

# Nannofossil biostratigraphy of the Paleocene-lower Eocene succession in the Thamad area, east central Sinai, Egypt

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**ABSTRACT:** In the Thamad area, east central Sinai, two stratigraphic sections are measured and sampled; Gebel El Mishiti and G. El Keeh, in order to determine the nannofossil biostratigraphy of the Paleocene-lower Eocene rocks. Gebel El Mishiti section is considered one of the most complete sections across the K/P boundary in Egypt where all the exposed rocks at G. El Keeh belong to the lower Eocene Egma Formation.

A nearly complete succession of Paleocene nannofossil biozones is recorded from the Esna Formation at G. El Mishiti. They are arranged from base to top as follows: *Markalius inversus* (NP1), *Cruciplacolithus tenuis* (NP2), *Chiasmolithus danicus* (NP3), *Ellipsolithus macellus* (NP4), *Fasciculithus tympaniformis* (NP5), *Heliolithus kleinpellii* (NP6), *Discoaster mohleri* (NP7/8) and *Discoaster multiradiatus* (NP9) zones.

The Danian/Selandian boundary is located at the base of Zone NP5 at the level of the first appearance of *Fasciculithus* taxa. The Selandian/Thanetian boundary can be traced tentatively at the base of the *Discoaster mohleri* Zone (NP7/8). The Paleocene/Eocene boundary is traced between the NP9a/NP9b subzonal boundary which is marked by the first appearances of *Discoaster araneus*, *Rhombaster calcitrata*, *R. bitrifida* and *R. cuspis*. The Paleocene/Eocene boundary lies within the upper part of the Esna Formation.

A very thin layer of conglomeratic chalk with no paleontological break is located between Zone NP9 and NP10. However, a very short nannofossil break is noted within Zone NP10 (subzones NP10b and NP10c are missing) which is overlain by Zone NP11. The lower part of the latter covers the topmost part of the Esna Formation where its upper part lies within the base of the Egma Formation; therefore, a conformable relationship between the two formations is suggested.

At Gebel El Mishiti, the lower Eocene nannofossil biozones NP11, NP12, NP13 and lower/middle Eocene Zone NP14 are recorded. On the other hand, Gebel El Keeh section, which is about 95m thick is only represented by the *Discoaster subloboensis* Zone (NP14).

## INTRODUCTION

The Thamad (Themed) area is located in east central Sinai between latitude 29°32'-29°52'N and longitudes 34°8'-34°40' E. The material for the present study was collected from the Paleocene and lower Eocene succession in this area. Two lithostratigraphic sections were measured, described and sampled in detail. These were Gebel El Mishiti and Gebel El Keeh (text-fig. 1).

The Paleocene-lower Eocene succession in the studied area comprises two mappable rock units with the Esna Formation (shale facies) underlying the Egma Formation (limestone facies). The Esna Formation consists of calcareous and argillaceous marl intercalated by carbonate ledges. The Egma Formation rests conformably on the Esna Formation and is composed of massive to poorly bedded chalky limestone with several chert bands (text-fig. 2).

This study describes the nannofossil biozones of the Paleocene-Eocene interval and discusses the most critical nannofossil evidences for the location of the Danian/Selandian, Selandian/Thanetian, Paleocene/Eocene and lower Eocene/middle Eocene boundaries in the Thamad area, east central Sinai, Egypt. Examination of the calcareous nannofossils was carried out in the present study with the help of the polarizing microscope (Olympus BH) using 1250X magnification. Smear slides of each sample were prepared using the techniques used by Perch-Nielsen (1985). Geochemical analyses were carried

out at the Central Laboratories Sector of the Egyptian Geological Survey.

## NANNOFOSSIL BIOSTRATIGRAPHY

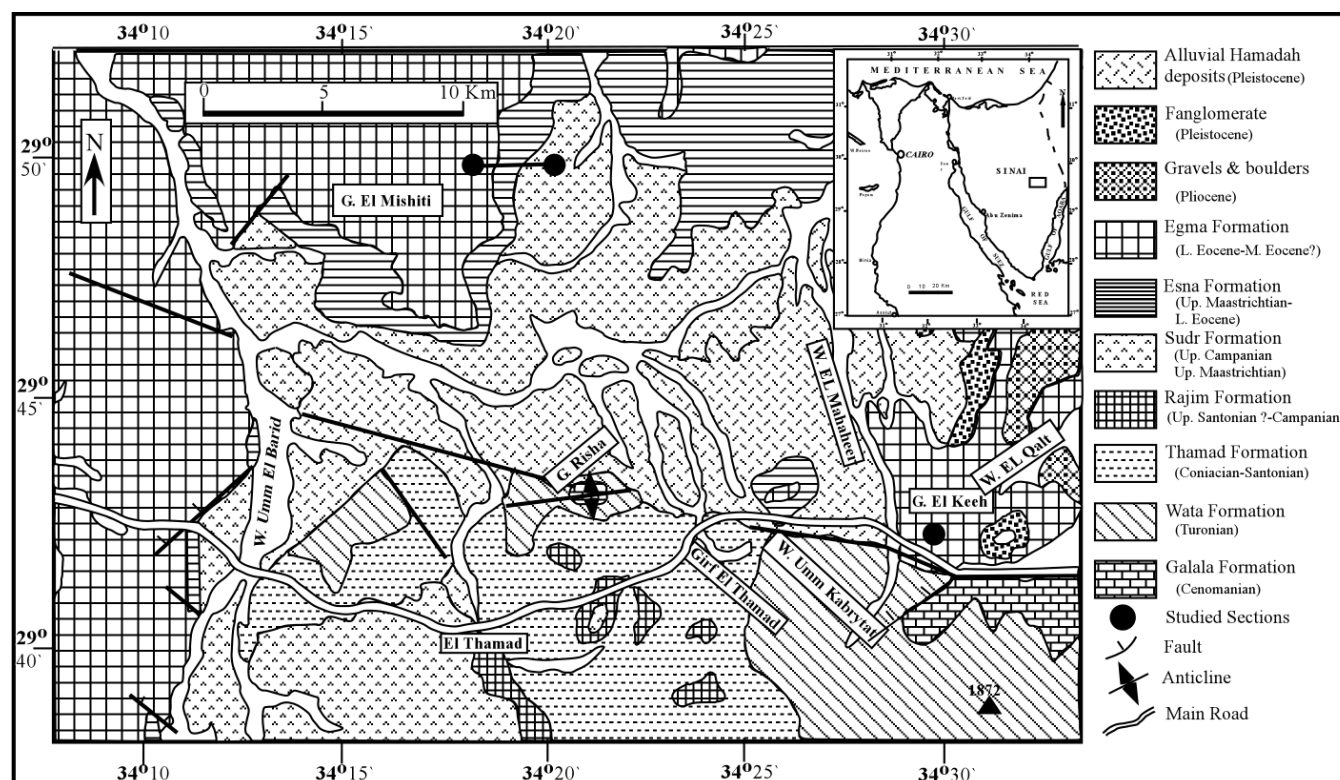
The lower Paleogene standard zonation proposed by Martini (1971) is adopted here. The nannofossil events in the Paleocene-Eocene interval in the studied sections are shown on text-figure 3. The distribution of the biozones and the stratigraphic ranges of the nannofossil species are presented in text-figures 4-5. Selected nannofossil taxa are illustrated on plates 1-3.

## PALEOCENE BIOZONES

At Gebel El Mishiti, all the Paleocene biozones of Martini (1971) are recognized and they conformably overlie the uppermost Maastrichtian *Micula prinsii* Zone. This section is regarded as one of the most complete Cretaceous/Paleocene boundary interval in Egypt (Faris and Abu Shama 2003). The Paleocene biozones at Gebel El Mishiti and their characteristics are discussed below:

### *Markalius inversus* Zone (NP1)

This zone includes the interval from the increased frequency of *Thoracosphaera operculata* to the lowest occurrence (LO) of the *Cruciplacolithus tenuis*. The calcareous nannoplankton taxa in Zone NP1 are the same as the *Micula prinsii* Zone, in addition to the increased frequency of *Thoracosphaera operculata* and *T. saxea* and the presence of rare *Biantholithus sparsus* and



TEXT-FIGURE 1  
Geological map of the Thamad area, east central Sinai (modified from Geological Map of Sinai, 1994).

*Biscutum constans*. The abundance of *Placozygus sigmoides* varies from rare to few. However, abrupt decrease of Cretaceous taxa is recorded in this zone. Rare specimens of *Cruciplacolithus primus* (small) are present at the lower part of this zone, but rare *C. primus* of large sizes are recorded at the top of the zone.

