The Dababiya Core: A window into Paleocene to Early Eocene depositional history in Egypt based on coccolith stratigraphy

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ABSTRACT: The composite Paleocene-lower Eocene Dababiya section recovered in the Dababiya Quarry 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). We investigate the significance of this contrast by reviewing calcareous nannofossil stratigraphic studies performed on sections throughout Egypt. We show that a regional pattern occurs, and distinguish six areas—Nile Valley, Eastern Desert and western Sinai, Central and eastern Sinai, northern Egypt and Western Desert. Based on patterns related to thicknesses of selected lithobiostratigraphic intervals and distribution of main stratigraphic gaps, we propose that the differences in the stratigraphic architecture between these regions result from differential latest Paleocene and Early Eocene subsidence following intense Middle to Late Paleocene tectonic activity in the Syrian Arc folds as a result of the closure of the Neo-Tethys.

INTRODUCTION

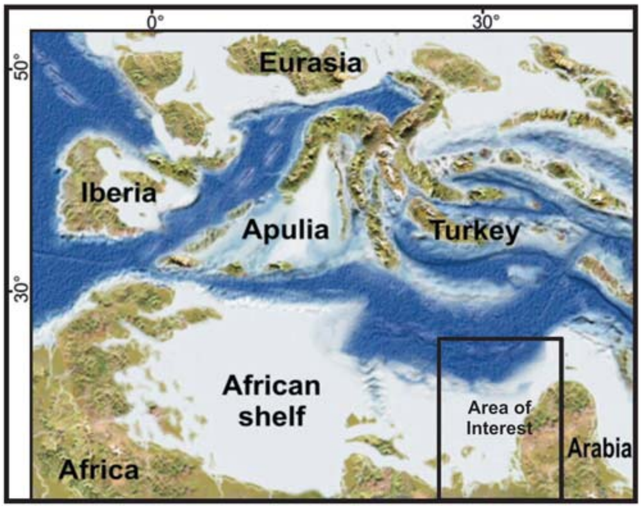
During the Late Cretaceous and Early Paleogene Egypt was part of a vast epicontinental shelf at the edge of the southern Tethys (text-fig. 1). Bounded by the Arabian-Nubian craton to the south, the southern part of the shelf was essentially stable whereas north of ~ Latitude 28° N an unstable shelf was affected by tectonic activity related to the Syrian Arc (text-fig. 2; Said 1962; Höntzsch et al. 2011). The Egyptian shelf functioned alternatively as a carbonate platform and a siliciclastic system, resulting in the stratigraphic succession of limestones and shales forming lithostratigraphic units of broad lateral extension, such as the Dakhla Shale, Tarawan Chalk, Esna Shale and Thebes Limestone. These extensive units have proven of great interest for sea level history (e.g., Höntzsch et al. 2011; Luning et al. 1998b; Speijer 1994; Speijer and Schmitz 1998; Speijer and Wagner 2002), the documentation of global climatic events (e.g., Soliman et al. 2011; Bornemann et al. 2009; Schulte et al. 2011; Sprong et al. 2012) as well as for exploratory chronostratigraphic research (e.g. definition of the Paleocene/Eocene boundary: Dupuis et al. 2003, Aubry et al. 2007; definition of the Danian/Selandian Boundary: Sprong et al. 2009, Aubry et al. 2012).

The Dababiya Quarry Core (DBQc) provided significant insights into the geological history of Upper Egypt as discussed in contributions in this volume. An unanticipated discovery was the striking contrast between the thinness (~70 m) of the Paleocene section in the core (which spans ~10 Myr) and the thickness (>160 m) of the lower Eocene section (which spans ~3.5 Myr) that outcrops above it in the Dababiya Quarry (see Aubry and Salem a, this volume). To document this contrast better we have conducted a survey of the literature on Maastrichtian through Lower Eocene sections throughout Egypt. We report here on our findings based on the first overview of coccolithophore studies in Egypt since their inception (1968). Coccolith-bearing sedimentary rocks as old as Cenomanian outcrop in central Sinai (Thamed area; Bauer et al. 2001; Faris and Abu Shama 2003). The youngest, as young as Late Pliocene, have been recovered from wells in the Cairo District and Fayum Oasis (Faris et al. 2007b; Zalat 1995). Marine deposits in the intervening interval are known in outcrops and/or cores and their coccolith contents have been described, but no stratigraphic interval is better represented in Egypt than Maastrichtian through Lower Eocene. This interval forms the plateaus of the Eastern and Western Desert and much of the relief of the Sinai. It extends East–West from eastern Sinai to West of Farafra and North–South from Minia to the southern part of the Nile Valley of Upper Egypt (Hermina 1990; Said 1990; Ouda and Aubry, [eds.], 2003). This interval is also developed, at least in part, in neighboring countries (e.g., Moshkovitz 1967; Romein 1979; Haq and Aubry 1981; El Dawoody 1994; Sagular and Görmüs 2006; Hawi 2000; Müller et al. 2010), but more micropaleontological investigations have been conducted on Egyptian Upper Cretaceous and lower Paleogene sedimentary successions than on any other coeval successions in the Middle East, placing Egyptian stratigraphy at the center of geohistorical research on the Arabian Platform and the Syrian Arc (e.g., Kuss 1989). We thus provide a framework of biostratigraphic events to serve as a reference for chronostratigraphic determination, and, importantly, for assessing the completeness of stratigraphic sections in the Middle East.

MATERIAL AND METHODS

Database

We have reviewed one hundred and seventeen papers representing 45 years of coccolithophore stratigraphy in Egypt with the objective of describing broad stratigraphic patterns, including



TEXT-FIGURE 1
Paleogeographic reconstruction of the western Tethys during the early Paleogene. (after Höntzsch et al. 2011: fig. 2a).

occurrence of unconformities and lateral variations in the thickness of stratigraphic packages. We have attempted to locate as many papers published in Egyptian journals as was possible. Since most were inaccessible to us we have ignored PhD theses even though they are often cited in the Egyptian literature. We do not cite abstracts, except the earliest that introduced coccolithophore research conducted in Egypt.

Based on this review, we have established a database of all sections studied in Egypt for coccolithophores, including their geographic location, stratigraphic extent, and references to the relevant publications. In this database we report on the biozonal extent of all marine coccolithophore-bearing stratigraphic units of Egypt without information on zones that are present/absent in the intervening interval.

Although the database covers the stratigraphic interval from Cenomanian through Pliocene, we restrict our discussion to the upper Maastrichtian (Zone CC26b) through Lower Eocene (essentially up to the NP11/ NP12 zonal boundary) interval, which is also the stratigraphic interval represented by a composite of the DBQ core and the DBD outcrop in the Dababiya Quarry. In terms of lithostratigraphy, this corresponds, from base to top, to the equivalent of the Sudr Formation and the Dakhla Shale, Tarawan Chalk, Esna Shale (with its four members) and Thebes Limestone formations (see Dupuis and Knox and Knox, this volume; Dupuis et al. 2003; Aubry et al. 2007). The reader is referred to Issawi et al. (1999) for background information on the lithostratigraphic subdivisions in Egypt, and to Scheibner et al. (2001a: fig. 5 for lithostratigraphic correlations across Egypt).

Biostratigraphic framework and biohorizon*s*

Following Sadek and Teleb (1978a) all post-1978 publications on Egyptian sections have relied on Martini's zonation (1971) for the Cenozoic. Following Sadek and Teleb (1978b) the upper Maastrichtian has been subdivided into three subzones (*L. quadratus*, *M. murus*, *M. prinsii*). Sissingh's zonation (1977) has been progressively introduced for older stages. Although included in the database and briefly discussed, pre-1978 studies have not been used in our description of Paleocene-Lower Eocene stratigraphic architecture in Egypt.

Subzones introduced to refine Martini's zonal framework (1971) have only been incorporated in recent studies (e.g., Tantawy 2006, Faris and Salem 2007; Steurbaut and Sztrakos 2008). Since these provide the means to assess the overall completeness of stratigraphic sections, we have attempted at delineating subzones based on the data presented in earlier studies. The sampling resolution is too low and the taxonomic inventory too incomplete in most of these studies to allow the delineation of biozones as defined in the detailed biostratigraphic framework of Varol (1989). However, both (sample resolution and taxonomic inventory) are sufficient to determine parts of zones whose chronozones correspond to long durations and are marked by significant biostratigraphic events. Thus we have systematically attempted to subdivide Zones NP4, NP9 and NP10 as occurring in Egyptian sections into their component subzones:

1) Zone NP4: The LO of *Diantholitha mariposa* is the most reliable criterion to define the base of Subzone NP4b. This recently described taxon has been overlooked in the literature, mostly because of its restricted stratigraphic range. This event is the oldest in a sequence of lowest and highest occurrences (LO and HO, respectively) in the vicinity of the Danian/ Selandian Boundary (Aubry et al. 2012; Monechi et al. 2013; Aubry and Salem, this volume), including the appearance of the genera *Lithoptychius* and *Sphenolithus*. *Lithoptychius*-fasciculiths (e.g., *Lithoptychius ulii* (Perch-Nielsen 1971)) differ from *Fasciculithus*-fasciculiths (e.g., *Fasciculithus tympaniformis* Hay and Mohler 1967, which is the oldest species of the genus) in consisting of three superposed cycles and possessing a "central body" (Aubry et al. 2011a; Aubry, in press; see also Monechi et al. 2012). There is no indication that specimens now assignable to *D. mariposa* were reported from Egyptian sections prior to the description of this species. Thus, we have approximated the subzonal boundary based on the LOs of species of *Lithoptychius* (formerly assigned to *Fasciculithus*, such as *Fasciculithus ulii*, *F. janii*, *F. bitectus*) and/or the LO of *S. primus* in the upper part of Zone NP4 (i.e., below the LO of *F. tympaniformis*) depending on the data available in specific sections.

