

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*, *Fascullithus* spp., *Coccolithus eopelagicus*, *Discoaster* spp., *Rhomboaster bitrifida* and *Tribrachiatum bramlettei* characterize the Palaeocene-Eocene transition and suggest global warming and the Palaeocene – Eocene Thermal Maximum (PETM).

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 & GHORBIAL (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).

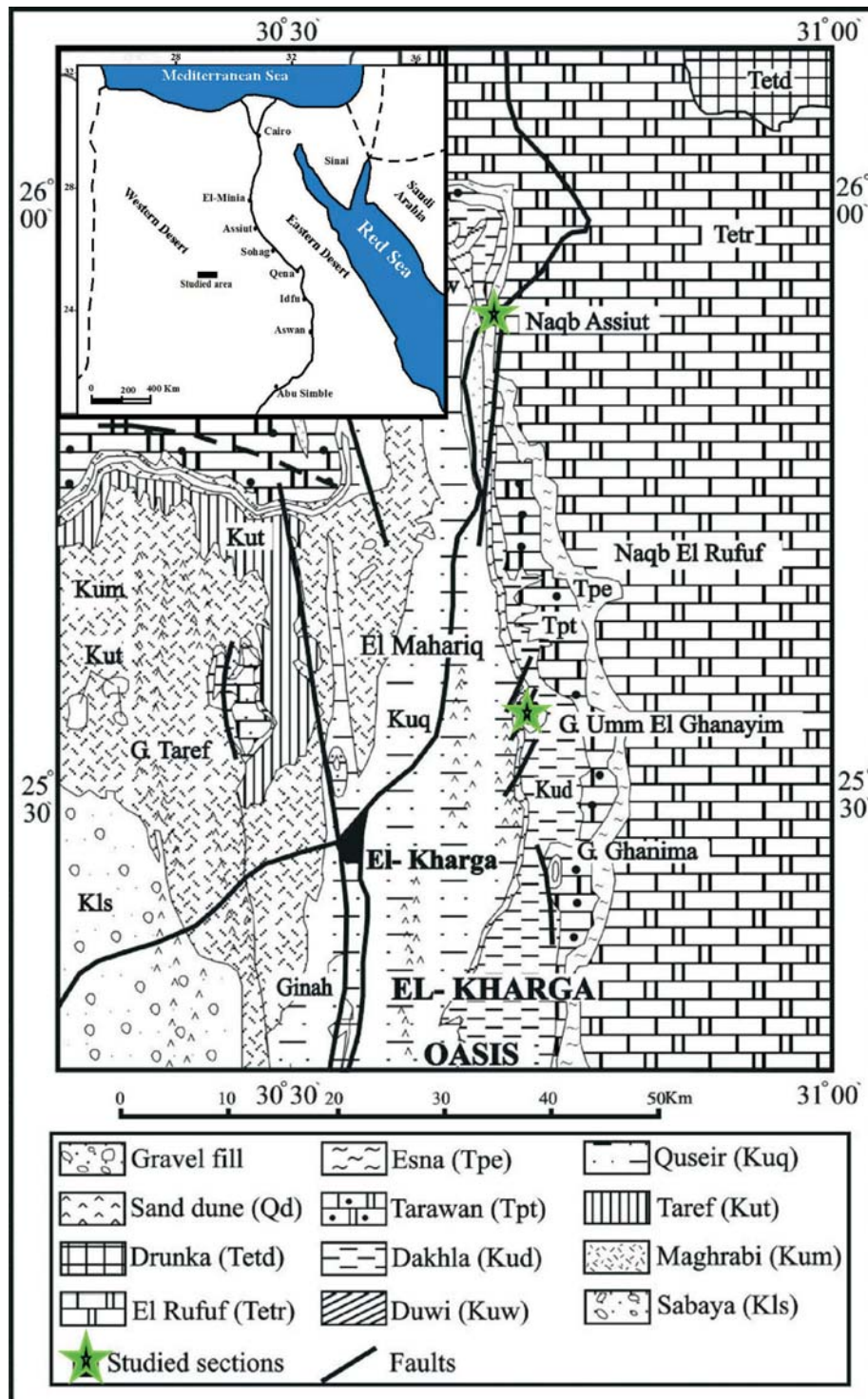


Figure 1. Geological map of the Kharga area (Western Desert, Egypt) with the location of the studied sections (modified after SAID, 1990).