#### ***Cruciplacolithus tenuis* Zone (NP2)**

The *Cruciplacolithus tenuis* Zone is the interval from the LO of *C. tenuis* to the LO of *Chiasmolithus danicus*. This zone reaches about one meter in thickness, and it consists of dark grey argillaceous marl. It is represented by Sample M46 and M47 where the nannofossils are very abundant and well preserved. Although Cretaceous taxa are still present, their abundance is greatly reduced. Survivors such as *Thoracosphaera operculata*, *T. saxea*, *Cyclagelosphaera reinhardtii*, *Chiastozygus ultimus* and *Placozygus sigmoides* are still abundant. However, *Zygolithus crux* does not occur in this zone. In addition, the total abundance of survivors has decreased in Zone NP2.

#### ***Chiasmolithus danicus* Zone (NP3)**

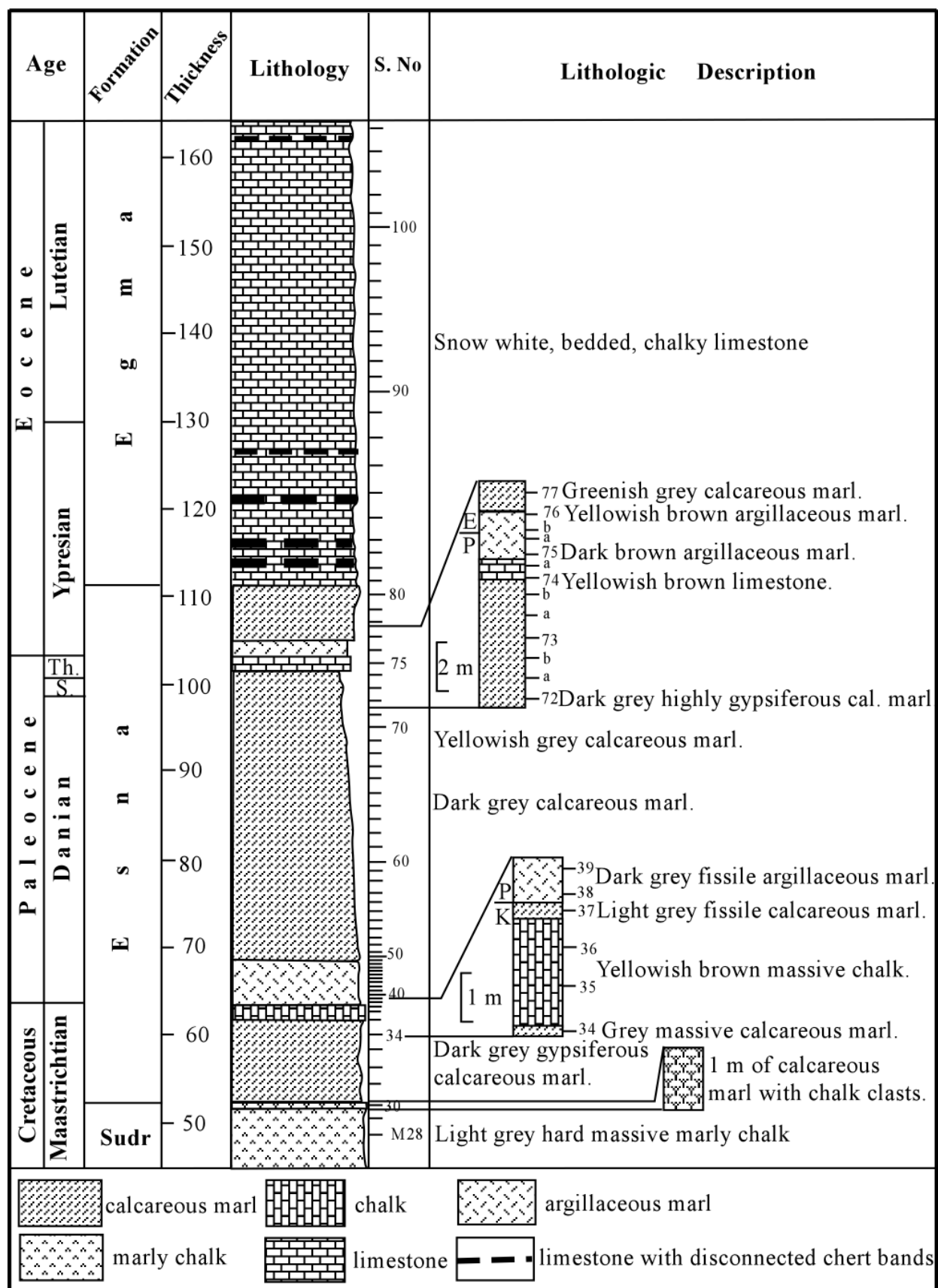
This zone is defined as the interval from the LO of *Chiasmolithus danicus* to the LO of *Ellipsolithus macellus*. Its thickness reaches about 21m; it consists of dark grey argillaceous marl and dark grey calcareous marl, represented by Samples M48-M69. Except for Samples M55, M60 and M61 that contain moderately preserved calcareous nannofossils, all samples yielded well-preserved taxa. The LOs of the two zonal markers *Chiasmolithus danicus* and *Cruciplacolithus edwardsii* are found together in Sample M48. At the top of this zone only

two vanishing Cretaceous species, *Micula decussata* and *Watznaueria barnesae*, are recorded. These are dissolution resistant forms. The incoming early Paleocene species become more common and diversified at the top of Zone NP3.

A count of tentatively interpreted warm-water and cool-water taxa in our sections reveals the prevalence of cool-water taxa at the end of Danian. Similarly, Bassiouni et al. (1991) recorded decreased values of the ratio between warm-water/cool-water taxa in the Ain Dabadib section, Kharga Oasis, suggesting a slight cooling in the surface waters at the end of the Danian. It is worth mentioning here that the mid Zone NP3 (Samples M55 and M56) contains none of the incoming Paleocene species but the abundance of the vanishing Cretaceous and survivors increases. At the base of this zone, the size of *Placozygus sigmoides* increases to about 10µm while the size of *Eiffelolithus turrisseffellii* is decreased.

#### ***Ellipsolithus macellus* Zone (NP4)**

It is defined as the interval from the LO of *Ellipsolithus macellus* to the LO of *Fasciculithus tympaniformis*. Noticeable lithologic changes took place from yellowish grey, nodular calcareous marl at the top of NP3 to dark grey, fissile calcareous marl at the base of Zone NP4. This zone is about 5.5m thick, and represented by Samples M70 and M71. The calcareous nannofossil assemblages which are very abundant at the base of the zone, becoming abundant at its top and most assemblages are well preserved. Except for the occurrence of the delicate form *Ellipsolithus macellus*, all the nannofossil taxa are the same as in the top of Zone NP3.



TEXT-FIGURE 2

Lithological description of the Upper Maastrichtian -Lower Eocene succession at Gebel El-Mishiti. (S: Selandian; Th: Thanetian ages)

#### ***Fasciculithus tympaniformis* Zone (NP5)**

This is the interval from the LO of *Fasciculithus tympaniformis* to the LO of *Heliolithus kleinpellii*. It consists of about 2.5m of dark grey, fissile calcareous marl that is intercalated with gypsum bands in its upper part. It is represented by Samples M72, M72a and M72b in which all the calcareous nannoplankton are very abundant and well preserved.

At the base of Zone NP5, *Fasciculithus* taxa are easily recognized and thus their lowest occurrence readily mark the NP4/NP5 zonal boundary. A number of new nannofossil taxa characteristic of the Paleocene are recorded in this zone such as rare *Bomolithus elegans*, *Fasciculithus pileatus* and few to rare *Chiasmolithus consuetus* (= *Sullivaniana consuetus*), *Fasciculithus billii*, *F. ulii*, few *Sphenolithus primus* in addition to the marker species *Fasciculithus tympaniformis*. According to Romein (1979) and Perch-Nielsen (1981), several new species of *Fasciculithus* and related genera such as *Heliolithus* and *Bomolithus* evolved prior to *Heliolithus kleinpellii*. A noticeable increase in abundance of *Ericsonia subpertusa* and *E. robusta* and a decrease in *E. cava/eoplatica* occurs in this zone. The warm-water species, such as *Ericsonia subpertusa*, *Fasciculithus* spp., *Sphenolithus* spp. are more abundant than the cool-water forms, *Ericsonia cava/eoplatica* and *Chiasmolithus* spp. Bassiouni et al. (1991) suggested a warm surface water paleotemperature for the middle part of *Ellipsolithus macellus* Zone in Dabadib, Kharga Oasis.

#### ***Heliolithus kleinpellii* Zone (NP6)**

This zone comprises the interval from the LO of *Heliolithus kleinpellii* to the LO of *Discoaster mohleri*. It is about 2m thick, of the same lithology as the underlying Zone NP5 (gypsiferous, dark grey calcareous marl), and is represented by Samples M73 and M73a. The calcareous nannofossil species are well preserved and are very abundant in Sample M73 and abundant in Sample M73a.