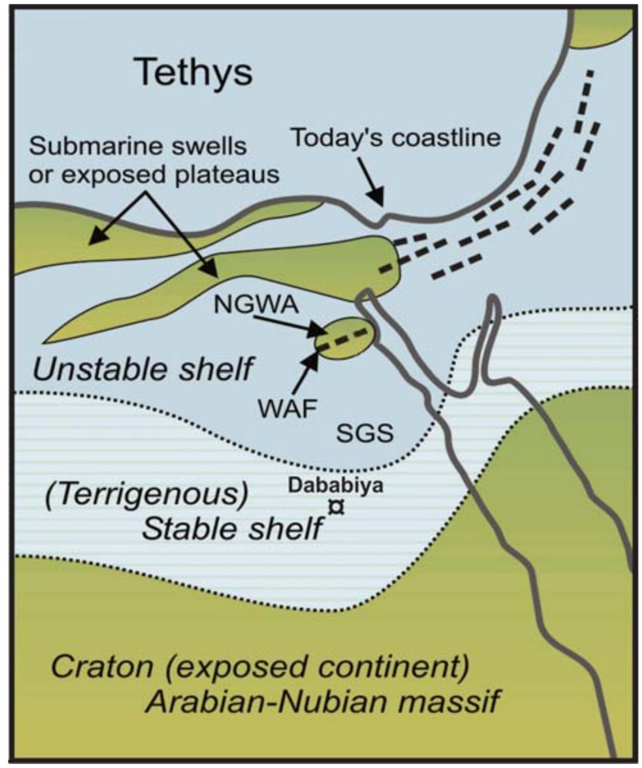
2) Zone NP9: The NP9/NP10 zonal boundary in Egypt has consistently been delineated at the LO of the genus *Tribrachiatus* (base NP10 herein) not at the LO of *Rhomboaster* spp. (base NP9b herein) as currently placed by many authors following Bybell and Self-Trail (1995). Also, numerous studies have shown that the LO of *T. bramlettei* is almost coincident with the HO of *Fasciculithus tympaniformis* (as shown in Martini 1971: table 2). We see no reason to modify the definition of the NP9/ NP10 boundary in order to 1) unsatisfactorily attempt to resolve a taxonomic disagreement (e.g., Bybell and Self-Trail 1995; Angori and Monechi 1996; Aubry et al. 2000b; see also Agnini et al. 2007) and 2) align it with a major chronostratigraphic boundary, particularly when such a move would result in the loss of chronologic resolution.

We have relied on the meaning of LO stated above (LO) of the so-called "RD assemblage" (Aubry et al. 2000a) and the coincident HO of *F. alanii* to delineate Subzones NP9a and NP9b. The RD Assemblage consists of several taxa, including *Heliodiscoaster anartios*, *H. araneus* and *Rhomboaster* spp. The taxon *H. araneus* exhibits great morphologic variability. Possibly a complex of several taxa, it includes *Discoaster aegyptiacus aegyptiacus* El-Dawoody 1988 and *Discoaster aegyptiacus duwiensis* El-Dawoody 1988 (see Appendix 1). The stratigraphic range of the RD is restricted to the carbon isotopic excursion (CIE; Kahn and Aubry 2004, Aubry et al. 2007). The stratigraphic interval between it and the LO of *Tribrachiatus bramlettei* is defined as Subzone NP9c. In practice, we have used the LOs of *Rhomboaster* spp. and *H. araneus* to delineate the NP9a/b subzonal boundary. When these taxa were not reported, the HO of *Fasciculithus alanii* and/or the LO of *Heliodiscoaster mahmoudii*, (or of *Pontosphaera minuta* or *Blackites solus*) were used to delineate Subzones NP9a and NP9c. In the GSSP for the base of the Eocene at Dababiya, the former event is located just below the CIE and the latter just above it (Aubry et al. 2007).

3) Zone NP10: We have relied on Aubry' subdivision (1996) of Zone NP10 into four subzones, in which the disjunct ranges of *Tribrachiatus digitalis* and *T. orthostylus* occupy a central role. This subzonation is demonstrably applicable to Egyptian stratigraphies (e.g., Aubry 1996; Tantawy 1998, 2006, Faris and Salem 2007). *Tribrachiatus digitalis* is a short-lived taxon, and delineation of the NP10b Total Range Subzone necessitates high-resolution sampling of sections. This has generally not been the case in the literature reviewed here. Additionally *T. digitalis* is a recently described taxon that has been generally incorporated in the concept of *T. contortus* (see Aubry 1996 and Appendix 1). In practice, thus, we have delineated Zone NP10d based on the occurrence of *T. contortus* in the absence of *T. bramlettei*. This assignment was supported in many sections by a thin overlap of the uppermost range of *T. contortus* and the lowermost range of *T. orthostylus*. In sections where the ranges of *T. bramlettei* and *T. contortus* overlapped, the latter taxon was reinterpreted as *T. digitalis*, and Subzone NP10b was inferred.

The zonal/chronal subdivisions introduced here for Egyptian stratigraphy are validated by the fact that they correspond with main events in Paleogene history or with well known evolutionary events: 1) Biochron NP4 straddles the Early/Middle Paleocene boundary in the vicinity of one of the most prominent radiations of the coccolithophores (Aubry 1998; Aubry et al. 2012 and reference therein); 2) Biochron NP9 straddles the Paleocene/Eocene boundary, itself marked by a sharp turnover in the coccolithophores and the occurrence of short-lived, distinctive, excursion taxa; 3) Biochron NP10 is known for the development of the *Tribrachiatus* lineage, one of the clearest lineages among coccolithophores (Romein 1979; Bord and Aubry 2013).

Based on the above we have constructed a framework of biohorizons to serve as a reference for stratigraphic correlations within Egypt and with neighboring regions (Text-fig. 3). This framework is deliberately simple, relying on only a few species that are characteristic, easily recognized and of wide occurrence in Egypt. It constitutes a reliable means of determining whether significant stratigraphic gaps occur in Paleocene-lower Eocene successions on the southern shelf of the Tethys Ocean, and is likely applicable to the Tethyan northern shelf as well. The rapid sequence of the events contributing to the radiation of the genera *Diantholitha* and *Lithoptychius* was established in the Qreiya section (Qreiya 3: see Table 2, caption) (Aubry et al. 2012) and requires comparison with other sections, in particular to sort out taxonomic heterogeneity (Compare Aubry et al.



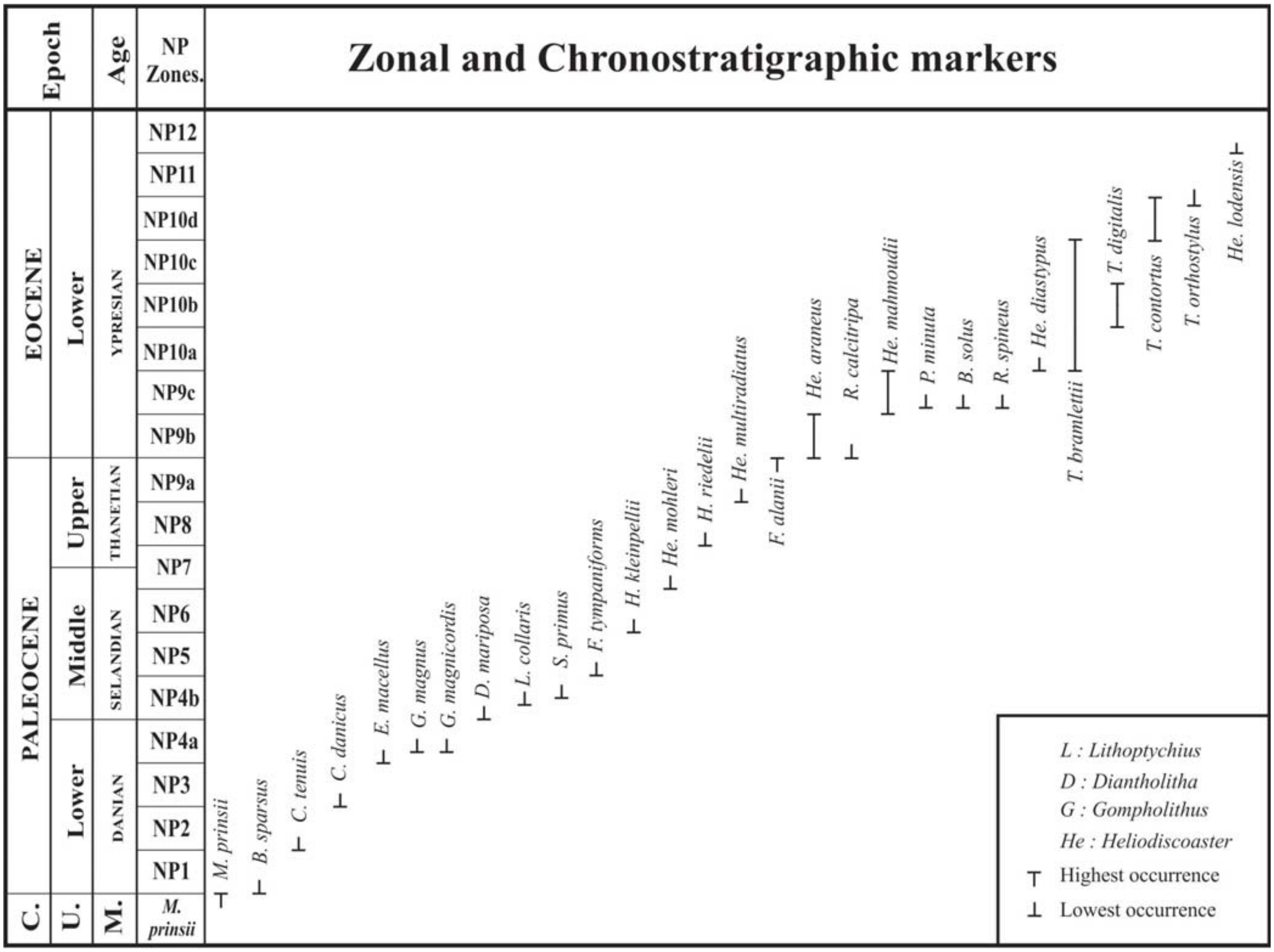
TEXT-FIGURE 2
Location of the Dababiya Quarry on part of the Early Eocene southern Tethys shelf (now Egypt). The succession recovered from the Dababiya Core represents siliciclastic sedimentation on the Tethyan stable shelf. In this reconstruction (from Höntzsch et al. 2011: fig. 2b) the boundary between the unstable and stable shelf is dotted. The dashed lines represent the Araba fault at the southern end of the Syrian Arc. The current Northern Galala Plateau was part of elevated above sea level (NGWA) and bordered to the south by the Southern Galala Subbasin (SGS).

