Pontosphaera versa*
							F	F	F	C	R	F	F	R	F	C	F	R	R	R	R	F	R	R	R	VR	R	R	VR		F	F	F			R	R	F	R	R		R	VR	VR	R	VR	R	*Discoaster multiradiatus**
							R	VR						VR	VR	R	VR		VR		VR	VR		R											VR		R	VR	VR	VR	VR		VR	VR	R	VR		*Campylosphaera eodela*
							VR	VR	VR				VR					VR	VR																													*Neococcolithes protenus*
								VR	VR	VR					VR																																	*Calcisolenia aperta*
								VR	R	R		VR	VR	R	VR	VR	VR		VR			VR		R			R	R	R	R	R	VR		VR	VR	R		VR	VR	R					R		VR	*Zygrhablithus bijugatus*
								R	R	R			VR			R	VR	VR		R	R																	VR										*Chiasmolithus consuetus*
								R		R	R				R		R		VR		VR																											*Ellipsolithus bollii*
									R	VR		VR	VR		VR	R		R	R	R			R		R	VR																						*Fasciculithus alanii*
									VR	R	VR	VR	VR					VR	VR																	VR				VR								*Ellipsolithus distichus*
										VR	VR	VR	VR	VR	R	R	VR	R	R	R				R	R													VR										*Chiasmolithus bidens*
										VR	R		VR		VR	R	VR	VR	VR	R	VR						R																					*Discoaster falcatus*
										VR																																					*Fasciculithus tonii*
												VR	R	VR		R	R	R		R																											*Fasciculithus schaubii*
												VR	VR	VR																																	*Fasciculithus lilianiae*
												VR																									VR										*Discoaster binodosus*
												VR	R	R							R												VR														*Fasciculithus bobii*
													VR																																		*Chiasmolithus eograndis*
														VR	VR	VR	VR	R	R	R	VR	R	R	VR	VR		R		R							VR		F		F								*Pontosphaera ocellata*
															R	R																															*Toweius occultatus*
															R	F		R	R			VR												F	R												*Ericsonia robusta*
															VR				VR					VR			VR	R	R	R	R		VR	R						R	VR					VR	VR	*Thoracosphaera saxea*
															VR	R					R																										*Fasciculithus richardii*
															R	R	R	VR			R		R																								*Fasciculithus thomasii*
															VR		R		VR				R																								*Discoaster mediosus*
															R		R	R	R	R	R		R	VR																							*Toweius pertusus*
																	VR						VR												F	VR	R	R	R	C	R		F	F		R	R	*Braarudosphaera bigelowii*
																		R	R		R	R	R	VR																							*Zygodiscus sheldoniae*
																										VR	VR	VR								R		R	F	R	R	R	R	R	R	R	R	*Pontosphaera plana*
																										VR	VR	VR				F	F	F	F												*Discoaster araneus**
																														VR	VR				R	F	F	F	C	C			F	F	R		R	*Micrantholithus attenuatus*
																														VR	R	F	F	F	F												*Discoaster anartios**
																																VR	VR	R	R	F												*Neochiastozygus chiastus*
																																		R	VR		VR	VR										*Rhomboaster cuspis**
																																	R															*Rhomboaster spineus* *
																																		VR	R				VR		VR							*Discoaster paelikei*
																																		R	R		VR											*Rhomboaster bitrifida* *
																																				VR		R										*Discoaster mahmoudii**
																																						VR	VR				VR					*Tribrachiatus bramlettei**
																																						VR										*Sphenolithus moriformis*
																																						VR		R	VR							*Discoaster barbadiensis*
																																							VR									*Discoaster backmanii*
																																								VR								*Tribrachiatus digitalis**
																																									VR	VR	VR					*Discoaster diastypus*
																																												VR			VR	*Chiasmolithus solitus*
																																												R	R	R		*Pontosphaera exilis*

Abundance:
A= Abundant
C= Common
F= Frequent
R= Rare
VR= Very Rare
*marker species

Preservation:
G= Good
M= Moderate

Figure 4. Stratigraphic distribution of calcareous nannofossil species in Umm El Ghanayim section, Kharga Oasis, Western Desert, Egypt.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Sample No.
Late Paleocene																			Early Eocene											Age
Esna Shale																														Formation
EL Hanadi																			DQM						EL Mahmiya Mb.					
F	F	A	F	A	A	A	C	A	F	F	A	F	F	C	F	A	R	A	A	A	F	F	F	F	R	F	F	F	R	Abundance
M	M	G	G	G	G	G	G	G	G	M	G	M	M	G	M	G	M	G	M	G	M	M	M	M	B	M	M	M	M	Preservation
NP9a																			NP9b											Nannofossil Zone (NP)
F	F	F	R	F	F	R	F	F	F	R	F	F	F	R	R	F	F	R	F	F	F	F	F	F	F	R	F	F	R	*Coccolithus pelagicus*
R	R	VR				F			R		F			F		R		F	F	F		R			VR		VR			*Coccolithus eopelagicus*
F	R	F	F	F	F	F	F	F	R	R	F	F	F	F	F	F	F	F	C	A	C	F	F	F	F	F	R	R	R	*Ericsonia subpertusa*
R	R	VR	R	F	R	R	R		VR	R	F	R		R						R	R	VR				R		R	R	*Zygrhablithus bijugatus*
VR	VR	R	VR	VR	R	VR	VR		VR	VR	VR	VR	VR	VR		VR		F	VR		VR	R						R		*Thoracosphaera operculata*
VR	F	F	R	F	R	F	F	F	R	R	F		R	F	R	F	R	F		F	R	F	R	R		R	R	R		*Sphenolithus primus*
R	R	R	R	F	R		R	F		R	R		R	R		R		R	R		VR	VR	R	VR	VR	F	R	R		*Discoaster multiradiatus**
VR		R	R	F	R			R		R	R			R		R		R	R											*Discoaster lenticularis*
VR		R	R	R	R	R	R	R	R		R		R	R	VR	F		VR	R			R	R			VR	R	R		*Toweius pertusus*
R		R	R		VR									R	R															*Toweius tovae*
R	VR	F	F	F	F	F		F	R			R		VR	R			VR			VR			VR	VR		R	R	R	*Fasciculithus tympaniformis**
VR		R	VR	R		VR		R	VR	R		R	R	R		R														*Fasciculithus schaubii*
VR		R	R	R	R		R				VR																			*Fasciculithus bobii*
R		F		F	F	R	R	R	VR	R	R	R	R	R	R	VR			R		VR	VR				VR	VR	R	R	*Fasciculithus involutus*
R	F	F		F	F	R	R		VR	R	F	R			R			VR	VR			VR				VR				*Zygolithus sheldoniae*
		R					VR						VR		VR								VR							*Toweius eminens*
		VR		VR	VR	R		VR	R	VR	VR	VR				VR	VR	VR	VR				VR	VR	VR	VR			R	*Campylosphaera eodela*
		R		F	F	F	R	R	R	R	F	R		VR	R			F	R	R						VR		R		*Zygodiscus plectopons*
		VR		VR	VR	VR	VR		VR					VR		VR		R		VR										*Calcisolenia aperta*
				VR		VR				VR		VR	VR	VR	R			R				R	VR	VR		VR	R	R	R	*Ellipsolithus macellus**
				VR			VR	VR		R	VR			R	VR											VR				*Braarudosphaera bigelowii*
				VR	VR			VR			VR		VR	VR	VR															*Ellipsolithus distichus*
				VR																										*Discoaster mohleri **
				VR	VR	R		VR																						*Chiasmolithus bidens*
				R		VR	R	R			R																			*Fasciculithus richardii*
					R	R		R			VR		VR			VR					VR									*Fasciculithus clinatus*
					VR	VR																								*Discoaster falcatus*
					R	R	R	R		R			R	R	R				R											*Zygodiscus adamas*
					R															R										*Thoracosphaera saxea*
					VR					VR																				*Bomolithus megastypus*
						VR		VR		VR	VR		VR	VR				VR					VR			VR	R		R	*Chiasmolithus consuetus*
								R	R		R																			*Pontosphaera exilis*
								R							R	VR		VR		VR	VR			VR	VR	F			F	*Neochiastozygus junctus*
									R										R	VR										*Ericsonia robusta*
											VR	R			R															*Pontoshphera pulchra*
											VR			R	VR															*Pontosphaera formosa*
												R				F										VR				*Pontosphaera ocellata*
													VR			VR					VR									*Neococcolithes protenus*
																R														*Pontosphaera plana*
																VR														*Discoaster backmanii*
																	VR		VR			VR								*Lophodolithus nascens*
																			VR		VR									*Discoaster araneus**
																			VR		VR									*Rhomboaster bitrifida**
																			VR											*Discoaster anartios**
																			F	R										*Ericsonia universa*
																					VR									*Discoaster paelikei*
																										VR		VR	VR	*Rhomboaster cuspis**
																										VR			R	*Pontosphaera multipora*
																										VR				*Discoaster mahmoudii**

Abundance :
A= Abundant
C= Common
F= F= Frequent
R= R= Rare
VR= Very Rare
*marker species
DQM= Dababiya Quarry Member

Preservation:
G= Good
M= Moderat

Figure 5. Stratigraphic distribution of calcareous nannofossil species in Naqb Assiut section, Kharga Oasis, Western Desert, Egypt.