*Bomolithus conicus*, *Heliolithus cantabriae*, *Chiasmolithus bidens*, *Toweius pertusus*, *Neochiastozygus denticulatus* and *Neochiastozygus digitosus* have their LO in this zone, in addition to the marker species *Heliolithus kleinpellii*. It is noted that *Fasciculithus pileatus*, *F. billii*, *F. ulii* occur from Zone NP5 through the base of Zone NP6. Although Perch-Nielsen (1985) mentioned that these *Fasciculithus* taxa became extinct Biochron NP6, Aubry (1989) recognized that *F. pileatus* ranges from NP5 through NP9.

#### ***Discoaster mohleri* Zone (NP7/8)**

This (combined) zonal entry is defined here following Romein (1979) as the interval from the LO of *Discoaster mohleri* to the LO of *Discoaster multiradiatus* due to the absence of the marker species for the top of Zone NP7 (*Heliolithus riedellii*). It is represented by Samples M73b, M74 and M74a. The first sample is a gypsiferous, dark grey calcareous marl (about 0.5m thick), whereas the other two samples (about 1m) form a hard yellowish brown limestone intercalation. The calcareous nannofossil assemblages are well preserved in all samples; they are abundant in the calcareous marl and very abundant in the limestone. The calcareous nannofossil assemblages are of generally similar composition as those of the underlying Zone NP6. Incoming species are *Discoaster mohleri*, *Rhabdosphaera pinguis* and *Neochiastozygus junctus*.

#### ***Discoaster multiradiatus* Zone (NP9)**

This zone is defined as the interval from the LO of *Discoaster multiradiatus* to the LO of *Tribrachiatus bramlettei*. It is represented by Samples M75, 75a and 75b. It consists of about 90cm of dark brown calcareous marl which overlies the hard yellowish brown limestone of Zone NP7/8. The calcareous nannofossils are very abundant and well preserved in Sample M75 while in Samples M75a and M75b they are abundant and moderately preserved.

The *Discoaster multiradiatus* Zone (NP9) is considered the last nannofossil zone in the Paleocene (Martini 1971, Romein 1979, Perch-Nielsen 1981, 1985 and others). In Egypt, the NP9 Zone is well represented in G. Owaina, G. Um el Ghanayem (Sadek and Teleb 1978); and Taramsa (Faris et al. 1985); as well as in NE Sinai (Faris 1988); Safaga area (Hewaidy and Faris 1989); Gurnah, Luxor (Faris 1991) and many other localities in Egypt (see Faris 1997; Ouda and Aubry 2003).

In this zone we record 13 incoming species characteristic of the Paleocene. Seven of these species have their LO at the base of the zone: *Discoaster multiradiatus*, *D. lenticularis*, *D. nobilis*, *Fasciculithus alanii*, *F. lilliana*, *F. bobii* and *Rhomboaster intermedia*. Six species have their LO in the middle part of the zone: *Fasciculithus involutus*, *Rhomboaster cuspis*, *R. calcitrapa*, *R. bitrifida*, *Discoaster mahmoudii* and *D. araneus*. The incoming taxa of zone NP7/8 also occur through this zone. In fact most taxa of Zone NP9 had their LO in older zones. This agrees well with the statement of Perch-Nielsen (1985) that Paleocene diversity reached a maximum in Zone NP9.

The NP9a/NP9b subzonal boundary occurs between samples M75 and 75a owing to the FOs of *Rhomboaster calcitrapa*, *R. cuspis*, *R. bitrifida* and *Discoaster araneus* in Sample M75a. The highest occurrence (HO) of *Fasciculithus alanii* is slightly above the NP9a/NP9b subzonal boundary as previously recorded by Aubry et al. (1999) in the Dababiya section, Nile Valley. We note also that all *Fasciculithus* spp. are absent in the upper part of Subzone NP9b except for *Fasciculithus tympaniformis* whose HO coincides with the NP9/NP10 zonal boundary.

### **EOCENE BIOZONES**

Four calcareous nannofossil biozones (NP10-NP13) are recorded from the lower Eocene at Gebel El Mishiti section. The lower middle Eocene Zone NP14 is recorded in the upper part of the Gebel El Mishiti section and from Gebel El Keeh section which is restricted mainly by this zone. The distribution of Eocene calcareous nannofossils at Gebel El Mishiti is given in text-figure 4; their distribution in the lower middle Eocene at Gebel El Keeh is given in text-figure 5. The identified biozones and their characteristics are discussed below.

#### ***Tribrachiatus contortus* Zone (NP10)**

This biostratigraphic interval is defined by the LO of *Tribrachiatus bramlettei* or *Discoaster diastypus* and its base, and the HO of *Tribrachiatus contortus* at its top. It occupies about 4.5m of yellowish to greenish grey calcareous marl at the upper most part of the Esna Formation. It is represented by Samples M76-M79. Most of the calcareous nannofossil taxa are very abundant and well-preserved except in Sample M77, in which they are abundant and moderately preserved.

Aubry (1996) has subdivided the Zone NP10 into four subzones based on the sequential occurrence of the different

Fm.	AGE	NANNOFOSSIL ZONE			NANNOFOSSIL BIOEVENTS		
E s n a	E g m a	E o c e n e	M	Early	<i>Discoaster sublodoensis</i>	NP14	L O <i>Discoaster sublodoensis</i>
					<i>Discoaster lodoensis</i>	NP13	L O <i>Toweius? crassus</i> Bukry, 1973
					<i>Tribrachiatus orthostylus</i>	NP12	L O <i>Discoaster lodoensis</i>
					<i>Discoaster binodosus</i>	NP11	L O <i>Tribrachiatus orthostylus</i>
					<i>Tribrachiatus contortus</i>	NP10	L O <i>Tribrachiatus bramlettei</i>
					<i>Discoaster multiradiatus</i>	NP9	L O <i>Discoaster multiradiatus</i>
					<i>Discoaster mohleri</i>	NP7/8	L O <i>Discoaster mohleri</i>
					<i>Hleiolithus kleinpellii</i>	NP6	L O <i>Hleiolithus kleinpellii</i>
					<i>Fasciculitius tympaniformis</i>	NP5	L O <i>Fasciculitius tympaniformis</i>
					<i>Ellipsilithus macellus</i>	NP4	L O <i>Ellipsilithus macellus</i>
					<i>Chiasmolithus danicus</i>	NP3	L O <i>Chiasmolithus danicus</i>
					<i>Cruciplacolithus tenuis</i>	NP2	L O <i>Cruciplacolithus tenuis</i>
					<i>Markalius inversus</i>	NP1	Increase frequency <i>Th. operculata</i>
					<i>Micula prinsii</i>		L O <i>Micula prinsii</i>
					<i>Micula murus</i>		L O <i>Micula murus</i>
Sudr	Maastrichtian	D a n i a n	S	T			

(Martini, 1971)

(Perch-Nielsen, 1979, 1983)

• (Perch-Nielsen, 1971, emended, Romein, 1979)

TEXT-FIGURE 3

Proposed calcareous nannoplankton zonal scheme in the studied area. (S: Selandian; T: Thanetian ages)

species of *Tribrachiatus*: 1) Subzone NP10a (*Tribrachiatus bramlettei*-*Tribrachiatus digitalis* Interval Range Subzone) is defined as the interval between the LO of *T. bramlettei* and the LO of *T. digitalis*; 2) Subzone NP10b (*T. digitalis* Total Range Subzone) is defined by the total range of the nominate taxon; 3) Subzone NP10c (*T. digitalis*-*T. contortus* Interval Subzone) is the interval between the HO of *T. digitalis* and the LO of *T. contortus*; 4) Subzone NP10d (*T. contortus* Total Range Subzone) is defined by the total range of the nominate taxon. In Egypt, Faris and Strougo (1998) have recorded the four subzones (NP10a through NP10c) in G. Gurnah section, Nile Valley.

In this study the base of Zone NP10 is delineated by the LO of *T. bramlettei*, *Discoaster binodosus*, and *D. diastypus*, recorded in the upper part of the Esna Formation. Other incoming taxa are *Discoaster falcatus*, *Pontosphaera* sp., *P. multipora*, *Campylosphaera dela* and *Tribrachiatus contortus*. In the Gebel Mishiti section, only subzones NP10a and NP10d are recorded, subzones NP10b and NP10c are missing. A minor gap is suggested to have formed in the Gebel El Mishti section slightly after the beginning of the early Eocene.