2011a and Monechi et al. 2013). However, the framework proposed here is not concerned with the details of successive occurrences of rapidly evolving species, but with the potential of determining whether major parts of three biozones (NP4, NP9, NP10) are present or not. It is basically the framework we have used to assess the completeness of sections in this study. We refrain from including planktonic foraminiferal datums at this time, although this should be an important future undertaking.

Comparison between sections

Having established a framework of correlations between sections, we compare thicknesses between selected intervals in different sections. To facilitate our demonstration, the means of comparison are introduced as needed in the discussion (see below).

When competitive descriptions of the calcareous nannofossil stratigraphy of a given section were available, we have selected the most comprehensive study. This committed us to adopt not only the biozonal framework in that study, but also the lithological framework, regardless of other correlations in other studies. As an example, we have relied on the biozonal description by Perch-Nielsen et al. (1978) of the Dakhla Shale-Tarawan succession. According to these authors the Dakhla/



TEXT-FIGURE 3
Biostratigraphic framework of reference for Paleocene–lower Eocene stratigraphy (Zones NP1-NP12) in the southern Tethys.

Tarawan contact falls in Zone NP7-8. In contrast, the lithologic contact lies in Zone NP6 according to Speijer and Schmitz (1998). The thickness assigned to successive biozones in any section is based on values stated in the text of selected published papers, or on approximate measurements from figures in them. There is necessarily a large uncertainty in our measurement of thickness of individual zones, but there is an equally large uncertainty (±2 m) due to broad spacing between samples in the available studies. However, as emphasized again below, we are not concerned with lateral changes in thickness of individual biozones but with that of packages several meters thick.

Biochronology

In reference to the time scale of Gradstein et al. (2012), the Cretaceous/Paleogene and Paleocene/Eocene boundaries are dated at 66 and 56 Ma, respectively, and the Early/Middle and Middle/Late Paleocene boundaries at 61.6 and 59.2 Ma. Also with reference to it, the duration of the Paleocene Epoch is 10 Myr and that of Biochron NP4 is 1.97 Myr. We depart, however, from Vandenberghe et al. (2012) by placing the NP9/NP10 biochronal boundary at the First Appearance Datum (FAD) of *Tribrachitaus bramlettei* as defined by Martini (1971), itself immediately following the Last Appearance Datum (LAD) of *Fasciculithus tympaniformis* (55.64 Ma in Anthonissen and Ogg 2012). Our estimate of the duration of Biochrons NP9 and NP10 are therefore 1.68 Myr and 1.47 Myr, respectively. We also accept the *Sparnacian Stage* as a useful chronostratigraphic unit at the base of the Eocene series (Aubry et al. 2003). Because of poor calibration of the range of *T. digitalis* (not compiled in Anthonissen and Ogg 2012), the duration of the Sparnacian is estimated at 0.8 to 0.9 Myr, in agreement with Cramer et al. (2003).

Sedimentary history

Our interpretation of the sedimentary history of sections is based on estimated duration of hiatuses in sections where zones and subzones are missing. As the Paleocene time scale is still unsettled with regard to astrochronology, we describe sections with reference to the magnetobiochronology of Berggren et al. (1995) with its updates in Quillévéré et al. (2002) and Wade et al. (2011). The literature data do not allow us to conduct a rigorous sedimentary interpretation as devised in Aubry (1995). Two factors have limited our ability of establish a comprehensive temporal interpretation of the Paleocene–Lower Eocene record of Egypt. One is that the stratigraphic resolution achieved in the coccolith studies reviewed here was generally low; the other is that it would have been difficult to integrate stratigraphic data from coccolith and planktonic foraminifera (see below). Thus, although the unconformitities are correctly located, the age of the bounding surfaces of stratigraphic gaps are only approximated and the hiatuses may be longer than shown. As will be shown below, the thickness of biozones varies greatly in sections regardless of the duration of the biochrons they represent. Comprehensive stratigraphic analysis has shown that, in the long-term, sedimentation rates vary little at any given location (Aubry 1993a, b, 1995) and that unconformities are the likely causes of apparent decreases in sedimentations rates. Therefore we have inferred the presence of unconformities in the cases of anomalously thin biozonal intervals, but without attempting to determine the corresponding hiatuses. This is in general agreement with sequence stratigraphic interpretation of the same sections and the determination of relative changes in sea level (e.g., Lunning et al. 1998b). The most difficult interval to interpret in this work is the Tarawan Chalk. In the absence of firm data to the contrary we deliberately make conservative interpretations although we suspect the presence of major stratigraphic gaps.

We cannot discuss unconformities while ignoring the question of biostratigraphic diachrony, especially because biostratigraphy often constitutes the primary, if not only means of temporal interpretation of Egyptian successions. The problem has been raised (Marzouk and Luning 1998; Faris et al. 1999a) and several explanations have been given to discrepant correlations between calcareous microfossil groups, including heterogeneity of taxonomic concepts, sensitivity of marker taxa to dissolution, ecologic controls on species distribution, facies variations, (?) difference in sedimentation rates (presumably a problem related to sample resolution), and truncation of sections by stratigraphic gaps. Heterogeneity of taxonomic concepts may be more frequent than recognized, and the compared range of *Tribrachiatus* species is a point in case (Faris et al. 1999a: fig. 10) that was resolved with the introduction of *Tribrachiatus digitalis* (Appendix 1, Fig. A). Bioturbation is another factor that may cause apparent diachrony, and it may also explain inverse relationships between biozonal boundaries delineated on the basis of different paleontologic groups. Both translatitudinal and regional diachrony have been documented (e.g., Aubry 1992; Gibbs 2008). The first generally involves temporal differences > 1 Myr, whereas the second is more modest, being associated with short spans of time that are mostly measurable through astrochronology. In this study we are concerned with neither, the latter because our study is conducted at a coarser scale, the former because the sections are all located in the same climatic belt. Stratigraphic gaps remain, by far, the major cause of (apparent) diachrony and this can be rigorously tested (Aubry 1995; Aubry et al. 2000a). Ideally the delineation of subzonal boundaries and the integration of biozonal schemes based on different fossil groups will help resolve the completeness of stratigraphic successions in Egypt in future studies.

A note of caution: We stress that our temporal interpretation is incomplete and voluntarily limited to the large hiatuses. We recognize that high resolution studies are needed for a comprehensive comparison between sections for 1) dating the two surfaces associated with each unconformity (Aubry 1991), 2) determining soundly the duration of hiatuses, and 3) delineating less prominent ones. We acknowledge that the use of planktonic foraminiferal stratigraphy may have improved the temporal correlations shown here although this would have proven quite difficult. To wit, very different interpretations have been given of the Paleocene-lower Eocene successions of the Wadi Dakhl and Saint Paul sections (Galala Plateau). El Ayyat and Obaidalla (2013) report a stratigraphic gap encompassing Zone P2 through E2 (= Subzone NP4b through NP10) in the latter section, although Faris (1994) and Scheibner et al. (2001) report a normal NP4 through NP9 succession in the same interval. Scheibner et al. (2001) and Strougo and Faris (1993) also show a normal zonal succession at Wadi Dakhl. However, this section is shown to be highly discontinuous above Zone P2 with only a thin interval of Zone P4b and Zone P5 being present (El Ayyat and Obaidalla 2013). In terms of nannoplankton stratigraphy, this would imply a composite stratigraphic gap encompassing Subzone NP4b to upper Zone NP10, with only (approximately) Zone NP7-lower NP8 and Zone NP9 present. Integrating coccolith and planktonic foraminiferal stratigraphies based on separate sampling would be clearly difficult. The data on Wadi Dakhl are reconcilable; those on Saint Paul are not. Thus for the purpose of this study we have delineated only the long, mostly 1 to several Myr, hiatuses corresponding to unrepresented biozones or subbiozones. Short hiatuses have been delineated in several sections, for instance within PETM-intervals (Ouda and Berggren 2003) and in the lowermost Danian (Keller et al. (2002). There is no doubt that many more small hiatuses occur in the sections examined here, and it is possible that some large ones are overlooked (i.e., in the Tarawan Chalk). To clarify, this study would be inappropriate for discussing the Paleocene to Lower Eocene stratigraphic record of Egypt in terms of allostratigraphy and/or sequence stratigraphy. The sequence stratigraphy of the core is described separately by King (this volume).

LITERATURE SURVEY

Following the demonstration by Sadek (1968) that coccolithophores are useful for the chronostratigraphic dating of marine sediments in the Cairo-Suez district, a large number of studies have been devoted to Upper Cretaceous—Paleogene calcareous nannofossil stratigraphy in Egypt. Whether parts of PhD theses and other academic projects, of research programs at the Geological Survey of Egypt, or of broader international projects, many of these studies have resulted in scattered, often difficult to access publications. Despite these difficulties, Egyptian micropaleontology has gained increasing recognition in the last 15 years: its thick sedimentary successions magnificently exposed in the cliffs of high plateaus (Gebels) or along beds of temporary rivers (wadis) have been shown to contain some of the best preserved evidence of global changes at or near major chronostratigraphic boundaries, among which the Cretaceous/Paleogene (K/P), Paleocene/Eocene (P/E) and Lower/Middle Paleocene (= Danian/Selandian [D/S]) boundaries.