The two subzones of AUBRY (1999) were identified in our study. The NP9a/NP9b is marked by the LO of *Discoaster araneus* at the Gabal Umm El Ghanayim section (Fig. 4) and the LOs of *Rhomboaster bitrifida*, *Discoaster araneus* and *D. anartios* can be used to delineate the base of NP9b at the Gabal Naqb Assiut section (Fig. 5).

The total range of *D. mahmoudii* characterizes the subzone NP9c (AUBRY & SALEM, 2012). In the Umm El Ghanayim section, *D. mahmoudii* first appears in sample 37. The LO of *R. spineus* in sample 34, is restricted to NP9c. We can conclude that the Subzone NP9c is approximately represented by a short interval (samples 34-38) in this section. In the Naqb Assiut section, the LOs of *D. araneus*, *D. anartios* and *R. bitrifida* (markers of NP9b) occur in sample 20. Nevertheless, *D. mahmoudii* appears only in sample 27 and the base of the NP9c can also be tentatively placed at this sample.

4.1.4. *Tribrachiatus contortus* Zone (NP10)

Definition: This biostratigraphic interval is defined by the LO of *Tribrachiatus bramlettei* or *Discoaster diastypus* at its base and the HO of *T. contortus* at its top.

Authors: HAY (1964)

Age: Early Eocene

Correlation: Subzones *Campylosphaera eodela* (CP8b) and *Tribrachiatus contortus* (CP9a) of OKADA & BUKRY (1980). It is equivalent to *Fasciculithus tympaniformis* TZ (CNE1), to *Toweius eminens* PRZ (CNE2) and to the lowermost part of *Tribrachiatus orthostylus* BZ (CNE3) of AGNINI et al. (2014) (Table 2).

Occurrence: At the Gabal Umm El Ghanayim section, *T. bramlettei* has rare occurrences and the top of the zone cannot be defined due to the complete absence of *Tribrachiatus contortus*.

Remarks on assemblages: A new species, *Tribrachiatus digitalis*, was described from the DSDP Site 550, and used to subdivide the NP10 Zone into four subzones (AUBRY, 1996). The LO of *T. bramlettei* defines the base of the NP10a Subzone, the LO of *T. digitalis* defines the base of the NP10b Subzone, the HO of *T. digitalis* defines the base of the NP10c Subzone, and the LO of *T. contortus* defines the base of the NP10d Subzone. The base of the NP11 Zone (= top of NP10d Subzone) is defined by the HO of *T. contortus*.

AUBRY et al. (1999) also used this subdivision in their description of the Esna Shale of Egypt (Gebel Qreiya, Gebel Kilabiya). DUPUIS et al. (2003) used the same four nannofossil subzones for dividing the NP10 of MARTINI (1971) at the Dababiya section.

Only the subzones NP10a and NP10b have been identified at the Gabal Umm El Ghanayim section. In the Umm El Ghanayim section, the NP10a Subzone includes the interval from sample 39 to 40. The interval from samples 41 to 48 can be assigned to the NP10b Subzone, based on the observed first rare occurrence of *T. digitalis*.

5. DISCUSSION

5.1. Palaeocene/Eocene (P/E) boundary

The onset of the carbon isotopic excursion (CIE) associated with the Palaeocene/Eocene Thermal Maximum (PETM) is considered as a best criterion for defining the P/E boundary in marine and non-marine sequences worldwide.

Table 3. Calcareous nannofossil bioevents at the Palaeocene/Eocene boundary recorded by different authors in the Eastern and Western Desert and Nile Valley.

Sections	Authors	Location	P/E boundary	Calcareous nannofossil bioevents
Taramsa	YOUSSEF (2016)	West Qena	NP9a/NP9b	LOs of *D. araneus*, *D. anartios*, *D. aegyptiacus*, *Rhomboaster* spp., *Ca. eodela/dela*
Duwi		Quseir		
Qeryia		Wadi Qena		
Arras		Safaga		
Darb Gaga-1	FARIS & ABDEL SABOUR (a; b; c) (in prep)	Southern Kharga Oasis	NP9a/NP9b	LOs of *D. araneus*, *D. anartios*, *R. intermedia*
Darb Gaga-2			NP9a/NP9b	LOs of *D. araneus*, *D. anartios*, *R. bitrifida*
AL Aguz area		Northern Kharga Oasis	NP9a/NP9b	LOs of *R. calcitrapa*, *R. spineus*, *D. araneus*, *D. anartios*
Nag El-Quda	Youssef (2015)	Eastern Desert	NP9a/NP9b	LAD of *D. araneus* and *Rhomboaster* spp.
Gebel Ghanima	KHALIL & AL SAWY (2014)	Kharga Oasis	NP9a/NP9b	LO of *R. cuspis* Abrupt decrease of *Fasciculithus* spp.
El Serai	TANTAWY (2006)	East Qena	NP9a/NP9b	LOs of *Ca. eodela/dela*, *D. araneus* Abrupt decrease of *Fasciculithus* spp.
Taramsa		West Qena		
Geirya (Abu Had)	AUBRY (1999)	East Qena	NP9a/NP9b	LOs of *D. araneus*, *R. spineus*, *R. cuspis*, *D.araneus*
Kilabiya		Nile Valley	NP9a/NP9b	
Teir/Tarawan	FARIS et al. (1999)	Kharga Oasis	within NP9	HOs of *Fasciculithus* spp.
Um El-Ghanayim				LOs of *T. bramlettei*, *D. binodosus*
El Sheikh Eissa		East Qena		HOs of *Fasciculithus* spp.
El-Homra El-Shanka		Esna	NP9/NP10	LO of T. *bramlettei*
G. El-Shaghab				LO of T. *bramlettei*
North Gunna	FARIS & STROUGO (1998)	Nile Valley	NP9/NP10	HOs of *F. tympaniformis*, *F. bobii*, *F. clinatus*, *F. clinatus*, *F. involutus*, *D. mediosus*
El Sheikh Marzouk			NP9/NP10	
Duwi	TANTAWY (1998)	Quseir	NP9a/NP9b	LO of *Ca. eodela/dela*
Oweina		Nile Valley	NP9a/NP9b	
Abu Had		NE Desert	NP9a/NP9b	
Wadi Tarfa		East Qena	NP9a/NP9b	
Wadi El Dakhl	STROUGO & FARIS (1993)	Southern Galala plateau	NP9/NP10	LO of *T. bramlettei*
Abu Had	FARIS et al. (1989)	Qena Region	NP9/NP10	LO of *D.mahmoudii* - HOs of *F.alanii*, *F. bobii*, *D. mohleri*, *D. falcatus*, *F. tympaniformis*
El Serai			top NP9	
Tarmsa			top NP9	
Wasif area	HEWAIDY & FARIS (1989)	Safaga District	NP9/NP10	LOs of *T. nunnii*, *D. diastypus* HO of *F. tympaniformis*
Um el Huetat	FARIS (1988b)		NP9/NP10	HOs of *F. alanii*, *F.tonii*, *F. tympaniformis*

LO= Lowest Occurrence; HO= Highest Occurrence; HA= Highest Appearance; LAD= Lowest Appearance Datum

At the Dababiya section (the Global Standard Stratotype section and Point – GSSP) the base of the lower Eocene beds (73 cm thick) is carbonate free and barren of calcareous nannofossils, and the taxa *Discoaster araneus, Discoaster anartios, Rhomboaster spineus,* and *Rhomboaster* spp. were recorded directly above this barren interval (DUPUIS et al., 2003).

El DAWY et al. (2016) studied the planktonic foraminifera at the Naqb Assiut section. They observed an irregular unconformity surface associated with pebbles and bioturbated sand at the Palaeocene/Eocene boundary interval, and they suggested the existence of a minor hiatus at this boundary. In the present study, this small hiatus cannot be detected by means of nannofossils.

At the Wadi Nukhul section, West Central Sinai, KHOZYEM et al. (2013), suggest that the lowermost Eocene sediments are absent. The presence of a short hiatus at the P/E boundary is also observed in other sections from Egypt (Gabal Duwi and G. Aweina sections; SPEIJER et al., 2000). The presence of a hiatus at the P/E boundary was recorded at the W. Nukhul, Wadi Matulla, and G. Mekattub sections (West Central Sinai) (FARIS et al., 2015b).

At the Gabal Umm El Ghanayim section, the LO of *Discoaster araneus* was used to delineate the base of Subzone NP9b, while the LOs of *Rhomboaster bitrifida, Discoaster araneus* and *D. anartios* can be used for approximation of the NP9a/NP9b subzonal boundary (early Eocene) at Gabal Naqb Assiut section.

