

The Dababiya Quarry Core: Coccolith Biostratigraphy

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ABSTRACT: We establish the coccolith stratigraphy of the Maastrichtian through lower Eocene section recovered from the Dababiya Core taken ~200 m from the GSSP for the Paleocene/Eocene boundary, and correlate coccolith biozones with lithostratigraphic units in the core. The section extends from Maastrichtian Subzone CC25a to lowermost Eocene Subzone NP9c. The composite Paleocene-lower Eocene Dababiya section recovered in the core and accessible in outcrop in the Dababiya Quarry exhibits an unexpected contrast in thickness between the Lower Eocene succession (~Esna Shales) and the Paleocene one (~Dakhla Shales and Tarawan Chalk).

INTRODUCTION

The Dababiya Quarry Core (DBQc) was taken with the expectation that it would provide a detailed sedimentary record of the Paleocene/Eocene Thermal Event (PETM) in the vicinity of the GSSP for the base of the Eocene (Aubry et al. 2007; see Berggren and Ouda, introduction, this volume, Text-fig. 1). It was also considered desirable to obtain a Paleocene section in the Luxor area where the Tarawan Chalk (Dababiya Quarry and Theban Hills Dupuis et al. 2003, 2011) and uppermost Dakhla Shales (Dababiya Quarry; Dupuis et al. 2003) are the oldest Paleocene deposits outcropping in this part of the Nile Valley and over a 150 km long stretch. Paleocene and upper Maastrichtian rocks outcrop further south (~ 70 km) at Gebel Owaina (around Esna), and further north (~ 70 km) at Gebel Qreiya, G. Taramsa, and G. Serai (in the vicinity of Qena) (see below). Compared to a field section, a core would be easier to sample at high resolution, and logging would eventually provide a proxy record of Early Paleogene climatic variability. It would also help correlate the DBH and DBD outcrop sections in the quarry. The 142 m-long DBQc did not fulfill all the objectives set prior to coring, partly because of recovery problems, partly because of the nature of the recovered lithologies. For instance, the location of the drilling site was moved for practical reasons, which prevented coring much of the El Mahmiya Member. Recovery was poor in some critical stratigraphic intervals (such as near the Lower/Middle Paleocene boundary), and preservation of microfossils was poor in others. However the core provided much needed information on the Cretaceous and Paleocene sedimentary record of the Upper Nile Valley as documented in Berggren et al. (2012). In this paper we describe the stratigraphy of the core based on coccolith occurrences, thus providing complementary information to the planktonic foraminiferal stratigraphy (Obaidalla, this volume; Ouda et al., this volume). Our objectives are to 1) provide data towards a comprehensive stratigraphic interpretation of the core and 2) help identify intervals of special interest for forthcoming high-resolution studies.

MATERIAL AND METHODS

Material

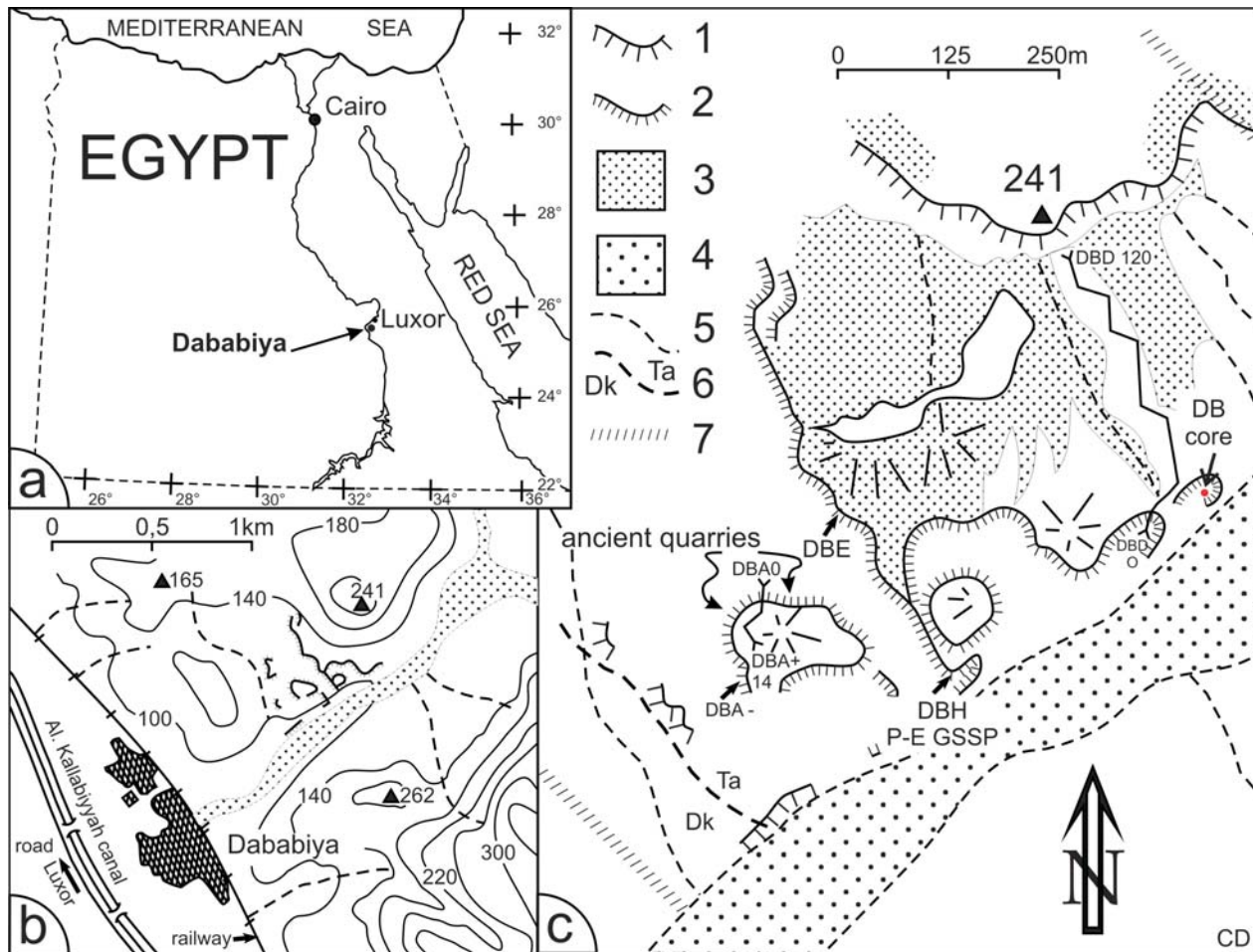
Eighty samples were analyzed initially for a biozonal interpretation of the core. They were taken at intervals of ~1 m in the Paleocene part of the core (between 79 m and 11.9 m), and at higher resolution (3 cm to 20 cm) in the Dababiya Quarry Member. The same samples served for mineralogical analysis (Dupuis, this volume). Thirty additional samples were subsequently analyzed to locate precisely the Cretaceous/Paleogene boundary, determine the age of rocks at the bottom of the core (at 139.8 m) and attempt to secure zonal assignment in the NP1-NP3 zonal interval (between 80.2 m and 72.45 m).

Methods

All samples were carefully cleaned, then broken to extract a chip from their center. Standard smear slides were prepared from the chips, following the method described by Perch-Nielsen (1985a), and studied with a Zeiss Axiophotomicroscope (Rutgers University) at 4 magnifications $\times 600$ and $\times 1250$, using alternatively bright field and cross polarized light. Photographs of the zonal markers were taken for each zone (plates 1-4).

No inventory of the assemblages encountered in the upper part of the core (i. e., above 69.5 m) is presented at this time because further analysis is underway based on a detailed resampling of the core. In contrast, the taxa encountered between 69.5 m and 83.9 m were inventoried and counted. For this, at least one hundred fields of view were examined in bright field and cross-polarized light at $\times 2000$. Coccolithophore species were counted and the relative abundance of species per field of view established. Coccoliths are common with a moderate to poor preservation in most studied core slides.

