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Upper Cretaceous to Lower Eocene calcareous nannofossil biostratigraphy from Malaqet and Mundassah sections western flank of the Northern Oman Mountains

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ABSTRACT

This work is the first attempt to undertake a biostratigraphic study on calcareous nannofossil assemblages of the exposed Upper Cretaceous to Lower Eocene rocks at the Malaqet and Mundassah sections, western flank of the Northern Oman Mountains. The Upper Cretaceous to Lower Eocene rocks belong to the Simsima Formation and the Muthaymimah Formation. Specimens of calcareous nannofossils identified during this study have been ascribed to 67 different species.

The Cretaceous/Palaeocene boundary can be placed in correspondence with the unconformity between the mentioned formations. The presence of a big hiatus in this area is suggested by the absence of the latest Maastrichtian *Micula prinsii* nannofossil Zone, and the Palaeocene NP1 and NP2 nannofossil Zones.

In the two study sections, the Danian/Selandian boundary is placed at the level of the first occurrence (FO) of *Fasciculithus tympaniformis* (base of NP5 Zone).

At Jabal Mundassah, the Selandian/Thanetian boundary is positioned at the FO of *Discoaster mohleri*, which is used to define the base of NP7/8 Zone. Unfortunately, a major hiatus is detected at the Selandian/Thanetian boundary at the Jabal Malaqet section as indicated by the absence of NP6 and NP7/8 Zones.

The Paleocene/Eocene boundary is placed at the base of Subzone NP9b at Jabal Mundassah, whereas at Jabal Malaqet the Paleocene/Eocene boundary interval is missing and a major hiatus is testified by the absence of the NP9b Subzone and NP10 Zone.

Keywords: Jabals: Malaqet and Mundassah, Calcareous Nannofossils, Simsima Formation, Muthaymimah Formation, Upper Cretaceous, Paleocene, Lower Eocene, Biostratigraphy, Northern Oman Mountains

1. INTRODUCTION

The Upper Cretaceous – Lower Eocene rocks are widely exposed in the western foothills of the Northern Oman Mountains (Fig. 1). Upper Cretaceous rocks are the oldest units lying unconformably upon the Semail Ophiolite and folded, thrusted Hawasina and Sumeini groups of Permian-Late Cretaceous age (GLENNIE et al., 1974, and WILSON, 2000).

The stratigraphy and facies of the Upper Cretaceous-Eocene Neoautochthonous sequence of the Northern Oman Mountains have been discussed in numerous papers, including GLENNIE et al. (1974); HAMDAN (1990); Al SHARHAN & KENDALL (1991); ANAN (1993); NOWEIR & EL OUTEFI (1997); NOWEIR et al. (1998); SAYED & MERSAL (1998); BOUKHARY et al. (1999); ALSHARHAN et al. (2000); NOWEIR & ABDEEN (2000); ABD-ALLAH

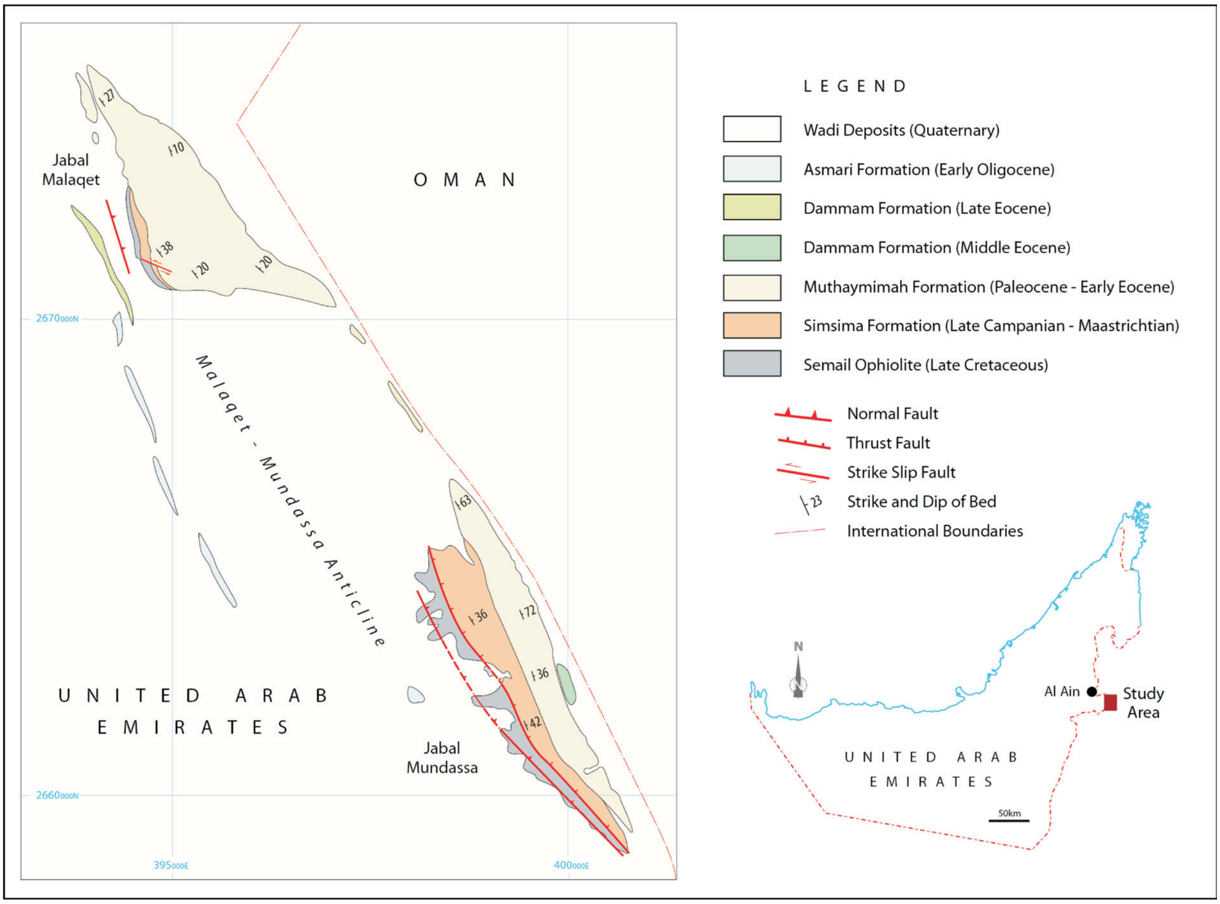

Figure 1: Simplified geologic map (modified from ABDEL-GAWAD et al., 2010 showing the location of the studied sections.

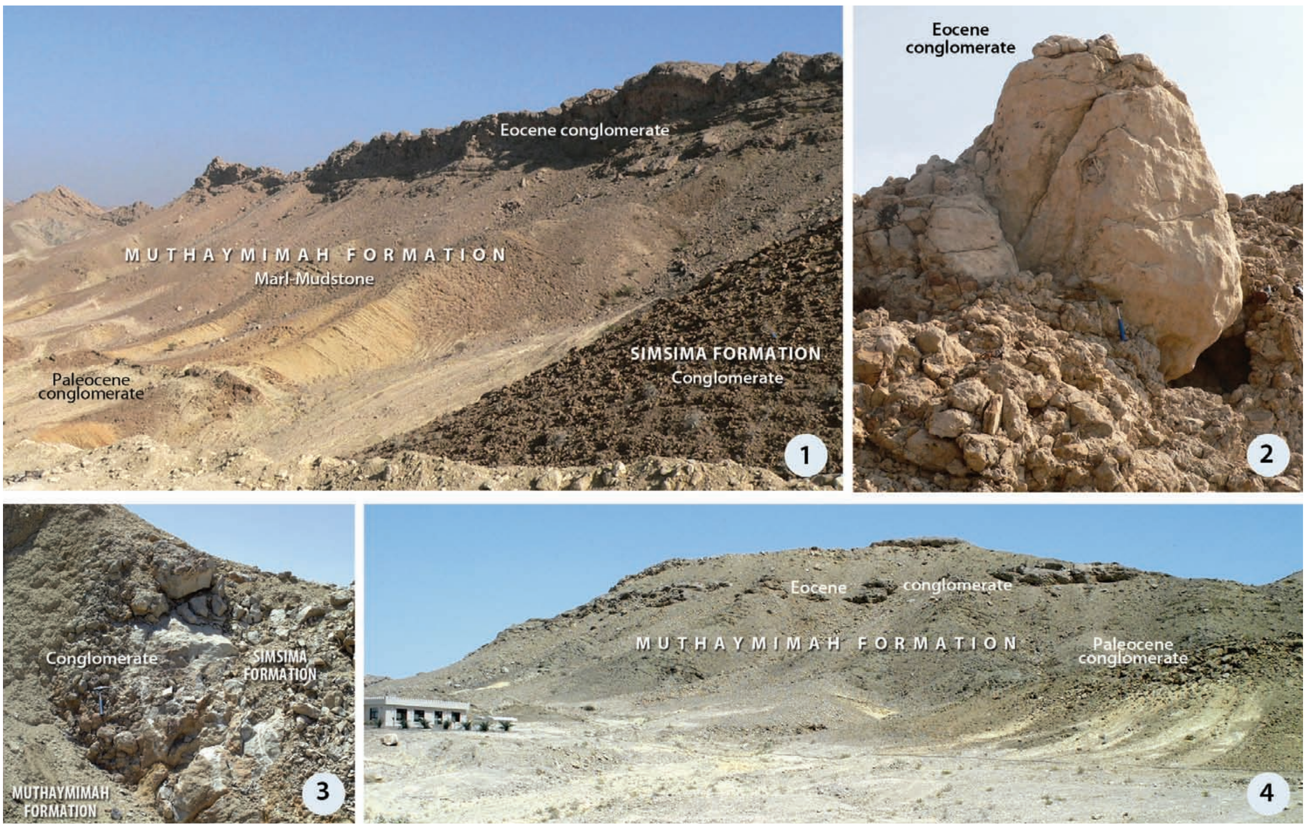

Figure 2: Field photographs of the study area: 1, 2 – Jabal Mundassah; 3, 4 – Jabal Malaqet.