The development of nannopaleontology in Egypt is best described in terms of three successive phases: 1) an initial phase of discovery; 2) a subsequent phase of systematic biozonal description of sections; and 3) an ongoing phase of detailed studies around major chronostratigraphic boundaries. The change from one phase to another was progressive. The delimiting dates chosen below are those reflecting shifts in methodological approach as seen in publications.

The early years (1968-1984)

Early calcareous nannofossil studies (Table 1) in Egypt were centered on 1) correlations between planktonic foraminifera and calcareous nannofossil biozonal schemes, and discussion on the location of Egyptian sedimentary successions in global chronostratigraphy (a double effort that was led by A. Sadek (e.g., Sadek 1971), 2) litho-biostratigraphic correlations in selected sections and their lateral extensions (as emphasized by A. S. El Dawoody 1969), and 3) taxonomic documentation (as exemplified by Shafik and Stradner 1971; Sadek and Teleb 1973, 1974; Perch-Nielsen et al. 1978). A turning point in this episode of discovery was reached when Sadek and Teleb (1978a, b) applied without modification the standard zonation of Martini (1971) for the Paleogene and the nascent biozonal subdivision of the Maastrichtian (Roth and Thierstein 1972, Cepek and Hay 1969). For the first time long distance correlations from the Qattara Depression to the Red Sea Coast via Kharga and the Nile Valley were established, and—importantly— unconformities were delineated in several sections. Ultimately, correlations were extended to neighboring countries (El-Dawoody 1994). Basic taxonomic documentation of stratigraphically significant species and most commonly encountered species accompanied many of these early papers. The stratigraphic data in papers published during this early phase are often difficult to integrate with more recent studies, because sample resolution was low, distribution charts were lacking in most instances, and composite rather than individual stratigraphic sections were discussed, resulting in the location of samples and the thickness of biozones being left unknown. Yet, these studies provided the basic biostratigraphic framework of Egyptian geology.

Expansion of the biostratigraphic effort: 1984-1999

Conducted at low stratigraphic resolution, the pioneering studies were determinant in launching an effort (~1984-present) towards systematically describing sections throughout Egypt. New sections were documented; at the same time, sections deemed more important were revisited and resampled at increasingly high resolution (Tables 2, 3). Discussions based on these studies focused on correlations between biozonal schemes based on different paleontological groups, and generally emphasized the location of chronostratigraphic boundaries in pre-GSSP times (e.g., Faris 1984, 1993a, 1997, 1999; Faris et al. 2005a). Other studies have documented changes in plankton assemblages associated with major events as, for instance, with the extinction event at the Cretaceous/Paleocene boundary (e.g., Faris 1984, 1997, 1999; Faris et al. 1986, Faris et al. 2007a). A few studies have dealt with taxonomy (e.g., El-Dawoody 1975, 1988; Mohammed et al. 1982; Faris 1993b).

Novel emphasis in the light of international collaboration (1999-current)

The impetus for international interest in the stratigraphic successions of Egypt has been the expansion of sequence stratigraphy and the development of GSSP-based chronostratigraphy (Tables 2, 3). The continued development of sequence stratigraphy since its initiation in the mid-seventies, has prompted the intensification of regional stratigraphic analysis for which a strong biostratigraphic component is needed. This has encouraged studies (e.g., Lüning et al. 1998a-c; Bauer et al. 2001; Scheibner et al. 2000, 2001a, b, 2003a, b; Höntzsche et al. 2011) in the Sinai and the Galala Mountains and the interpretation of their sedimentary successions in terms of eustasy and local tectonics. Notable also are the studies of cored sections along downdip transects as in Northern Sinai (Marzouk and Soliman 2004).

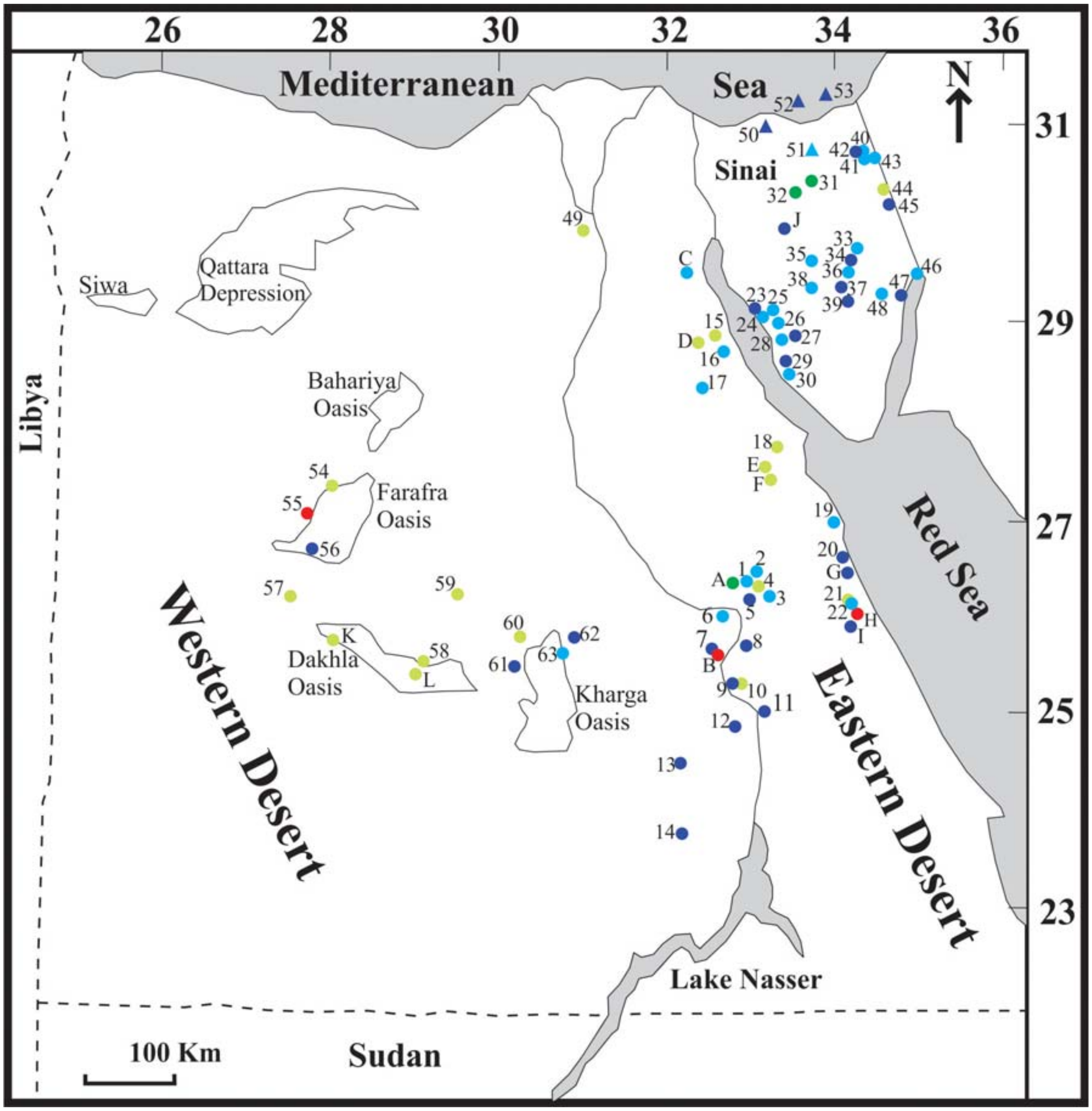
The introduction of the concept of Global Standard Stratotype section and Point (GSSP) (e.g., Remane at al. 1996) in an effort to stabilize the definitions of chronostratigraphic boundaries, has shifted stratigraphic emphasis from the general description of sections to the detailed description of specific stratigraphic intervals. The emphasis placed on globally occurring criteria for chronostratigraphic correlation has led to association of chronostratigraphy with the study of global events in Earth history, while simultaneously encouraging international collaboration. This has opened a new episode of stratigraphic research in Egypt, often with collaborative projects centered on the Cretaceous/Paleogene (e.g., Keller et al. 2002; Tantawy 2003), Paleocene/Eocene (Schmitz et al. 1996; Bolle et al. 2000; Ouda and Aubry 2003 [eds.]; Youssef and Muterlose 2004; Tantawy 2006), and the Danian/Selandian boundaries (e.g., Steurbaut and Sztrakos 2008; Bornemann et al. 2009; Ali Youssef 2009; Sprong et al. 2011, 2012; Aubry et al. 2012).

Few papers have been devoted to coccolithophore taxonomy, even though brief taxonomic diagnosis with illustrations may have accompanied biozonal descriptions. Research around chronostratigraphic boundaries has renewed the taxonomic interest of the early years.

Discussion: Over 150 sections have been investigated to date for calcareous nannofossil stratigraphy in Egypt, several of them repeatedly over the years (text-figs. 4, 5; tables 2, 3). In reference to Said (1962) most sections are from the stable platform, located along the Nile Valley, the Eastern Desert and the Sinai. A few are from the tectonically unstable shelf of northern Egypt. The boundary between the stable and unstable shelf, that is the southern limit of tectonic influence associated with the emplacement of the Syrian Arc (Said 1990; Hussein and Abd-Allah 2001) has become rather fluid. For instance, a tectonic component is now recognized in the stratigraphic architecture of the Galala Mountains (Höntzsch et al. 2011), and the boundary between the stable and unstable shelf in the Western Desert, formerly placed north of the Bahariya Oasis, is now seen to lie in the vicinity of the Farafra Oasis (Ouda, Dupuis and Aubry, Field Season November 2011). The southern limit of the unstable shelf and the northern edge of the African craton are delineated for reference (text-figs. 4, 5).

As long known, and emphasized by the database, the Maastrichtian to Lower Eocene stratigraphic record is by far the best developed in Egypt, with essentially uniform lithologic packages outcropping from the southern part of the Nile Valley (text-fig. 6), to the Red Sea Coast, Galala Mountains and western Sinai (text-fig. 7), central and eastern Sinai (text-fig. 8), to the Western Desert (text-fig. 9) and recovered in cores from northern Egypt (text-fig. 10) (see also Appendix 2 online). This is the stratigraphic interval discussed below.