We have used Martini's zonal scheme (NP zones; 1971) for the Paleogene, and Sissingh's (CC zones; 1977) for the upper Maastrichtian. Following Perch-Nielsen (1979) Zone CC26 (= total range of *Nephrolithus frequens*) was subdivided based on



TEXT-FIGURE 1

Location maps redrawn from the 1/50000 topographic maps Al-Uqsur (Luxor) NG 36 F6a and Isna NG 36 F3c. a, b: location of quarries near Dababiya, east bank of the Nile River; c: detailed map of outcrops and quarries, including antique quarries, and location of partial sections DBA, DBD, DBE and DBH (P-E GSSP). DBA0= reference level for measuring the whole section; this is a flint bed. Subsection DBA is measured as DBA- below DBA0 and DBA+ above DBA0. Dababiya Corehole is adjacent to Section DBD (from Dupuis and Knox, *Lithostratigraphy*, text-figure 1, this volume).

the LO of *Micula prinsii*, and Subzone CC25 (= *Arkangle-skiella cymbiformis* Zone; between the HO of *Reinhardtites levis* and the LO of *N. frequens*) was subdivided into Subzones CC25a 25b and 25c based on the LO of *Lithraphidites quadratus* and the LO of *M. murus*, respectively. The chronostratigraphic boundaries are delineated based on the means of correlation associated with the definition of their GSSPs, including the HOs of *Micula prinsii* and the LO of *B. sparsus* for the base of the Paleocene (Molina et al. 2006), the HO of *F. alanii* and the LO of the *Rhombaster* spp.–*Discoaster araneus* (RD) assemblage at the Paleocene/Eocene boundary (Aubry et al. 2007). The base of the Middle Paleocene (= base Selandian Stage at Zumaia) is marked by the “second radiation of the fasciculiths” itself characterized by the LO of *L. ulii* (Schmitz et al. 2011; see also Monechi et al. 2013). Aubry et al. (2012) have documented a major radiation at Qreiya, marked by the evolutionary appearance and rapid diversification of two genera, *Diantholitha* and *Lithoptychius*, in the vicinity of the Neo-Duwi event, itself possibly correlative with the Danian/Selandian boundary in Spain (Bornemann et al. 2009; Sprong et al. 2011,

2012). The stratigraphic correlations shown by Monechi et al. (2013: fig. 5) differ markedly from this placement, implying that the Danian/ Selandian boundary markedly postdates the Neo-Duwi Event in Egypt, with an interval ~5 m thick between the El-Qreiya Beds and the “second radiation” of the fasciculiths. (Studies by Rodriguez and Aubry [unpublished data] and D. Bord [pers. comm.] do not replicate the findings by Monechi et al. of an interval (between Levels 13 m and 13.5 m) barren of fasciculiths immediately predating the LO of *L. ulii* in the Qreiya section; however, fasciculiths are almost absent in the El-Qreiya Beds (Aubry et al. 2012). In this work we approximate the base of the Selandian using the *Diantholitha-Lithoptychius* sequence. The base of the Upper Paleocene (= base of the Thanetian Stage) cannot be precisely delineated based on coccoliths. Magnetic Chron C26n (whose base defines the base of the Middle/Upper Paleocene boundary) is bracketed by the LOs of *Heliolithus kleinPELLI* and *Helio-discoaster mohleri* (Schmitz et al. 2011). of Gradstein et al. (2012) and Berggren et al. (1995) with its updates in Quillévéré et al. (2002) and Wade et al. (2011).

quency of *Thoracosphaera operculata* and *Braarudosphaera bigelowii*.

Paleogene section (80.4 m to 11.85 m)

A normal zonal succession occurs in the Paleocene part of the Dakhla Shales, that belongs to Zone NP1 through NP6 (Table 1)

Zone NP1, between the HO of *M. prinsii* / LO of *Biantholithus sparsus* and the LO of *Cruciplacolithus tenuis*, is 1 m thick, extending from 80.2 m to 79.2 m. Samples yielded assemblages mainly composed of persistent species (with *Placozygus sigmoides* and abundant *Braarudosphaera bigelowii*), reworked coccoliths (Cretaceous species that have vanished) and the incoming species *B. sparsus*. The LO of *Cruciplacolithus primus* is also in this zone, although the minute specimens of this species have been shown to occur in uppermost Maastrichtian levels (which we could not confirm here; Mai et al. 2003).

Zone NP2, between the LOs of *Cruciplacolithus tenuis* and *Chiasmolithus danicus*, is ~ 1.55 m thick, extending from 79 m to 77.45 m. The composition of the assemblages remains unchanged except for the occurrence of *C. tenuis* and *Ericsonia cava*. We note the LO of *M. inversus* in this zone, although the range of this species is known to extend into the Maastrichtian (e.g., Perch-Nielsen 1985b).

Zone NP3, between the LOs of *C. danicus* and *Ellipsolithus macellus* is ~ 4.60 m thick, between 72.45 to 77.05 m. The qualitative composition of the assemblages is the same as in the underlying zone, with the addition of *C. danicus*. The persistent species *Thoracosphaera operculata*, and *Placozygus sigmoides* are still present in this zone.

The interval between 70.45 m and 33 m belongs to Zone NP4, marked by the LO of *E. macellus* at level 69 m. The LO of *Diantholitha mariposa* at 47.05 m (= the NP4a/b subzonal boundary), those of *D. magnolia* and *Lithoptychius collaris* at 43.15, and *D. alata* and *Lithoptychius* spp. at 41 m is a characteristic sequence in the vicinity of the NeoDuwi event in the upper part of Zone NP4 (Aubry et al. 2012). The radiation of *Lithoptychius* (first radiation of the fasciculiths, Romein 1979) begins between 45.2 m and 43.15 m. The LO of *Sphenolithus primus* was noted at 35 m. The assemblages of Zone NP4 include *C. tenuis*, *C. danicus*, *Ericsonia cava*, *E. ovalis*, *E. subpertusa*, *Neochiastozygus modestus*, *N. perfectus*, *P. sigmoides*, *T. operculata*. Reworked Cretaceous species are few. Broken pentoliths of *B. bigelowii* occur abundantly at level 53 m. There is a sudden drop in the abundance of *E. macellus* between levels 43.15 m and 41 m. In terms of composition of the rock, we note a sudden influx of detrital particles at level 73 m.

The interval between 31 m and 27 m belongs to Zone NP5. *Fasciculithus tympaniformis* is common. The assemblages are of low diversity. Noteworthy is the occurrence of typical specimens of *Lithoptychius jani*, a taxon that has often been mistaken in the literature with other fasciculiths (see discussion in Aubry et al. 2011).

The interval between 25 m and 24 m belongs to Zone NP6. *Heliolithus kleinpellii* is exceedingly rare. The occurrence of *Sphenolithus anarrhopus* at 25 m supports this zonal assign-

ment. Nannofossils are abundant but preservation hampers taxonomic determination.

The assemblage at level 23 m is highly unusual with a remarkable frequency of *Heliolithus megastypus*. The LO of this species is given in Zone NP8 and on this basis this level may tentatively be assigned to NP8. However, no discoaster was encountered at this level, perhaps because of intense dissolution. The zonal age of Level 23 is thus indeterminate.

The interval between 22 m and 11.90 m belongs to Subzone NP9a, characterized by the co-occurrence of *D. multiradiatus* and *Fasciculithus alanii*. Coccoliths are common and preservation is moderate to poor (dissolution) throughout this interval. Diversity is exceptionally low for a tropical setting. The assemblages include *C. tenuis*, *Ellipsolithus macellus*, *Ericsonia subpertusa*, *Fasciculithus lilianae*, *F. tonii*, *F. tympaniformis*, *Heliodiscoaster delicatus*, *H. elegans*, *H. falcatus*, *H. splendidus*, *H. mohleri*, *H. salisburgensis*, *Heliolithus megastypus*, *P. sigmoides*, *S. primus*, *Sullivania consueta*, *Toweius pertusus*, *Zygodiscus plectopons*, *Zygrhablithus kerabyi*.