#### *Discoaster binodosus* Zone (NP11)

Zone NP11 is the interval from the HO of *Tribrachiatus contortus* to the LO of *Discoaster lodoensis*. This zone is represented by Sample M80 from the upper 70cm of the greenish grey calcareous marl on the top of the Esna Formation and Sample M81 from the lowest 80cm of the base of the Esna Formation. The calcareous nannofossil assemblages are very abundant and well preserved in Sample M80 (Esna Formation) and become abundant and moderately preserved in Sample M81 (Esna Formation).

An exceptional abundance of *Tribrachiatus contortus* is recorded (< 1 specimen/field of view) in Sample M79. The overlying sample M80 yielded few specimens (1-3 specimens/field of view) of *Tribrachiatus orthostylus* and *Sphenolithus radians* and no *T. contortus*. The LO of *T. orthostylus* usually occurs in the uppermost part of Zone NP10, whereas the LO of *Sphenolithus radians* is recorded in the lower part of Zone NP11 in many areas in the world. The co-occurrence of *Tribrachiatus orthostylus* and *Sphenolithus radians* in Sample M80 may suggest a minor hiatus between Subzone NP10d and Zone NP11 within the uppermost part of the Esna Formation, although no lithologic changes are observed. However, this may be due to sampling gaps rather than non deposition. Zone NP11 extends from the uppermost part of the Esna Formation to the basal part of the Egma Formation. Therefore, the Egma Formation is conformably overlying the Esna Formation. It is noted that nearly all the recorded specimens of *T. orthostylus* in this zone have three arms with slight bifurcation.

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

This zone is defined as the interval from the LO of *Discoaster lodoensis* to the HO of *Tribrachiatus orthostylus* or the LO of *Toweius (?) crassus*. It occupies about 4.5m of the basal part of the Egma Limestone and is represented by Samples M82-M84. All calcareous nannofossil species are abundant and moderately preserved in this zone except at its top, where they are very abundant. As a rule, the lowest few meters of the Egma Formation yielded abundant and moderately preserved calcareous nannofossil assemblages.

All the calcareous nannofossil taxa in Zone NP11 are observed in this zone. Additional seven genera represented by 14 species are introduced into the calcareous nannofossil assemblages of

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### Incoming Paleogene Species



TEXT-FIGURE 5  
Distribution of calcareous nannofossil species in Gebel El Keeh section, east El Thamad Village.

*Tribrachiatus orthostylus* is common in many early Eocene (uppermost of Zone NP10 to the top of Zone NP12) sections in the world but it is more abundant at mid and high latitudes. The last occurrence of *T. orthostylus* is usually used to define the base of Zone NP13 (Martini 1971). Although the Zone NP12 has generally been distinguished by the overlap of the *Tribrachiatus orthostylus* and *Discoaster lodoensis*, the last occurrence of *T. orthostylus* may range higher than previously indicated. In Arroyo El Bulito section, California, Bukry (1973b) mentioned that the stratigraphic range of *T. orthostylus* is high as the middle Eocene *Nannotetrina quadrata* (= *N. fulgens*) Zone as several zones present above its presumed level of disappearance. He defined the top of NP12 Zone by the LO of *Coccolithus crassus* (= *Toweius crassus*). From the ODP Hole 690B, Aubry et al. (1996) also recorded *T. orthostylus* in Zone NP14, but they considered these forms as reworked species. Perch-Nielsen (1985) dashed the range of *T. orthostylus* up to

Except for *Chiasmolithus eograndis* and *Discoaster cruciformis*, all the calcareous nannofossils recorded in Zone NP12 are still observed in this zone. Rare of *Toweius? crassus*, *Helicosphaera seminulum*, *Reticulofenestra dictyoda*, *Blackites*



TABLE 1

Mineralogical and geochemical data in some samples around the P/E boundary at Gebel El Mishiti section.

S. No.	Zone	CaCO <sub>3</sub>	Organic matter %	P <sub>2</sub> O <sub>5</sub> %	Clay Minerals		
					Kaolinite	Illite	Smectite
79	NP10d	68.7	0.7	n.d.	0.9	6.3	92.9
77	NP10a	63.3	0.76	n.d.	0.0	3.80	96.2
76		47.4	0.76	0.87	0.0	3.85	96.15
75a	NP9b	49.2	0.86	1.7	0.5	3.2	96.3
75	NP9a	59.27	0.8	1.71	2.2	6.3	91.5
74	NP7/8	95.84	0.3	0.78	2.5	14.8	82.64
73	NP6	84.5	0.3	n.d.	1.7	16.2	82.1

n.d.: not determined

*spinus*, *Discoaster distinctus*, *D. germanicus* and *Lophodolichus nascens*, few *Transversopontis rectipons* and *Helicosphaera lophota* are observed. *Tribrachiatus orthostylus* ranges above its presumed level of disappearance and having sizes smaller than its sizes in the lower zones (NP11 and NP12). Therefore, ecological factors may be responsible for this sporadic occurrence rather than reworking.

#### *Discoaster sublodoensis* Zone (NP14)

This zone is defined as the interval from the LO of *Discoaster sublodoensis* to the LO of *Nannotetrina fulgens* and/or LO of *Rhabdosphaera inflata*. It is represented by Samples M89-M105 at Gebel El Mishiti, is about 40m thick, and consists of white yellowish chalky limestone intercalated with the discontinuous chert bands of the Egma Formation. The exposure of Gebel El Keeh, which consists of about 95m of the Egma Limestone belongs mainly to this zone.

At Gebel El Mishiti the calcareous nannofossil assemblages in this zone are very abundant except in Sample M103 of partially solidified chalk. The assemblages are poorly preserved in two samples, moderately in four samples and well preserved in eleven samples. At Gebel El Keeh, most of the samples are fossiliferous with very poorly preserved calcareous nannofossils. From a total of 46 samples, 8 are poorly preserved, 16 are moderately preserved, 9 samples are well preserved, and 13 samples are barren (text-fig. 5).

The base of the *D. sublodoensis* Zone is defined by the LO of the nominative taxon in Sample M89 at Gebel El Mishiti. Except for the disappearance of *Toweius occultatus*, all the calcareous nannofossil taxa of Zone NP13 occur in Zone NP14 at Gebel El Mishiti. Additional taxa include rare *D. wemmelensis*, rare to few *Neococcolithus minutus*, *D. nonaradiatus* and *Scyphosphaera* sp. The latter taxon is recorded for the first time in Egyptian Eocene sedimentary rocks. Rare *D. septemradiatus*, *D. strictus*, *D. saipanensis* and very rare *Braarudosphaera bigelowii*, and *Micrantholithus vesper* also occur in the upper part of the section.

At Gebel El Keeh, *D. sublodoensis* is recorded in Sample K1 through Sample K45. *Discoaster lodoensis* is recorded from sample K1 through sample K42, being completely absent above this sample. *Discoaster kuepperi* is sporadic above sample L14, very rare up to Sample K29. It is absent above Sample K29. The LO of *D. kuepperi* defines the top of CP12a (Okada and Bukry 1980). An overlap between *D. sublodoensis*, *D. lodoensis* and *D. Kuepperi* is observed from Sample K1 up to Sample K29. The co-occurrence of these three taxa characterizes Subzone NP14a (see Aubry 1991).

TABLE 2

Geochemical data of some trace and rare earth elements in some selected samples at Gebel El Mishiti section

S. No.	Cr ppm	Ni ppm	V ppm	Nb ppm	Y ppm	La ppm	Ba ppm	Cu ppm
76	61.9	272.6	52.8	4.8	39.4	19.9	2000	104.6
75a	115.5	283.6	135.0	12.5	81.4	56.8	2000	133.2
70	82.9	88.8	81.9	3.0	28.4	23.1	972	99

At Gebel El Keeh, the LOs of *D. saipanensis* and *D. martini* are located in Sample K11. Perch-Nielsen (1985) tentatively extended the occurrence of *D. saipanensis* throughout Zone NP15, its range being confidently established from Zone NP16 through the top of Zone NP20. However, Aubry (1986) noted the first appearance of *D. saipanensis* in upper Zone NP14. While Prins (1971) showed a distribution of *D. martini* from Zone NP13 through Zone NP16, Aubry (1983) used its presence to indicate Zone NP15 and the basal part of Zone NP16 only. In this study, the first occurrence of *D. bifax* is observed in Sample K23. According to Okada and Bukry (1980) its presence defines Zone CP14a (= NP16). However, Aubry (1983, 1986) found *D. bifax* ranging down into NP14 in the hemipelagic or neritic sediments of the Paris and London Basins. Therefore, it is difficult to establish the zonal age of the interval above Subzone NP14a (above Sample K9) in this study. It is surprising that *D. lodoensis* overlaps with *D. sublodoensis* through 85m of the Egma Formation in Zone NP14 at Gebel El Keeh. In the literatures, difficulties related to calcareous nannofossil biostratigraphy of epicontinental deposits are mostly restricted to reworking (Hay and Mohler 1967; Hay et al. 1967) and diagenetic processes, in particular, secondary silicification (Aubry 1986).