Lithostratigraphy plays a major role in Maastrichian through Lower Eocene Egyptian geology (Said, [Ed.] 1990). This is because 1) the same lithologies extend with little to moderate lateral variation over long distances, and 2) they form a natural lithologic subdivision that permeates the landscapes, with cliff-forming carbonate lithologies (Sudr Limestone, Kohman Chalk, Tarawan Chalk, Thebes Limestone) separated by thick bodies of shales (Dakhla and Esna Shales). The Sudr Limestone is restricted to the Sinai and the northern part of the Red Sea Coast (Galala Mountains), and the Khoman Chalk to the northern parts of the Western and Eastern Desert (the latter chalk was



TEXT-FIGURE 4
Location of outcrop sections (dots) and wells (triangles) analyzed for calcareous nannofossil stratigraphy in Egypt and reviewed in this work. Light blue: Cretaceous to Lower Eocene; light green: Cretaceous to Paleocene; blue: Paleocene and lower Eocene; green: Paleocene, only; red: lower Eocene, only. Full names of numbered localities are given in Table 1a-h. Numbered sections are those further studied herein. Lettered sections have been eliminated from this study because data are too few.

identified by Shafik and Stradner [1971] as Tarawan, leading to the suggestion of lithostratigraphic diachrony). They pass southwards into the Dakhla Shales. The two shales yield the lithologic record of the events chosen to characterize early Paleogene chronostratigraphic boundaries. The Dababiya Quarry Member of the Esna Shale Formation are indicative of the Paleocene/Eocene Thermal Maximum (Ouda and Aubry [eds.] 2003) and the Qreiya Beds in the upper part of the Dakhla Shale Formation may be associated with a Paleocene hyperthermal in the vicinity of the Danian/Selandian boundary (Bornemann et al. 2009; Sprong et al. 2012; Aubry et al. 2012).

The upper part of the Sudr Limestone belongs to Zones CC25 and 26 (text-figs. 7a, b, 8a, b). The Sudr/Dakhla formational contact (that encompasses the K/P boundary) is unconformable in most sections. The Khoman Chalk (Western Desert) also encompasses Zone CC25 and CC26 in the North Farafra section where it is unconformable with the overlying Dakhla Shale (text-fig. 9). Zones CC25c to CC26b have also been identified in a chalk facies in northern Egypt (text-fig. 10). The Cretaceous part of the Dakhla Shale south of the Dakhla Oasis is a lateral equivalent to these carbonate facies, and an unconformity marks the Cretaceous/Paleocene boundary in most sections (text-figs. 6–10). The Dababiya section is among the most continuous/complete across this boundary.

The Dakhla Shale encompasses Zone NP1 through at least Zone NP5 (partim). However the location of the Dakhla Shale/

Tarawan lithostratigraphic contact is inconsistent with regard to calcareous nannofossil zonal assignment in different sections. The contact may lie within Zone NP5, Zone NP6 and even Zone NP7-8 (text-figs. 6–10). There is no regional pattern to the relation between lithostratigraphic and biostratigraphic boundaries, and in adjacent sections the relative age of the contact may differ by two biozones. For example, in the Western Desert the Dakhla/Tarawan contact lies in Zone NP5 in the Amr section, but in Zone NP7-8 in the Ain Dabadib section, and in Zone NP6 at Gebel Ghanima (text-fig. 9). In the Dababiya Quarry Core the lithostratigraphic contact lies in Zone NP4b, which is the oldest age assignment given to it (Aubry and Salem a, this volume, a).

We have not attempted to elucidate the cause(s) for the lithologic diachrony. These may include subjective means of determining the lithological contact and poor preservation of microfossils leading to controversial biozonal assignment, but we also suggest that the diachrony may relate to water depth at the time of deposition. The Dakhla /Tarawan contact is unconformable in numerous localities.

The thickness of the Tarawan Chalk varies depending on the age of its contact with the Dakhla Shales. In contrast to the latter, the Tarawan Chalk/Esna Shale contact is very consistent. Its location at the NP7-8/NP9 zonal boundary, slightly below it, or above it, is easily explained by the transitional aspect of the Tarawan-Esna contact. However, two exceptions are the location of the boundary in Zone NP6 at Gebel Um El Huetat and Gebel Duwi (although in the intervening section at Gebel Atshan, the boundary correlates with the NP7-8/NP9 boundary; text-fig. 7). In the Dababiya Core the base of the Esna Shale is coincident with the base of Subzone NP9a, but the zonal age of the upper part of the Tarawan Chalk is indeterminate.

The contact between the Esna Shale and Thebes Limestone is also transitional, the Abu Had Member consisting of interbedded stringers of limestones and shales. This is possibly one of the reasons for the inconsistent location of the lithostratigraphic contact in the zonal succession (Zone NP11 or NP12). Another reason is the poor preservation of coccoliths in the micritic Thebes Limestone, resulting in a difficult characterization of the NP11/NP12 zonal boundary. Two exceptions are the anomalous dating of the base of the "Thebes Formation" in Zone NP10 (Gebel Um El Huetat section, text-fig. 7) and at the NP10/NP11 zonal boundary (Gebel Serai, text-fig. 6; Gebel Belayim, text-fig. 7).

A TECTONIC COMPONENT IN PALEOCENE-LOWER EOCENE DEPOSITIONAL PATTERNS

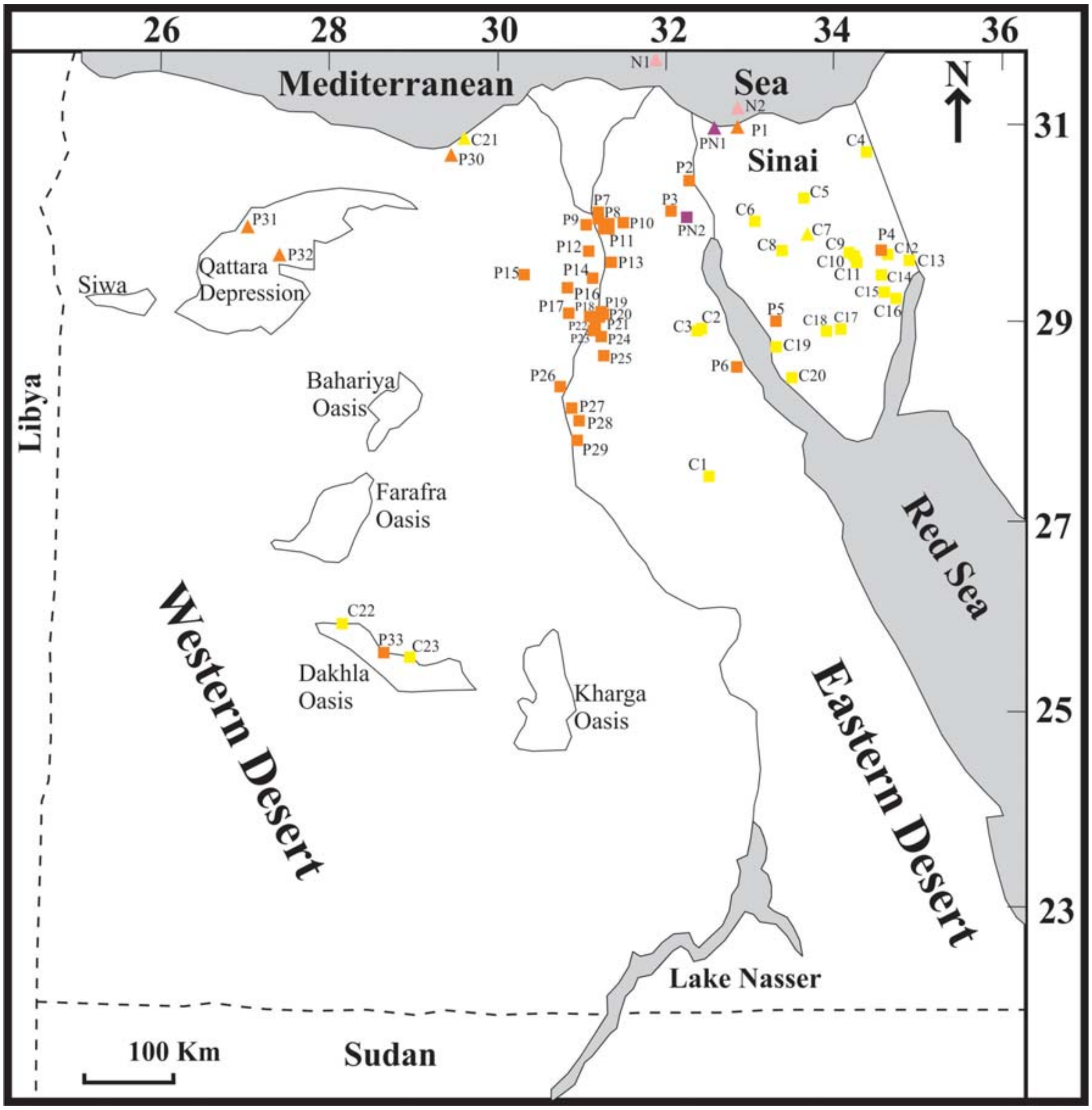
Whereas numerous upper Maastrichtian-Lower Eocene sections have been described from different parts of Egypt, there has been no attempt at comparing their thickness and completeness across Egypt. The discovery that the Paleocene record at Dababiya is much thinner than the lower Eocene alone, although representing a duration almost five times greater, invites an inquiry as to whether this is a general character of the southern Tethys, or a regional or local one indicative of differential geological histories across Egypt (see above). We thus have selected the sections that encompass the Maastrichtian through Sparnacian-lower Ypresian (Lower Eocene), and organized them in essentially North–South and West–East transects in order to follow lateral variations in lithologic and zonal composition and in thickness (text-figs. 6–10), a suite of characters used here to describe stratigraphic architecture.