The interval between 11.56-11.58 and 10.98 m belongs to Subzone NP9b. It contains the so-called *Rhombaster* spp.-*Discoaster araneus* assemblage (or RD) that is correlative with the CIE (Dupuis et al. 2003; Aubry et al. 2007). Dissolution is high between 11.58 and 11.47 m. There is a flood of *Toweius pertusus* and *Rhombaster* spp. at 11.45-11.47 m. Reworking (*F. alanii* in particular) occurs throughout this interval. The RD dwindles in abundance at 10.98 m, indicative of the NP9b/c subzonal boundary between this level and 10.80 m (see above). The LOs of *Pontosphaera minuta*, and *Heliodiscoaster mahmoudii* are noted at 10.34 m and 9.22 m respectively. The extent of Subzone NP9c above 7.70 m is difficult to establish. Coccoliths are exceedingly rare at level 6.73 m and between 5.10 and 2.20 m. A sample at 5.82 m yielded *F. tympaniformis* and *F. aubertae* is also assigned to Subzone NP9c. Levels 1.25 and 0.25 have yielded few, moderately preserved coccoliths without *F. tympaniformis* and *Tribrachiatius bramlettei*. *Heliodiscoaster mahmoudii* occurs at 1.25, but not at 0.25 m, suggesting close proximity to the NP9/NP10 zonal boundary.

DISCUSSION

Lithobiostratigraphic correlations

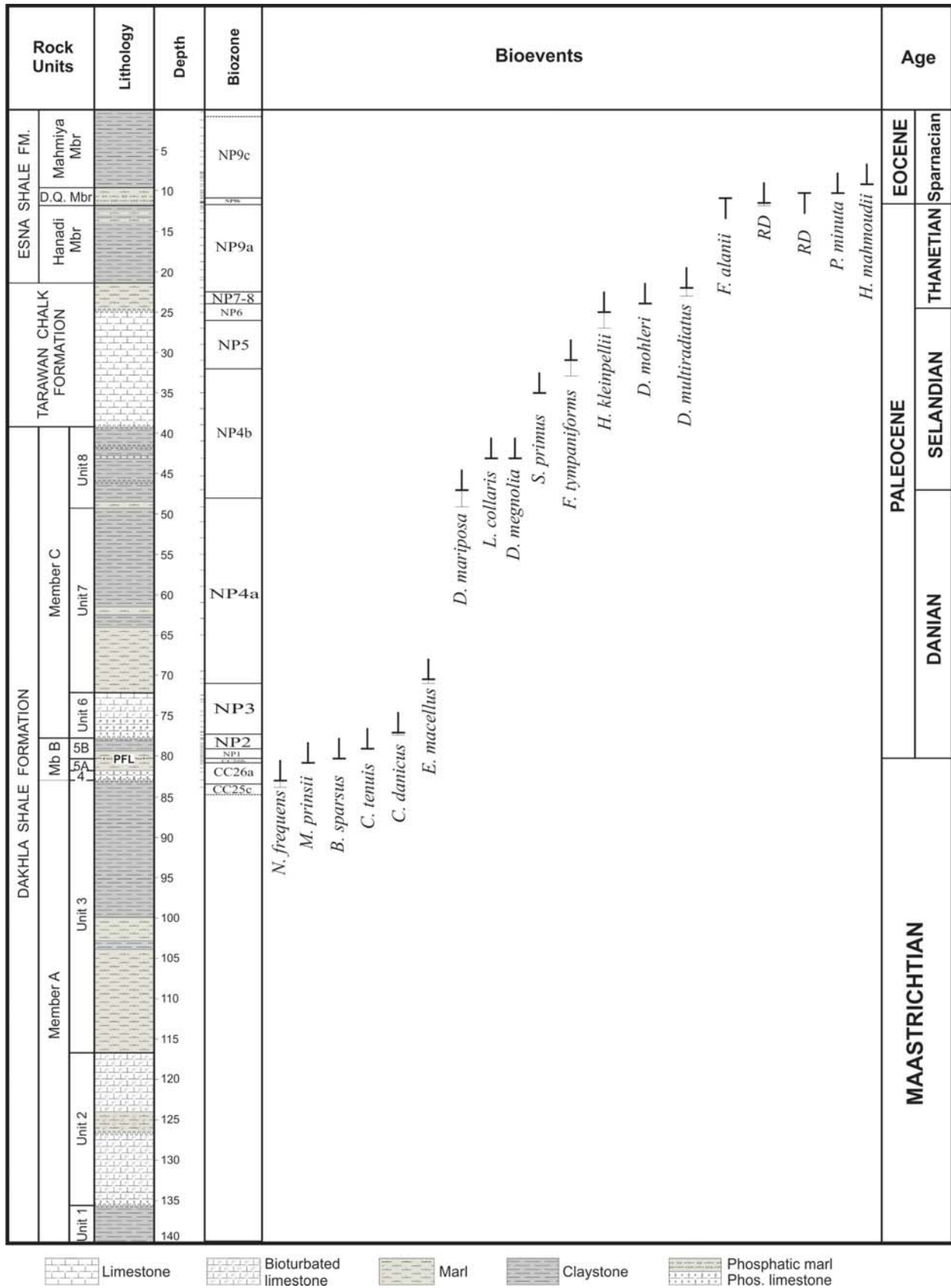
The biozonal ages of the lithologic units recovered in the core (Knox and Dupuis, this volume, Knox, this volume) are as follows (text-fig. 2):

— Members A and B (unit 5A) of the Dakhla Shale (140 m to 80.36 m) belong to the Maastrichtian, extending from at least Zone CC25a to Subzone CC26b. The uppermost Maastrichtian is thus present in the core.

— Member B (unit 5B) and Member C of the Dakhla Shale (80.36 m to 39.20 m) belong to Zone NP1 to Subzone NP4b.

—The Tarawan Chalk (39.20 m to 21.40 m) spans the interval of upper Zone NP4 to Zone NP7. Its contact with the Dakhla Shale at 40 m lies in Subzone NP4b. The interval transitional between the Tarawan Chalk and the Esna Shale (25 to 21.15 m) is extremely difficult to date due to dissolution.

— The Esna Shale (21.40 m to top of the core) belongs to Zone NP9, at least up to ~ 5.50 m; because of dissolution the age of



TEXT-FIGURE 2
Litho-bio-chronostratigraphy of the core. Lithology and lithostratigraphy from Knox, this volume. Tick-marks in biostratigraphic column indicates position of samples studied for biostratigraphic interpretation.

younger levels could not be determined on the basis of sample availability. In the absence of *F. tympaniformis* and *H. mahmoudii* the top of the core probably lies in Zone NP10, very close to the NP9/NP10 zonal boundary.

— As in the Dababiya Quarry and elsewhere in the Nile Valley, the Hanadi Member (21.40 to 11.85 m) belongs to Subzone NP9a, the Dababiya Quarry Member (11.85 to 9.66 m) to Subzone NP9b (upper Bed 2 to lower Bed 4) and NP9c (upper Bed 4 and Bed 5). The lower part of the Mahmiya Member (up to ~ 5.80 m) in the core also belongs to Subzone NP9c.