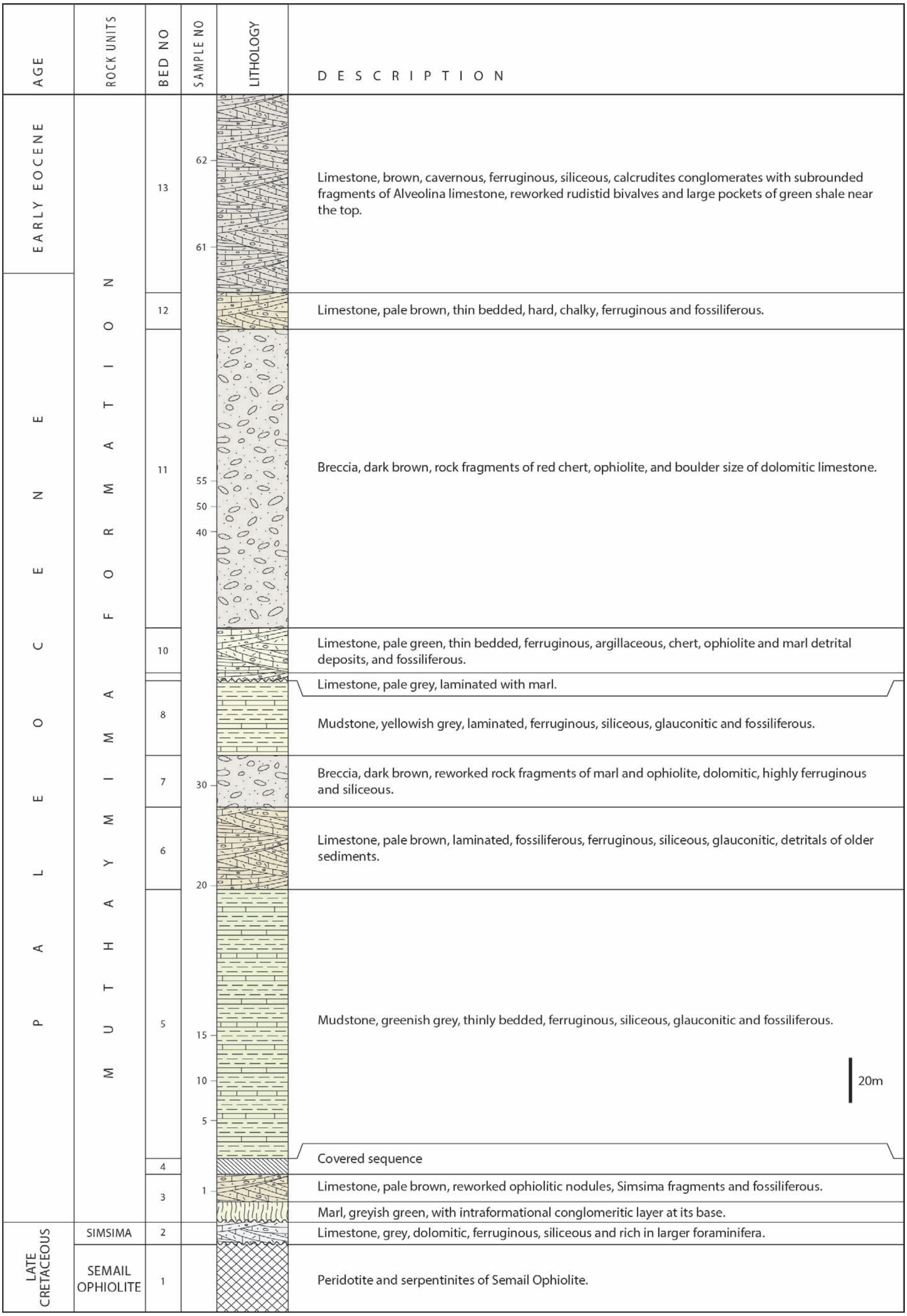

Figure 3: Lithostratigraphic description of Jabal Malaqet section.

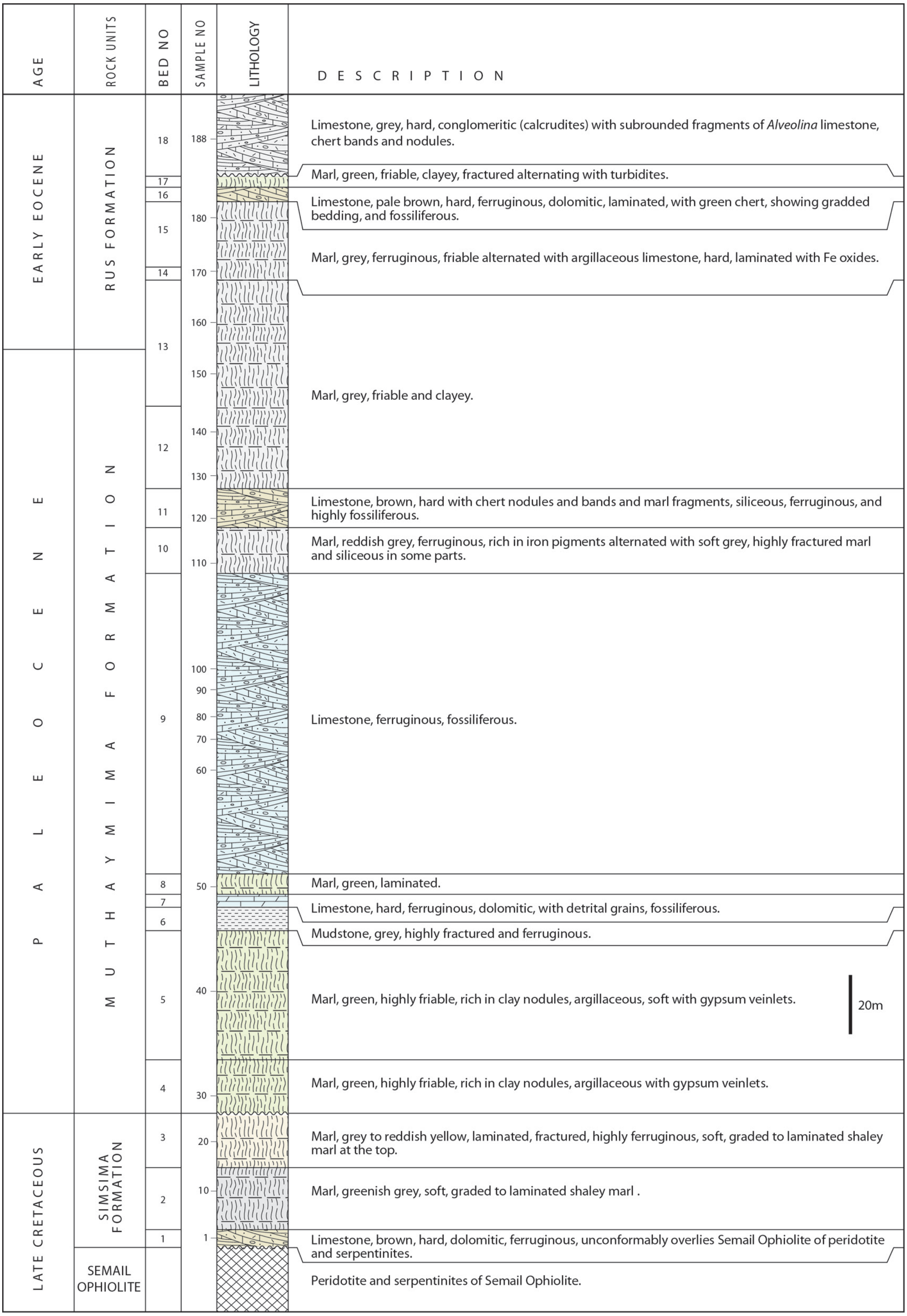

Figure 4: Lithostratigraphic description of Jabal Mundassah section.

(2001); WILSON & TAYLOR (2001); ABDELGHANY (2003); BAGHDADY & ABU-ZEID (2003); SHEBL (2004) and ABDEL GAWAD et al. (2010).