Our interest in the Maastrichtian unit resides essentially in the fact that it bounds the Paleocene interval: whether conformable or unconformable, the Cretaceous/Paleocene contact constitutes a level of reference from which to measure sections. Ideally, the NP11/NP12 zonal boundary (close to the top of the Esna Shale) would serve as the youngest bounding horizon, but not all measured sections studied for coccolith stratigraphy extend this high. Instead we use the NP10/NP11 zonal boundary that is well documented in most studies. The base of Zone NP9 constitutes another level of reference. Well-delineated in all reviewed sections, it coincides with (or is very close to) the Tarawan/Esna contact (see above). Together, the three reference levels delineate two stratigraphic units. The lower unit comprises Zone NP1 to NP8 and corresponds to the (Paleocene part of the) Dakhla Shale –Tarawan Chalk succession in most sections; it is referred to below as "DT". The upper unit, which includes Zone NP9 and NP10, corresponds to the lower part of the Esna Shale; it is referred to as LE. The two units are essentially Paleocene and lower Eocene, respectively, although the P/E boundary occurs in the lower part of Unit LE. The interval of Zone NP 11 corresponds essentially (although not exactly) to the upper part of the Esna and is conveniently referred to as "UE" herein. We stress that the equivalence between biozones and lithologic units is made here for practical reasons only: 1) the litho- and biostratigraphic boundaries are not always coincident (see above), and 2) the Tarawan Chalk is unknown in eastern Sinai where the interval between the Sudr and Thebes Limestone is informally referred to as Dakhla/Tarawan/Esna following Scheibner et al. (2001a; see above).

Some Maastrichtian through Lower Eocene sections were unusable, for instance if no range chart was provided, or in the cases where a composite section represented several field sections. We have incorporated in this study partial sections of either the Paleocene or the Lower Eocene because they add documentation of the architecture in a given area. One serious concern to our approach is that our analysis is based on samples collected for other purposes than our own, and that the thickness given for individual zones is approximate (despite the calculated precision of the measurements in the figures). Another valid concern is that sample resolution in some studies was low and that some subzones would perhaps have been recovered should sample resolution have been higher. In regard to these concerns, we estimate the error on the location of the DT/LE in sections to be ±2 m. Also, we are not examining here the lateral extent of discrete biozones, but their combined extents in two main stratigraphic units (DT and LE).

Variations in thickness of specific lithologic units

The thickness of Paleocene–Lower Eocene (DT+LE) successions varies considerably in Egypt. Thick intervals occur in the Nile Valley, reaching ~150 m at Dababiya, 115 m in Taramsa, and ~105 m at Abu Had and Gebel Owaina (text-fig. 6; Table 4). The thickest interval is the ~ 212 m thick El Ain section in eastern Sinai (text-fig. 8), and the nearby El Falig section is almost as thick as Dababiya, even though it does not extend to the K/P boundary. These two sections are, however, highly anomalous compared to the seven other sections in the same area and those in Central Sinai. We venture to suggest that the two sections were incorrectly measured, and ignore them in the discussion below.

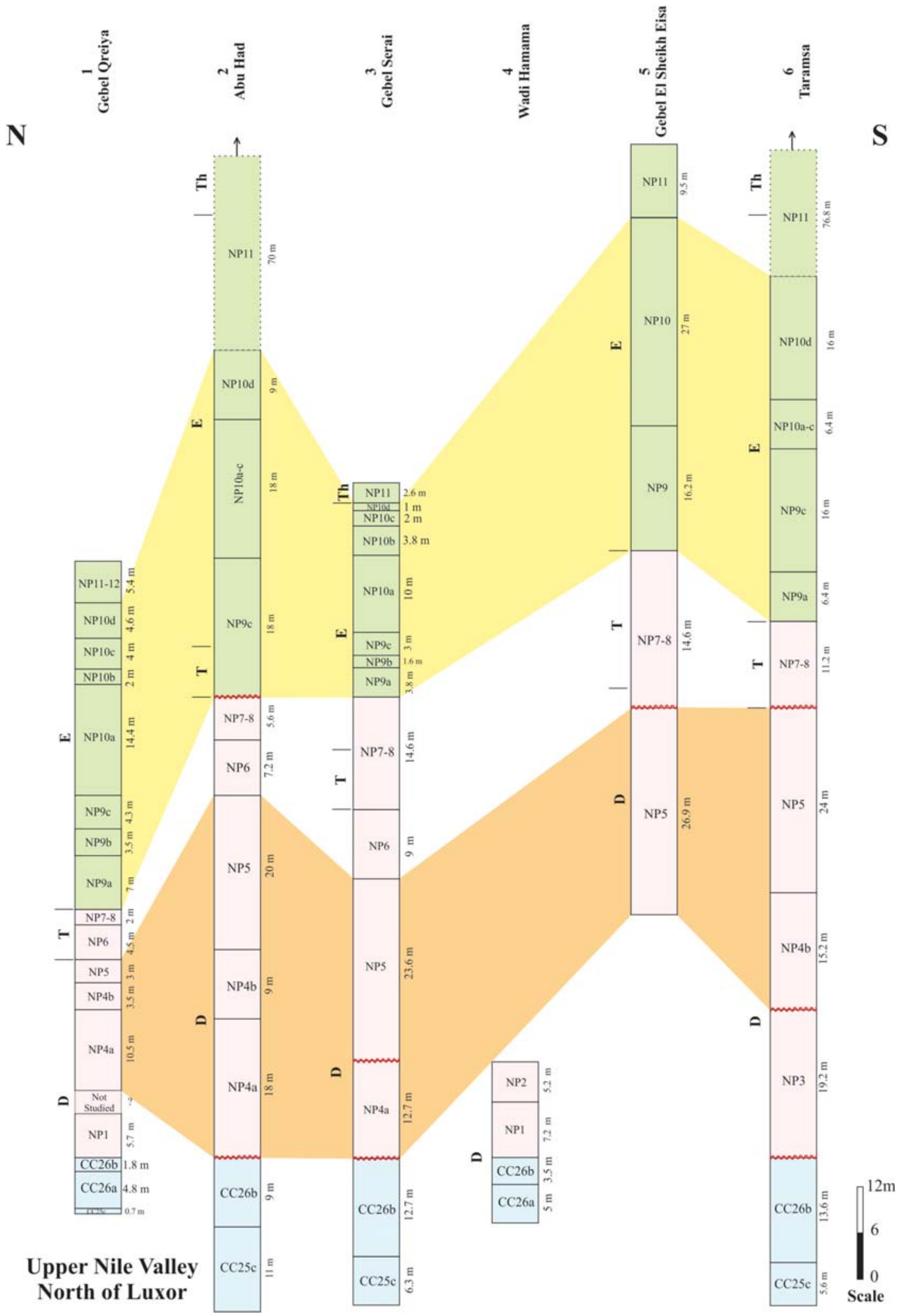


TEXT-FIGURE 5
Location of outcrop sections (squares) and wells (triangles) with only Cretaceous deposits or with deposits younger than Early Eocene analyzed for calcareous nannofossil stratigraphy.
yellow: Cretaceous only; orange: Paleogene younger than Lower Eocene, only; pink: Neogene only; purple: Paleogene (< lower Eocene) to Neogene. Full names of numbered localities are given in Tables 1a-c.

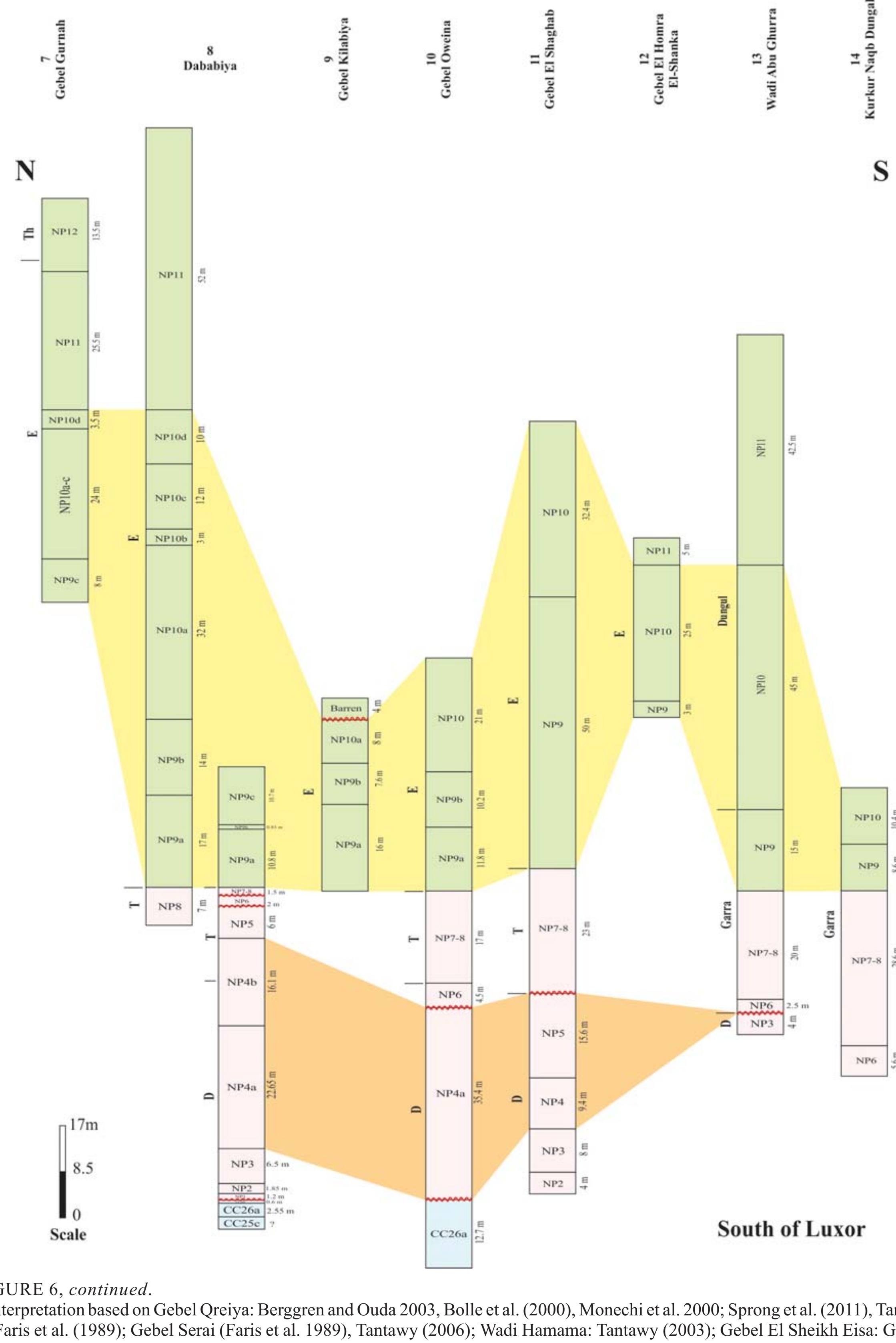
The thickness of the Nile Valley sections increases substantially when the UE is also taken into account (Table 4). However, the maximum thickness (>112 m; NP10-NP11 zonal interval) of LE +UE is reached at El Sheik Marzouk (Western Desert, text-fig. 9, Table 4). The thinner Paleocene–Lower Eocene (DT+LE) successions are five to six times thinner than the thickest ones. Most are located in the Sinai (Table 4). The thinnest, at Bir El Markha (western Sinai), is only ~22.5 m. The next thinnest interval (~28 m) is in the Galala Mountains. The DT+LE interval in the Ghamina section (Western Desert) is only 50 m thick.