## STAGE BOUNDARIES

### Cretaceous /Paleogene Boundary

The K/P boundary in Gebel El Mishiti section has been delineated between samples M37 and M38 based on the increased frequency of *Thoracosphaera operculata* in sample M38 (Faris and Abu Shama 2003). They mentioned also that the first occurrence of *Biantholithus sparsus* was in Sample M39 (about 0.5m above the boundary). The next taxon to appear in the early Paleocene is *Cruciplacolithus primus* (small), followed by *C. tenuis*, *Ericsonia cava*, and *C. edwardsii*. This plus the presence of *Micula prinsii* suggested a complete succession from uppermost Maastrichtian through lower Paleocene (Danian).

### Danian/Selandian Boundary

The total thickness of rocks of Danian age is about 30m in Gebel El Mishiti section. The base of the Selandian stage was placed by Berggren et al. (1995) in the upper part of Zone NP4. The most profound evolutionary changes in the Paleocene calcareous nannoplankton occurred during the later part of Biochron NP4 (Aubry 1998) and the most characteristic genera of the Paleocene originated during this time. The closely related genera *Sphenolithus* and *Fasciculithus* evolved during the Biochron NP4, subsequently giving rise to *Heliolithus* and *Discoaster*. At Gebel El Mishiti, the Danian/Selandian boundary is tentatively placed at the base of Zone NP5 (LO of *Fasciculithus* taxa).

In this study, as mentioned earlier, the base of Zone NP5 is defined by the LO of *Fasciculithus tympaniformis* as well as the LO of *Sphenolithus*. The latter is generally found in Zone NP4 and shortly before the LO of *Fasciculithus tympaniformis*.

However, at Gebel El Mishiti, the LO of *S. primus* coincides with the LO of *Fasciculithus tympaniformis*. Thus either the LO of *S. primus* represented a delayed first occurrence, and Zone NP5 overlies Zone NP4 conformably or the stratigraphy juxtaposition reflects a short hiatus without visible lithologic changes. The Danian age was a time of particularly pronounced global highstand of sea level followed by regression at its end (Vail et al. 1977). However, based on the calcareous nannofossils complete sequences across the Paleocene interval recorded in localities in Egypt (Faris 1988; Faris et al. 1999; El Dawoody 1990; Marzouk and Luning 1998) as in this study.

#### Selandian/Thanethian Boundary

On the bases of calcareous nannofossil bioevents, the Selandian/Thanethian is tentatively placed at the uppermost part of Zone NP6 or the lowermost part of Zone NP7/8 (Berggren et al. 1995). In the current study the first appearance of *D. mohleri* (marker taxon of Zone NP7/8) is used to delineate the boundary. A marked lithologic change from gypsiferous, dark grey calcareous marl to yellowish brown limestone is noted from the upper part of Zone NP6 to Zone NP7/8.

#### The Paleocene/Eocene (P/E) Boundary

The latest Paleocene-earliest Eocene boundary now clearly appears as a critical interval in earth history. Many events took place in this interval such as global warming (Stott and Kennett

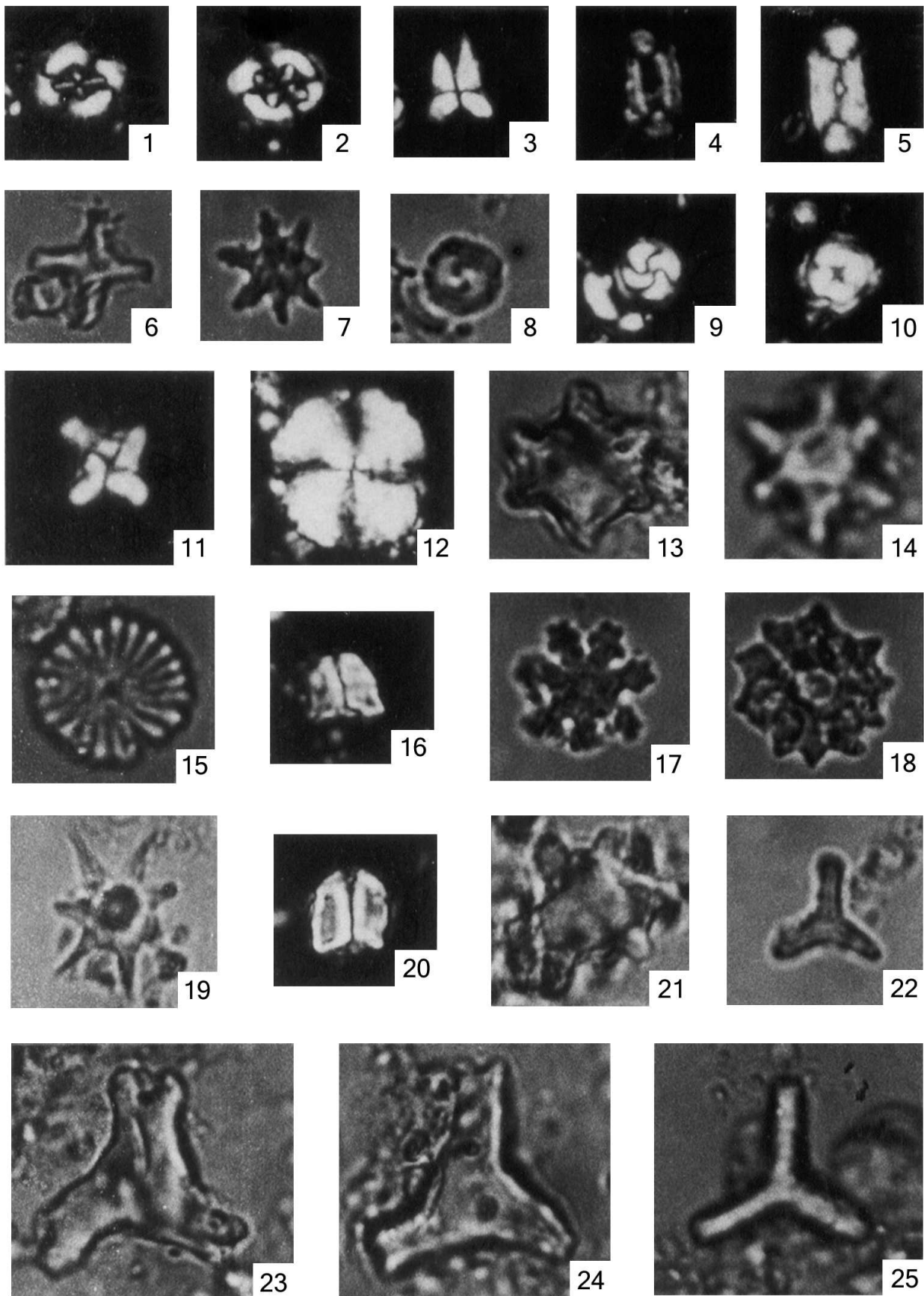
1990; Kennett and Stott 1991), reduction in atmospheric circulation (Rea et al. 1990) and changes in oceanic circulation associated with brief production of deep water at low latitude (Miller et al. 1987; Kennett and Stott 1991; Thomas 1990a, b, 1993). These events were concomitant with major turnovers in the bathyal and abyssal benthic foraminifera (Tjalsma and Lohmann, 1983; Thomas 1990a, b) and the terrestrial mammals (see review in Hooker 1991). Isotopic ( $\delta_{13}C$  and  $\delta_{18}O$  excursion) and mineralogical (kaolinite peak) evidence suggest that these evolutionary turnovers were related to deep water warming associated with climatic change. Although the proximate cause of the carbon isotope excursion (CIE) may be the massive dissociation of carbon hydrates, the ultimate cause for global warming has not been well identified.