Chronostratigraphic age

The sedimentary succession recovered between 83.9 m and 0.25 m extends from upper Maastrichtian through lowermost Eocene (text-fig. 2, Table 2). The oldest levels at the bottom of the core (139.8 m) are older than CC25b. The Cretaceous/Paleogene boundary occurs between 80.2 m (Zone NP1) and 80.4 m (CC26b), at the lithological contact (80.3 m) between Units 4C and 5 of the Dakhla Shale (Knox and Dupuis, this volume). Subzone CC26b was recovered and Zone NP1 is 1 m thick, which suggests that the record is *essentially* complete across the Cretaceous/Paleogene boundary. However, the acmes of *Thoracosphaera operculata* and *Braarudosphaera bigelowii* that mark the K/P boundary in some Egyptian sections (e.g., Tantawy 2003) were not encountered in the core. This may indicate a thin stratigraphic gap at the boundary, in agreement with Obaidalla (this volume) who delineates a stratigraphic gap/short hiatus encompassing the upper Maastrichtian *Plummerita hantkeninoides* Zone and the lowermost Danian *Guembelitria cretacea* Zone (= P0).

The Paleocene/Eocene boundary lies at 11.85 m, as defined by the base of Bed 1 of the Dababiya Quarry Member. This corresponds to the NP9a/b subzonal boundary, the upper part of Bed 2 (27 cm above the base of Bed 1) belonging to Subzone NP9b (characterized by the RD assemblage). The lower 27 cm of the Dababiya Quarry Member is barren of coccoliths. This is in agreement with the influx of *Acarinina sibaiyaensis* at 11.56 m (Ouda et al., this volume)

The Lower/Middle Paleocene (Danian/Selandian) boundary is approximately between 43.15 m and 41 m. This is based on a suite of biostratigraphic events that characterizes the first Early Cenozoic radiation of the Order Discoasterales (i.e., the first radiation of the fasciculiths), and is associated with the Qreiya Beds (= Neo-Duwi event of Guasti et al. 2005) in the Qreiya section, ~ 80 km North of Dababiya (see Aubry et al. 2012). The LO of *Diantholitha mariposa* at 47.10 m and that of *L. varolii* between 45.20 and 43.15 m, both of which are located below the Qreiya Beds in Gebel Qreiya, indicate that the chronostratigraphic boundary is above 43.15 m. This is in agreement with a sharp peak in the gamma ray log at 43 m (Senosy and Abdel Sabour, this volume, b).

In general, the Middle/Upper Paleocene (Selandian/Thanetian) boundary is extremely difficult to delineate on the basis of coccoliths because it is bracketed by the LOs of *Heliolithus kleinpelli* and *Heliodiscoaster mohleri*. However, it is easily placed in the core at ~24.5 m.

Completeness of the stratigraphic succession and sedimentation rates

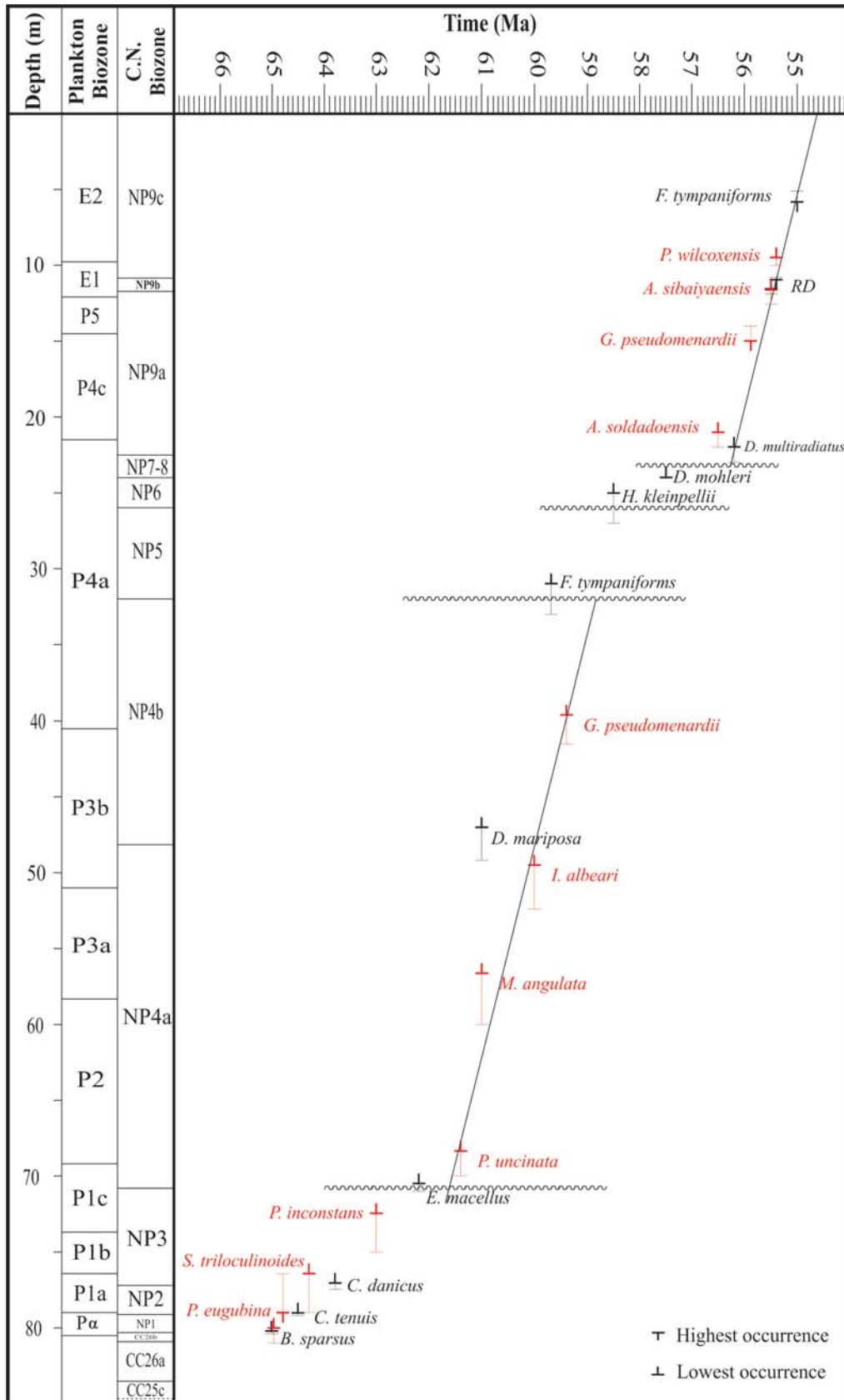
Uneven biozonal representation is a striking feature of the Paleocene-Lower Eocene succession recovered from the

Dababiya core. (Bio)zones NP4 and NP9 are thick, ~38.70 m and >17 m, respectively, whereas the NP1 to NP3 zonal interval is only 10.30 m, and the NP5-?NP8 zonal interval only ~9.5 m (see Table 2). This is significant because the former corresponds to shorter chronozones than the latter (Table 3). If we assume that the core represents a complete Paleocene-Lower Eocene succession, the sedimentation rates during deposition of the Dakhla Shale have varied between 0.37 and 2.29 cm/10³ yr, which is unlikely. There are no sharp changes in the composition of the shales (such as influx of coarse elements) that would explain such variations. More likely, the NP1–NP8 zonal interval includes substantial stratigraphic gaps, particularly in the lower part of Member C of the Dakhla Shales and in the Tarawan Chalk. This is supported by 1) the presence of omission surfaces in the core (in particular between 76.20 m and 73.45 m; Knox et al., this volume), 2) the thinness of Zones NP5 and NP6, and the absence of Zone NP8, and 3) the sedimentation rate curve (text-fig. 3a, b) established on the basis of coccolith and planktonic foraminiferal datum (Obaidalla, this volume; Ouda et al., this volume; Tables 4a, b).