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 (~0.71 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 colophonane 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																																																																																																					
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																																								El Hanadi Mb.	El-Shaghab Mb.	Esna Unit 2	El Mahmiya Mb.	El Mahmiya Mb.	El Mahmiya Mb.	El Mahmiya Mb.	El Mahmiya Mb.	El Mahmiya Mb.	El Mahmiya Mb.																																																																
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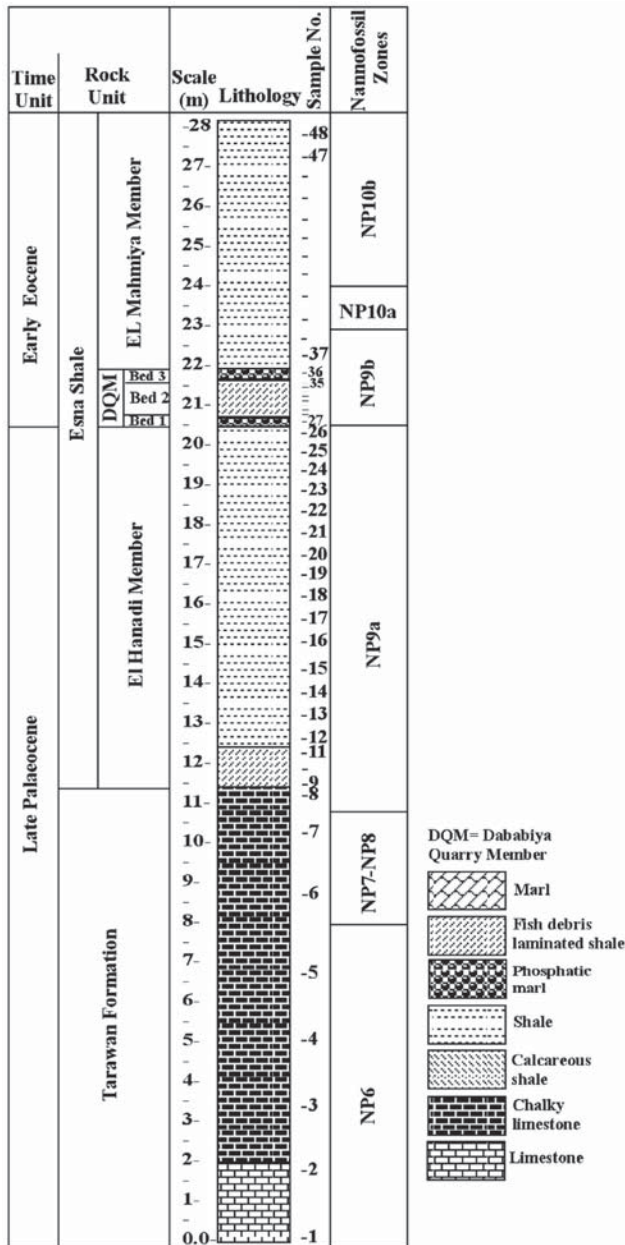


Figure 2. Lithostratigraphy and biostratigraphy of Umm El Ghanayim section (Kharga Oasis, Western Desert, Egypt), samples position and correlation to the standard zonation of MARTINI (1971).

Palaeotemperatures from calcareous nannofossil proxies were calculated using the Microsoft Excel program in accordance with the mentioned authors in the palaeoecology section 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.

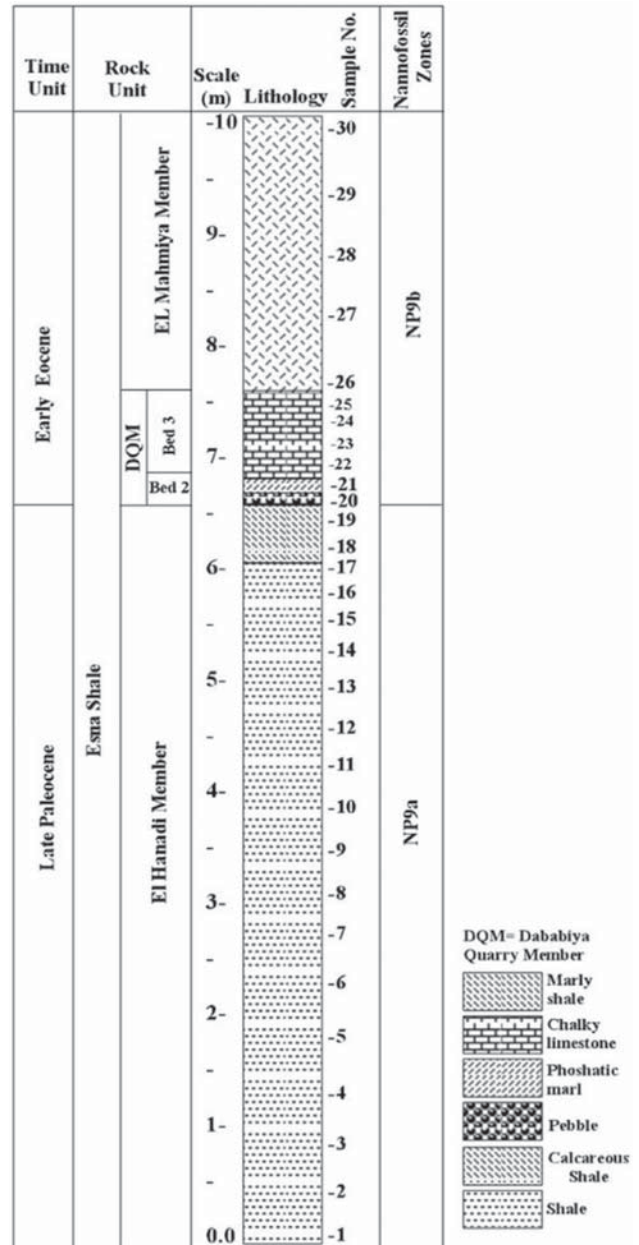


Figure 3. Lithostratigraphy and biostratigraphy of Naqb Assiut section (Kharga Oasis, Western Desert, Egypt), samples position and correlation to the standard zonation of MARTINI (1971).