In addition to this general variability, there is a regional variability, such that the same stratigraphic interval may exhibit different thicknesses in neighboring sections. For example, in the Western Desert the DT is >95 m at Ain Dabadib, ~42 m at Ain Amur, and only ~26 m in the Ghamina section (text-fig. 7). In the western Sinai the DT is ~25.5 m at Gebel Nukhul, but only less than half of this (~11.5 m) at Bir El Makha (text-fig. 7). Likewise, the DT in the Amr section, eastern Sinai, is also half (~23 m) the thickness of the Sheikh Attiya (54 m) (text-fig. 8). The local variability, such that lithostratigraphic units vary markedly in thickness over a short distance as shown for example in the Wadi Tarfa section (Scheibner et al. 2001a: fig. 7) and the Dababiya section (Dupuis et al. 2003 and in progress), is beyond the scope of this study.

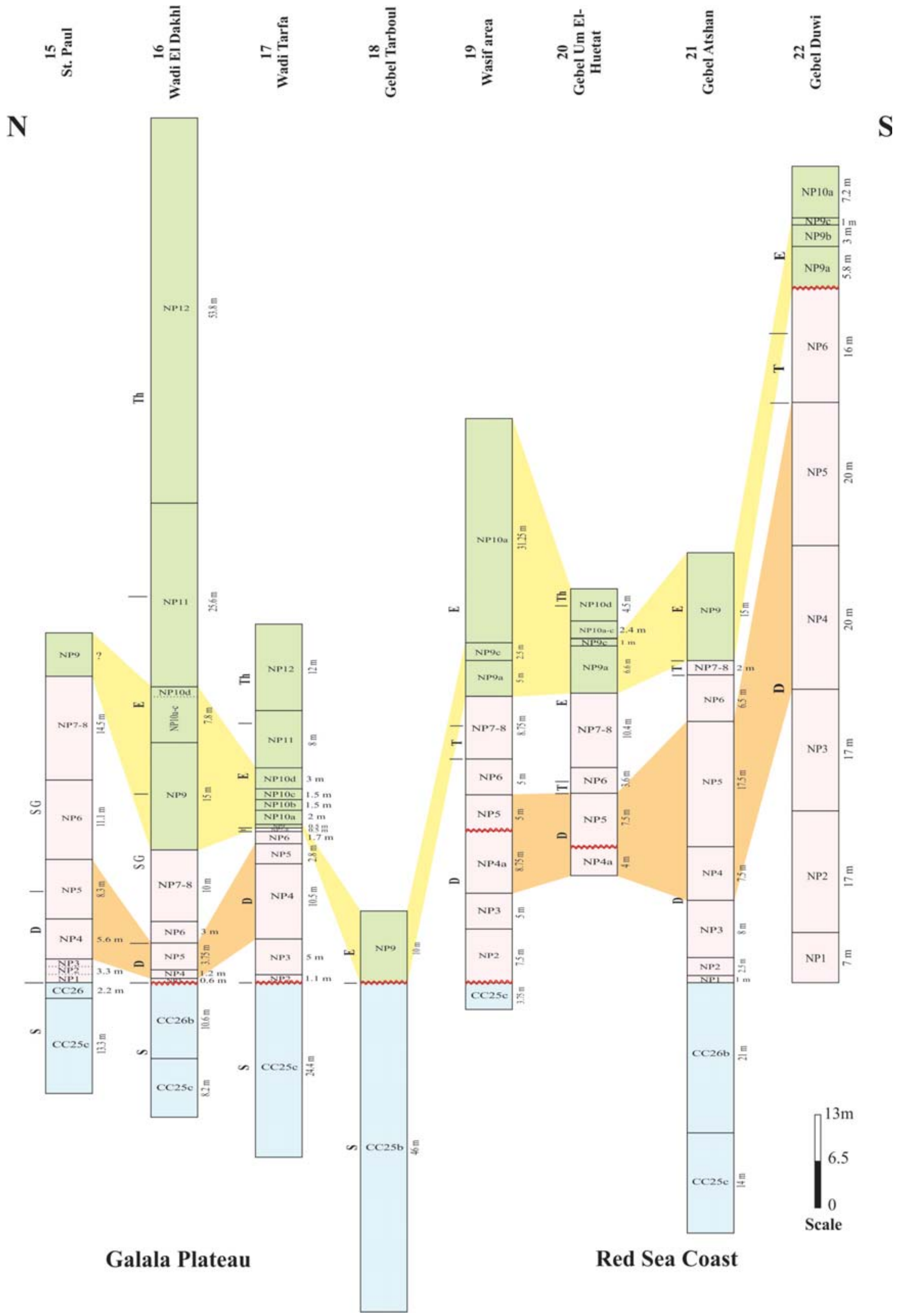
Beyond the dual global and regional variability described above, there is a geographic pattern to the thickness of the DT



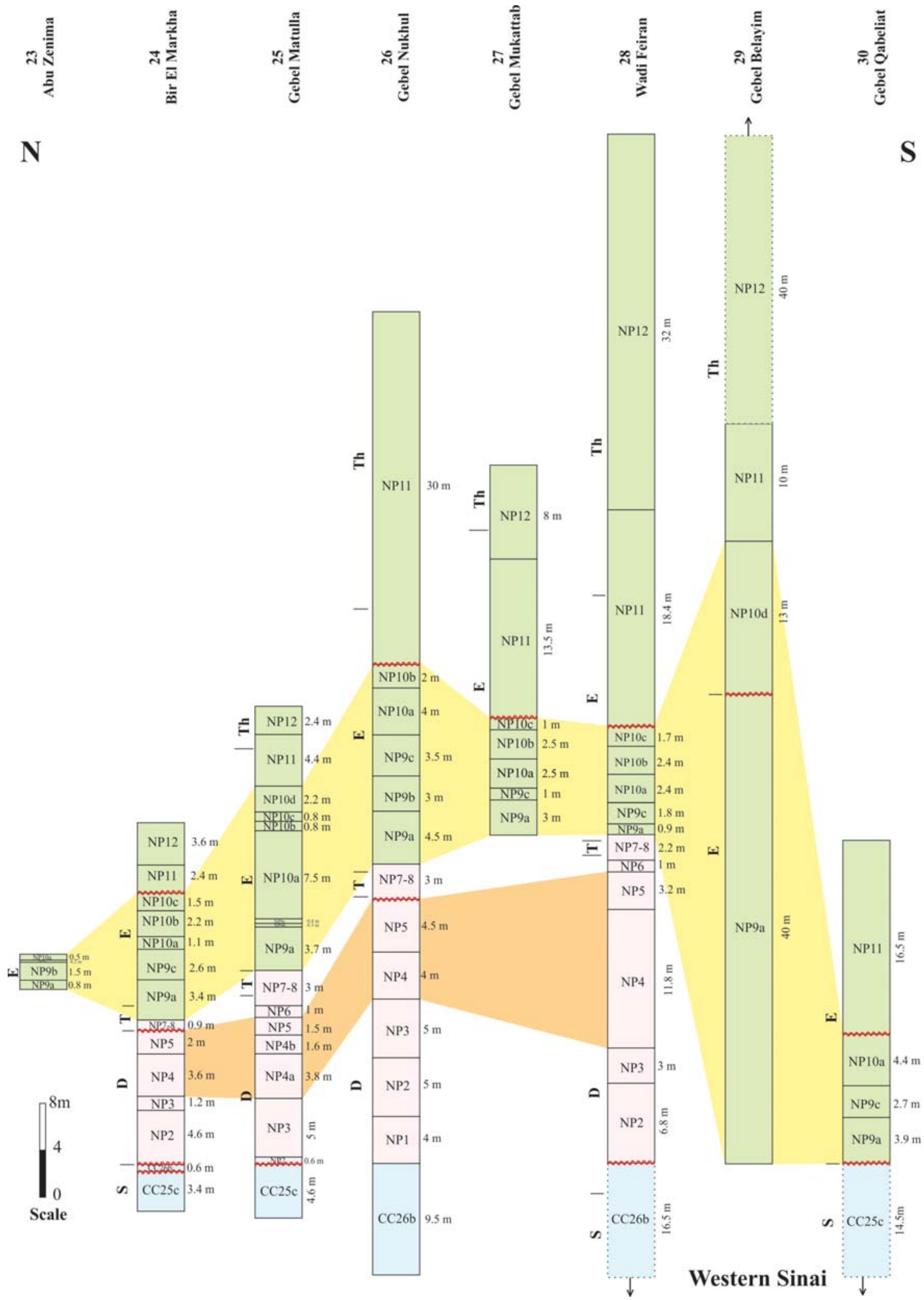
TEXT-FIGURE 6
Maastrichtian through Lower Ypresian stratigraphic successions on the edges of the Western and eastern Deserts along the Nile Valley, interpreted in terms of coccolith stratigraphy (see above for descriptions of zones and subzones). Locations of formational boundaries are shown where possible, as delineated in references used to construct figures. D = Dakhla Shale Formation; E = Esna Shale Formation; T= Tarawan Chalk; Th= Thebes Limestone Formation. Bold line: correlation of the Paleocene/Eocene boundary (=NPa/b boundary). Note that all sections in this figure as in text-figures 7 through 10 are reproduced at the same scale in Appendix 2 (online only). Note that in all sections red wavy lines indicate inferred unconformities.