Discussion of the calcareous nannofossil biostratigraphy of Upper Cretaceous to Lower Eocene rock units (Simsima and Muthaymimah formations) cropping out at Jabals Malaqet and Mundassah is presented here. In addition, an attempt is made to identify the Maastrichtian/Danian, Danian/Selandian, Selandian/Thanetian and the Thanetian/Ypresian boundaries by means of calcareous nannofossil biostratigraphy.

2. MATERIALS AND METHODS

Two sedimentary successions have been measured and sampled at Jabals Malaqet and Mundassah. All together ca. 250 rock samples were collected for this study (Figs. 1–4).

Smear slides for calcareous nannofossil investigation were prepared according to the techniques proposed by BRAMLETTE & SULLIVAN (1961) and HAY (1964, 1970). The slides were examined using a Carl Zeiss microscope at 1250x magnification in both plane polarized light and crossed nicols. Our data is reported in Tables 1 and 2. Photomicrographs of some representative taxa are provided in Plates 1 and 2.

3. STRATIGRAPHIC BACKGROUND

The post-obduction neoautochthonous Upper Cretaceous-Eocene sedimentary succession unconformably overlies Upper Cretaceous serpentinite, peridotite and pyroxenite of the Semail Ophiolite. The first marine transgression initiated deposition of shallow marine sediments and fluvial facies inland (Qahlah Formation) over the eroded knappes of the Semail Ophiolite (GLENNIE et al., 1974). The Qahlah Formation is overlain by deposition of shallow-water limestones referred to as the Simsima Formation. They are exposed at Jabals Qarn El Barr, El Faiyah Range Mountains, El Rawdah, Malaqet and Mundassah. However, farther to the north at Jabal Qarn El Barr, the Simsima Formation is represented by deep marine deposits of pelagic sediments, based on the evidence of the occurrence of planktonic foraminifera. The Simsima Formation is unconformably overlain by the Muthaymimah Formation.

3.1. Simsima Formation

The Simsima Formation was first described by GLENNIE et al. (1974). Since the type section of the Simsima Formation is no longer accessible, NOLAN et al. (1990) designated the Jabal Buhays section, El Fayiah Range Mountains, on the western side of the Northern Oman Mountains (19 km

Table 1: Stratigraphic ranges of calcareous nannofossils of Jabal Malaqet.

Paleocene																					Early Eocene	Age
Danian					Selandian						Thanetian										Ypresian	
Muthaymimah																						Formation
3	4	5	6	15	17	20	24	25	26	29	36	43	47	48	49	54	55	56	57	58	61	Sample no.
C	C	C	C	VR	VR	VR	VR	VR	VR	VR	VR	VR	VR	VR	VR	R	VR	F	R	R	F	Abundance
M	M	G	G	P	P	M	M	M	P	P	P	P	P	P	P	P	P	M	M	P	M	Preservation
NP4					NP5						NP9a										NP11	Biozones (NP)
R	R	R	R																			*Thoracosphaera operculata*
F	R	R	F																			*Cruciplacolithus primus*
R	R	R	F																			*Cruciplacolithus tenuis**
R	F	F	F																			*Chiasmolithus danicus**
R	R	R	R																			*Placozygus sigmoides*
R	R	R	R																			*Neochiastozygus medestus*
VR	VR	VR																				*Ellipsolithus macellus**
F	F	F	F		VR	VR			VR		VR	VR	VR			R	VR	R	VR	R		*Ericsonia cava*
				VR		VR			VR	VR		VR	VR			R		R				*Sphenolithus primus*
					VR	VR	VR	VR	VR	VR	VR	VR	VR	VR	VR	R	VR				VR	*Fasciculithus tympaniformis**
											VR	VR	VR		VR	R	VR		R	R	R	*Discoaster multiradiatus**
													VR				VR	R	VR		R	*Coccolithus pelagicus*
																	VR	R	VR		R	*Discoaster barbadiensis*
																		VR	R	VR	R	*Discoaster binodosus*
																					VR	*Zygrhablithus bijugatus*
																					VR	*Braarudosphaera bigelowii*
																					VR	*Tribrachiatus orthostylus**

Abundance: A= Abundant, C= Common, F= Frequent, R= Rare, VR= Very rare Preservation: G= Good, M= Moderate, P= Poor, *= Marker species

Table 2: Stratigraphic ranges of calcareous nannofossils of Jabal Mundassah.

Late Cretaceous																				Paleocene																Age
Late Maastrichtian																				Danian																
Simsima																				Muthaymimah																Formation
2	5	6	7	8	9	11	12	13	14	15	16	17	18	20	21	22	23	24	25	26	27	28	29	29	30	30	31	32	33	34	35	36	37	38	39	Sample no.
VR	VR	VR	VR	VR	R	VR	VR	R	VR	R	R	VR	VR	VR	VR	R	VR	R	VR	R	R	F	F	F	F	F	F	C	C	R	R	F	R	VR	VR	Abundance
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	G	G	M	M	G	G	G	G	G	M	M	G	M	M	M	Preservation
Micula murus																				*Chiasmolithus danicus* (NP3)																CN Biozone
VR	VR	VR	VR		VR	VR	VR	VR	VR	VR	VR	VR	VR	VR		VR	VR	VR	VR																	*Watznaueria barnesae*
VR	VR	VR	VR		VR	VR	VR	VR	VR		VR		VR	VR	VR	VR	VR	VR	VR																	*Micula murus* *
		VR		VR	VR	VR	VR	VR	VR	VR	VR	VR	VR	VR	VR	VR	VR	VR	VR																	*Micula decussata*
					VR			VR		VR	VR																									*Arkhangelskiella cymbiformis*
								VR																												*Cribrosphaerella ehrenbergii*
								VR																												*Micula concava*
								VR	VR																											*Lucianorhabdus cayeuxii*
											VR																									*Stradneria crenulata*
												VR																								*Eiffellithus turrisieffelii*
																				VR	VR															*Cruciplacolithus primus*
																				VR	R	R	R	R	F	F			F	F	VR	F	R	F	R	*Ericsonia cava*
																				VR	VR	VR			VR		VR	R	VR	VR	VR	VR	VR	VR	VR	*Thoracosphaera operculata*
																				R		R	R		VR		R		R		VR	VR	VR	VR	VR	*Chiasmolithus danicus**
																				VR		R			R			R	VR	VR						*Cruciplacolithus tenuis**
																						VR	F		F		F	F			F	F	R	VR		*Ericsonia subpertusa*
																							VR		R			R				R		VR		*Coccolithus pelagicus*
																											VR	VR	VR			VR	VR	VR	VR	*Placozygus sigmoides*

Table 2: continued.

Age	Paleocene																																										
	Danian																					Selandian																					
Formation	Muthaymimah																																										
Sample no.	40	41	42	43	44	45	46	47	48	49	50	52	53	54	55	56	57	58	59	60	61	62	63	65	67	69	71	72	73	75	76	78	79	84	91	92	95	99	100	101	103	104	105
Abundance	F	F	C	F	R	R	C	F	F	F	C	F	R	F	R	VR	VR	R	VR	R	F	c	C	F	F	R	VR	VR	VR	VR	VR	VR	VR	VR	R	VR	R	R	VR	R	R	F	R
Preservation	M	M	M	M	M	P	M	M	M	G	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
CN Biozone	NP4																					NP5																				NP6	
Ericsonia cava	R	R	F	F	F									R	VR	VR				VR	R	F	R			VR		VR		VR	VR	VR	VR									VR	R
Thoracosphaera operculata	VR	VR		VR	R		R	R	R	R	F	F	R	R	VR	VR	VR	VR	VR	VR	R	R	F	R	VR	VR						VR	VR	VR			VR				VR	VR	VR
*Chiasmolithus danicus**	VR	VR	VR	VR	VR		VR	VR	VR	VR	VR		VR	R	VR		VR	VR	VR	VR	R	F	F	F	VR														VR				
Ericsonia subpertusa	R	R	C	F	F		C							R		VR					R	F	R	R	R																		
Coccolithus pelagicus	VR				VR																			R	VR	VR	VR	VR	VR					VR	VR	VR	VR	VR	VR	VR	VR	VR	R
*Ellipsolithus macellus**	R										VR	VR	VR																														
Placozygus sigmoides		VR	VR							VR	VR		VR								VR	R	R	VR	VR																		
*Cruciplacolithus tenuis**				VR			VR				R	VR	VR									VR	VR	R	VR																		
Neochiastozygus medestus								VR	VR	VR	VR			VR							VR		R	VR	VR																		
Markalius inversus									VR																																		
Thoracosphaera saxea											F		VR									R	F																				
Chiasmolithus consuetus																						VR	F			VR																	
*Fasciculithus tympaniformis**																						VR	F			VR				VR					VR		VR	VR			VR	VR	VR
Sphenolithus primus																						VR	F	R	R			VR		VR	VR	VR	VR	VR	VR			VR		VR	R	VR	R
Bomolithus elegans																							R		VR					VR													
Fasciculthus billii																							VR					VR	VR														
Neochiastozygus imbriei																							VR																				
Fasciculthus bobii																							R																				
Fasciculithus ulii																												VR	VR			VR	VR		VR		VR		VR			VR	
Fasciculithus pileatus																														VR			VR				VR						
*Heliolithus kleinpellii**																																										VR	VR
Fasciculithus stonehengei																																										VR	

Table 2: continued.