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 & ZAHNAN, 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 eoepelagicus*, *Ericsonia subpertusa*, *E. universona*, *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 *Tribrachiatius 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	<i>T. contortus</i> Zone (NP10)	← <i>T. bramlettei</i>	<i>T. contortus</i> Subzone (CP9a)	← <i>T. bramlettei</i>	<i>T. eminens</i> PRZ (CNE2)	← <i>T. F. tympaniformis</i>	NP10b	← <i>T. digitalis</i>		
									NP10a	← <i>T. bramlettei</i>		
Palaeocene	Late	Thanetian	<i>D. multiradiatus</i> Zone (NP9)	← <i>T. bramlettei</i>	<i>D. multiradiatus</i> Zone (CP8)	← <i>T. bramlettei</i>	<i>F. tympaniformis</i> TZ (CNE1)	← <i>T. F. richardii</i> gr.	NP9b	← <i>D. araneus Rhomboaster</i> spp.		
									NP9a	← <i>D. multiradiatus</i>		
											NP7/8	← <i>D. multiradiatus</i>
									NP6	← <i>D. mohleri</i>		
Palaeocene	Late	Thanetian	<i>H. riedelii</i> Zone (NP8)	← <i>D. multiradiatus</i>	<i>D. nobilis</i> Zone (CP7)	← <i>D. multiradiatus</i>	<i>D. backmanii</i> BZ (CNP10)	← <i>B. D. backmanii</i>	NP7/8	← <i>D. multiradiatus</i>		
											NP9a	← <i>D. multiradiatus</i>
											NP6	← <i>D. mohleri</i>
Palaeocene	Late	Thanetian	<i>D. mohleri</i> Zone (NP7)	← <i>H. riedelii</i>	<i>D. mohleri</i> Zone (CP6)	← <i>D. nobilis</i>	<i>D. moheri</i> BZ (CNP9)	← <i>B. D. backmanii</i>	NP7/8	← <i>D. multiradiatus</i>		
											NP9a	← <i>D. multiradiatus</i>
											NP6	← <i>D. mohleri</i>
Palaeocene	Late	Selan.	<i>H. kleinpellii</i> Zone (NP6)	← <i>D. mohleri</i>	<i>H. kleinpellii</i> Zone (CP5)	← <i>D. mohleri</i>	<i>H. cantabriae</i> BZ (CNP8)	← <i>B. D. moheri</i>	NP6	← <i>D. mohleri</i>		
											NP6	← <i>D. mohleri</i>