5.2. Calcareous nannofossil bioevents

Fasciculithus alanii occurs below the P/E boundary, and is restricted to the NP9a subzone (DUPUIS et al., 2003). The HO of this species has also been reported in several areas in Egypt such as Gabal Aweina, Gabal Duwi, Gabal Abu Had (AUBRY, 1998; VON SALIS et al., 1998; AUBRY & SALEM, 2013) and at Wadi Nukhul in West Central Sinai (KHOZYEM et al., 2013). The HO of *F. alanii* at the Markha section (WC Sinai), can be used to approximate the P/E boundary (FARIS & FAROUK, 2015). In the present study, the HO of *Fasciculithus alanii* was recorded at the base of the NP9b Subzone (sample 27) at the Gabal Umm El Ghanayim section.

The first occurrence of *Discoaster mahmoudii* is noticed in the uppermost part of the NP9b Subzone in the investigated sections (Figs. 4, 5), and has its last appearance (HO in sample 39) in the lower part of the NP10a Subzone at the Gabal Umm El Ghanayim section.

The lowest occurrence of *Campylosphaera eodela* is within the NP9a Subzone (late Palaeocene) at the Gabal Umm El Ghanayim section, indicating that this species cannot be used as a reliable marker for subdividing the CP8 (=NP9) of OKADA & BUKRY (1980) into CP8a and CP8b (=NP9a and NP9b). The calcareous nannofossil bioevents, recorded by different authors in many sections in Egypt, are summarized in Tables 3 and 4.

5.3. Calcareous nannofossil turnover

The calcareous nannofossil assemblages displayed turnover at the P/E boundary transition (Figs. 4, 5). Several species became extinct, others continued into the Eocene and some new taxa appeared in the Eocene. Some *Fasciculithus* (*Fasciculithus tonii, F. richardii, F. schaubii. F. thomasii, F. clinatus*, *F. lillianiae*) and *Discoaster* species (*D. mediosus, D. mohleri*) disappeared within the NP9a Subzone. The coccoliths that survived include *Campylosphaera eodela, Discoaster lenticularis*, *D. multiradiatus, Fasciculithus tympaniformis, F. involutus* and *Zygrhablithus bijugatus*.

Table 4. Calcareous nannofossil bioevents at the Palaeocene/Eocene boundary recorded by different authors in Sinai.

Sections	Authors	Location	P/E boundary	Calcareous nannofossil bioevents
Abu Zenima	BOLLE et al. (2000)	Western Sinai	wihin NP9	*C. pelagicus* acme
Bir	FARIS et al. (2005)	West Central Sinai	NP9a/NP9b	HA of *Fasciculithus* spp.
El Markha	FARIS & FAROUK (2015)		NP9a/NP9b	*Co. bownii* acme LOs of *R. bitrifida*, *R. intermedia* HO of *F. alanii*
Matulla	ABU SHAMA et al. (2007)		NP9a/NP9b	LOs of *R. cuspis*, *R. calcitrapa*, *D. mahmoudii*, *D. araneus*
	BOLLE et al. (2000)		wihin NP9	LOs of *D. araneus*, *R. bitrifida*, *R. intermedia*
	FARIS et al. (2015)		NP9a/NP10	LO of *T. bramlettei*
	FARIS & FAROUK (2015)		NP9a/NP9b	LO of *R. intermedia*
Nukhul	FARIS & SALEM (2007)	East Central Sinai	NP9a/NP9b	LOs of *R. intermedia*, *R. calcitrapa*
	KHOZYEM et al. (2013)		NP9a/NP9b	LOs *Ca. eodela/dela*, *R. cuspis*
	FARIS et al. (2015)		NP9a/NP10	LOs of *T. bramlettei*, *D. anartios*, *D. araneus*, *R. bitrifida*, *R. cuspis*, *R. intermedia*, *R. spineus*
Mukattab	FARIS et al. (2015)	West Central Sinai	NP9a/NP10	LOs *T. bramlettei*, *D. anartios*, *D. araneus*, *R. bitrifida*, *R. cuspis*, *R. intermedia*, *R. spineus*
Wadi Feiran	FARIS & SALEM (2007)		NP9a/NP9b	LO of *R. solus*
	FARIS et al. (2015)		NP9a/NP10	LOs *T. bramlettei*, *D. anartios*, *D. araneus*, *R. bitrifida*, *R. cuspis*, *R. intermedia*, *R. spineus*
El Mishiti	FARIS & ABU SHAMA (2007)	EC Sinai	NP9/NP10	LOs of *R. cuspis*, *R. calcitrapa*, *D. mahmoudii*, *D. araneus*
Muwaylih Amr	AYYAD et al. (2003)	NE Sinai	NP9a/NP9b	HO of *F. alanii*
El Burk area	FARIS & ZAHRAN (2002)	NC Sinai	NP9/NP10	LO of *T. bramlettei*
El Sheikh Attya	LUNING et al. (1998)	EC Sinai	NP9/NP10	LOs of *D. diastypus*, *D. binodosus* HOof *F. tympaniformis*
El Ain El Falig	FARIS (1988a)	NE Sinai	NP9/NP10	LOs of *T. contortus*, *D. diastypus*, *D. mahmoudii*

The Eocene assemblage includes *Rhomboaster* taxa (*R. intermedia*, *R. bitrifida*, *R. cuspis,* and *R. spineus*) in addition to the first appearances of *Discoaster araneus, D. anartios, D. paelikei,* and *D. mahmoudii* which occurred within the NP9b Subzone (early Eocene).

In the present study, the *Rhomboaster-Discoaster* taxa did not occur simultaneously, having very rare relative abundances (Figs. 4, 5). The first appearance of *D. araneus* is at the base of NP9b at the Um El Ghanayim section. Other taxa occurred in sequential order: *D. anartios, R. bitrifida, R. cuspis* and *R. spineus*. At the Gabal Naqb Assiut section, *D. araneus, D. anartios* and *R. bitrifida* co-occurred at the base of the NP9b Subzone, and *R. cuspis* appeared later at a higher level within NP9b.

5.4. Diversity

The diversity of calcareous nannofossils is the number of species in each sample. It reaches its maximum in the late Palaeocene (PERCH-NIELSEN, 1985; FARIS & SALEM, 2007). The calcareous nannofossil diversity reaches a maximum of 26 species in the NP9a Subzone (sample no. 17), with 21 species in NP9b at G. Umm El Ghanayim section. Above this subzone, fluctuations in species diversity occur, with variations from 24 to 7 species in the NP10 Zone with a generally decreasing trend.

At the Naqb Assiut section, the number of species fluctuates within NP9a from 5 to a maximum of 23 species (sample no 6), and reaches about 16 species in the upper part of late Palaeocene, while above that level the diversity fluctuates from 7 to 18 species in the NP9b Subzone (early Eocene).

The *Fasciculithus* diversity decreases sharply within the NP9b Subzone and it disappears completely shortly in the lowermost part of NP10 (Fig. 4). In the basal part of Zone NP10, *F. tympaniformis* and *F. involutus* were recorded. The same observations were recorded in the Qreiya, Duwi and Oweina sections (VON SALIS et al., 1998), in G. Taramsa, G. Serai (TANTAWY, 2006) and in the Gabal Qreiya, Gabal Arras, and Gabal Duwi sections (YOUSSEF, 2009, 2015, 2016).

5.5. Palaeoecology

Several authors have proposed a link between some nannofossil species abundance and oceanographic changes that may have occurred during the PETM (e.g. BRALOWER, 2002; KAHN & AUBRY, 2004; TREMOLADA & BRALOWER, 2004; GIBBS et al., 2006 a, b; JIANG & WISE, 2006). Several nannofossil taxa are known to be adapted to warmer, more oligotrophic surface water environments. The genus *Discoaster* has often been associated with warm water species (EDWARDS, 1968; BUKRY, 1973), while AUBRY (1992) proposed that this genus was also adapted to oligotrophic conditions. The genera *Fasciculithus* and *Sphenolithus* were adapted to warmer, more oligotrophic environments, as noted in different ODP sites (BRALOWER, 2002; GIBBS et al., 2006a, b). Taxa belonging to the *Rhomboaster-Tribrachiatus* lineage have been regarded as proxies for warm-waters and oligotrophic conditions (AUBRY, 1998; BRALOWER, 2002; TANTAWY, 2006; MUTTERLOSE et al., 2007).