Age	Late Paleocene																																												
	Thanetian																																												
Formation	Muthaymimah																																												
Sample no.	106	107	109	110	112	113	114	115	117	118	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154
Abundance	C	C	C	c	VR	R	R	R	R	F	F	F	F	F	F	VR	VR	VR	VR	R	VR	F	F	R	R	VR	F	F	R	R	F	F	C	C	C	R	R	R	C	C	C	F	F	R	C
Preservation	M	M	M	M	M	M	M	M	M	G	M	M	G	G	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	G	G	G	M	M	M	G
CN Biozone	NP7/8																														NP9a														
Thoracosphaera operculata	VR	VR	VR	VR																																	VR			VR	VR				
Ericsonia cava	R	R	R	F	VR																			VR					R																
Coccolithus pelagicus	R	R	VR	F		VR	VR	R	VR	R	VR	R	R	F	R	R	VR	VR	VR	VR	VR	F	R	VR	VR	VR	R	R	VR	VR	R	R	R	F	F	VR	VR	VR	R	R	R	VR	VR	VR	R
*Fasciculithus tympaniformis**	F	F	F	R	VR	VR	VR							R	R	VR		VR				VR		VR		VR	R	R	R		VR	VR	VR	F	F	VR	VR	VR	VR	R	F	R	R	VR	VR
Sphenolithus primus	F	F	F	C	VR	VR	VR	R	VR	R	VR	VR		F	R	R		VR			VR	R	R	VR	VR	VR	VR	VR	R	VR	VR	F	F	R	R		VR	VR	VR	F	F	R	F	VR	F
*Discoaster mohleri**	VR		VR	VR		VR		VR		VR	VR	VR	VR	R	VR							VR																							
Bombolithus conicus	VR	VR	VR																																										
Bomolithus elegans	VR		VR																																										
*Chiasmolithus danicus**		VR	VR																																										
*Heliolithus kleinpellii**	VR	VR	R																																										
Discoasteroides bramlettei	VR		VR																																										
Fasciculithus alanii		VR																																											
Chiasmolithus californicus		VR	VR																																										
Heliolithus cantabriae			VR																																										
Fasciculithus clinatus			VR																																										
Chiasmolithus consuetus			VR					VR		VR				VR								VR																							
Fasciculithus ulii			VR	VR																																									
Ericsonia subpertusa								R		VR	VR	VR	VR	F	R		VR	R	R	VR	VR	R	R																						
Fasciculithus lillianae											VR																								VR			VR		VR	VR				
Fasciculthus bobii														VR						VR		VR													VR	VR				VR		VR	VR		VR
Fasciculthus billii																					VR												VR	VR	R			VR	VR	VR	VR				
*Ellipsolithus macellus**																											VR				VR														
*Discoaster multiradiatus**																															VR	R	R	F	VR	F	VR	F	F	F	F	R	F	R	F
Discoaster binodosus																																VR	VR	VR	R		VR	VR	VR	R	R				
Fasciculithus involutus																																	VR	VR	R					VR	R				
Fasciculithus bitectus																																		VR	R		VR			VR	VR				
Fasciculithus schaubi																																		VR	R										VR
Discoaster falcatus																																			R										
Fasciculithus thomasii																																			VR										
Fasciculithus tonii																																			VR					VR					
Fasciculithus aubertae																																					VR			VR	VR				VR
Discoaster lenticularis																																					R			R					

Table 2: continued.

Early Eocene																													Age
Ypresian																													
Rus																													Formation
155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	172	173	175	176	177	178	181	182	183	184	185	186	187	Sample no.
F	F	C	F	C	F	R	R	C	C	C	C	F	R	R	F	F	F	VR	F	R	F	F	C	C	R	C	F	C	Abundance
M	M	G	M	M	M	M	M	G	G	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	G	M	G	Preservation
NP9b																	NP10								NP11				CN Biozone
																	a						b						
VR	VR	VR	VR	VR	VR	VR	VR	R	VR	VR	VR	VR				VR	R		VR	VR					VR	R			*Coccolithus pelagicus*
VR	VR	F	VR	VR	R	VR	R	F	F	F	R	VR	VR																*Fasciculithus tympaniformis**
R	R	R	R	R	F	VR	R	F	F	F	F	VR	VR	R	R	VR	R			VR	VR	R	R	VR	F	F	VR	F	*Sphenolithus primus*
F	R	F	F	F	F	VR	R	R	F	F	F	VR	VR	VR	VR	F	R	VR	F	R	F	R	R	R	VR	R	VR		*Discoaster multiradiatus**
VR	VR	F	R	R	R					VR	VR			VR		R	VR	VR	VR			VR	VR	VR		VR	VR	R	*Discoaster binodosus*
VR	VR	VR			VR			VR	VR	VR	VR		VR				VR												*Fasciculthus bobii*
VR			VR	VR	VR			VR	VR																				*Fasciculithus schaubi*
VR	VR	VR	VR											VR	VR		VR		VR										*Discoaster araneus**
VR				VR			VR		VR	VR	VR		VR																*Fasciculithus aubertae*
		VR			VR									VR		VR	VR		VR										*Discoaster falcatus*
			VR			VR											VR	VR											*Fasciculithus alanii*
			VR	VR				VR	VR	VR																			*Fasciculithus richardii*
			VR	VR	R		VR	R		R	R			VR	VR	VR	VR	VR		VR		VR	R			F			*Sphenolithus moriformis*
				VR	VR	R	VR	VR	R	VR	VR		VR	VR	VR	VR	F	VR	R	VR		R	R	R	VR	VR	VR	R	*Ericsonia cava*
					VR				VR	VR			VR																*Fasciculithus bitectus*
							VR		VR	VR	VR		VR	VR	VR	VR	VR		VR			VR				VR			*Fasciculithus involutus*
								VR		VR	VR		VR			VR	F	VR	VR	VR	VR	R	VR	F		F		F	*Zygrhablithus bijugatus*
								VR									VR					VR	VR	VR		VR		VR	*Braarudosphaera bigelowii*
									VR																				*Fasciculithus lillianae*
									VR	VR	VR	VR	VR	VR	VR	VR	VR		VR			VR	VR		VR		VR		*Thoracosphaera operculata*
										VR																			*Chiasmolithus consuetus*
													VR								VR								*Fasciculithus clinatus*
																VR	VR	VR	VR	VR									*Discoaster mahmoudii**
																VR													*Fasciculithus richardii*
																	VR					R	VR			VR		VR	*Neochiastozygus junctus*
																	VR								VR				*Tribrachiatus bramlettei**
																						VR	VR	F	R	VR		F	*Discoaster barbadiensis*
																							R	R					*Tribrachiatus digitalis**
																							VR	R		VR		R	*Discoaster diastypus**
																									VR	VR	VR	F	*Tribrachiatus orthostylus**
																												VR	*Pontosphaera multipora*
																												VR	*Camplylosphaera dela*
																												R	*Ericsonia formosa*
																												VR	*Sphenolithus radiatus*
																												VR	*Chiasmolithus solitus*