Selan.: Selandian

TZ= Top Zone
BZ= Base Zone
CRZ= Concurrent Range Zone
PRZ= Partial Range Zone

T= Top
B= Base

Highest Occurrence
Lowest Occurrence

Late Paleocene															Early Eocene										Age									
Esná Shale																									Formation									
EL Hanadi															DQM					EL Mahmiya Mb.					Sample No.									
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	Abundance	Preservation			
NP9a															NP9b										Nannofossil Zone (NP)									
F	F	F	R	F	F	R	F	F	F	F	F	F	F	R	R	R	F	F	F	F	F	F	F	F	F	R	F	F	R	<i>Coccolithus pelagicus</i>				
R	R	VR				F				R					F			F	F	F					VR		VR			<i>Coccolithus eoelagicus</i>				
F	R	F	F	F	F	F	F	F	F	R	F	F	F	F	F	F	F	F	C	A	C	F	F	F	F	F	R	R	R	<i>Ericsonia subpertusa</i>				
R	R	VR	R	R	R	R	R	R	R	VR	R	R	R	R	R	R				R	R	VR								<i>Zygrhablithus bijugatus</i>				
VR	VR	R	VR	VR	R	VR	VR			VR	VR	VR	VR	VR	VR				F	VR										<i>Thoracosphaera operculata</i>				
VR	F	F	R	F	R	F	F	F	R	R	F			R	F	R	F		F	R	F	R	R			R	R	R		<i>Sphenolithus primus</i>				
R	R	R	R	F	R		R	F		R	R			R	R			R	R		VR	VR	R	VR	VR	F	R	R		<i>Discoaster multiradiatus*</i>				
VR		R	R	F	R					R	R			R	R	R														<i>Discoaster lenticularis</i>				
VR		R	R	R	R	R	R	R			R			R	R	VR	F		VR	R				R	R		VR	R	R		<i>Toweius pertusus</i>			
R		R	R		VR									R	R																<i>Toweius tovae</i>			
R	VR	F	F	F	F	F	F	R			R			VR	R								VR					R	R	R	<i>Fasciculithus tympaniformis*</i>			
VR	R	VR	R	R	VR			R	VR	R				R	R	R															<i>Fasciculithus schaubii</i>			
VR		R	R	R	R			R			VR																				<i>Fasciculithus bobii</i>			
R		F		F	F	R	R	R	VR	R	R	R	R	R	R	VR			R		VR	VR					VR	VR	R	R	<i>Fasciculithus involutus</i>			
R	F	F		F	F	R	R	R	VR	R	F	R			R			VR	VR												<i>Zygodiscus sheldoniae</i>			
		R		R				VR						VR	VR																<i>Toweius eminens</i>			
		VR		VR	VR	R		VR	R	VR	VR	VR						VR	VR	VR	VR					VR	VR	VR	VR		<i>Campylosphaera eodela</i>			
		R		F	F	F	R	R	R	R	F	R			VR	R			F	R	R										<i>Zygodiscus plectopons</i>			
				VR	VR	VR	VR	VR						VR	VR	R																<i>Calcisolenia aperta</i>		
				VR	VR									VR	VR	VR	R															<i>Ellipsolithus macellus*</i>		
				VR		VR	VR	R	VR					R	VR																	<i>Braarudosphaera bigelowii</i>		
				VR	VR			VR						VR	VR	VR																<i>Ellipsolithus distichus</i>		
				VR																												<i>Discoaster mohleri*</i>		
				VR	VR	R		VR																								<i>Chiasmolithus bidens</i>		
				R		VR	R	R			R																					<i>Fasciculithus richardii</i>		
				R	R		R				VR	VR																				<i>Fasciculithus clinatus</i>		
				VR	VR																											<i>Discoaster falcatus</i>		
				R	R	R	R				R	R	R																			<i>Zygodiscus adamas</i>		
				R																												<i>Thoracosphaera saxea</i>		
				VR							VR																					<i>Bomolithus megastypus</i>		
						VR		VR		VR	VR			VR	VR																	<i>Chiasmolithus consuetus</i>		
						R	R																									<i>Pontosphaera exilis</i>		
						R																										<i>Neochiastozygus junctus</i>		
																																	<i>Ericsonia robusta</i>	
																																	<i>Pontosphaera pulchra</i>	
																																	<i>Pontosphaera formosa</i>	
																																	<i>Pontosphaera ocellata</i>	
																																	<i>Neococcolithes protenus</i>	
																																	<i>Pontosphaera plana</i>	
																																	<i>Discoaster backmanii</i>	
																																	<i>Lopholithus nascens</i>	
																																	<i>Discoaster araneus*</i>	
																																	<i>Rhomboaster bitrifida*</i>	
																																	<i>Discoaster anartios*</i>	
																																	<i>Ericsonia univera</i>	
																																	<i>Discoaster paelikei</i>	
																																	<i>Rhomboaster cuspis*</i>	
																																	<i>Pontosphaera multipora</i>	
																																	<i>Discoaster mahmoudii*</i>	

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 sec-

tion, *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. *Tribrachiatius contortus* Zone (NP10)

Definition: This biostratigraphic interval is defined by the LO of *Tribrachiatius 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 *Tribrachiatius 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 *Tribrachiatius 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 *Tribrachiatius contortus*.

Remarks on assemblages: A new species, *Tribrachiatius 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 Kila-biya). DUPUIS et al. (2003) used the same four nannofossil sub-zones 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 <i>D. araneus</i> , <i>D. anartios</i> , <i>D. aegyptiacus</i> , <i>Rhombaster</i> spp., <i>Ca. eodela/dela</i>
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 <i>D. araneus</i> , <i>D. anartios</i> , <i>R. intermedia</i>
Darb Gaga-2		Northern Kharga Oasis	NP9a/NP9b	LOs of <i>D. araneus</i> , <i>D. anartios</i> , <i>R. bitrifida</i>
AL Aguz area		Northern Kharga Oasis	NP9a/NP9b	LOs of <i>R. calcitrapa</i> , <i>R. spineus</i> , <i>D. araneus</i> , <i>D. anartios</i>
Nag El-Quda	Youssef (2015)	Eastern Desert	NP9a/NP9b	LAD of <i>D. araneus</i> and <i>Rhombaster</i> spp.
Gebel Ghanima	KHALIL & AL SAWY (2014)	Kharga Oasis	NP9a/NP9b	LO of <i>R. cuspis</i> Abrupt decrease of <i>Fasciculithus</i> spp.
El Serai	TANTAWY (2006)	East Qena	NP9a/NP9b	LOs of <i>Ca. eodela/dela</i> , <i>D. araneus</i> Abrupt decrease of <i>Fasciculithus</i> spp.
Taramsa		West Qena		
Geirya (Abu Had)	AUBRY (1999)	East Qena	NP9a/NP9b	LOs of <i>D. araneus</i> , <i>R. spineus</i> , <i>R. cuspis</i> , <i>D. araneus</i>
Kilabiya		Nile Valley	NP9a/NP9b	
Teir/Tarawan	FARIS et al. (1999)	Kharga Oasis	within NP9	HOs of <i>Fasciculithus</i> spp.
Um El-Ghanayim				LOs of <i>T. bramlettei</i> , <i>D. binodosus</i>
El Sheikh Eissa		East Qena		HOs of <i>Fasciculithus</i> spp.
El-Homra El-Shanka				LO of <i>T. bramlettei</i>
G. El-Shaghab		Esna	NP9/NP10	LO of <i>T. bramlettei</i>
North Gunna	FARIS & STROUGO (1998)	Nile Valley	NP9/NP10	HOs of <i>F. tympaniformis</i> , <i>F. bobii</i> , <i>F. clinatus</i> , <i>F. clinatus</i> , <i>F. involutus</i> , <i>D. mediusus</i>
El Sheikh Marzouk			NP9/NP10	
Duwi	TANTAWY (1998)	Quseir	NP9a/NP9b	LO of <i>Ca. eodela/dela</i>
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 <i>T. bramlettei</i>
Abu Had	FARIS et al. (1989)	Qena Region	NP9/NP10	LO of <i>D. mahmoudii</i> - HOs of <i>F. alanii</i> , <i>F. bobii</i> , <i>D. mohleri</i> , <i>D. falcatus</i> , <i>F. tympaniformis</i>
El Serai			top NP9	
Tarmsa			top NP9	
Wasif area	HEWAIDY & FARIS (1989)	Safaga District	NP9/NP10	LOs of <i>T. nunnii</i> , <i>D. diastypus</i> HO of <i>F. tympaniformis</i>
Um el Huetat	FARIS (1988b)		NP9/NP10	HOs of <i>F. alanii</i> , <i>F. tonii</i> , <i>F. tympaniformis</i>