Coccolithus pelagicus is a dominant species of the high latitudes from the Neogene to the present, based on palaeobiogeo-

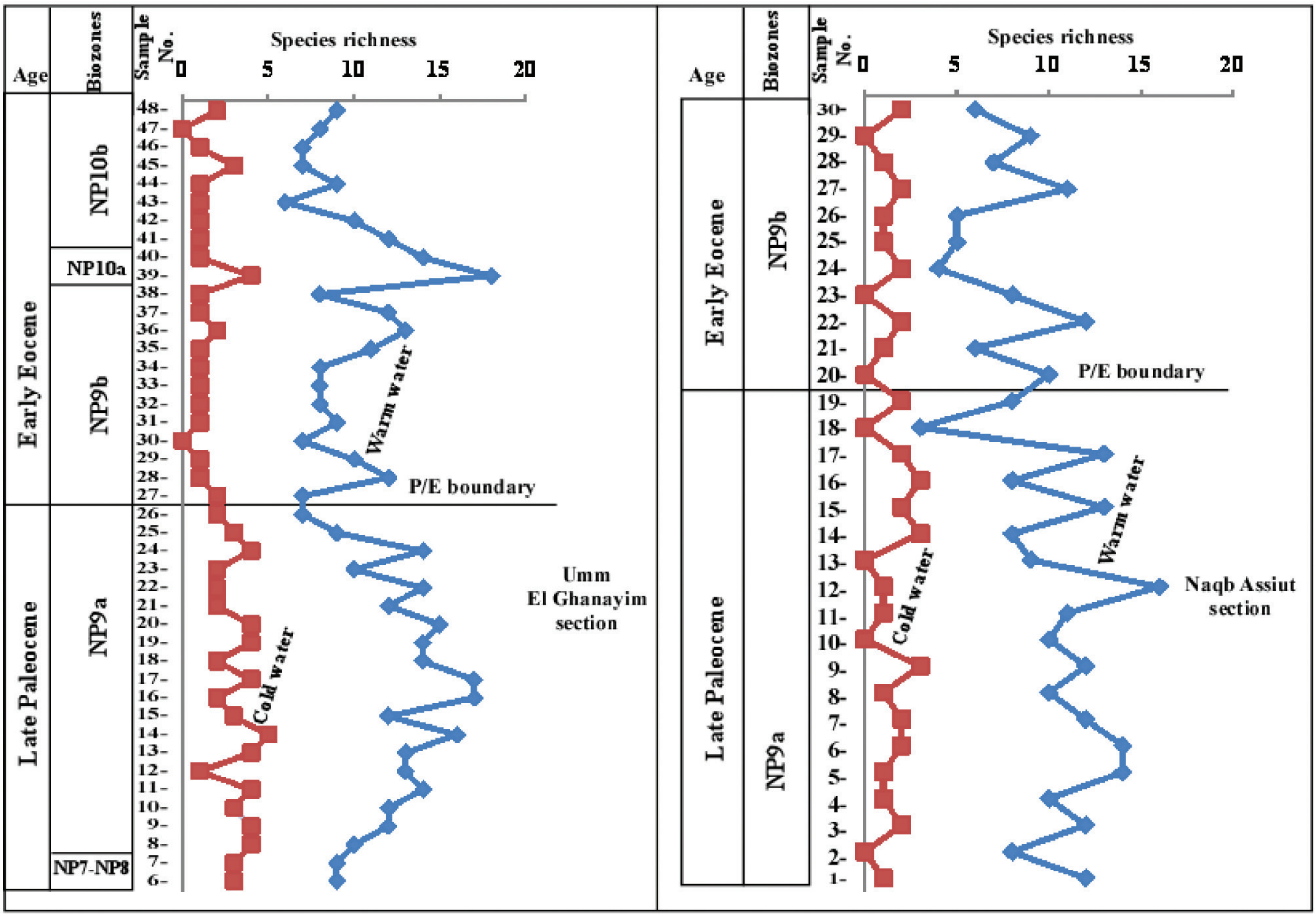
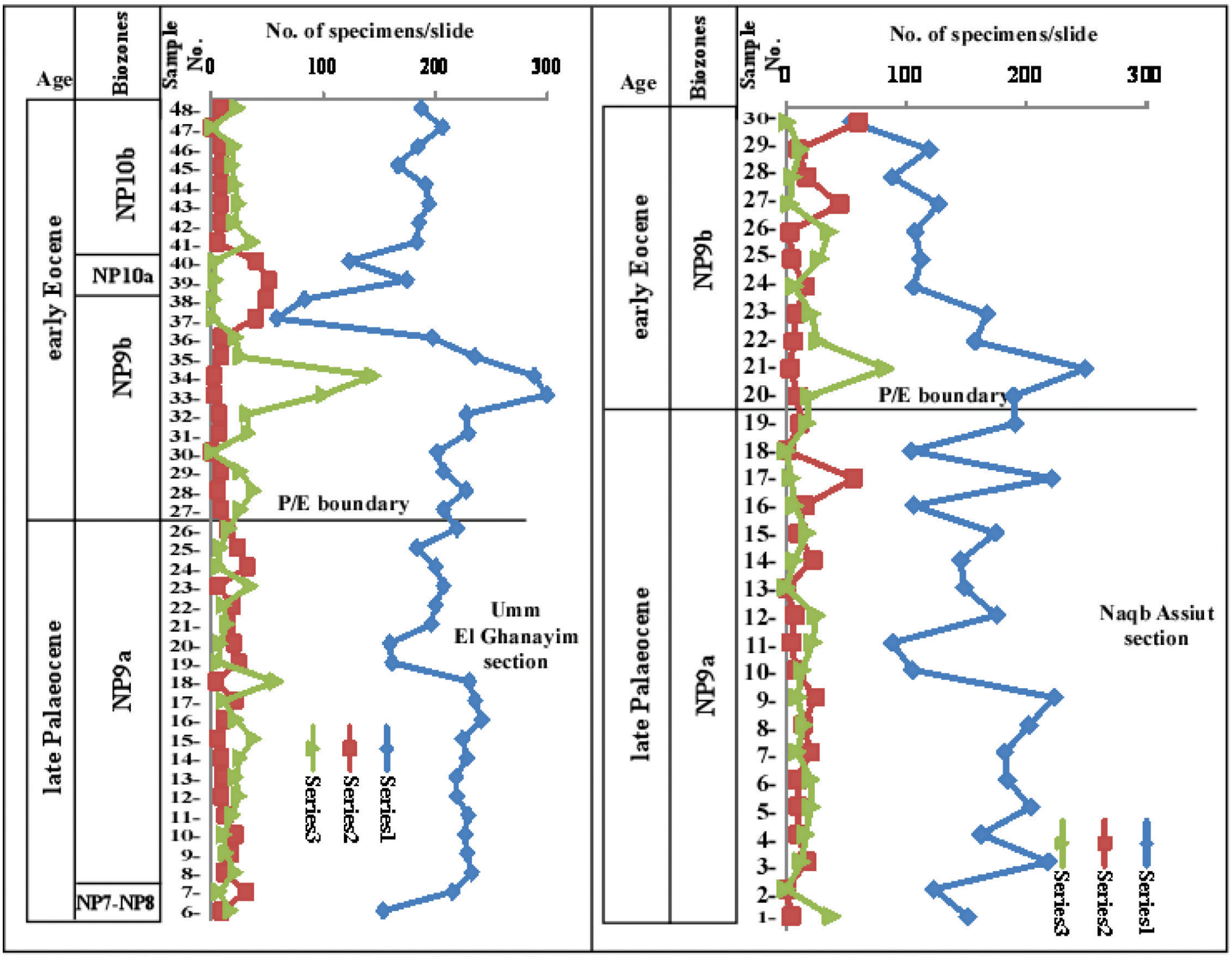


Figure 6. Vertical variations in the number of warm water and cold water species in Umm El Ghanayim and Naqb Assiut sections.



Series 1= Warm water specimens; Series 2= Cold water specimens and Series 3= Total warm/cold water specimens

Figure 7. Total warm and cold water specimens/slide and warm/cold water specimens in Umm El Ghanayim and Naqb Assiut sections.

graphic studies (MCINTYRE & BE, 1967, HAQ & LOHMANN, 1976, HAQ, 1980). In addition, *C. pelagicus* s. ampl. prevails in lower latitudes during mid-Palaeocene to early Eocene, where *C. eopelagicus* is documented in the early Eocene (HAQ & LOHMANN, 1976) as in this study as characterizing global warming and early Eocene climatic optimum. Nevertheless, *Coccolithus pelagicus* dominates in the low latitudes throughout late Palaeocene-early Eocene time, indicating nutrient improvement (JIANG & WISE, 2006), which could also be the cause of our results too. *Coccolithus pelagicus* s. ampl. dominates in assemblages together with *Ericsonia subpertusa* in our sections too. An increase of the relative abundance of *Coccolithus pelagicus* and *Ercisonia subpertusa* (*C. subpertusus*) during the PETM in the studied two sections was observed. They are interpreted as indicators of warm waters and were presumably adapted to oligotrophic environment based on their close association with the excursion taxa (discoasters, rhomboasters, tribrachiatus). It is evident that changes in the abundance of the calcareous nannofossil species can be interpreted as a response to palaeoecologic conditions such as palaeotemperature and nutrients. The acme of *Ericsonia subpertusa* (*Coccolithus subpertusus*) was recorded at the Dababyia section above the dissolution horizon with the LOs of *D. anartios* and *Rhomboasters* (base of NP9b) and coincides with the negative δ13C value of the CIE (DUPUIS et al., 2003), which proves the aforementioned Benthic Foraminiferal Extinction Event (BFEE). These authors correlated this acme with that recorded at the Equatorial Pacific Ocean Drilling Site 865 (KELLY et al. 1996) and concluded that the acme of *E. subpertusa* is a global Acme possibly as a response to global warming. *E. subpertusa* (*C. subpertusus*) is common in the lower part of PETM, then reaches its acme in the middle part of the PETM in the Matulla section (West Central Sinai (ABU SHAMA et al., 2007) and coincides with the LO of *Rhomboaster* taxa. In the studied two sections, the relative abundance of *E. subpertusa* varies from frequent to common indicating warming conditions and eutrophication that occurred around the Palaeocene/Eocene boundary. The lower abundances of early Eocene oligotrophic, warm water *Rhomboaster* species are possible consequences of the aforementioned nutrient-richer water condition. This is also evident from the domination of eutrophic, warm water *C. eopelagicus* detected in *the* early Eocene at the Um El Ghanayim section. Today, large forms of *C. pelagicus* can be observed at lower latitudes and upwelling regions (ZIVERI et al., 2004, BAUMANN et al., 2000).