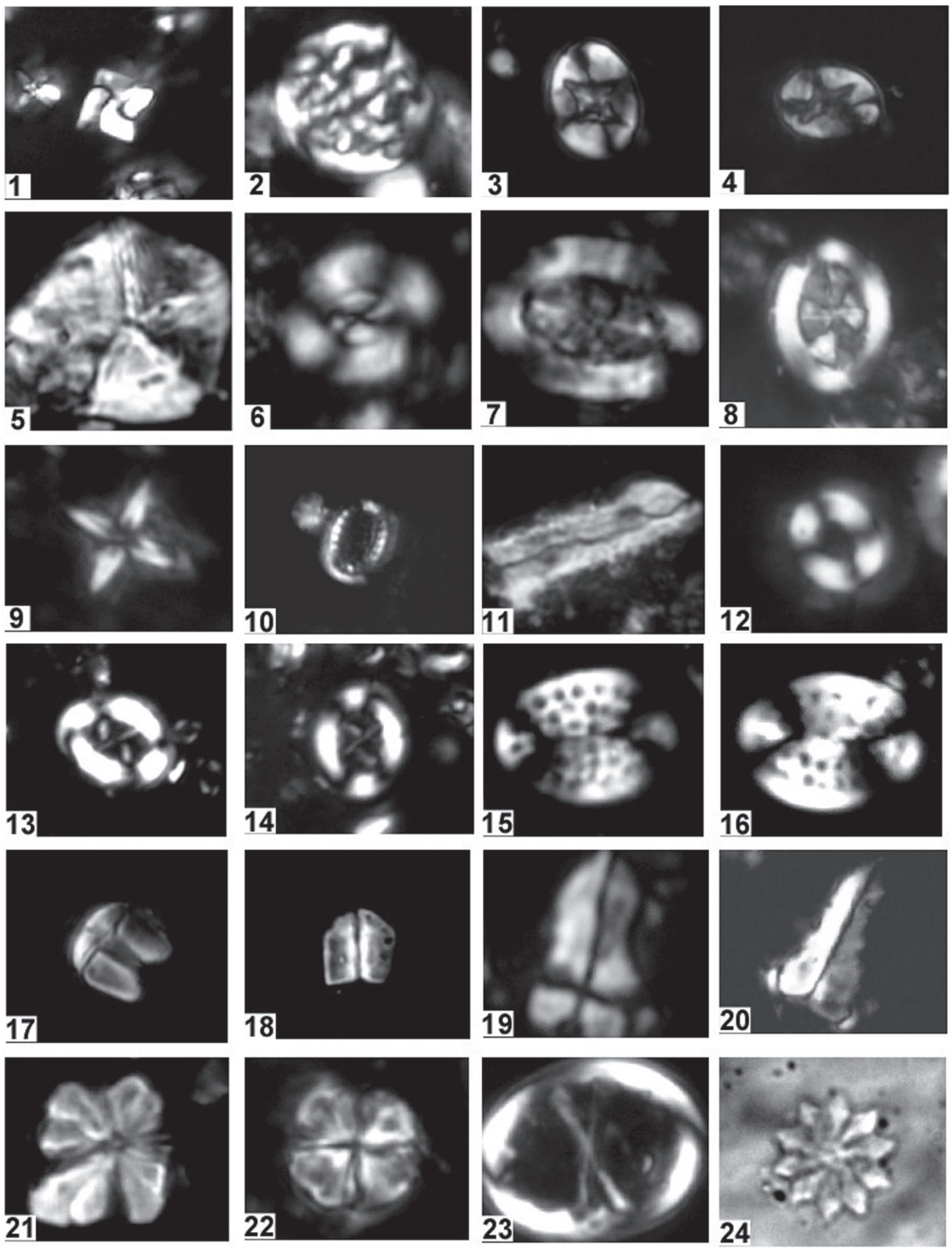

PLATE 1
1 *Micula* ***murus*** (MARTINI, 1961) BUKRY (1973), sample #12, Mundassah section
2 *Thoracosphaera* ***saxea*** STRADNER (1961), sample #35, Mundassah section
3–4 *Eiffellithus* ***turriseiffelii*** (DFLANDRE in DEFLANDRE & FERT, 1954), sample #17, Mundassah section
5 *Braarudosphaera* ***bigelowii*** (GRAN & BRAARUD, 1935), sample #61, Malaqet section
6 *Watznaueria* ***barnesae*** (BLACK *in* BLACK & BARNES, 1959), sample #25, Mundassah section
7–8 *Arkhangelskiella* ***cymbiformis*** VEKSHINA (1959), sample #16,Mundassah section
9 *Micula* ***concava*** (STRADNER *in* MARTINI & STRADNER, 1960), sample #13, Mundassah section
10 *Cribrosphaerella* ***ehrenbergii*** (ARKHANGELSKY, 1912), sample #13, Mundassah section
11 *Lucianorhabdus* ***cayeuxii*** DELLANDRE (1959), sample #13, Mundassah section
12 *Ericsonia* ***subpertusa*** (HAY & MOHLER, 1967), sample #30, Mundassah section
13–14 *Chiasmolithus* ***solitus*** (BRAMLETTE & SULLIVAN, 1961), sample #187, Mundassah section
15–16 *Pontosphaera* ***multipora*** (KAMPTNER, 1948) ROTH (1970), sample #187, Mundassah section
17 *Fasciculithus* ***pileatus*** BUKRY (1973), sample #75, Mundassah section
18 *Fasciculithus* ***involutus*** BRAMLETTE & SULLIVAN (1961), sample #164, Mundassah section
19 *Sphenolithus* ***radians*** DEFLANDRE *in* GRASSE (1952), sample #187, Mundassah section
20 *Zygrhablithus* ***bijugatus*** (DEFLANDRE *in* DEFLANDRE & FERT, 1954), sample #168, Mundassah section
21–22: *Sphenolithus* ***primus*** PERCH-NIELSEN (1971), sample #15, Malaqet section
23 *Neochiastozygus* ***junctus*** (Bramlette & Sullivan, 1961), sample #181, Mundassah section
24 *Discoaster* ***barbadiensis*** Tan (1927), Sample #183, Mundassah section
***all figures** X 1250

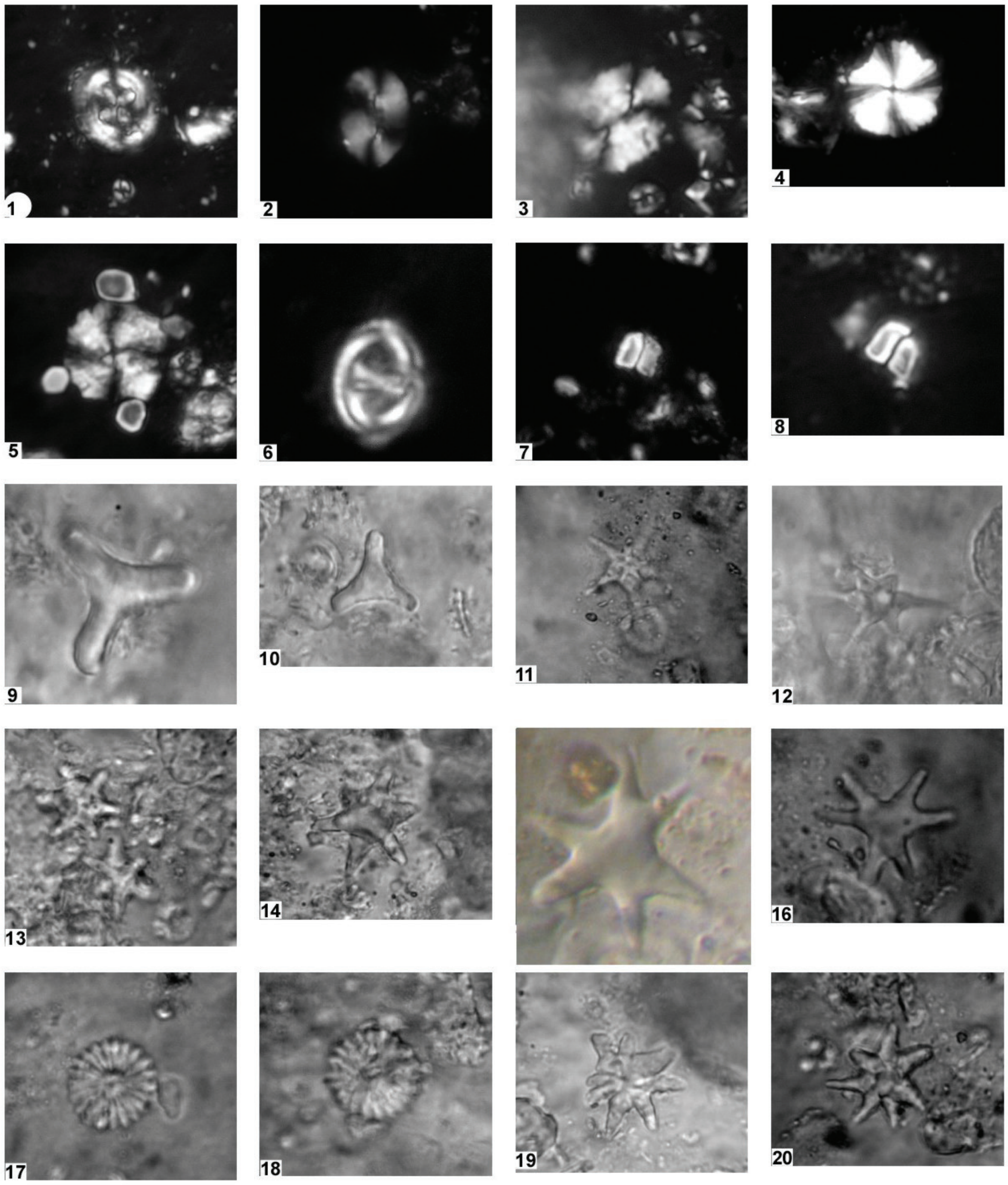

PLATE 2
1 *Chiasmolithus danicus* (BROTZEN, 1959), sample # 6, Jabal Malaqet.
2–3 *Ellipsolithus macellus* (BRAMLETTE & SULLIVAN, 1961), sample #52, Jabal Mundassah
4–5 *Heliolithus kleinpellii* SULLIVAN (1964), sample #109, Jabal Mundassah
6 *Placozygus sigmoides* (BRAMLETTE & SULLIVAN, 1961), sample # 6, Jabal Malaqet
7–8 *Fasciculithus tympaniformis* HAY & MOHLER in HAY et al. (1967), sample #24, Jabal Malaqet
9–10 *Tribrachiatus orthostylus* SHAMRAI (1963), sample #184, Jabal Mundassah
11–12 *Discoaster mahmoudii* PERCH-NIELSEN (198 l), sample #175, Jabal Mundassah
13–14 *Tribrachiatus bramlettei* (BRONNIMANN & STRADNER, 1960), sample #173, Jabal Mundassah
15–16 *Tribrachiatus* digitalis AUBRY (1996), sample #182, Jabal Mundassah
17–18 *Discoaster multiradiatus* BRAMLETTE & REIDEL (1954), sample #56. Jabal Malaqet
19–20 *Discoaster araneus* BUKRY (1971), sample #158, Jabal Mundassah
***all figures** X 1250