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*, *Rhombaster spineus*, and *Rhombaster* 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 *Rhombaster 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. thomasi*, *F. clinatus*, *F. lillianaie*) 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	<i>C. pelagicus</i> acme
Bir	FARIS et al. (2005)		NP9a/NP9b	HA of <i>Fasciculithus</i> spp.
El Markha	FARIS & FAROUK (2015)	West Central Sinai	NP9a/NP9b	<i>Ca. bowonii</i> acme LOs of <i>R. bitrifida</i> , <i>R. intermedia</i> HO of <i>F. alanii</i>
	ABU SHAMA et al. (2007)		NP9a/NP9b	LOs of <i>R. cuspis</i> , <i>R. calcitrata</i> , <i>D. mahmoudii</i> , <i>D. araneus</i>
Matulla	BOLLE et al. (2000)	West Central Sinai	wihin NP9	LOs of <i>D. araneus</i> , <i>R. bitrifida</i> , <i>R. intermedia</i>
	FARIS et al. (2015)		NP9a/NP10	LO of <i>T. bramlettei</i>
	FARIS & FAROUK (2015)		NP9a/NP9b	LO of <i>R. intermedia</i>
Nukhul	FARIS & SALEM (2007)	East Central Sinai	NP9a/NP9b	LOs of <i>R. intermedia</i> , <i>R. calcitrata</i>
	KHOZYEM et al. (2013)		NP9a/NP9b	LOs <i>Ca. eodela/dela</i> , <i>R. cuspis</i>
	FARIS et al. (2015)		NP9a/NP10	LOs of <i>T. bramlettei</i> , <i>D. anartios</i> , <i>D. araneus</i> , <i>R. bitrifida</i> , <i>R. cuspis</i> , <i>R. intermedia</i> , <i>R. spineus</i>
Mukattab	FARIS et al. (2015)	West Central Sinai	NP9a/NP10	LOs <i>T. bramlettei</i> , <i>D. anartios</i> , <i>D. araneus</i> , <i>R. bitrifida</i> , <i>R. cuspis</i> , <i>R. intermedia</i> , <i>R. spineus</i>
	FARIS & SALEM (2007)		NP9a/NP9b	LO of <i>R. solus</i>
Wadi Feiran	FARIS et al. (2015)		NP9a/NP10	LOs <i>T. bramlettei</i> , <i>D. anartios</i> , <i>D. araneus</i> , <i>R. bitrifida</i> , <i>R. cuspis</i> , <i>R. intermedia</i> , <i>R. spineus</i>
El Mishiti	FARIS & ABU SHAMA (2007)	EC Sinai	NP9/NP10	LOs of <i>R. cuspis</i> , <i>R. calcitrata</i> , <i>D. mahmoudii</i> , <i>D. araneus</i>
Muwaylih Amr	AYYAD et al. (2003)	NE Sinai	NP9a/NP9b	HO of <i>F. alanii</i>
El Burk area	FARIS & ZAHRAN (2002)	NC Sinai	NP9/NP10	LO of <i>T. bramlettei</i>
El Sheikh Attya	LUNING et al. (1998)	EC Sinai	NP9/NP10	LOs of <i>D. diastypus</i> , <i>D. binodosus</i> HO of <i>F. tympaniformis</i>
El Ain El Falig	FARIS (1988a)	NE Sinai	NP9/NP10	LOs of <i>T. contortus</i> , <i>D. diastypus</i> , <i>D. mahmoudii</i>

The Eocene assemblage includes *Rhombaster* 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 *Rhombaster-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 *Rhombaster-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 palaeobioge-