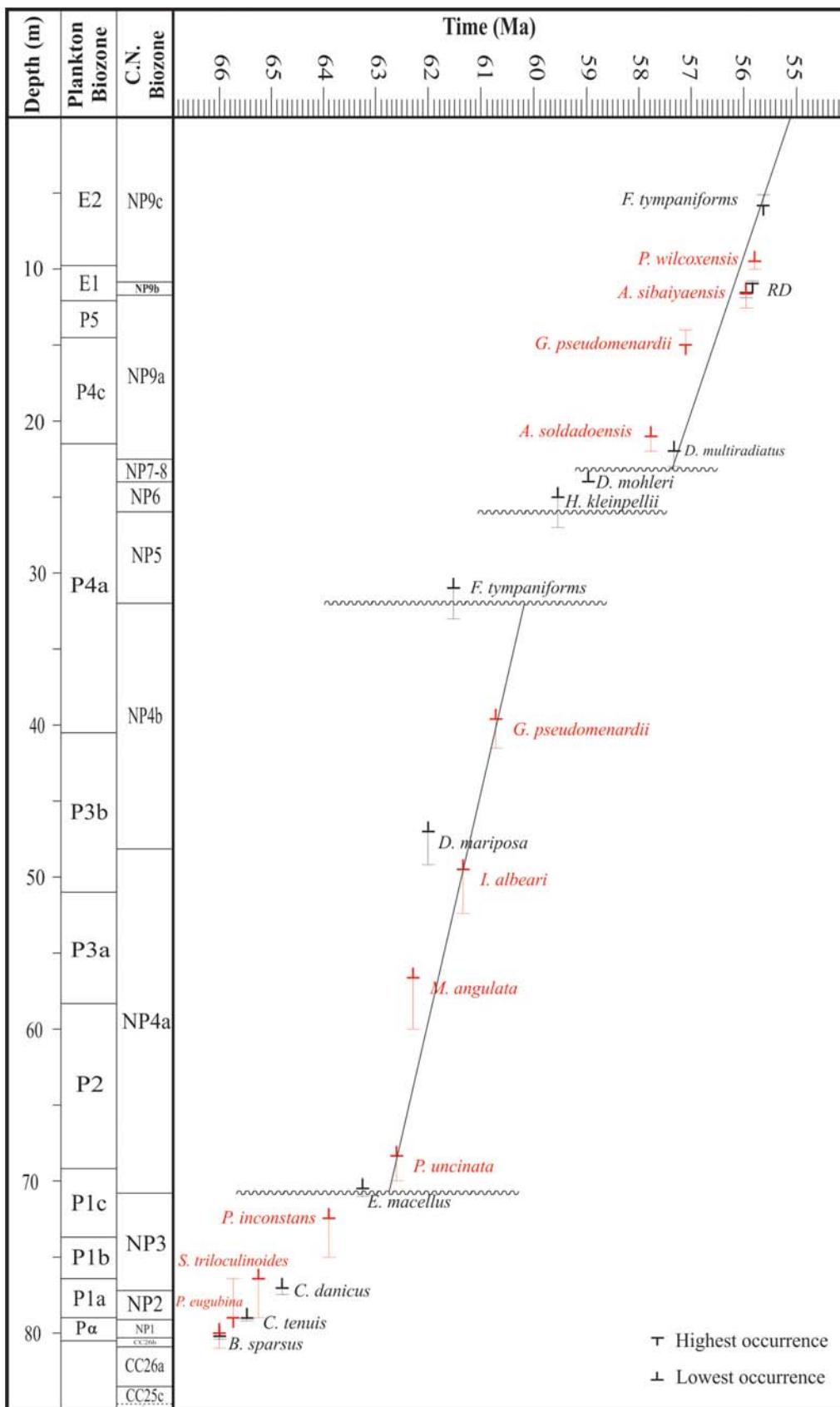
Another striking feature at Dababiya is the difference in thickness between the combined Paleocene part of the Dakhla Shale (Member C) and the Tarawan Chalk on the one hand (as recovered in the core), and the Esna Shale on the other hand. The Esna Shale in nearby outcrops is 120 to 130 m thick, depending on the calculated overlap between subsections DBH and DBD (Dupuis et al. 2003). Bracketed between the FAD of *D. multiradiatus* (57.32 Ma) recorded at the Tarawan/Esna formational contact, and the FAD of *D. lodoensis* (53.70 Ma) recorded 4.65 m above the Esna/Thebes contact (Aubry, pers. obs.), the Esna shale represents <3.5 Myr. In contrast, the cumulative thickness of Member C of the Dakhla Shale and the Tarawan Chalk is 59 m, corresponding to ~8.7 Myr. In other words, the Esna Shale would have been deposited, apparently, five times faster than the underlying deposits. This is indicative of a Late Paleocene change in sedimentary regime. During the first ~8.6 Myr of the Paleocene, sedimentation rates may have been low and substantial stratigraphic gaps formed. Then (in the latest Paleocene equivalent to early Magnetic Chron C24r) a new sedimentary regime was established manifested by high sedimentation rates and essentially continuous deposition including during the PETM. As the benthic foraminiferal assemblages show that outer neritic to upper bathyal conditions persisted throughout the deposition of the Esna Shale (W. A. Berggren, pers. comm., August 2012), increased subsidence would have been necessary to accommodate abundant sediment supply during Chron C24r in the Dababiya area. It is possible that the sudden increase in sedimentation rates was a local effect, but it is equally possible that it represents a regional feature related to shelf evolution. We attempt to resolve this question in a companion paper (Aubry and Salem, this volume, b) in which we compare the thicknesses of the stratigraphic interval encompassing the Paleocene part of the Dakhla Shale and the Tarawan Chalk (NP1 through NP8) with that of the Esna Shale (NP9–NP11) in different regions of Egypt.

CONCLUSIONS

We have established the calcareous nannofossil stratigraphy of the Dababiya Quarry Core between upper Maastrichtian Subzone CC25c and lowermost Eocene Subzone NP9c, delineated or approximated the Paleocene chronostratigraphic boundaries and determined the biozonal extent of the lithostratigraphic units in the core. The sedimentary record appears



TEXT-FIGURE 3a
 Sedimentation rate curve for the Paleocene-Lower interval, Dababiya Core. Stratigraphic datum levels and ages of datum events are given. Biochronology from Berggren et al. (1995)



TEXT-FIGURE 3b
Sedimentation rate curve for the Paleocene-Lower interval, Dababiya Core. Stratigraphic datum levels and ages of datum events are given. Biochronology from Gradstein et al. (2012).

TABLE 2

Location of Datum events, biostratigraphic, lithostratigraphic and chronostratigraphic boundaries in the Dababiya Quarry Core.

Datum	Zone/ Subzone	> level (m)	<level (m)	Fm/Mbr.	Series	Stages
HO <i>D. mahmoudii</i>	?	1.25	0.25			
HO <i>F. tympaniformis</i>	Top NP9c	25.82	5.10			
LO <i>D. mahmoudii</i>	Base NP9c	9.48	9.22	Mahmiya Mbr		
LO <i>P. minuta</i>	Base NP9c	10.60	10.34			
HO RD	Top NP9b	10.98	10.80	DQM Bed 4		
LO RD	Base NP9b	11.90	11.50–11.58	DQM Bed 2	L. Eocene	Sparnacian
HO <i>F. alanii</i>	Top NP9a	11.90	11.50–11.58	Hanadi Mbr.	U. Paleocene	Thanetian
LO <i>D. multiradiatus</i>	Base NP9a	23	22	Tarawan Chalk		
LO <i>D. mohleri</i>	NP7	24	24			
LO <i>S. anarrhopus</i>		27	25			
LO <i>H. kleimpelli</i>	NP6	27	25			Thanetian
LO <i>F. tympaniformis</i>	NP5	33	31			Selandian
LO <i>S. primus</i>		37	35	Tarawan Chalk		Selandian
LO <i>L. varolii</i>		45.3	43.15	Dakhla Shale		Danian
LO <i>D. mariposa</i>	NP4b	49.2	47.05			
LO <i>E. macellus</i>	NP4a	71.0	70.45			
LO <i>C. danicus</i>	NP3	77.45	77.05			
LO <i>C. tenuis</i>	NP2	79.2	79.0			
LO <i>B. sparsus</i>	NP1	80.4	80.2		L. Paleocene	Danian
HO <i>M. prinsii</i>	CC26b	80.4	80.2		U. Cretaceous	Maastrichtian
LO <i>M. prinsii</i>	CC26b	81	80.8			
LO <i>N. frequens</i>	CC26a	83.9	83			
LO <i>M. murus</i>	CC25c	—	83.9	Dakhla Shale		Maastrichtian?