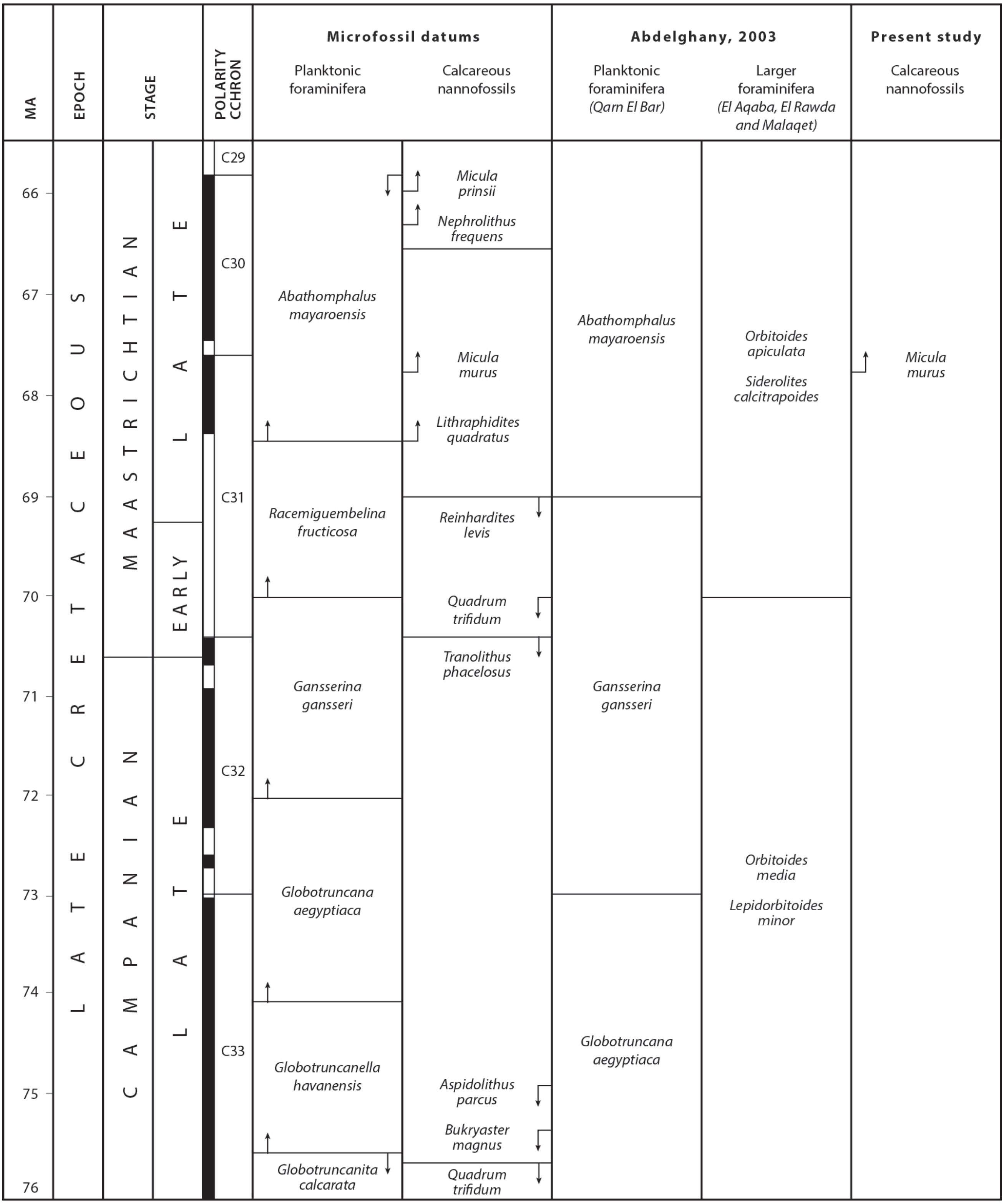

Figure 5: Correlation between the identified calcareous nannofossil zones and the studied foraminiferal zones (ABDELGHANY, 2003).

northwest of Jabal El Rawdah) as an alternative type-section.

The Simsima Formation is unconformably overlain by the Muthaymimah Formation and overlies the Semail Ophiolite. At Jabal Malaqet, it consists of an 8 m-thick dolomitic limestone, with the presence of iron oxide and a rich assemblage of large foraminifera. At Jabal Mundassah, the Simsima Formation also consists of a basal dolomitic limestone with iron oxide and rich in large foraminifera, followed by approximately 30 m of greenish-grey to reddish-yellow laminated marls, rich in planktonic foraminifera, and calcareous nannofossils (Fig. 5).

3.2. Muthaymimah Formation

This formation was firstly described by NOLAN et al. (1990) on the northwestern side of Sayh Muthaymimah, southeast of Buraymi, Sultanate of Oman. The formation unconformably overlies the Simsima Formation and consists of shale, marl, clay nodules and argillaceous limestone, mudstone, and breccia with conglomerate interbeds including clasts of Simsima Limestone, reworked rudists, coral fragments, reworked ophiolite and Hawasina chert. It is both ferruginous and highly fossiliferous. At Jabal Malaqet, the lower parts of the Muthaymimah Formation are composed of greenish grey marl, mudstone and limestone with intraformational conglomerate layers at the base. The middle part of the formation is represented by a 160 m thick sequence of breccia beds with limestone and chert fragments derived from the older rocks (Figs. 2, 3). It is topped by marl interlayered with nummulitic, alveolinid limestone of Early Eocene age. The formation measures about 490 m in thickness.

Otherwise, at Jabal Mundassah (Figs. 3, 4), the Muthaymimah Formation unconformably overlies the Upper Cretaceous Simsima Formation and consists of interlayered clay-rich marl with gypsum veinlets, followed by fossiliferous and argillaceous limestone. Its measured thickness is about 340 m. It unconformably overlies the Upper Cretaceous Simsima Formation, and is topped by marl interlayered with nummulitic, alveolinid limestone of Early Eocene age.

4. CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY

Calcareous nannofossils are a valuable tool in biostratigraphy, and it was decided to test the use of Paleogene calcareous nannofossil zonations (MARTINI, 1971) and successive emendation by ROMEIN (1979), and AUBRY et al. (2000) in the studied area. The present paper describes the distribution of calcareous nannofossil taxa throughout the Simsima and Muthymimah formations. The identified calcareous nannofossils are generally diverse and abundant in the studied sections, and have enabled subdivision of the studied stratigraphic intervals into nine biozones (Tables 1 to 2). The list of the Upper Cretaceous, Paleocene and Early Eocene calcareous nannofossil taxa is documented in Appendix (1), follows that outlined in PERCH-NIELSEN (1985a,b).

4.1. Upper Cretaceous biostratigraphy

The Upper Cretaceous Zonal Scheme of ROMEIN (1979) is adapted here. Abbrevations used in the present work are: FO = First Occurrence, LO= Last Occurrence.

4.1.1.- The *Micula murus* Zone (ROMEIN, 1979)

The *Micula murus* Zone of ROMEIN (1979) is defined by the FO of *M. murus* for the base and the Last Occurrence of *Micula murus* and other Cretaceous taxa and the AB of *Thoracosphaera* and *Braarudosphaera* for the top.

Age: Late Maastrichtian

Occurrence: Jabal Mundassah section

Common species: *M. murus* Zone of ROMEIN (1979) is equivalent to the lower part of *Nephrolithus frequens* Zone (CC 26) of SISSINGH (1977). At Jabal Mundassah, this interval is characterized by a well-diversified nannofossil assemblage which include *Watznaueria barnesiae, Micula decussata, Arkhangelskiella cymbiformis, Cribrosphaerella ehrenbergii, Eiffellithus turriseiffelii, Lucianorhabdus* spp., *Prediscosphera* spp., *Lithraphidites quadratus* and *Zygodisus spiralis.*

4.2. The Paleocene and Eocene biostratigraphy

For the Paleocene and Eocene, we adopt the biozonation proposed by MARTINI (1971) and emended by AUBRY et al. (2000).

4.2.1. The *Chiasmolithus danicus* Zone (NP3)

This is defined as the interval from the first occurrence FO of *Chiasmolithus danicus* to the FO of *Ellipsolithus macellus*.

Age: Early Palaeocene (latest Danian).

Occurrence: Jabal Mundassah section.

Common species: *Thoracosphaera operculata*, and *Placozygus* spp. The following Palaeocene nannofossil species first appeared in this zone: *Cruciplacolithus tenuis,*

C. primus, *Coccolithus pelagicus*, *Ericsonia subpertusa* and *C. danicus*.

4.2.2. The *Ellipsolithus macellus* Zone (NP4)

Author: MARTINI (1970)

The *Ellipsolithus macellus* Zone is defined as the interval from the FO of *Ellipsolithus macellus* to the FO of *Fasciculithus tympaniformis*.

Age: Early Paleocene (late Danian).

Occurrence: Jabals Malaqet and Mundassah sections

Common species: The nannofossil taxa present in the NP4 Zone are those recorded in the NP3 Zone, plus *Ellipsolithus macellus*. The first taxon ascribable to genus *Sphenolithus*, *S. primus*, is observed in the upper part of this zone. The first radiation of the *Fasciculithus* genus occurs within NP4 Zone.