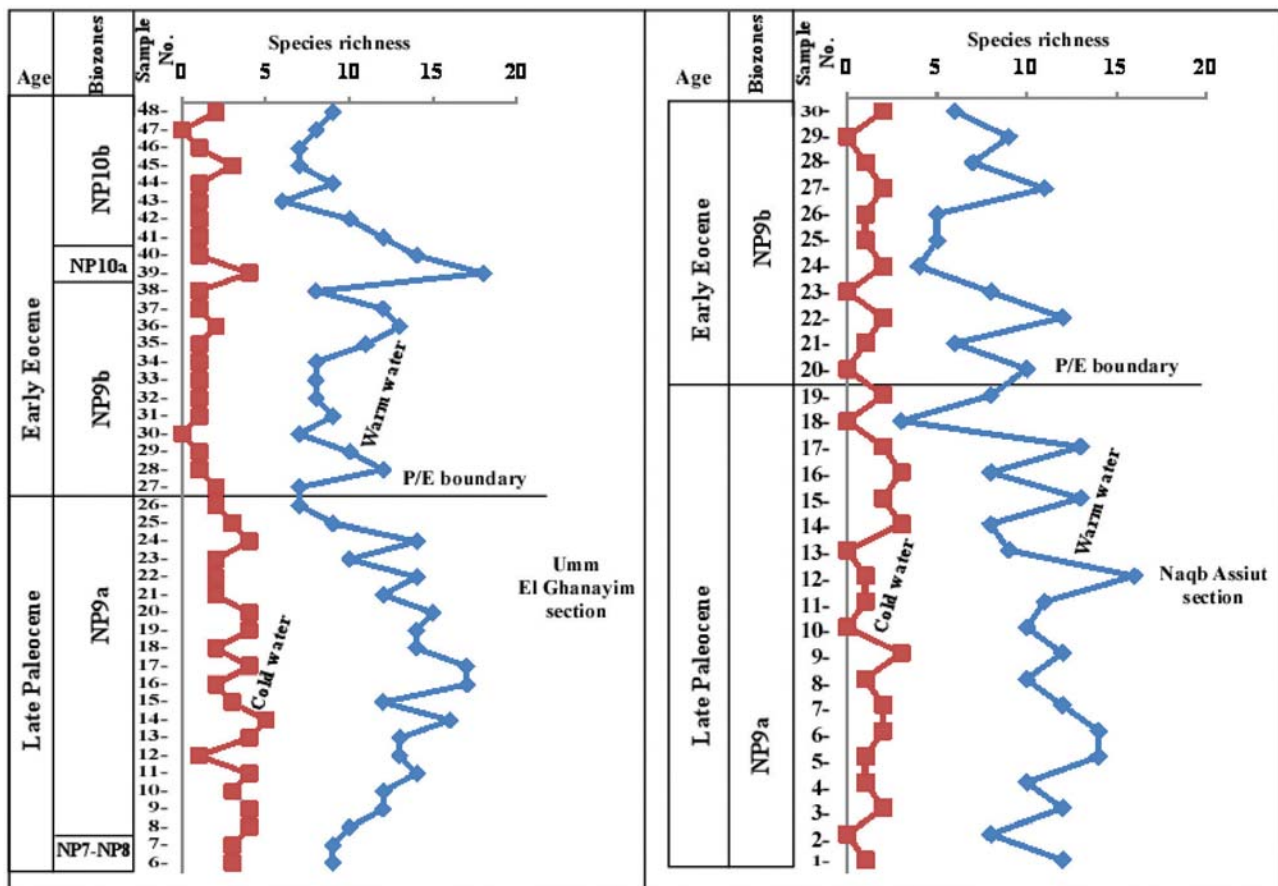


Figure 6. Vertical variations in the number of warm water and cold water species in Umm El Ghanayim and Naqb Assiut sections.