In the studied sections, semi-quantitative analyses of calcareous nannofossil assemblages were performed for the interval from NP7-8 to the basal part of the NP10 Zone. At the Um EL Ghanayim section, the number of warm water nannofossil taxa fluctuates between 6-17 species in the late Palaeocene (NP7-8

Table 5. Calcareous nannofossils from Umm El Ghanayim section, grouped according to their paleoecological behaviour into warm water, cold water and non-characteristic species.

Age	Formation		Sample No.	Nannofossil Zone (NP)	Warm water																														
					Coccolithus pelagicus	*Coccolithus eopelagicus*	*Ericsonia subpertusa*	*Sphenolithus primus*	*Thoracosphaera operculata*	*Heliolithus kleinpellii**	*Discoaster mohleri**	*Fasciculithus clinatus*	*Fasciculithus tympaniformis**	*Fasciculithus involutus*	*Discoaster lenticularis*	*Pontosphaera versa*	*Discoaster multiradiatus**	*Zygrhablithus bijugatus*	*Fasciculithus alanii*	*Discoaster falcatus*	*Fasciculithus tonii*	*Fasciculithus schaubii*	*Fasciculithus lilianiae*	*Discoaster binodosus*	*Fasciculithus bobii*	*Pontosphaera ocellata*	*Thoracosphaera saxea*	*Fasciculithus richardii*	*Fasciculithus thomasii*	*Braarudosphaera bigelowii*	*Discoaster mediosus*	*Discoaster anartios**	*Rhomboaster cuspis**	*Rhomboaster spineus **	*Discoaster paelikei*
early Eocene	Esna Shale	EL Mahmiya Mb.	48	NP10b	x		x		x								x	x									x			x					
			47		x		x	x									x										x			x					
			46		x		x		x								x	x																	
			45		x		x		x								x													x					
			44		x	x	x	x									x													x					
			43		x		x		x								x																		
			42		x	x	x		x																		x			x					x
			41		x		x	x	x								x	x								x	x			x					
			40	NP10a	x	x	x	x	x				x	x			x	x												x					x
			39		x	x	x	x	x				x	x			x	x						x		x				x			x		
			38	NP9b	x			x	x				x				x													x			x		
			37		x		x	x	x				x	x			x	x								x				x					
		Dababiya Quarry Mb.	36		x	x	x	x	x					x				x												x		x	x		x
			35		x		x	x										x							x		x					x	x		x
			34		x		x	x									x										x					x		x	
			33		x	x	x	x									x	x														x			
			32		x		x						x		x		x	x									x					x			
			31		x	x	x	x					x		x			x									x					x			
			30		x		x	x									x	x								x	x								
			29		x	x	x	x					x				x	x									x								
			28		x	x	x	x							x		x	x		x						x	x								
			27		x	x	x										x		x																
late Palaeocene		EL Hamdi Member	26	NP9a	x	x	x	x									x		x							x									
			25		x	x	x	x						x			x	x								x	x								
			24		x		x	x	x			x	x	x	x		x		x							x			x	x	x				
			23		x		x	x	x			x		x	x		x	x								x									
			22		x	x	x	x	x			x	x	x			x			x					x	x		x	x						
			21		x		x	x	x			x	x	x			x		x	x		x				x									
			20		x	x	x	x	x			x	x	x			x	x	x	x						x	x				x				
			19		x		x	x	x			x	x	x	x		x		x	x		x				x			x						
			18		x		x	x	x			x			x		x	x		x		x				x			x	x	x				
			17		x	x	x	x	x			x	x	x		x	x	x	x	x		x				x		x	x						
			16		x		x	x				x	x	x	x	x	x	x	x	x						x	x	x	x		x				
			15		x			x	x			x	x	x			x	x				x	x		x	x									
			14		x	x	x	x	x			x	x	x	x		x	x	x	x		x	x		x										
			13		x		x		x				x	x	x		x	x	x			x	x	x	x										
			12		x	x	x	x	x	x		x	x	x	x	x	x			x															
			11		x		x	x	x	x		x	x	x	x		x	x	x	x	x														
			10		x		x	x	x	x		x	x	x	x		x	x	x																
			9		x	x	x	x	x			x	x	x	x	x	x	x																	
	Tarawan		8		x		x	x	x			x	x	x	x	x	x																		
			7	NP7-NP8	x	x	x	x	x	x	x		x	x																					
			6		x	x	x	x	x		x	x	x	x																					

Table 5. continued

												Cold water											Non-characteristic															
Pontosphaera plana	*Discoaster araneus**	*Rhomboaster bitrifida **	*Discoaster mahmoudii**	*Tribrachiatus bramlettei**	*Sphenolithus moriformis*	*Discoaster barbadiensis*	*Discoaster backmanii*	*Tribrachiatus digitalis**	*Discoaster diastypus*	*Pontosphaera exilis*	Species richness	*Toweius tovae*	*Toweius eminens*	*Neochiastozygus junctus*	*Neococcolithes protenus*	*Chiasmolithus danicus*	*Chiasmolithus californicus*	*Chiasmolithus consuetus*	*Chiasmolithus bidens*	*Chiasmolithus solitus*	*Chiasmolithus eograndis*	Species richness	*Ericsonia universa*	*Ellipsolithus macellus**	*Zygodiscus plectopons*	*Zygodiscus adamas*	*Campylosphaera eodela*	*Neochiastozygus perfectus*	*Calcisolenia aperta*	*"Ellipsolithus bollii*	*Ellipsolithus distichus*	*Ericsonia robusta*	*Toweius pertusus*	*Toweius occultatus*	*Zygodiscus sheldoniae*	*Micrantholithus attenuatus*	*Neochiastozygus chiastus*	Species richness
x										x	9			x						x		2														x		1
x										x	8											0					x											1
x										x	7			x								1					x									x		2
x										x	7	x		x						x		3					x									x		2
x				x					x		9			x								1					x									x		2
x									x		6			x								1																0
x						x			x		10			x								1					x											1
x						x		x			12			x								1					x				x					x		3
x				x			x				14			x								1					x									x		2
x			x	x	x	x					18		x	x				x	x			4					x									x		2
		x									8			x								1			x		x									x		3
x			x								12			x								1			x	x					x	x				x	x	6
	x	x									13		x	x								2	x		x		x					x				x	x	6
	x	x									11		x									1				x											x	2
	x										8			x								1			x												x	2
	x										8			x								1			x												x	2
											8			x								1			x	x										x		3
											9			x								1			x											x		2
											7											0			x													1
x	x										10			x								1			x	x												2
x	x										12			x								1			x													1
x	x										7			x			x					2			x	x												2
											7			x					x			2			x													1
											9		x	x					x			3		x	x	x	x						x		x			6
											14	x	x	x			x					4			x								x		x			3
											10			x			x					2		x	x	x	x					x			x			6
											14			x				x				2			x	x	x			x			x		x			6
											12							x	x			2		x	x	x							x					4
											15	x			x	x			x			4			x		x			x	x	x	x		x			7
											14	x			x			x	x			4	x		x	x		x			x	x	x		x			8
											14							x	x			2		x	x	x	x			x			x					6
											17	x	x					x	x			4			x	x	x					x		x				5
											17	x							x			2		x	x		x		x	x		x	x	x				8
											12	x	x						x			3			x		x											2
											16	x			x			x	x		x	5		x	x	x					x							4
											13	x	x				x		x			4			x	x		x			x							4
											13								x			1	x		x	x		x		x	x							6
											14	x	x					x	x			4	x	x	x				x	x	x							6
											12	x			x			x				3	x	x	x	x		x	x		x							7
											12	x	x		x			x				4	x	x	x	x	x	x	x	x								8
											10	x	x		x		x					4		x	x	x	x	x										5
											9	x	x			x						3	x	x	x			x										4
											9	x		x		x						3		x														1