to be almost complete across the K/P boundary. The biostratigraphic succession (bioevents) in the Danian/Selandian boundary interval would seem to be directly comparable with that described at Qreiya and deserves future attention. The Tarawan Chalk proved to be very difficult to date by coccoliths, and appears to be highly discontinuous in the core. It is one of the least well documented sedimentary interval of the Egyptian Paleogene (e.g., Perch-Nielsen et al. [1978] also noted the difficulty in delineating biozones in the Chalk). The record of the PETM is directly comparable with that in the nearby GSSP outcrop section, although less expanded (see Berggren et al., this volume, for discussion). Importantly, this study has revealed a marked contrast between the thickness of the Lower Eocene succession as exposed in outcrops in the vicinity of the core, and the comparative thinness of the cored Paleocene succession. The contrast is further explored in a companion paper in this volume.

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TABLE 3
Comparison between thicknesses of selected zonal intervals in the Dababiya Core.

Zonal interval	Thickness (m)	Duration (Myr)	Sedimentation rates (cm/10 ³ yr)
NP9	>17	1.68	1.01
NP5-NP8	~9.5	4.09	0.23
NP4	38.70	1.74	2.29
NP1-NP3	10.30	2.75	0.37
CC25c-CC26b	3.6	3	1.2

TABLE 4
Location of Datum levels in the Dababiya Quarry Core, and ages of corresponding Datum events.
4a: coccolith events according to (1) Berggren et al. (1995) and Quillévéré et al. (2002), and (2): Gradstein et al. (2012).

Datum	Zone/Subzone	> Level (m)	<Level (m)	Ages (Ma) (1)	Ages (Ma) (2)
HO <i>F. tympaniformis</i>	NP9c	75.82	5.10	55	55.64
HO RD	NP9b	10.98	10.80	55.4	55.86
LO RD	NP9b	11.90	11.50–11.58	55.5	55.96
LO <i>D. multiradiatus</i>	NP9a	23	22	56.2	57.32
LO <i>D. mohleri</i>	NP7	24	24	57.5	58.97
LO <i>H. kleinPELLI</i>	NP6	27	25	58.5	59.54
LO <i>F. tympaniformis</i>	NP5	33	31	59.7	61.51
LO <i>D. mariposa</i>	NP4b	49.2	47.05	~61	~62
LO <i>E. macellus</i>	NP4a	71.0	70.45	62.2	63.25
LO <i>C. danicus</i>	NP3	77.45	77.05	63.8	64.81
LO <i>C. tenuis</i>	NP2	79.2	79.0	64.5	65.47
LO <i>B. sparsus</i>	NP1	80.4	80.2	65	66
HO <i>M. prinsii</i>	CC26b	80.4	80.2		66
LO <i>M. prinsii</i>	CC26b	81	80.8		67.30
LO <i>N. frequens</i>	CC26a	83.9	83		67.84
LO <i>M. murus</i>	CC25c	—	83.9		69.00

4b: Foraminiferal events according to (1) Berggren et al. (1995) and Wade et al. (2011), and (2): Gradstein et al. (2012).

Datum	Zone/Subzone	> level (m)	<level (m)	Ages (Ma) (1)	Ages (Ma) (2)
LO <i>P. wilcoxensis</i>	E2	10	9.5	55.4	55.81
LO <i>A. sibaiyaensis</i>	E1	12.6	11.6	55.5	55.96
HO <i>G. pseudomenardii</i>	P5	15	14	55.9	57.10
LO <i>A. soldadoensis</i>	P4c	22	21	56.5	57.79
LO <i>G. pseudomenardii</i>	P4a	41.5	39.6	59.4	60.73
HO <i>P. carinata</i>	upper P3b	44.45	41.45		
LO <i>I. albeeri</i>	lower P3b	52.4	49.45	60	61.33
LO <i>M. angulata</i>	P3a	60	56.6	61	62.29
LO <i>P. uncinata</i>	P2	70	68.35	61.4	62.60
LO <i>P. inconstans</i>	P1c	75	72.4	63	63.90
LO <i>S. triloculinoides</i>	P1b	79	76.4	64.3	65.25
HO <i>P. eugubina</i>	P1a	79	76.4	64.8	65.72
LO <i>P. eugubina</i>	P α	81	80	64.97	66

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PLATE 1

Scale bar is 5 μm for all figures (all plates).

Figs. 3, 5, 7, 9, 17, 20: Bright Field. All other figures: Crossed Nicols.

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| 1-2 <i>Micula murus</i> (Martini); 1, Sample DBC 83.98-84, <i>M. murus</i> Subzone; 2, Sample DBC 80.8-80.82, <i>M. prinsii</i> Subzone. | 13-15 <i>Micula decussata</i> Vekshina; 13, Sample DBC 83.0-83.02, <i>N. frequens</i> Zone; 14-15, Sample DBC 77.85-77.9, Zone NP2. |
| 3-4 <i>Lithraphidites quadratus</i> Bramlette and Martini; Sample DBC 83.98-84, <i>M. murus</i> Subzone. | 16 <i>Microrhabdulus decoratus</i> Deflandre; Sample DBC 83.98-84, <i>M. murus</i> Subzone. |
| 5-8 <i>Arkhangelskiella cymbiformis</i> Vekshina; 5-6, Sample DBC 139.9-139.92, <i>R. levis?</i> Zone; 7-8, Sample DBC 82.0-82.02, <i>N. frequens</i> Zone. | 17-19 <i>Eiffellithus turriseiffelii</i> (Deflandre) 17-18, Sample DBC 77.05-77.15, Zone NP3; 19, Sample DBC 81.5-81.52, <i>N. frequens</i> Zone. |
| 9-10 <i>Chiastozygus amphipons</i> (Bramlette and Martini); Sample DBC 80.8-80.82, <i>M. prinsii</i> Subzone. | 20,24 <i>Tetrapodorhabdus decorus</i> (Deflandre); Sample DBC 83.98-84, <i>M. murus</i> Subzone. |
| 11 <i>Prediscosphaera grandis</i> Perch-Nielsen; Sample DBC 139.9-139.92, <i>R. levis?</i> Zone. | 21-23 <i>Watznaueria barnesae</i> (Black); 21, Sample DBC 82.0-82.02, <i>N. frequens</i> Zone, CN; 22-23, Sample DBC 139.9-139.92, <i>R. levis?</i> Zone, CN. |
| 12 <i>Prediscosphaera cretacea</i> (Arkhangelsky); Sample DBC 83.98-84, <i>M. murus</i> Subzone. | |