The P/E boundary has traditionally been correlated on the basis of the NP9/NP10 zonal boundary which is defined by the LO of *Tribrachiatus bramlettei* (Martini 1971). The LO of *Discoaster diastypus* was used by Okada and Bukry (1980) to recognize this boundary. Romein (1979) has shown how *T. bramlettei* evolved into *T. contortus* which itself evolved into *T. orthostylus* in the later part of Biochron NP10. *Tribrachiatus contortus* seems to be less restricted in occurrence than *T. bramlettei*. In the absence of *T. bramlettei*, the LO of *Fasciculithus tympaniformis* (or *Fasciculithus* spp.) is used to approximate the NP9/NP10 zonal boundary (Shackleton et al. 1984). Although the three species of *Tribrachiatus* clearly constitute a

### PLATE 1

All Figures  $\times 2000$ , from Gebel El Mishiti

- 1 *Cruciplacolithus tenuis* (Stradner 1961) Hay and Mohler in Hay et al. 1967. Sample No. 49, *Chiasmolithus danicus* Zone.
- 2 *Chiasmolithus danicus* (Brotzen 1959) Hay and Mohler 1967. Sample No. 54, *Discoaster lodoensis* Zone.
- 3 *Sphenolithus radians* Deflandre in Grasse 1952. Sample No.80, *Discoaster binodosus* Zone.
- 4,5 *Ellipsolithus macellus* (Bramlette and Sullivan 1961) Sullivan 1964; 4, Sample No.70; 5, Sample No.71, *Ellipsolithus macellus* Zone.
- 6 *Discoaster cruciformis* Martini 1958. Sample No.83, *Tribrachiatus orthostylus* Zone.
- 7 *Discoaster binodosus* Martini 1958. Sample No. 83, *Tribrachiatus orthostylus* Zone.
- 8,9 *Toweius ? gammation* (Bramlette and Sullivan 1961) Romein (1979). Sample No. 8; 8, *Discoaster lodoensis* Zone.
- 10 *Toweius ? crassus* (Bramlette and Sullivan 1961) Perch-Nielsen (1984). Sample No. 88, *Discoaster lodoensis* Zone.
- 11 *Micula prinsii* Perch-Nielsen 1979. Sample No.39, *Markalius inversus* Zone.
- 12 *Heliolithus kleinpellii* Sullivan 1964. Sample No.73, *Heliolithus kleinpellii* Zone.
- 13,14 *Tribrachiatus bramlettei* (Bronnimann and Stradner 1960) Proto Decima et al. 1975. Sample No.79, *Tribrachiatus contortus* Zone.
- 15 *Discoaster multiradiatus* (Bramlette and Riedel 1954). Sample No. 83, *Tribrachiatus orthostylus* Zone.
- 16,20 *Fasciculithus tympaniformis* Hay and Mohler in Hay et al. 1967. Sample No. 72, *Fasciculithus tympaniformis* Zone.
- 17 *Discoaster gemmifer* Stradner 1961. Sample No.83, *Tribrachiatus orthostylus* Zone.
- 18 *Discoaster barbadiensis* Tan 1927. Sample No.83, *Tribrachiatus orthostylus* Zone.
- 19 *Discoaster araneus* Bukry 1971. Sample No.75b, *Discoaster multiradiatus* Zone.
- 21 *Tribrachiatus contortus* (Stradner 1958) Bukry 1972. Sample No.83, *Tribrachiatus orthostylus* Zone.
- 22-25 *Tribrachiatus orthostylus* Shamrai 1963. 22, sample No. 87, *Discoaster lodoensis* Zone; 23, 24, sample No. 80, *Discoaster binodosus* Zone; 25, sample No. 83, *Tribrachiatus orthostylus* Zone.



lineage, their stratigraphic relationships remain somewhat unclear (see Aubry et al. 1996 for detailed discussion).

In Egypt, the calcareous nannofossil events at the standard P/E boundary were studied by El-Dawoody (1992, 1994), Faris (1991, 1993a), Strougo and Faris (1993), Aubry et al. (1999, 2000), Faris et al. (1999), Dupuis et al. (2003) and Knox et al. (2003). Faris (1993a) used the LO of *T. bramlettei*, *Discoaster diastypus* and *D. binodosus* to delineate the base of the Eocene in several Egyptian sections. The HO of *Fasciculithus* spp. may have taken place below or slightly above the P/E boundary in different sections in Egypt (see Faris et al. 1999). The boundary lies in the upper part of the Esna Formation and can be traced between the nannofossil zones NP9 and NP10 in some sections and in the uppermost part of Zone NP9 in other sections (Faris et al. 1999). The boundary is marked by a lithologic change in some sections (Strougo and Faris 1993) while no lithologic variations were observed in others (Faris 1991). In West Central Sinai, El-Dawoody (1992) placed the P/E boundary at the contact between the Esna and Thebes Formations which corresponds to the *Discoaster multiradiatus/Tribrachiatus contortus* zonal boundary.

The P/E boundary GSSP is located between Subzones NP9a and NP9b in the Dababiya Quarry section (Dupuis et al. 2003). The NP9a/NP9b subzonal boundary is characterized by the LOs of *Discoaster anartios*, *D. araneus* and *Rhomboaster* spp. In the present study, the P/E boundary is located between Subzones NP9a and NP9b at Gebel El Mishiti based on the LOs of *Rhomboaster calcitrapa*, *R. cuspidus*, *R. bitrifida* and *Discoaster araneus* in Sample M75a.

A sedimentological discontinuity between NP9 and NP10a is noted by the presence of intraclasts of calcareous marl of the underlying strata, normally 1-2mm in diameter, forming a few centimeters of intraformational conglomeratic bed. However, this discontinuity can not be detected by the means of calcareous nannofossils. Moreover, the Subzones NP10b and NP10c are absent in Gebel Mishiti section. Therefore, the Zone NP9 is conformably overlain by Subzone NP10a which is uncomfortably overlain by Subzone NP10d. This suggests that Subzones

NP10b and NP10c have been eroded slightly after the beginning of the early Eocene.

Smectite reaches about 91.5% (Table 1) in the uppermost Paleocene and its maximum value (96.3%) is just above the Paleocene/Eocene boundary. It is surprising to find that kaolinite completely disappeared at the beginning of the Eocene and instead smectite reaches its maximum value. Very small peak of kaolinite representing about 0.9% of the total clay fraction occur at about 5 meters above the P/E boundary. This contrasts with the observations by many authors such as Egger et al. (1999) who suggested that an increase of kaolinite input took place near the end of Paleocene as a result of climatic change toward more humid conditions.

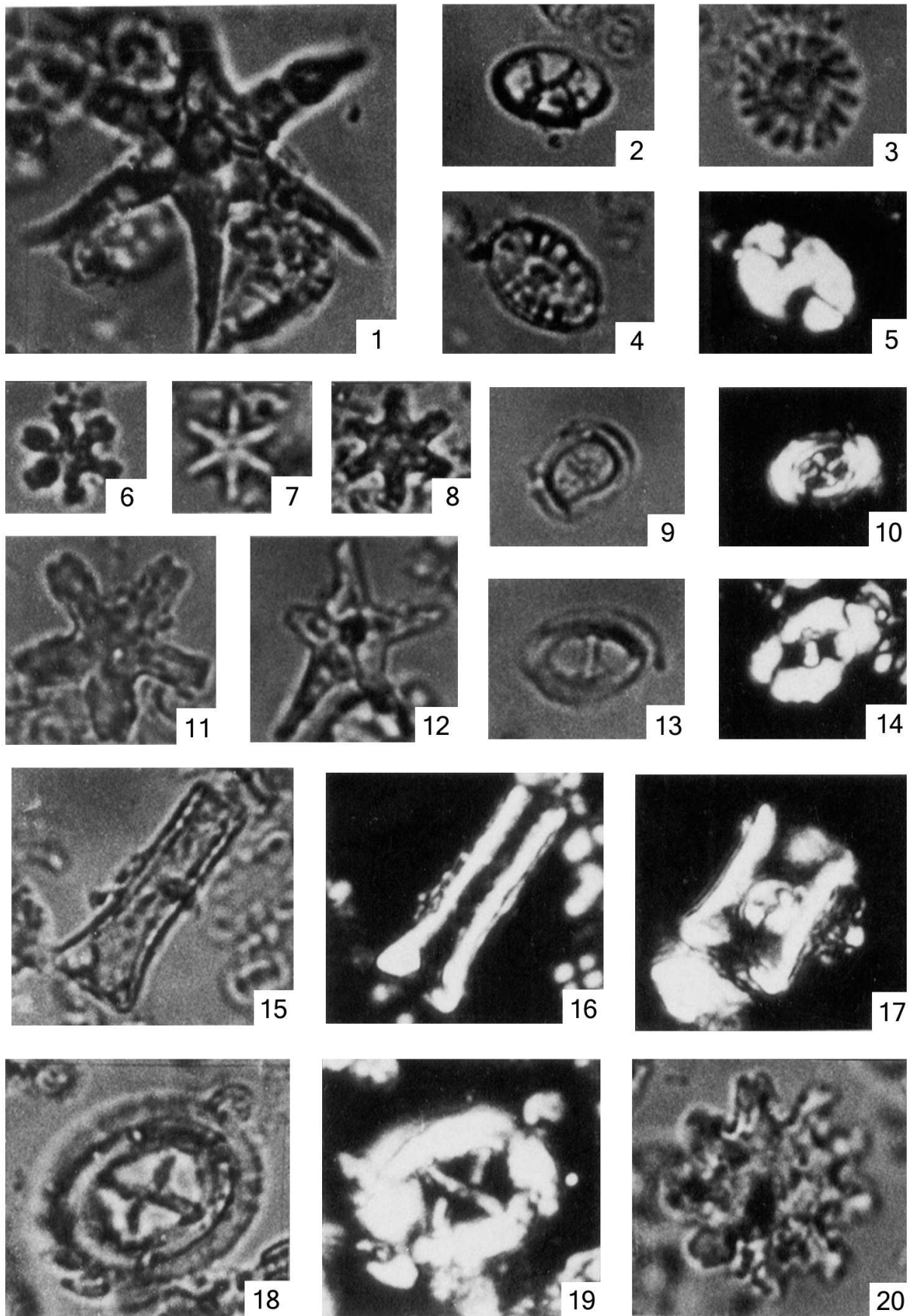
In Gebel El Mishiti section, the CaCO<sub>3</sub> content reach about 95.84% (Table 1) at the top of Zone NP7/8 and decreased to about 54.3% (avg.) through Zone NP9. P<sub>2</sub>O<sub>5</sub> is relatively higher at the P/E boundary (Table 2). An increase of total organic matter around the P/E boundary is detected at Gebel El Mishiti section (Table 1). A strong positive correlation between the organic carbon and phosphorous was recorded through the Esna Formation at this section (Abu Shama 2002). Geological system that enriched by organic carbon are also enriched in their phosphorous content.