Table 6. Calcareous nannofossils from Naqb Assiut section, grouped according to their paleoecological behaviour into warm water, cold water and non-characteristic species

late Palaeocene																			early Eocene											Age	
Esna Shale																														Formation	
EL Hanadi Member																			DQM						EL Mahmiya Mb.						
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Sample No.	
NP9a																			NP9b											Nannofossil Zone (NP)	
×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	*Coccolithus pelagicus*	Warm water
×	×	×				×			×		×			×		×		×	×	×		×			×		×			*Coccolithus eopelagicus*	
×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	*Ericsonia subpertusa*	
×	×	×	×	×	×	×	×		×	×	×	×		×						×	×	×				×		×		*Zygrhablithus bijugatus*	
×	×	×	×	×	×	×	×		×	×	×	×	×	×		×		×	×		×	×						×		*Thoracosphaera operculata*	
×	×	×	×	×	×	×	×	×	×	×	×		×	×	×	×	×	×		×	×	×	×	×		×	×	×		*Sphenolithus primus*	
×	×	×	×	×	×		×	×		×	×		×	×		×		×	×		×	×	×	×	×	×	×	×		*Discoaster multiradiatus**	
×		×	×	×	×			×		×	×			×		×		×	×											*Discoaster lenticularis*	
×	×	×	×	×	×	×		×	×			×		×	×			×			×			×	×		×	×	×	*Fasciculithus tympaniformis**	
×		×	×	×		×		×	×	×		×	×	×		×														*Fasciculithus schaubii*	
×		×	×	×	×		×				×																			*Fasciculithus bobii*	
×		×		×	×	×	×	×	×	×	×	×	×	×	×	×			×		×	×				×	×	×	×	*Fasciculithus involutus*	
				×			×	×		×	×			×	×											×				*Braarudosphaera bigelowii*	
				×																										*Discoaster mohleri **	
				×		×	×	×			×																			*Fasciculithus richardii*	
					×	×		×			×		×			×					×									*Fasciculithus clinatus*	
					×	×																								*Discoaster falcatus*	
					×															×										*Thoracosphaera saxea*	
								×	×		×																			*Pontosphaera exilis*	
											×	×			×															*Pontoshphera pulchra*	
					×					×																				*Bomolithus megastypus*	
											×			×	×															*Pontosphaera formosa*	
												×				×										×				*Pontosphaera ocellata*	
																×														*Pontosphaera plana*	
																×														*Discoaster backmanii*	
																			×		×									*Discoaster araneus**	
																			×		×									*Rhomboaster bitrifida**	
																			×											*Discoaster anartios**	
																					×									*Discoaster paelikei*	
																										×		×	×	*Rhomboaster cuspis**	
																										×			×	*Pontosphaera multipora*	
																										×				*Discoaster mahmoudii**	
12	8	12	10	14	14	12	10	12	10	11	16	9	8	13	8	13	3	8	10	6	12	8	4	5	5	11	7	9	6	Species richness	
×		×	×		×									×	×															*Toweius tovae*	Cold water
		×					×						×		×								×							*Toweius eminens*	
				×	×	×		×																						*Chiasmolithus bidens*	
						×		×		×	×		×	×				×					×			×	×		×	*Chiasmolithus consuetus*	
								×							×	×		×		×	×			×	×	×			×	*Neochiastozygus junctus*	
													×			×					×									*Neococcolithes protenus*	
1	0	2	1	1	2	2	1	3	0	1	1	0	3	2	3	2	0	2	0	1	2	0	2	1	1	2	1	0	2	Species richness	
																														Toweius pertusus	Non-characteristic
×	×	×		×	×	×	×		×	×	×	×			×			×	×			×				×				*Zygolithus sheldoniae*	
		×		×	×	×		×	×	×	×	×				×	×	×	×				×	×	×	×			×	*Campylosphaera eodela*	
		×		×	×	×	×	×	×	×	×	×		×	×			×	×	×						×		×		*Zygodiscus plectopons*	
		×		×	×	×	×		×					×		×		×		×										*Calcisolenia aperta*	
				×		×				×		×	×	×	×			×				×	×	×		×	×	×	×	*Ellipsolithus macellus**	
				×	×			×			×		×	×	×															*Ellipsolithus distichus*	
					×	×	×	×		×			×	×	×				×											*Zygodiscus adamas*	
									×										×	×										*Ericsonia robusta*	
																	×		×			×								*Lophodolithus nascens*	
																			×	×										*Ericsonia universa*	
1	1	4	0	6	6	6	4	4	5	5	4	4	3	5	5	2	2	5	7	4	0	3	2	2	1	4	1	2	2	Species richness	

Zone to NP9a Subzone) and reaches a maximum in a single sample of 12 species in the NP9b of the early Eocene, while the cold water taxa gradually decreases around this boundary (Table 5). At the Naqb Assiut section, the warm water species range from 7 to 15 in number below the P/E boundary and decreases to 3 near this boundary. Nevertheless, warm-water *Coccolithus eopelagicus, Discoaster multiradiatus*, *D. araneus*, *Ericsonia subpertrusa, Sphenolithus primus, Zygrhablithus bijugatus* in conjunction to cold water *Neochiastozygus junctus* are the most common species of the late Palaeocene – early Eocene interval in the two studied sections. This suggests the Palaeocene–Eocene Thermal Maximum (PETM) with the pick in the samples 21 and 33 of the Naqb Assiut and Umm El Ghanayim sections respectively during this time interval (Figs. 6,7).

The warm, cold water and non-characteristic calcareous nannofossils near the P/E boundary at the Umm El Ghanayim and Naqb Assiut sections are shown in Tables 5 and 6. The vertical variations in the number of warm water and cold water species in these two sections are shown in Fig. 6. On the other hand, the total warm and cold water specimens/slide and warm/cold water specimens are shown in Fig. 7.

The last abundant appearance of *Coccolithus subpertusus*, and the frequent occurrence of excursion taxa including *Discoaster araneus, D. anartios* with rare *Rhomboaste*r spp. across the PETM in four outcrops in Central Egypt are present in response to the beginning of the warming period (YOUSSEF, 2016).

6. CONCLUSIONS

Two upper Palaeocene – lower Eocene stratigraphic sequences at Kharga Oasis (the Umm El Ghanayim and Naqb Assiut sections) were studied biostratigraphically for their calcareous nannofossil content. The investigated interval comprises the upper part of the Tarawan and the Esna formations. The Esna Shale can be divided from the base to top as follows: the El Hanadi, the Dababiya Quarry and El Mahmiya members.

At the Umm El Ghanayim section, the Dababiya Quarry Member consists of three beds: an organic rich-clay layer (15 cm), brown-coloured fish debris and coprolite-rich laminated shale (90 cm) and marls (15 cm). At the Naqb Assiut section, the Dababiya Quarry Member is composed of 20 cm of massive phosphatic marls rich with collophane grains at the base and 70 cm of marly limestone at the top. At the Naqb Assiut section, the P/E boundary interval is marked by the absence of the organic rich-clay layer (Bed no.1) of the Dababiya Quarry Member at the Dababiya section (GSSP) which may indicate the presence of a minor hiatus at the base of the Eocene. This minor unconformity could not be detected palaeontologically by means of nannofossils.

At the Gabal Umm El Ghanayim section, the exposed part of the Tarawan Chalk encompasses nannofossil zones NP6, NP7/8 and the basal part of the NP9a Subzone. The El Hanadi Member includes the middle and upper parts of the NP9a Subzone, and this means that a conformable relationship exists between these two units. In this section, the Dababiya Quarry Member includes the NP9b Subzone (early Eocene) and the El Mahmiya Member includes the upper NP9b, the NP10aand NP10b Subzones.

The base of the NP9b Subzone is delineated by the LO of *Discoaster araneus* at the G. Umm El Ghanayim section, while at the Gabal Naqb Assiut section, the first appearances of the nannofossil taxa *Rhomboaster bitrifida, Discoaster araneus* and *D. anartios* can be used to place the NP9a/NP9b subzonal boundary.

The current study indicates that the Umm El Ghanayim section appears to be stratigraphically complete, at least based on nannofossil biostratigraphic resolution, and spans a late Palaeocene – early Eocene time interval encompassing zones NP9 to the base of NP10. The Palaeocene–Eocene boundary is placed at the base of the Dababiya Quarry Member of the Esna Fomation.

Several nannofossil species became extinct in the upper part of the NP9a Subzone (late Palaeocene): *Fasciculithus tonii, F. richardii*, *F. schaubii*, *F. thomasii*, *F. clinatus*, *F. lillianiae*, *Discoaster mediosus* and *D. mohleri*. Other taxa which crossed the P/E boundary include: *Campylosphaera eodela*, *Discoaster lenticularis*, *D. multiradiatus*, *Fasciculithus tympaniformis*, *F. involutus* and *Zygrhablithus bijugatus*. The excursion taxa (*Rhomboaster intermedia*, *R. bitrifida*, *R. cuspis, R. spineus*, *Discoaster araneus, D.anartios*) in addition to *D. paelikei* and *D. mahmoudii* have their first occurrences within NP9b Subzone.

On the other hand**,** the species richness (diversity) fluctuates with a detected minimum around the Palaeocene/Eocene boundary and *Fasciculithus* spp. decreases in diversity and abundance above the Palaeocene/Eocene boundary in the studied sections which is in agreement with other aforementioned research in the region and globally.