4.2.3. The *Fasciculithus tympaniformis* Zone (NP5)

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

The *Fasciculithus tympaniformis* Zone is defined as the interval from the FO of *Fasciculithus tympaniformis* to the FO of *Heliolithus kleinpellii*.

Age: Middle Palaeocene (Selandian)

Occurrence: Jabals: Malaqet and Mundassah sections

Common taxa: In the studied sections (Mundassah, Malaqet), this zone contains a similar assemblage to Zone NP4 but it is distinguished by the presence of *Fasciculithus tympaniformis,* and *Bomolithus elegans*.

A big hiatus is detected in the Jabal Malaqet section, as shown by the absence of the complete NP6 and NP7/8 Zones.

4.2.4. The *Heliolithus kleinpellii* Zone (NP6)

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

The *Heliolithus kleinpellii* Zone is defined as the interval from the FO of *Heliolithus kleinpellii*) to the FO of *Discoaster mohleri*.

Age: Middle Paleocene (Selandian)

Occurrence: Jabal Mundassah section

Common species: This zone includes the same nannofossil species observed in the

F. tympaniformis Zone plus *H. kleinpelli*, *H. cantabriae* and *Bomolithus conicus*.

The NP6 Zone occupies a thin interval at Jabal Mundassah and is completely absent at Jabal Malaqet.

4.2.5. The *Discoaster mohleri* Zone (NP7/8)

Authors: HAY (1964) and MOHLER in HAY et al. (1967) emend ROMEIN (1979)

Since *Heliolithus riedeli* has not been observed in many localities worldwide, ROMEIN (1979) emended the definitions of the NP7 and NP8 Zone as originally proposed by MARTINI (1971), defining the *Discoaster mohleri* Zone (Zone NP7/8) as the interval from the FO of *D. mohleri* to the FO of *D. multiradiatus*, thus merging together the NP7 and NP8 Zones. We have also combined NP7 Zone and NP8 Zone into a NP7/8 because *H. riedeli* is missing in these sections.

Age: Late Palaeocene (Thanetian)

Occurrence: Jabal Mundassah section

Common species: The NP7/8 Zone is well represented at Jabal Mundassah.

The NP7/8 Zone includes the same nannofossil assemblage recorded in the NP6 Zone, with *D. mohleri*, *D. bramlettei*, *Fasciculithus alanii*, *F. clinatus, F. lilianae* and *Heliolithus cantabriae*.

4.2.6. The *Discoaster multiradiatus* Zone (NP9)

Authors: BRAMLETTE & SULLIVAN (1961) emend. MARTINI (1971) and BUKRY & BRAMLETTE (1970).

The *Discoaster multiradiatus* Zone is defined as the interval from the FO of *D. multiradiatus* to the FO of *Tribrachiatus bramlettei*.

Age: Late Paleocene – Early Eocene

Occurrence: Jabals: Malaqet and Mundassah sections

Common species: In the studied sections, the diversity of nannofossil assemblages reaches its maximum within the NP9 Zone.

The *Discoaster multiradiatus* Zone is recorded in the Jabal Malaqet and Mundassah sections with variable thicknesses. The second radiation of new *Fasciculithus* species is initiated in Zone NP9 and includes the FOs of *F. involutus*, *F. schaubii*, *F. thomasii*, *F. tonii*, *F. aubertae* and *F. richardii*, which is consistent with previous data (e.g. PERCH-NIELSEN, 1985; AGNINI et al., 2007). Other taxa first appearing in this zone include: *Discoaster mahmoudii*, *D. binodosus, D. falcatus*, *D. lenticularis*, *D. araneus D. barbadiensis*, *D. diastypus* and *Zygrhablithus bijugatus*.

AUBRY et al. (2000) and FARIS & ABU SHAMA (2007) subdivided the *D. multiradiatus* Zone (NP9) into two Subzones NP9a and NP9b using the FOs of *Rhamboaster* spp. and/ or

D. araneus. These biohorizons were proposed by the International Subcommission on Palaeogene Stratigraphy (ISPS) to approximate the Paleocene/Eocene (P/E) boundary.

At Jabal Mundassah, The FO of *D. areneus* has been observed in sample 155 and is used to mark the P/E boundary in this section. At the Malaqet section, the top of the NP9a Subzone cannot be pinpointed due to the absence of *Rhamboaster* taxa and *Discoaster araneus* (markers of the base of the NP9b Subzone), and the absence of *Tribrachiatus contortus* (the marker of the base of the NP10 Zone). This suggests the presence of a major hiatus at the P/E transition in this section.

4.2.7. The *Tribrachiatus contortus* Zone (NP10)

Authors: HAY (1964) and BUKRY (1973)

The *Tribrachiatus contortus* Zone is defined as the interval from the FO of *Tribrachiatus bramlettei* to the LO of *T. contortus*.

Age: Early Eocene (Ypresian)

Occurrence: Jabal Mundassah section

Common species: The NP10 Zone has been subdivided into four Subzones (NP 10a–d) based on the successive biohorizons, the FO of *Tribrachiatus bramlettei*, the FO and LO of *T. digitali*s, the FO and LO of *T. contortus* (AUBRY, 1996).

The *T.digitalis* morphotype shows intermediate morphological features between *T. contortus* and *T. orthostylus* and disappears within the lower part of the range of the latter species (RAFFI et al., 2005).

On the other hand, the However, the FO of *T. digitalis* at ODP Site 1262 is recorded within the lowermost part of the range of *T. contortus* (AGNINI et al., 2007), in agreement with the previous findings of RAFFI et al. (2005), in palaeoequatorial Pacific and North Atlantic sections.

This implies that the previously proposed subdivision of MARTINI'S (1971) Zone NP10 (NP10a-NP10d of AUBRY, 1999) collapses. Consequently the exact duration of Subzone NP10b (= range of *digitalis*) remains uncertain.

The *Tribrachiatus digitalis* morphotype is often reported from only a few samples. It was recorded in single samples at DSDP Site 577 and ODP Site 1051 (CRAMER et al., 2003), in two samples from DSDP Site 550 (AUBRY, 1995, AUBRY et al., 1996), in six samples in the poorly recovered cores 5 and 6 at DSDP Hole 117A (AUBRY, 1995), and in probably only two samples from the proposed P/E GSSP section of Dababiya in Egypt (DUPUIS et al., 2003).

The *T. contortus* Zone (NP10) is tentatively recognized at Jabal Mundassah (*T. bramlettei*, is observed in samples

173 and 184), and *T. digitalis* is identified from samples 182 and 183 (Table 2). It is remarkable that Zone NP10 is missing at Jabal Malaqet, suggesting either a small hiatus within the Early Eocene or a potential sampling gap.

4.2.8. The *Discoaster binodosus* Zone (NP11)

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

The *Discoaster binodosus* Zone is defined as the interval from the LO of *T. contortus* and the FO of *Discoaster lodoensis*.

Age: Early Eocene (Ypresian)

Occurrence: Jabals: Malaqet and Mundassah sections

Common species: The LO of *T. orthostylus* is usually found in the uppermost part of Zone NP10 in many localities in the world (PERCH-NIELSEN, 1985b). PERCH-NIELSEN, (1985b) mentioned that in case of the absence of *T. contortus* (its highest occurrence defines the base of the NP11 Zone) the FO of *T. orthostylus* can be used to approximate the base of NP11 Zone. Following the reasoning of PERCH-NIELSEN (1985b), the FO of *T. orthostylus* has been utilized here in order to place the base of NP11 Zone in the studied two sections. Besides the nannofossil taxa identified in the NP10 Zone, other species that first appeared in the NP11 Zone include *T.orthostylus, Sphenolithus radians*, *Ericsonia formosa* and *Chiasmolithus solitus.*

4.3. Stage boundaries

The studied Upper Cretaceous – Lower Eocene sequence contains a set of biozones covering several stages. The calcareous nannofossils provide a useful global marker for the precise placement of stages and boundaries**.** In terms of the identified calcareous nannofossils, the Cretaceous/Palaeogene (K/Pg), the Danian/Selandian, the Selandian/Thanetian and the Paleocene/Eocene (P/E) boundaries are briefly discussed below.

4.3.1. The K/Pg boundary

The Global Stratotype Section and Point (GSSP) for the K/Pg boundary which has been voted by the International Committee on Stratigraphy (ICS) and ratified by the International Union of Geological Science (IUGS) are defined in the El Kef section in Tunisia. The boundary lies at the base of the boundary clay which consists of a 2.0 mm thick, rust colored ferruginous layer overlain by a 1.0m thick black clayey bed within a monotonous succession of marl. This level coincides with the largest extinction event in planktonic foraminifera, together with an Iridium anomaly and an abrupt change in the stable isotope values as well as the carbonate content (ARENILLAS et al., 2002).

At the Jabal Mundassah section, there is a stratigraphic gap around the K/Pg boundary interval which includes the uppermost Maastrichtian (*Micula prinsii* Zone) and the Early Danian (*Markalius inversus* and *Cruciplacolithus tenuis* Zones).

Cretaceous nannofossils rarely occurred above the K/P boundary in the NP3 Zone at the Jabal Mundassah section. In the present study, the authors believe that not all of the Cretaceous forms present in the Lower Danian sediments are due to reworking, but some of them may represent surviving taxa.