The study of some trace elements (Table 2) reveals anomalous values at the P/E boundary in Gebel El Mishiti section. These anomalous values of Cr, Ni and V at this boundary may be due to scavenging of the trace elements at the sea floor over years to prevailing reducing conditions, or to as-yet-unidentified events. The anomalous values of Nb, Y and La in the current study may be associated with one or more phosphate minerals as previously shown in pelagic sediments by Arthur et al. (1989). Abnormal values of Barium are also recorded around the P/E boundary. Schmitz (1987) suggested that barium concentration is high in the sediments of high biological productivity. The high anomalies of Ba, Cr, Ni, V and Rees around the P/E Boundary at Gebel el-Qreiya suggest their incorporation in phosphatic components as well as organic matter (Solimann 2003)

## PLATE 2

All Figures ×2000, from Gebel El Mishiti section, *Discoaster sublodoensis* Zone.)

- |  |  |
|--|--|
| 1 <i>Discoaster lodoensis</i> Bramlette and Reidel 1954. Sample No. 95.              | 9,10 <i>Campylosphaera dela</i> (Bramlette and Sullivan 1961) Hay and Mohler (1967)            |
| 2 <i>Neococcolithus dubius</i> (Deflandre 1954) Black (1967). Sample No. 95.         | 12 <i>Discoaster sublodoensis</i> Bramlette and Sullivan 1961, Sample No. 93.                  |
| 3 <i>Discoaster wemmelensis</i> Achuthan and Stradner 1969. Sample No. 95.           | 13,14 <i>Helicosphaera seminulum</i> Bramlette and Sullivan 1961, Sample No. 95                |
| 4,5 <i>Pontosphaera multipora</i> (Kamptner 1948) Roth (1970). Sample No. 91.        | 15-17 <i>Scyphosphaera</i> sp. Lohmann 1902. 15, 16, Sample No. 91; 17, Sample No. 89.         |
| 6,11 <i>Discoaster distinctus</i> Martini 1958. 6, sample No. 95; 11, Sample No. 94. | 18,19 <i>Chiasmolithus grandis</i> (Bramlette and Riedel 1954) Radomski (1968). Sample No. 95. |
| 7,8 <i>Discoaster germanicus</i> Stradner 1959. 7, Sample No. 94. 8, Sample No. 91.  | 20 <i>Discoaster nonaradiatus</i> Klumpp 1953. Sample No. 92.                                  |



### The lower Eocene/middle Eocene Boundary

The location of lower Eocene/middle Eocene boundary (Ypresian/Lutetian) is correlated with the NP13/NP14 zonal boundary (Martini 1971; Hazel et al. 1984; Perch-Nielsen 1985; Martini and Muller 1986). However, the base of the middle Eocene (Lutetian) is slightly younger (passes within the base NP14) according to some authors (Aubry 1983; Bolli et al. 1985; Berggren et al. 1985, Cavelier and Pomerol 1986). Calcareous nannofossil studies by Steurbaut (1988) and Steurbaut and Nolf (1986) on the Paris and Belgian Basins placed this boundary in the lower part of the NP14.

In Egypt, Strougo and Faris (1993) suggested that the lower Eocene/middle Eocene boundary, if present at Wadi El Dakhl, should lie in the terminal part of the section, at least as high as the NP13/NP14 zonal boundary. In the neritic sequences of the Nile Valley where planktonic species are rare and poorly preserved, Janin et al. (1993) placed this boundary near the Minia/Samalut Formation boundary depending on the abundance variation of 5-rayed discoasters. At Gebel El Mishiti, the NP13/NP14 zonal boundary is located between Sample M88 and Sample 89 (about 17m above the base of Egma Formation). The total thickness of Gebel El Keeh reaches about 95m, and there are no lithologic changes except in the upper 10m; all the section belongs to Zone NP14. Although, the marker species *Discoaster sublodoensis* and other taxa of the younger zones such as *Discoaster bifax* and *D. saipanensis* occur in the uniform Egma Formation, both *Rhabdosphaera inflata* (marker of Subzone NP14b) and *Nannotetrina fulgens* (marker of the Zone NP15) are absent.

Both the Braarudospherids and *Micrantholithus* of the family Braarudosphaeraceae occur in the last sample in Gebel El Mishiti and in most samples of Gebel El Keeh sections. This group is usually common in near-shore and hemi-pelagic deposits (Haq and Lohmann 1976), of the Paleogene where they bloomed repeatedly especially shortly after the Cretaceous/Paleogene (K/P) boundary events and during the middle

Eocene (Bybell and Gartner 1972; Perch Nielsen 1985). This group is known to be a marine hypohaline indicator (Gran and Braarud 1935; Bukry 1974). Martini (1965, 1970) and Bukry (1971) considered that *Braarudosphaera* and *Micrantholithus* are characteristic of near shore deposits and considered as warm water indicators by Bukry (1973a).

In Egypt, *Braarudosphaera discula* was reported from the middle Eocene of Wadi Nukhul (El-Dawoody and Morsi 1983). A high percentage of Braarudosphaeraceae was recorded in the middle Eocene of Wadi Daqer, Nile Valley (Janin et al. 1993). The stratigraphic occurrences and geographic distributions of the Early Paleogene pentolith forms in Egyptian localities were discussed by Faris (1993b). He suggested that the presence of some pentolith taxa may be useful as alternative indicators of stratigraphic age in the absence of conventional index species of the middle and late Eocene. *Braarudosphaera* and *Micrantholithus* are absent in the Maastrichtian and Paleocene of the studied area, but they occur in the lower middle Eocene. This means at least that changes in the environment of deposition from deep shelf in the Maastrichtian to neritic environment took place in the early middle Eocene. This might be due to tectonic uplifting of the sea floor or falling in the sea level at this time.

At Gebel El Mishiti, the warm-water taxa in Subzone NP14a such as *Thoracosphaera operculata*, *Sphenolithus* spp., *Discoaster* spp., *Zygrhablithus bijugatus*, *Pontosphaera* spp., *Ericsonia formosa*, *Braarudosphaera* spp. and *Micrantholithus vesper* dominate over the cool-water taxa (such as *Ericsonia cavaeoplatica*, *Chiasmolithus* spp., *Neococcolithus dubius* and *Blackites* spp.) At Gebel El Keeh, the cool-water taxa dominate the assemblages above Sample K39.