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LIST OF CALCAREOUS NANNOFOSSIL TAXA

Bomolithus megastypus (BRAMLETTE & SULLIVAN, 1961) BOWN, 2005
Braarudosphaera bigelowii (GRAN & BRAARUD, 1935) DEFLANDRE, 1947
Calciosolenia aperta (HAY & MOHLER, 1967) BOWN, 2005
Campylosphaera eodela BUKRY & PERCIVAL, 1971
Chiasmolithus bidens (BRAMLETTE & SULLIVAN, 1961) HAY & MOHLER, 1967
Chiasmolithus californicus (SULLIVAN, 1964) HAY & MOHLER, 1967
Chiasmolithus consuetus (BRAMLETTE & SULLIVAN, 1961) HAY & MOHLER, 1967
Chiasmolithus danicus (BROTZEN, 1959) HAY & MOHLER, 1967
Chiasmolithus eograndis PERCH-NIELSEN, 1971
Chiasmolithus solitus (BRAMLETTE & SULLIVAN, 1961) LOCKER, 1968
Coccolithus eopelagicus (Bramlette & Riedel, 1954) Bramlette & Sullivan 1961
Coccolithus pelagicus (WALLICH, 1877) SCHILLER, 1930
Discoaster anartios BYBELL & SELF-TRAIL, 1995
Discoaster araneus BUKRY, 1971
Discoaster backmanii AGNINI & FORNACIARI, 2008
Discoaster barbadiensis TAN, 1927
Discoaster binodosus MARTINI, 1958
Discoaster diastypus BRAMLETTE & SULLIVAN, 1961
Discoaster falcatus BRAMLETTE & SULLIVAN, 1961
Discoaster lenticularis BRAMLETTE & SULLIVAN, 1961
Discoaster mahmoudii PERCH-NIELSEN, 1981
Discoaster mediosus BRAMLETTE & SULLIVAN, 1961
Discoaster mohleri BRAMLETTE & PERCIVAL, 1971
Discoaster multiradiatus BRAMLETTE & REIDEL, 1954
Discoaster paelikei AGNINI et al., 2008
Ellipsolithus bollii PERCH-NIELSEN, 1977
Ellipsolithus distichus (BRAMLETTE & SULLIVAN, 1961) SULLIVAN, 1964
Ellipsolithus macellus (BRAMLETTE & SULLIVAN, 1961) SULLIVAN, 1964
Ericsonia robusta (BRAMLETTE & SULLIVAN, 1961) EDWARDS & PERCH-NIELSEN, 1975
Ericsonia subpertusa HAY & MOHLER, 1967
Ericsonia universa (WIND & WISE, 1977) ROMEIN, 1979
Fasciculithus alanii PERCH-NIELSEN, 1971
Fasciculithus clinatus BUKRY, 1971
Fasciculithus bobii PERCH-NIELSEN, 1971
Fasciculithus involutus BRAMLETTE & SULLIVAN, 1961
Fasciculithus lillianiae PERCH-NIELSEN, 1971
Fasciculithus richardii PERCH-NIELSEN, 1971
Fasciculithus thomasii PERCH-NIELSEN, 1971
Fasciculithus tonii PERCH-NIELSEN, 1971
Fasciculithus schaubii HAY & MOHLER, 1967
Fasciculithus tympaniformis HAY & MOHLER *in* HAY et al., 1967
Heliolithus kleinpelli SULLIVAN, 1964
Lophodolithus nascens BRAMLETTE & SULLIVAN, 1961
Micrantholithus attenuatus BRAMLETTE & SULLIVAN, 1961
Neochiastozygus chiastus (BRAMLETTE & SULLIVAN, 1961) PERCH-NIELSEN, 1971
Neochiastozygus junctus (BRAMLETTE & SULLIVAN, 1961) PERCH-NIELSEN, 1971
Neochiastozygus perfectus PERCH-NIELSEN, 1971
Neococcolithes protenus (BRAMLETTE & SULLIVAN, 1961) BLACK, 1967
Pontosphaera exilis (BRAMLETTE & SULLIVAN, 1961) ROMEIN, 1979
Pontosphaera formosa (BUKRY & BRAMLETTE, 1969) ROMEIN, 1979
Pontosphaera multipora (KAMPTNER, 1948 ex DEFLANDRE in DEFLANDRE & FERT, 1954) ROTH, 1970
Pontosphaera ocellata (BRAMLETTE & SULLIVAN, 1961) PERCH-NIELSEN, 1984
Pontosphaera plana (BRAMLETTE & SULLIVAN, 1961) HAQ, 1971

Geologia Croatica

Pontosphaera pulchra (DEFLANDRE *in* DEFLANDRE & FERT, 1954) ROMEIN, 1979
Pontosphaera versa (BRAMLETTE & SULLIVAN, 1961) SHERWOOD, 1974
Rhomboaster bitrifida ROMEIN, 1979
Rhomboaster cuspis BRAMLETTE & SULLIVAN, 1961
Sphenolithus moriformis (BRONNIMANN & STRADNER, 1960) BRAMLETTE & WILCOXON 1967
Sphenolithus primus PERCH-NIELSEN 1971
Thoracosphaera operculata BRAMLETTE & MARTINI, 1964
Thoracosphaera saxea STRADNER, 1961
Toweius eminens (BRAMLETTE & SULLIVAN, 1961) PERCH-NIELSEN, 1971
Toweius occultatus (LOCKER, 1967) PERCH-NIELSEN, 1971
Toweius pertusus (SULLIVAN, 1965) ROMEIN, 1979
Toweius tovae PERCH-NIELSEN, 1971
Tribrachiatus bramlettei (BRONNIMANN & STRADNER, 1960) PROTO DECIMA et al., 1975
Tribrachiatus digitalis AUBRY, 1996
Rhomboaster cuspis BRAMLETTE & SULLIVAN, 1961
Rhomboaster spineus (SHANK & STRADNER, 1971) PERCH-NIELSEN, 1984
Zygodiscus adamas BRAMLETTE & SULLIVAN, 1961
Zygodiscus sheldoniae BOWN, 2005
Zygodiscus plectopons BRONNIMANN & STRADNER, 1961
Zygrhablithus bijugatus (DEFLANDRE in DEFLANDRE & FERT, 1954) DEFLANDRE, 1959

Plate 1

1) *Braarudosphaera bigelowii* (GRAN & BRAARUD, 1935) DEFLANDRE, 1947, sample 12, Naqb Assiut section.
2) *Chiasmolithus bidens* (BRAMLETTE & SULLIVAN, 1961) HAY & MOHLER 1967, sample 6, Um El Ghanayim section.
3, 4) *Campylosphaera eodela* BUKRY & PERCIVAL, 1971, sample 8, Um El Ghanayim section
5, 6) *Ericsonia subpertusa* HAY & MOHLER, 1967, sample 8, Naqb Assiut section.
7) *Ellipsolithus distichus*(BRAMLETTE & SULLIVAN, 1961) SULLIVAN, 1964, sample 20, Um El Ghanayim section.
8) *Ellipsolithus macellus* (BRAMLETTE & SULLIVAN, 1961) SULLIVAN, 1964, sample 23, Naqb Assiut section.
9, 10) *Fasciculithus clinatus* BUKRY 1971, sample 5, Naqb Assiut section.
11, 14) *Fasciculithus involutus* BRAMLETTE & SULLIVAN, 1961.
11, 12) Sample 14, Naqb Assiut section.
13, 14) Sample 20, Naqb Assiut section.
15) *Fasciculithus tympaniformis* HAY & MOHLER in HAY et al. 1967, sample 12, Um El Ghanayim section.
16) *Heliolithus kleinpellii* SULLIVAN (1964) sample 5, Um El Ghanayim section.
17, 18) *Micrantholithus attenuatus* BRAMLETTE & SULLIVAN (1961) *s*ample 44, Um El Ghanayim section.
19, 20) *Neochiastozygus junctus* (BRAMLETTE & SULLIVAN, 1961) sample 23, Um El Ghanayim section.
21–23) *Zygrhablithus bijugatus* (DEFLANDRE *in* DEFLANDRE & FERT, 1954) DEFLANDRE, 1959.
21, 22) Sample 13 Naqb Assiut section.
23) Sample 41, Um El Ghanayim section.
24, 25) *Calciosolenia aperta* (HAY & MOHLER, 1967), BOWN, 2005, sample 9, Um El Ghanayim section.
26, 27) *Zygodiscus plectopons* BRAMLETTE & SULLIVAN, 1961, sample 7, Naqb Assiut section.