4.3.2. The Danian/Selandian boundary

The subdivision of the Palaeocene into the Danian, Selandian and Thanetian was proposed by the ISPS (JENKINS & LUTERBACHER, 1992).

The Global Stratotype Section and Point (GSSP) for the base of the Selandian Stage coincides with; the second evolutionary radiation of the calcareous nannofossil genus *Fasciculithus*, a sharp decrease in the abundance of *Braarudosphaera* and is close to the NP4/NP5 zonal boundary (BERNAOLA et al., 2009). In the Thamad area, east central Sinai, Egypt, the Danian/Selandian boundary is tentatively placed at the base of Zone NP5 (FARIS & ABU SHAMA, 2007).

The base of Danian Stage can be approximated by the base of the NP1 Zone, while the base of the Selandian Stage can be approximated at the base of NP 5 Zone (CLEMMENSEN & THOMSEN, 2005). In the studied two sections, the FO of *F. tympaniformis* was used to delineate the Danian/Selandian boundary which coincides with the NP4/NP5 zonal boundary.

4.3.3. The Selandian/Thanetian boundary

The base of the Thanet Formation in Kent, England was used to define the Selandian/ Thanetian boundary. It corresponds to the lower part of the planktonic foraminiferal P4 Zone (BERGGREN et al., 1995). The calcareous nannofossil studies showed that the base of the Thanetian Stage could be referred to the uppermost part of NP6 or NP6/ NP7 (undifferentiated) (BERGGREN et al., 1995).

At Jabal Mundassah, the Selandian Stage comprises the NP5 and NP6 Zones and the Selandian/Thanetian boundary is marked at the base of Zone NP7/8 (*D. mohleri* Zone). At the Malaqet section, a major hiatus is suggested at the Selandian/Thanetian transition because the NP6 and NP7/8 p.p. Zones cannot be recognized.

4.3.4. The P/E boundary

The Palaeocene/Eocene working group placed the GSSP for the base of the Eocene series in the abandoned Quarry of Dababiya at the base of the Dababiya Quarry Beds (DQB), Luxor, Nile Valley, Egypt and it is defined at the onset of the Carbon Isotope Excursion (CIE) (AUBRY et al., 2007). According to DUPUIS et al. (2003) the base of the Eocene Series (base NP 9b Subzone) can be approximated by the FO of warm-water species (e.g. *Rhamboaster spineus*, *R.cuspis*, *R. intermedia*, *R. calcitrapa*, *R. bitrifida* and *Discoaster araneus*).

At the Jabal Mundassah section, the FO of *Discoaster araneus* (which defines the base of the NP9b Subzone,) is used to approximate the base of the Eocene. At the Malaqet section, the P/E boundary interval is missing and a major hiatus is present as indicated by the absence of the NP9b Subzone, in addition to the complete absence of the NP10 Zone (see Table 1).

5. SUMMARY AND CONCLUSIONS

This work presents a calcareous nannofossil biostratigraphic study spanning the Maastrichtian – Ypresian interval at Malaqet and Mundassah (southeast of Al-Ain City, UAE). Two rock stratigraphic units were recognized in the study area; the Simsima Formation (Late Maastrichtian), and the Muthayminah Formation (Palaeocene-Early Eocene). A stratigraphic gap is located around the K/Pg boundary at the Mundassah section, where the *M. prinsii* Zone (latest Maastrichtian) and NP1 to NP3 Zones (Early Danian) are absent. The Danian/ Selandian boundary is positioned where *Fasciculithus tympaniformis* first occurred (at the base of Zone NP5).

The Selandian/Thanetian boundary is placed at the level of the FO of *Discoaster mohleri* (base of the NP7/8 Zone), at the Jabal Mundassah section. A major hiatus is present around the Selandian/Thanetian boundary at the Jabal Malaqet section as indicated by the absence of the NP6 and NP7/8 Zones.

The Palaeocene/Eocene boundary is placed at the base of Zone NP9b (which is defined by the FO of *Discoaster araneus*) at the Jabal Mundassah section. At the Jabal Malaqet section the Palaeocene/Eocene boundary interval is missing and a major hiatus is testified by the absence of the NP9 b Subzone and NP10 Zone.

ACKNOWLEDGEMENT

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APPENDIX

Taxonomy in general follows that outlined in PERCH-NIELSEN (1985a and b).

UPPER CRETACEOUS CALCAREOUS NANNOFOSSIL TAXA

Arkhangelskiella cymbiformis VEKSHINA (1959)

Cribrosphaerella ehrenbergii (ARKHANGELSKY, 1912) DEFLANDRE in PIVETEAU (1952)

Eiffellithus turriseiffelii (DEFLANDRE in DEFLANDRE and FERT, 1954) REINHARDT, 1965.

Lucianorhabdus cayeuxii DEFLANDRE (1959)

Micula concava (STRADNER in MARTINI & STRADNER, 1960) VERBEEK (1976b)

Micula decussata VEKSHINA (1959)

Micula murus (MARTINI, 1961) BUKRY (1973)

Stradneria crenulata (BRAMLETTE & MARTINI, 1964) NOEL (1970)

Thoracosphaera operculata BRAMLETTE & MARTINI (1964)

Watznaueria barnesiae (BLACK in BLACK & BARNES, 1959) PERCH-NIELSEN (1968)

PALEOCENE AND EOCENE CALCAREOUS NANNOFOSSILS TAXA

Bomolithus conicus (PERCH-NIELSEN, 1971) PERCH-NIELSEN (1984a)

Bomolithus elegans ROTH (1973)

Braarudosphaera bigelowii (GRAN & BRAARUD, 1935) DEFLANDRE (1947)

Campylosphaera dela (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 solitus (BRAMLETTE & SULLIVAN, 1961) LOCKER, 1968

Coccolithus pelagicus (WALLICH, 1877) SCHILLER (1930)

Cruciplacolithus primus PERCH-NIELSEN (1977)

Cruciplacolithus tennuis (STRADNER, 1961) HAY & MOHLER in HAY et al. (1967)

Discoaster araneus BUKRY (1971)

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 (198l)

Discoaster mohleri BUKRY & PERCIVAL (1971)

Discoaster multiradiatus BRAMLETTE & REIDEL (1954)

Discoasteroides bramlettei (BUKRY & SULLIVAN,1971)

Ellipsolithus macellus (PERCH-NIELSEN, 1961) SULLIVAN (1964)

Ericsonia cava (HAY & MOHLER, 1967) PERCH-NI ELSEN (1969)

Ericsonia formosa (KAMPTNER, 1963) HAQ (1971)

Ericsonia subpertusa HAY & MOHLER (1967)

Fasciculithus alanii PERCH-NIELSEN (1971)

Fasciculithus aubertae HAQ & AUBRY (1981)

Fasciculithus billii PERCH-NIELSEN (1971)

Fasciculithus bitectus ROMEIN (1979)

Fasciculithus bobii PERCH-NIELSEN (1971)

Fasciculithus clinatus BUKRY (1971)

Fasciculithus involutus BRAMLETTE & SULLIVAN (1961)

Fasciculithus lilianae PERCH-NIELSEN (1971)

Fasciculithus pileatus BUKRY (1973)

Fasciculithus richardii PERCH-NIELSEN (1971)

Fasciculithus schaubii HAY& MOHLER (1967)

Fasciculithus stonehengei HAQ & AUBRY, 1981

Fasciculithus thomasii PERCH-NIELSEN (1971)

Fasciculithus tonii PERCH-NIELSEN (1971)

Fasciculithus tympaniformis HAY & MOHLER in HAY et al. (1967)

Fasciculithus ulii PERCH-NIELSEN (1971)

Heliolithus cantabriae PERCH-NIELSEN (1971)

Heliolithus kleinpellii SULLIVAN (1964)

Markalius inversus (DEFLANDRE in DEFLANDRE & FERT, 1954) BRAMLETTE & MARTINI (1964)

Neochiastozygus imbriei HAQ & LOHMANN (1976)

Neochiastozygus junctus (BRAMLETTE & SULLIVAN, 1961) PERCH-NIELSEN (1971)

Neochiastozygus modestus PERCH-NIELSEN (1971)

Placozygus sigmoides (BRAMLETTE & SULLIVAN, 1961) ROMEIN (1979)

Pontosphaera multipora (KAMPTNER, 1948) ROTH (1970)

Sphenolithus moriformis ((BRONNIMANN & STRADNER, 1960) BRAMLETTE & WILCOXON (1967)

Sphenolithus primus PERCH-NIELSEN (19710)

Sphenolithus radians DEFLANDRE in GRASSE (1952)

Thoracosphaera operculata BRAMLETTE & MARTINI (1964)

Thoracosphaera saxea STRADNER (1961)

Tribrachiatus bramlettei (BRONNIMANN & STRADNER, 1960) PROTO DECIMA et al. (1975)

Tribrachiatus digitalis AUBRY(1996)

Tribrachiatus orthostylus SHAMRAI (1963)

Zygrhablithus bijugatus (DEFLANDRE in DEFLANDRE & FERT, 1954) DEFLANDRE (1959).

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