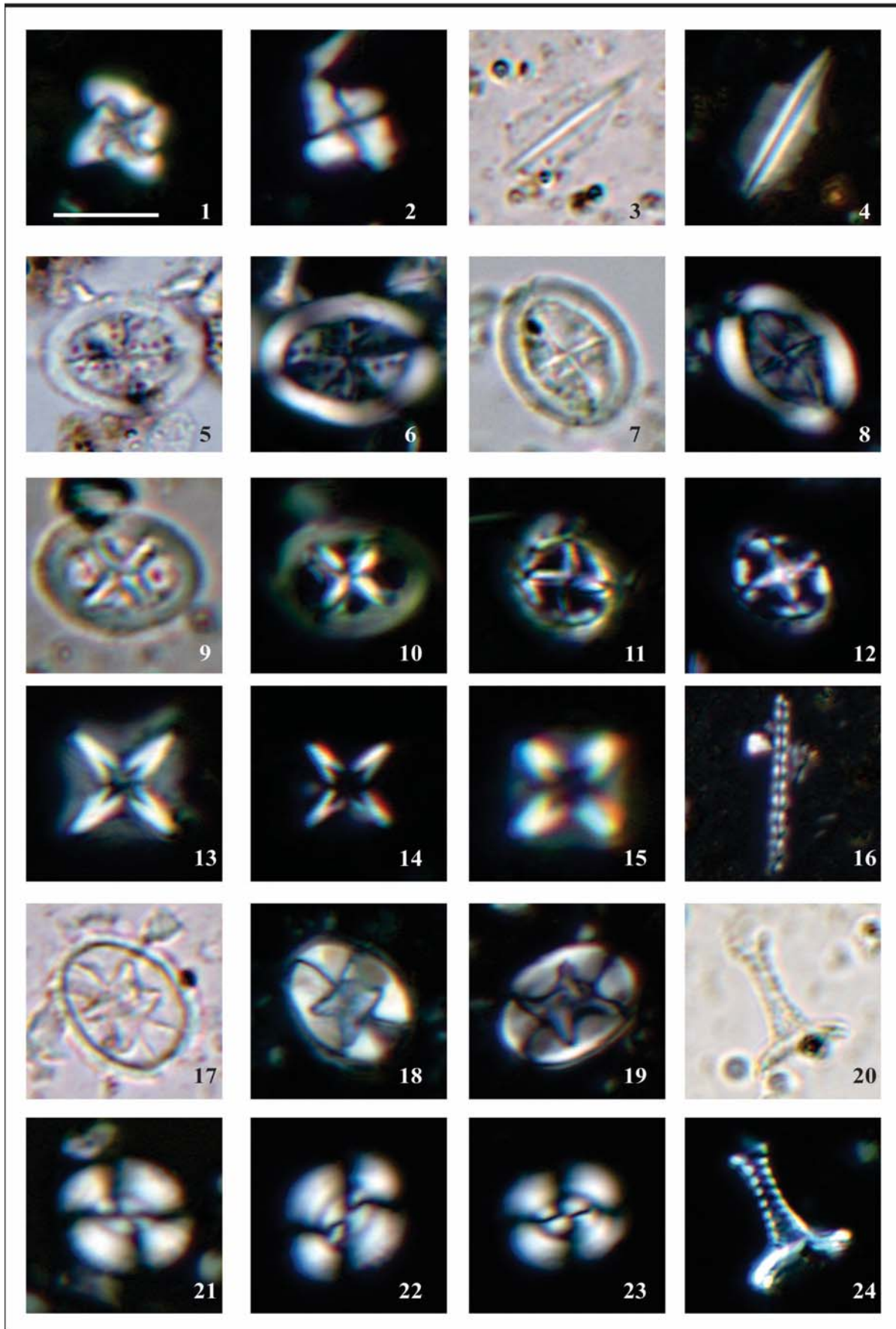


PLATE 2

Figures 17, 19, 22: Bright Field. All other figures: Crossed Nicols.

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| 1-8 <i>Cruciplacolithus tenuis</i> (Stradner); 1-2, Sample DBC 76.4-76.5, Zone NP3; 3-4, Sample DBC 69.5-69.6, Zone NP4; 5-6, Sample DBC 77.85-77.9, Zone NP2; 7-8, Sample DBC 73.3-73.4, Zone NP3. | 15-16 <i>Micula prinsii</i> Perch Nielsen; Sample DBC 80.4-80.42, <i>M. prinsii</i> Subzone. |
| 9-10 <i>Cruciplacolithus primus</i> Perch-Nielsen; Sample DBC 77.85-77.9, Zone NP2, CN. | 17-18 <i>Nephrolithus frequens</i> Gorka; Sample DBC 77.85-77.9, Zone NP2. |
| 11-12 <i>Obliquipithonella saxea</i> Stradner; 11, Sample DBC 69.5-69.6, Zone NP4; 12, Sample DBC 80.8-80.82, <i>M. prinsii</i> Subzone. | 19-20 <i>Ceratolithoides aculeus</i> (Stradner); Sample DBC 77.85-77.9, Zone NP2. |
| 13-14 <i>Biantholithus sparsus</i> Bramlette and Martini; Sample DBC 80.2-80.22, Zone NP1. | 21 <i>Obliquipithonella operculata</i> (Bramlette and Martini); Sample DBC 70.45-70.55, Zone NP4. |
| | 22-24 <i>Braarudosphaera bigelowii</i> (Gran and Braarud); 22-23, Sample DBC 53, Zone NP4; 24, Sample DBC 79.2-79.22, Zone NP1. |