### SUMMARY AND CONCLUSIONS

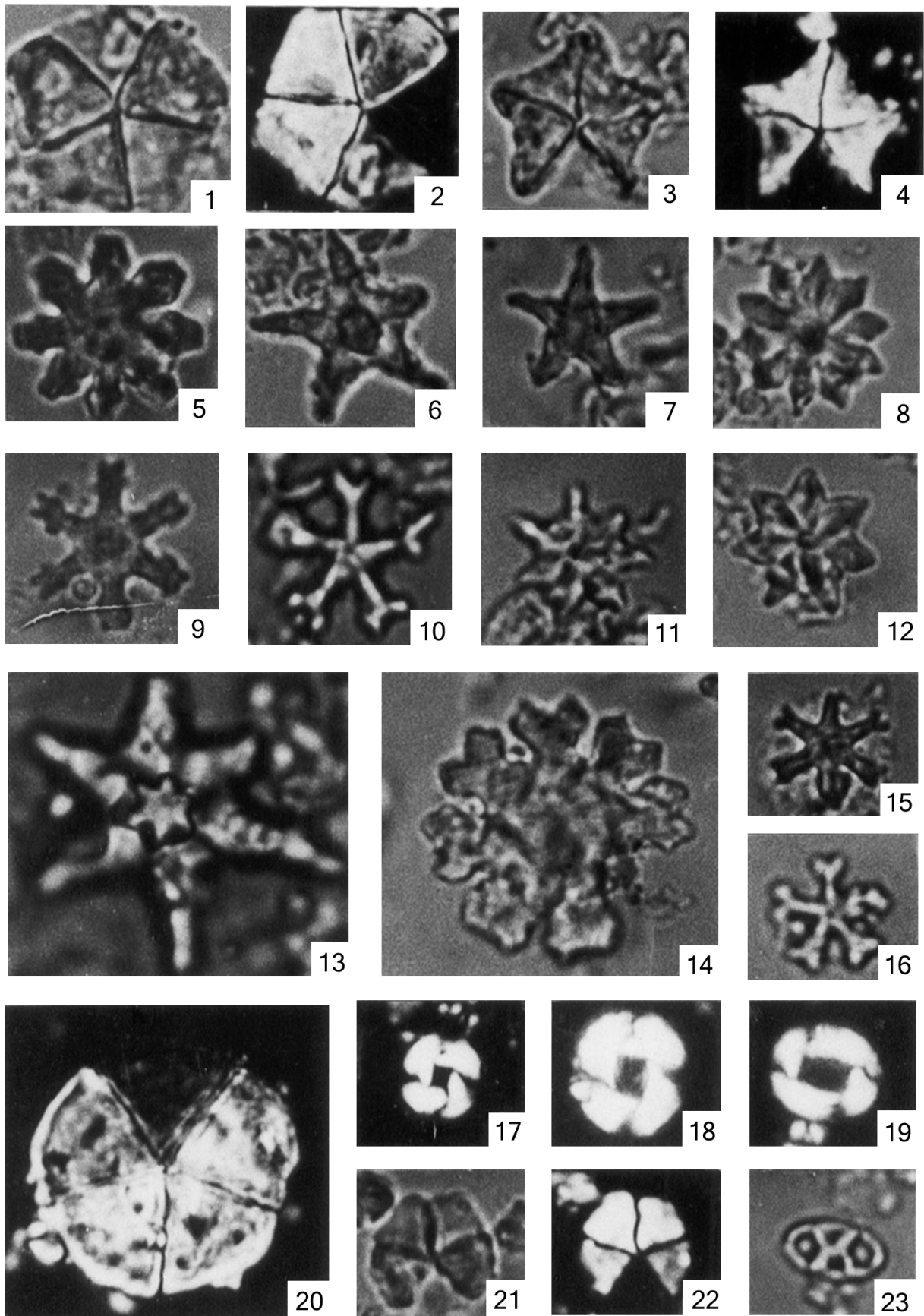
In east central Sinai (Gebel El Mishiti and G. El Keeh sections), the Paleocene-lower Eocene sediments are divided into the following nannofossil biozones; *Markalius invesus* (NP1), *Cruciplacolithus tenuis* (NP2), *Chiasmolithus danicus* (NP3),

### PLATE 3

All figures ×2000, from Gebel El Keeh section, *Discoaster sublodoensis* Zone

- |  |   |
|--|---|
| 1, 2 <i>Braarudosphaera bigelowii</i> (Gran and Braarud 1935) Deflandre 1947. Sample No. 18.         | 13 <i>Discoaster lodoensis</i> Bramlette and Riedel 1954. Sample No. 4.   |
| 3, 4 <i>Micrantholithus vesper</i> Deflandre 1954. Sample No. 23.                                    | 14 <i>Discoaster septemradiatus</i> (Klump 1953) Martini 1958. Sample No. 29.   |
| 5 <i>Discoaster binodosus</i> Martini 1958. Sample No. 1.  | 17, 18 <i>Reticulofenestra dictyoda</i> (Deflandrei in Deflandrei and Fert 1954) Strander in Strander and Edwards 1968; 17, Sample No. 9. 18, sample no.35. |
| 6, 7 <i>Discoaster sublodoensis</i> Bramlette and Sullivan 1961. 6, Sample No.1. 7, Sample No. 38.   | 19 <i>Reticulofenestra samodurovii</i> (Hay, Mohler and Wade 1966) Roth 1970. Sample No. 29.  |
| 8 <i>Discoaster barbadiensis</i> Tan 1927. Sample No. 21.  | 20-22 <i>Braarudosphaera discula</i> Bramlette and Riedel 1954. 20, Sample No. 23; 21-22, Sample No.21.   |
| 9, 15 <i>Discoaster distinctus</i> Martini 1958. 9, Sample No. 29. 15, Sample No. 9.                 | 23 <i>Neococcolithus minutus</i> Perch-Nielsen 1967, Perch-Nielsen 1971. Sample No. 21.   |
| 10, 16 <i>Discoaster martinii</i> Strander 1959. 10, Sample No. 23; 16, Sample No.35.                |   |
| 11, 12 <i>Discoaster saipanensis</i> Bramlette and Riedel 1954. 11, Sample No. 11; 12, Sample No.31. |   |







*Ellipsolithus macellus* (NP4), *Fasciculithus tympaniformis* (NP5), *Heliolithus kleinpellii* (NP6), *Discoaster mohleri* (NP7/8), *Discoaster multiradiatus* (NP9), *Tribrachiatus contortus* (NP10), *Discoaster binodosus* (NP11), *Tribrachiatus orthostylus* (NP12), *Discoaster lodoensis* (NP13) and *Discoaster sublodoensis* (NP14).

At Gebel El Mishiti section, the Danian/Selandian boundary is placed at the base of Zone NP5 delineated by the LO of *Fasciculithus* taxa. The Selandian/Thanetian boundary is tentatively placed at the base of Zone NP7/8 (FO of *Discoaster mohleri*).

Zone NP9 (*Discoaster multiradiatus*) in the present study is subdivided into two subzones (NP9a and NP9b) delineated on the basis of LO of *Rhomboaster calcitrapa*, *R. cuspidis*, *R. bitrifida* and *Discoaster araneus*. The Paleocene/Eocene (P/E) boundary interval at Gebel El Mishiti section is located between these subzones. The disappearance of most *Fasciculithus* taxa occurs in the upper part of Subzone NP9b (Sample M75b). The entry of *Tribrachiatus bramlettei*, *Discoaster binodosus* and *D. diastypus* in Sample M76 indicates the base of Zone NP10. A sedimentological discontinuity between Zone NP9 and Subzone NP10a indicates the presence of intraclasts of calcareous marls of the underlying strata, forming a few centimeters of intraformational conglomeratic bed.

Some mineralogical and geochemical changes are recorded at the P/E boundary in the Gebel El Mishiti section. It is surprising to find that kaolinite completely disappears in the base of the Eocene, and instead smectite reaches a maximum value. Again, a small peak of kaolinite occurs about 5 meters above the P/E boundary. CaCO<sub>3</sub> content decreased through Zone NP9, where P<sub>2</sub>O<sub>5</sub> and organic matter are relatively increased at this boundary in such section. Around this boundary, anomalous values of Cr, Ni, V, Nb, Y, La and Ba are also recorded.

The subdivisions of Zone NP10 into NP10a, b, c, d as suggested by Aubry (1996) are applied in this study. However, at Gebel Mishiti section, the only two subzones NP10a and NP10d are recorded while other subzones NP10b and NP10c are absent. So a minor hiatus is suggested slightly after the beginning of the early Eocene in the uppermost part of the Esna Formation in this section.

Although, the LAD of *Tribrachiatus orthostylus* lines the top of Zone NP12 (*Discoaster lodoensis* Zone), it is recorded here together with *Discoaster sublodoensis* (marker taxon of Zone NP14). Therefore, the top of Zone NP12 located here at the LO of *Towieus crasus*. In the Gebel Mishiti section, the NP13/NP14 zonal boundary is located at about 17m above the base of the Egma Formation. The early Eocene/middle Eocene boundary is tentatively placed at this level and more detailed works are necessary to precisely determine this boundary. Although, the Gebel El Keeh section is represented by about 95m of the Egma Limestone, it belongs to a single nannofossil zone, Zone NP14. Moreover, it is difficult to subdivide this zone into two subzones NP14a and NP14b because both *Rhabdosphaera inflata* (marker of Subzone NP14b) and *Nannotetrina fulgens* (marker taxon of Zone NP15) are absent.

The near shore and hemipelagic Braarudospherids and *Micrantholithus* of the family Braarudosphaeraceae occur in the younger samples of Gebel El Mishiti and in most samples of Gebel El Keeh. These taxa may indicate warm water conditions in the early Middle Eocene.

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