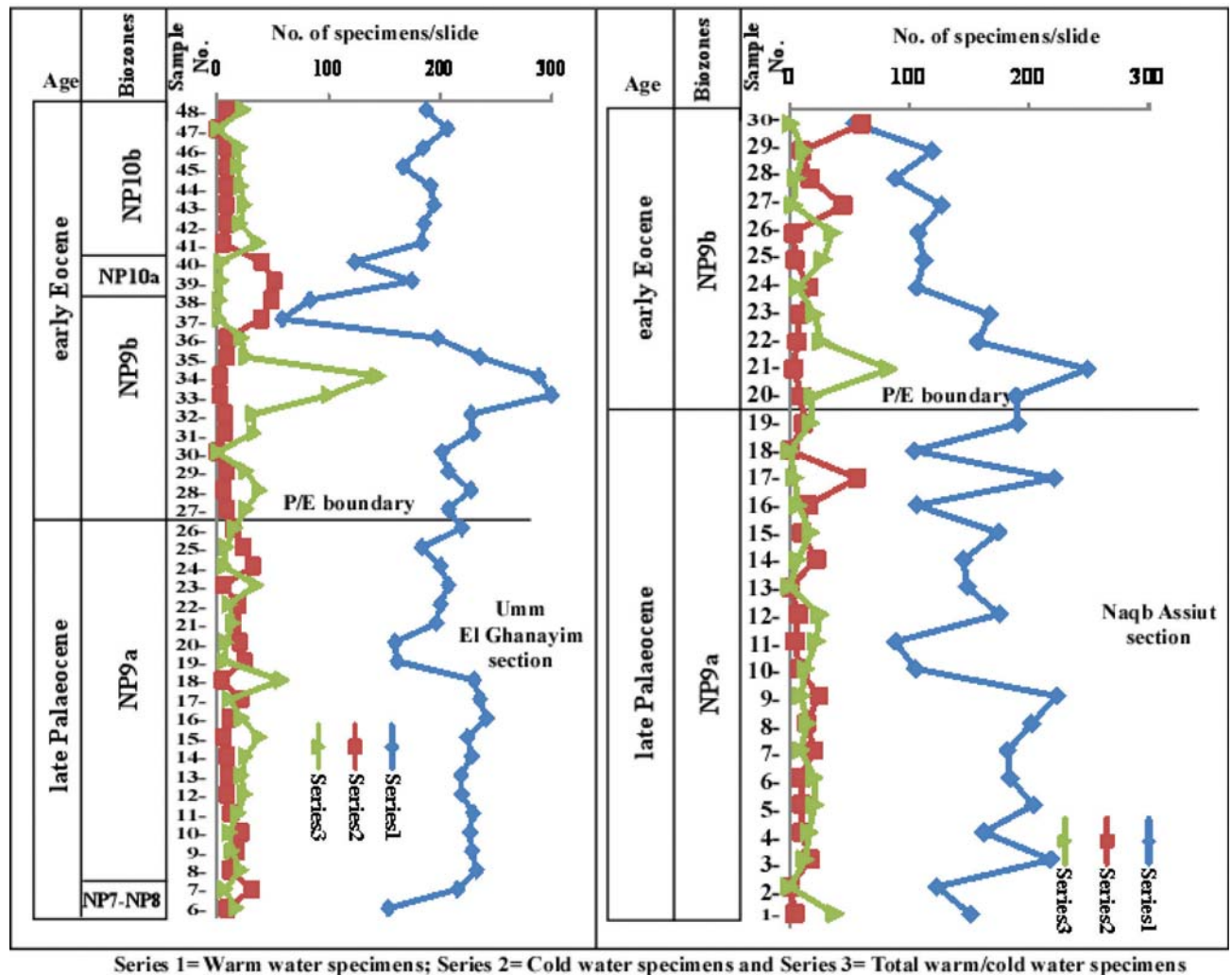


Figure 7. Total warm and cold water specimens/slide and warm/cold water specimens in Umm El Ghanayim and Naqb Assiut sections.

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 *Ericsonia 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 nanofossil 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 *Rhombasters* (base of NP9b) and coincides with the negative $\delta^{13}C$ 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 *Rhombaster* 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 *Rhombaster* 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 nanofossil 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 nanofossil taxa fluctuates between 6-17 species in the late Palaeocene (NP7-8

Table 5. continued

		Cold water													Non-characteristic																											
<i>Pontosphaera plana</i>	<i>Discoaster araneus*</i>	<i>Rhombaster bitrifida*</i>	<i>Discoaster mahmoudii*</i>	<i>Tribracliatius bramletter*</i>	<i>Sphenolithus moriformis</i>	<i>Discoaster barbadensis</i>	<i>Discoaster backmanii</i>	<i>Tibracliatius digitalis*</i>	<i>Discoaster diastypus</i>	<i>Pontosphaera exilis</i>	Species richness	<i>Toweius tovae</i>	<i>Toweius emimens</i>	<i>Neochiastozygus junctus</i>	<i>Neococcolithes protenus</i>	<i>Chiasmolithus danicus</i>	<i>Chiasmolithus californicus</i>	<i>Chiasmolithus consuetus</i>	<i>Chiasmolithus bidens</i>	<i>Chiasmolithus solitus</i>	<i>Chiasmolithus eoograndis</i>	Species richness	<i>Ericsonia universa</i>	<i>Ellipsolithus macellus*</i>	<i>Zygodiscus plectopons</i>	<i>Zygodiscus adamas</i>	<i>Campyloosphaera eodela</i>	<i>Neochiastozygus perfectus</i>	<i>Calaisolenia aperta</i>	<i>Ellipsolithus bollii</i>	<i>Ellipsolithus distichus</i>	<i>Ericsonia robusta</i>	<i>Toweius pertusus</i>	<i>Toweius occultatus</i>	<i>Zygodiscus sheldoniae</i>	<i>Micrantholithus attenuatus</i>	<i>Neochiastozygus chiastus</i>	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				6		
											14		x				x				2			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						4	x		x	x		x									x	x	x		8		
											14										2			x	x	x	x										x			6		
											17	x	x								4			x	x	x												x		5		
											17	x									2			x	x	x											x	x	x		8	
											12	x	x								3			x		x														2		
											16	x			x						5			x	x	x													x		4	
											13	x	x								4			x	x															x		4
											13										1			x	x	x														x		6
											14	x	x								4			x	x	x															6	
											12	x			x						3			x	x	x	x														7	
											12	x	x		x						4			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		8	
											10	x	x		x						4			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		5	
											9	x	x								3			x	x	x															4	
											9	x			x						3			x																	1	

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 peak 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 subpertrusus*, and the frequent occurrence of excursion taxa including *Discoaster araneus*, *D. anartios* with rare *Rhombaster* 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 colophonane 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 NP10a and 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 *Rhombaster 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 Formation.