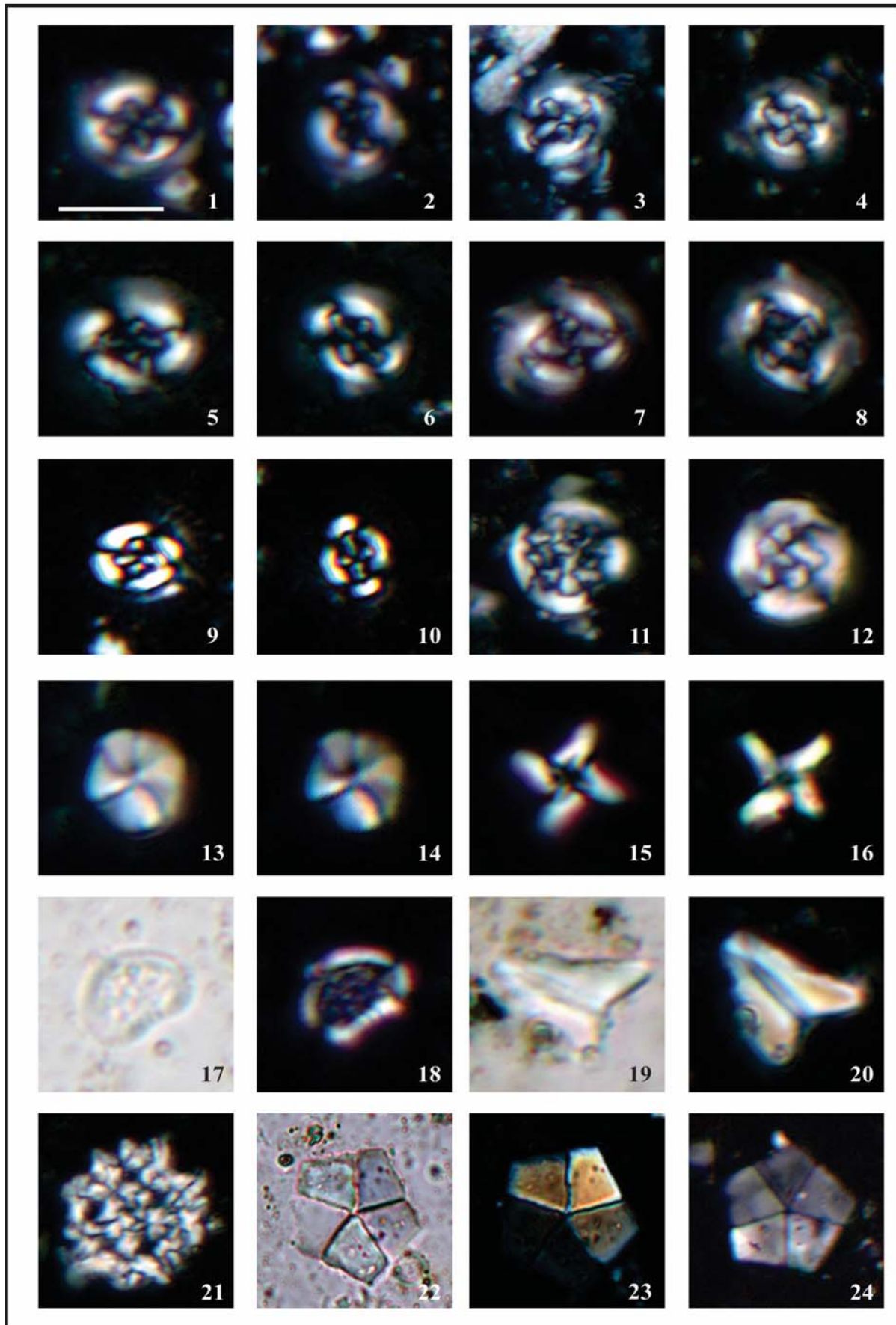


PLATE 3

Figures 1, 3, 5, 7, 13. 15: Bright Field. All other figures: Crossed Nicols

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|-------|-----------------------------------------------------------------------------------------------------------------------------|-------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1–6 | <i>Diantholitha mariposa</i> Rodriguez and Aubry; 1–2, Sample DBC 43.15, Subzone NP4b; 3–6: Sample DBC 47.05, Subzone NP4b. | 15–16 | <i>Ericsonia subpertusa</i> Hay and Mohler; Sample DBC 69.5–69.6, Zone NP4a. |
| 7–8 | Indeterminate taxon of the Order Discoasterales; Sample DBC 53, Subzone NP4a. | 17–21 | <i>Chiasmolithus danicus</i> (Brotzen); 17–18, Sample DBC 72.45–72.55, Zone NP3; 19–20, Sample DBC 76.4–76.5, Zone NP3; 21, Sample DBC 74.45–74.55, Zone NP3. |
| 9–10 | <i>Neochiastozygus perfectus</i> Perch-Nielsen; Sample DBC 69.5–69.6, Subzone NP4a. | 22–24 | <i>Chiasmolithus edwardsii</i> (Romein); 22, Sample DBC 77.85–77.9, Zone NP2; 23, Sample DBC 74.45–74.55, Zone NP3; 24, Sample DBC 75.45–75.55, Zone NP3. |
| 11–12 | <i>Ellipsolithus macellus</i> (Bramlette and Sullivan); Sample DBC 70.45–70.55, Subzone NP4a. | | |
| 13–14 | <i>Neochiastozygus modestus</i> Perch-Nielsen; Sample DBC 69.5–69.6, Subzone NP4a. | | |

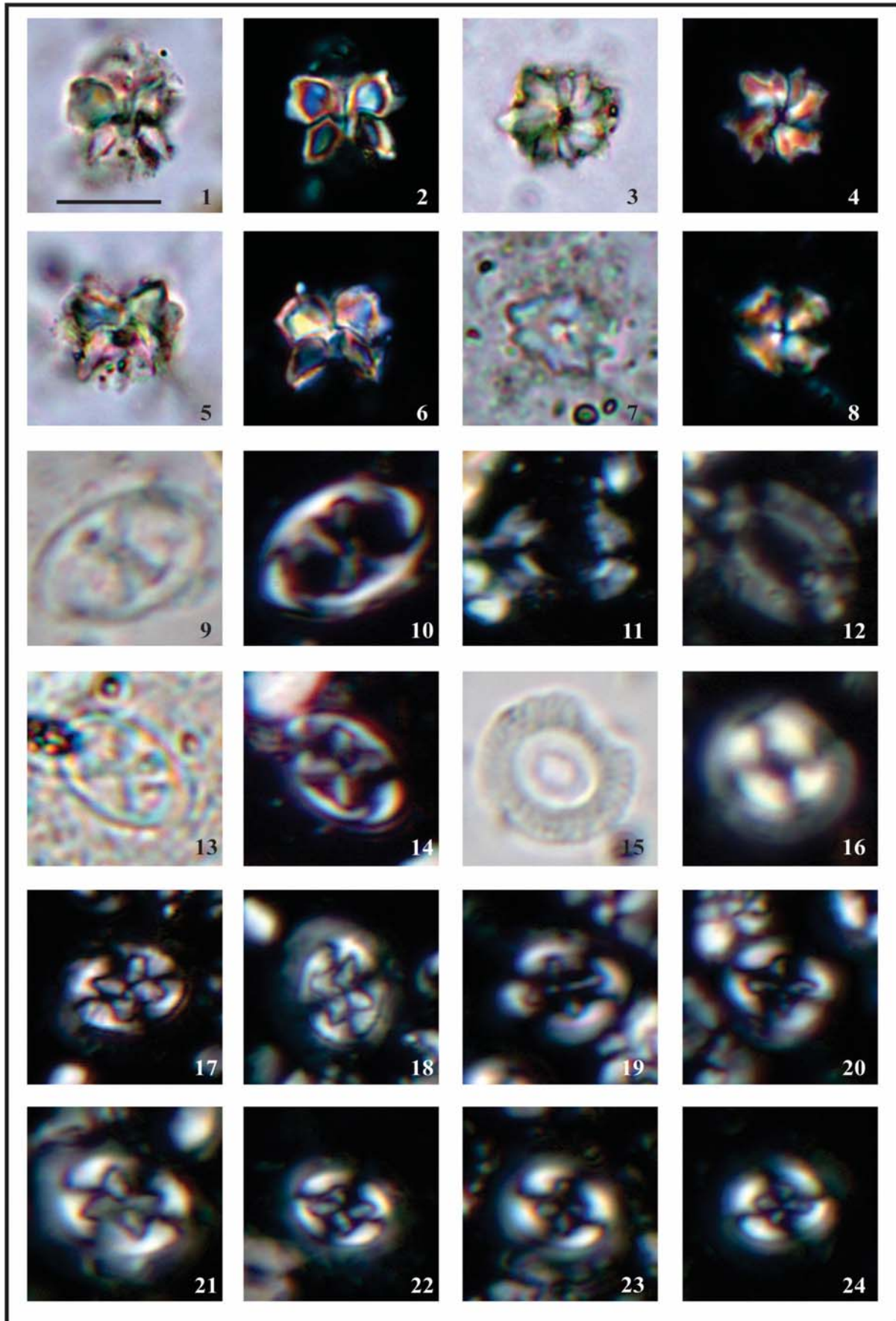


PLATE 4

Figures 1–6, 8, 9, 11, 13, 17, 18, 21, 23: Bright Field. All other figures: Crossed Nicols.

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| 1–2 <i>Discoaster mahmoudii</i> Perch-Nielsen; Sample DBC 1.25, Subzone NP9c. | 11–12 <i>Heliolithus kleinpellii</i> Sullivan; Sample DBC 25, Zone NP6. |
| 3–4 <i>Rhombaster</i> sp.; Sample DBC 11.56, Subzone NP9b. | 13–14 <i>Lithoptychius janii</i> Perch-Nielsen; Sample DBC 27, Zone NP5. |
| 5–6 <i>Discoaster multiradiatus</i> Bramlette and Reidel; 5, Sample DBC 11.9, Subzone NP9a; 6, Sample DBC 20.7, Subzone NP9a. | 15–16 <i>Fasciculithus tympaniformis</i> Hay and Mohler; Sample DBC 31, Zone NP5. |
| 7 <i>Fasciculithus alanii</i> Perch-Nielsen; Sample DBC 11.9, Subzone NP9a. | 17–20 <i>Biantholithus astralis</i> Steinmetz and Stradner; Sample DBC 31, Zone NP5. |
| 8 <i>Discoaster mohleri</i> Bukry and Percival; Sample DBC 23, Zone NP7? | 21–22 <i>Diantholitha alata</i> Aubry and Rodriguez; Sample DBC 43.15, Subzone NP4b. |
| 9–10 <i>Discoaster megastypus</i> (Bramlette and Sullivan); Sample DBC 23, Zone NP7? | 23–24 <i>Diantholitha magnolia</i> Aubry and Rodriguez; Sample DBC 43.15, Subzone NP4b. |