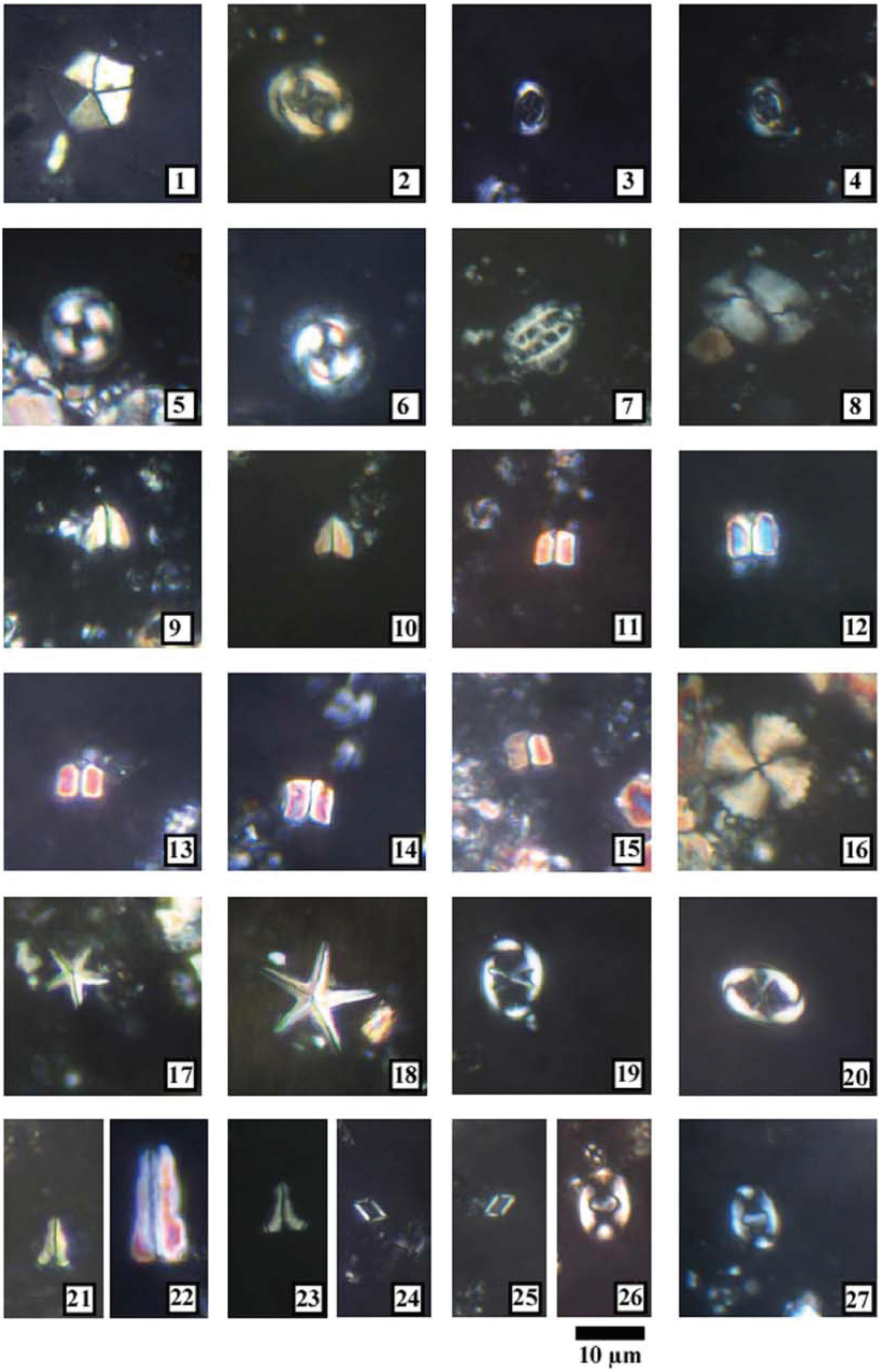
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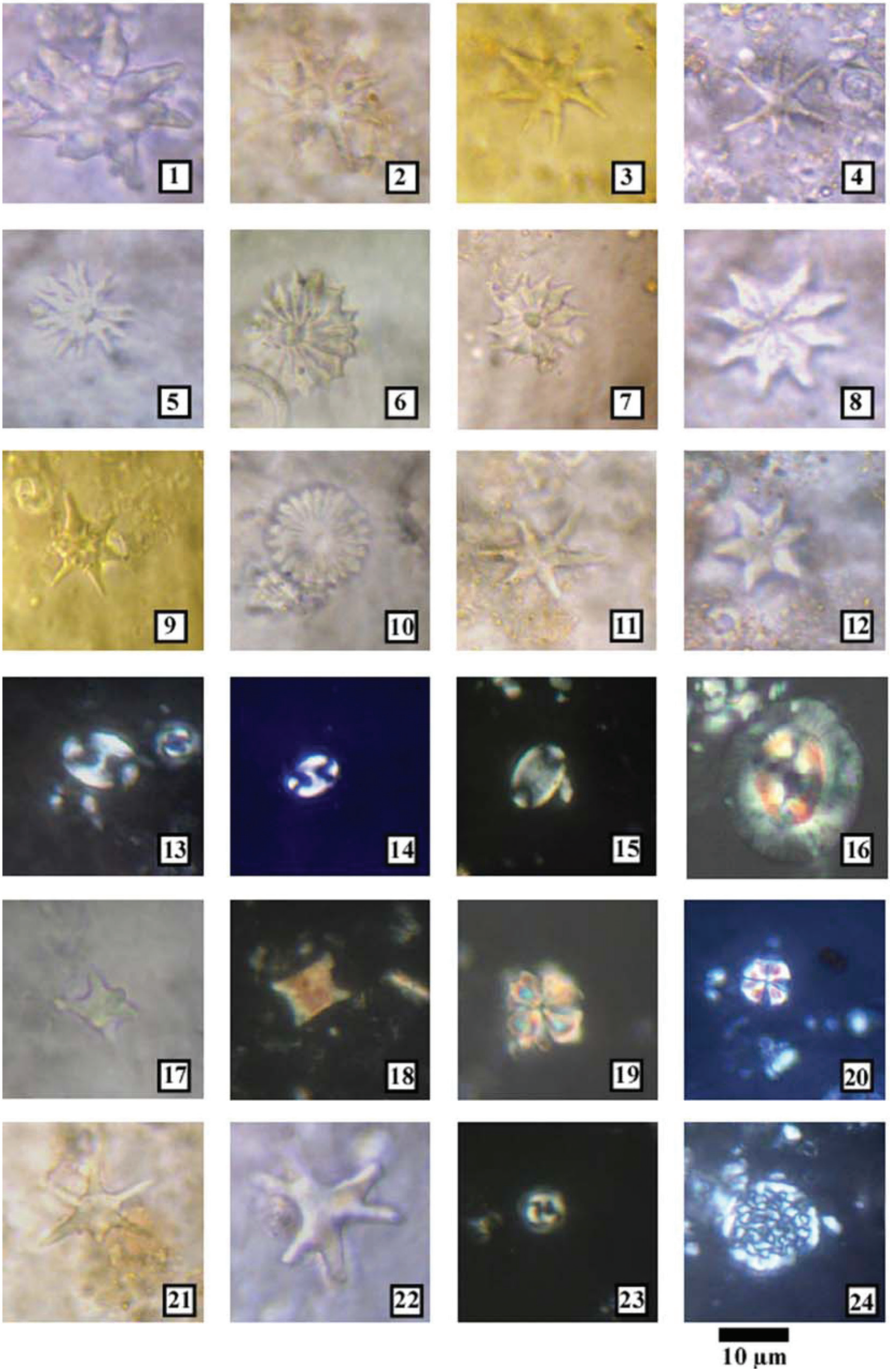
Plate 2

1-4) *Discoaster araneus* BUKRY, 1971, 1, 2) sample 20, Naqb Assiut section
3, 4) Sample 35, Um El Ghanayim section.
5) *Discoaster anartios* BYBELL &SELF-TRAIL 1995, sample 20, Naqb Assiut section.
6) *Discoaster barbadiensis* TAN 1927, sample 42, Um El Ghanayim section.
7) *Discoaster diastypus* BRAMLETTE & SULLIVAN 1961, sample 42, Um El Ghanayim section.
8) *Discoaster falcatus* BRAMLETTE & SULLIVAN 1961, sample 22, Um El Ghanayim section.
9) *Discoaster mahmoudii* PERCH-NIESEN 1981, sample 27, Naqb Assiut section.
10) *Discoaster multiradiatus* BRAMLETTE & REIDEL 1954, sample 5, Naqb Assiut section.
11, 12) *Discoaster paelikei* AGNINI et al. 2008, sample 36, Um El Ghanayim section.
13, 14) *Pontosphaeraexilis* (BRAMLETTE & SULLIVAN, 1961) ROMEIN, 1979, sample 9, Naqb Assiut section.
15) *Pontosphaera plana* (BRAMLETTE & SULLIVAN, 1961) HAQ 1971, sample 17, NaqbAssiut section
16) *Coccolithus eopelagicus* (WALLICH, 1877) SCHILLER, 1930, sample 44, Umm El Ghanayim section
17) *Rhomboaster bitrifida* ROMEIN 1979, sample 38, Um El Ghanayim section.
18) *Rhomboaster cuspis* BRAMLETTE & SULLIVAN 1961, sample 27, Naqb Assiut section
19) *Sphenolithus moriformis* (BRONNIMANN & STRADNER, 1960) BRAMLETTE & WILCOXON, 1967, sample 39, Um El Ghanayim section.
20) *Sphenolithus primus* PERCH-NIELSEN 1971, sample 19, Um El Ghanayim section.
21) *Tribrachiatus bramlettei* (BRONNIMANN & STRADNER, 1960) PROTODECIMA et al., 1975, sample 39, Um El Ghanayim section.
22) *Tribrachiatus digitalis* AUBRY 1996, sample 41, Um El Ghanayim section.
23) *Toweius eminens* (BRAMLETTE & SULLIVAN, 1961), PERCH NIELSEN, 1971, sample 16, Naqb Assiut section.
24) *Thoracosphaera operculata* BRAMLETTE & MARTINI (1964), sample 4, Um El Ghanayim section.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