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 medius* 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 (*Rhombaster intermedia*, *R. bitrifida*, *R. cuspsis*, *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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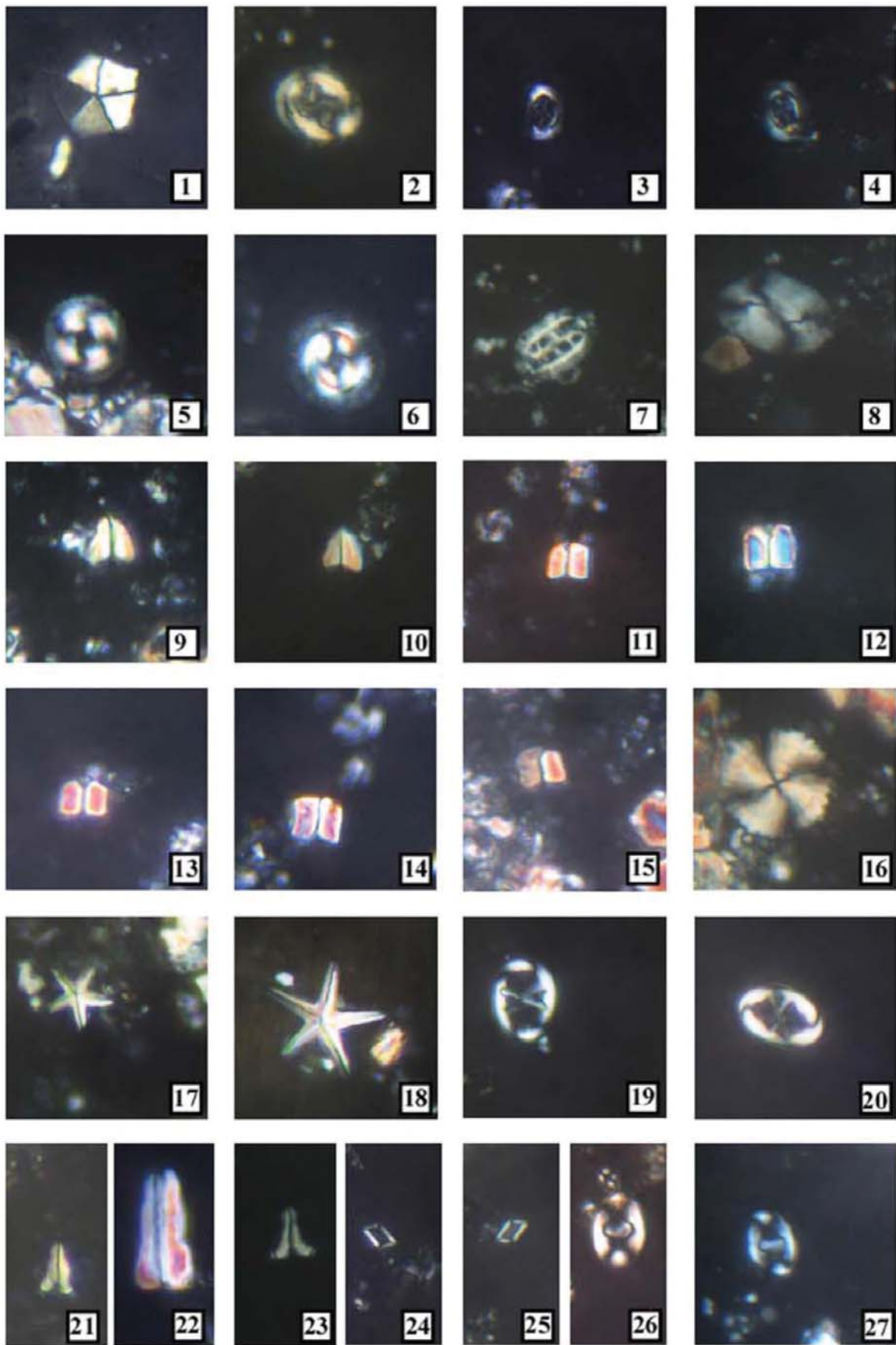
LIST OF CALCAREOUS NANNOFOSSIL TAXA

- 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
- Lophodolichus 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

- 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 emimens (BRAMLETTE & SULLIVAN, 1961) PERCH-NIELSEN, 1971
Toweius occultatus (LOCKER, 1967) PERCH-NIELSEN, 1971
Toweius pertusus (SULLIVAN, 1965) ROMEIN, 1979
Toweius tovae PERCH-NIELSEN, 1971
Tribrahiatus bramlettei (BRONNIMANN & STRADNER, 1960) PROTO DECIMA et al., 1975
Tribrahiatus 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) *Helolithus kleinpellii* SULLIVAN (1964) sample 5, Um El Ghanayim section.
- 17, 18) *Micrantholithus attenuatus* BRAMLETTE & SULLIVAN (1961) sample 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.



10 μ m

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) *Pontosphaera exilis* (BRAMLETTE & SULLIVAN, 1961) ROMEIN, 1979, sample 9, Naqb Assiut section.
- 15) *Pontosphaera plana* (BRAMLETTE & SULLIVAN, 1961) HAQ 1971, sample 17, Naqb Assiut 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) *Tribrachiatos bramlettei* (BRONNIMANN & STRADNER, 1960) PROTODECIMA et al., 1975, sample 39, Um El Ghanayim section.
- 22) *Tribrachiatos 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.