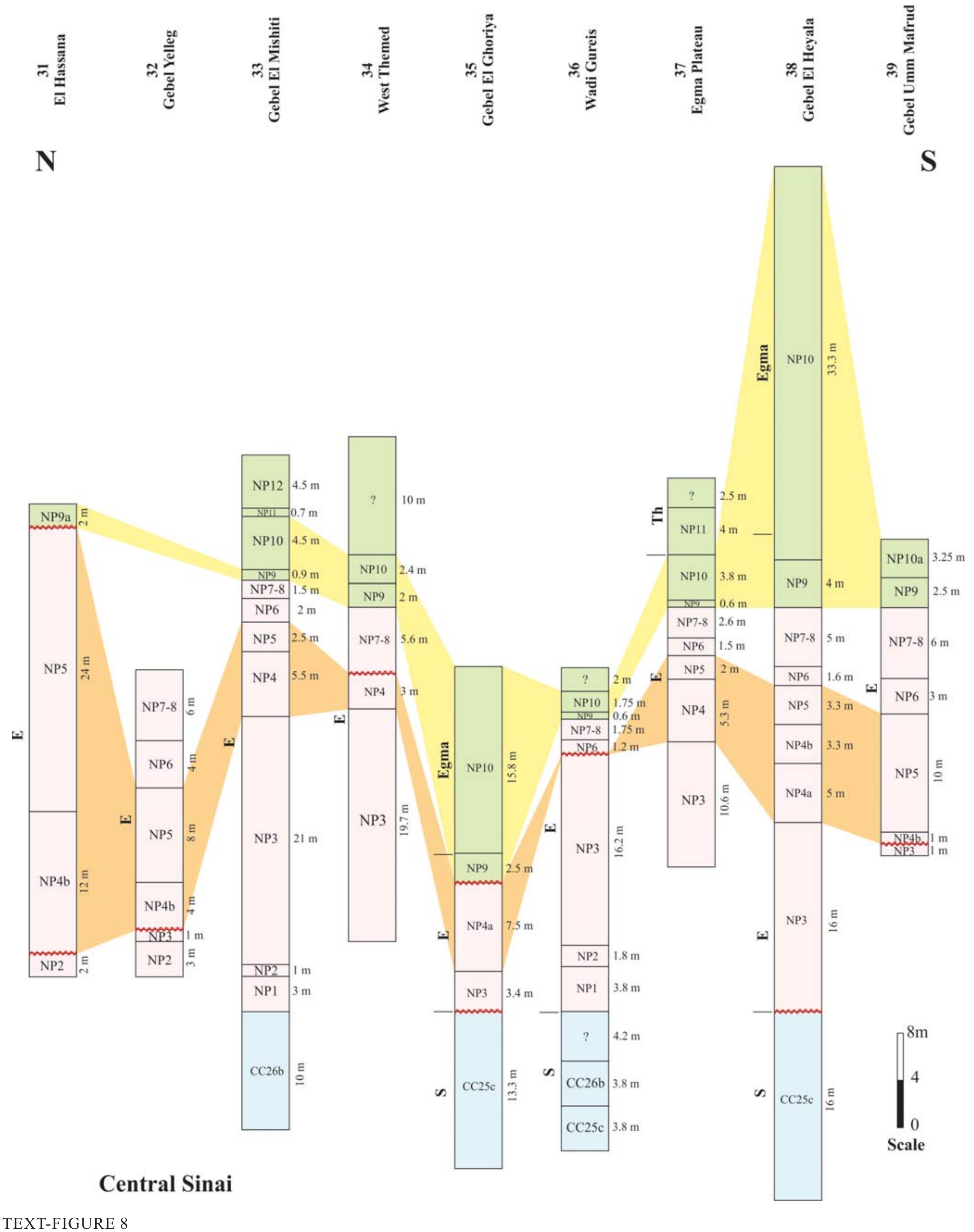
TEXT-FIGURE 6, *continued*.
Biozonal interpretation based on Gebel Qreiya: Berggren and Ouda 2003, Bolle et al. (2000), Monechi et al. 2000; Sprong et al. (2011), Tantawy (2003); Abu Had: Faris et al. (1989); Gebel Serai (Faris et al. 1989), Tantawy (2006); Wadi Hamama: Tantawy (2003); Gebel El Sheikh Eisa: Ghandour et al. (2004); Taramsa (Faris et al. 1989). Gebel Gurnah: Perch-Nielsen et al. (1978); Dababiya: Dupuis et al. (2003), this paper; Gebel Kilabiya: Ouda et al. (2003); Gebel Owaina: Perch-Nielsen et al. (1978), Ouda et al. (2003); Gebel El Shaghab: Ghandour et al. (2004); Gebel El Homra El-Shanka: Faris et al. (1999a); Wadi Abu Ghurra: Youssef and Mutterlose (2004); Kurkur Naqb Dungal: Youssef and Mutterlose (2004).



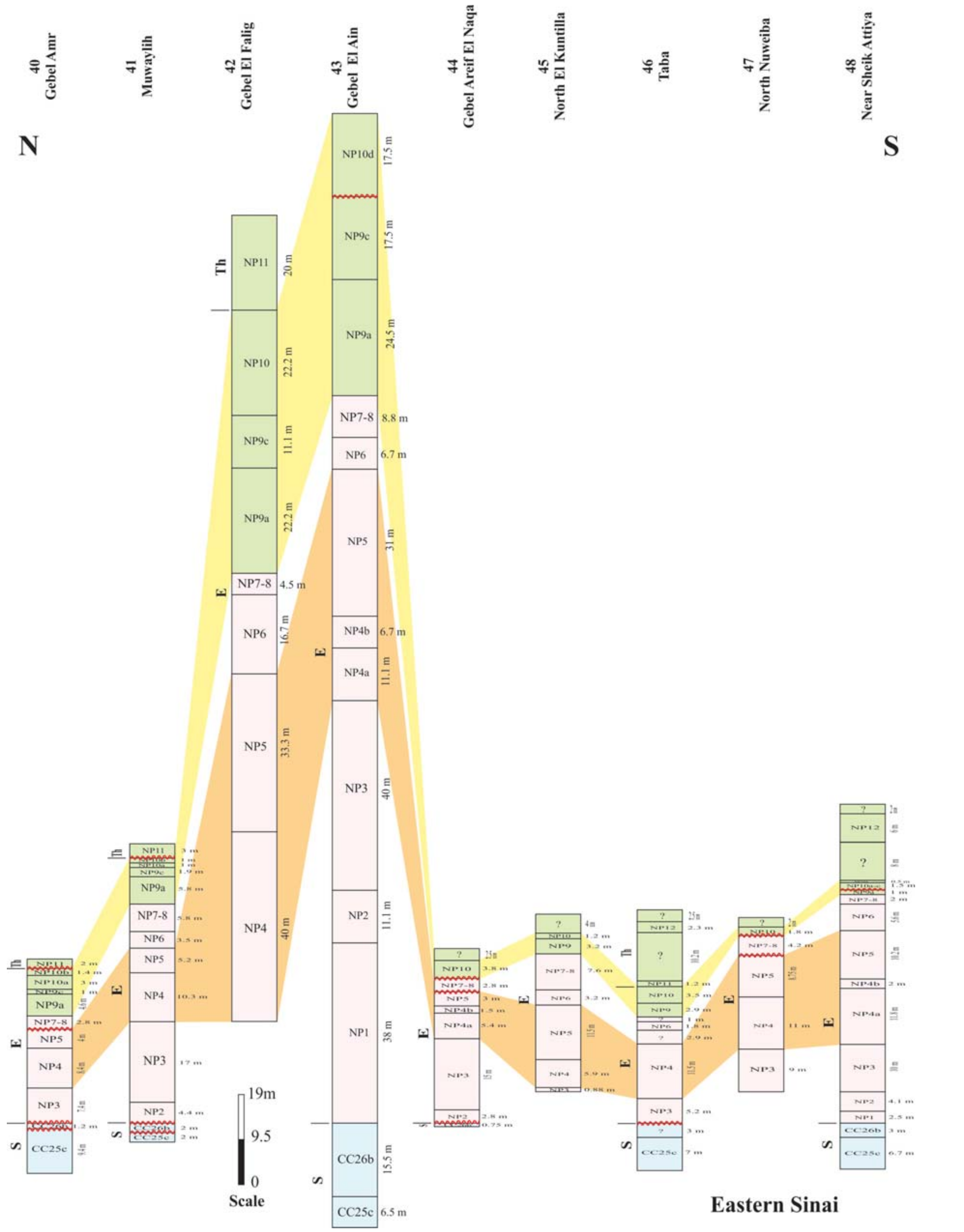
TEXT-FIGURE 7
Maastrichtian through Lower Ypresian stratigraphic successions in the Eastern Desert (Galala Mountains west of the Gulf of Suez to the Quseir area along the Red Sea Coast) and western Sinai, interpreted in terms of coccolith stratigraphy (see above for descriptions of zones and subzones). Locations of formational boundaries are shown where possible, as delineated in references used to construct figures. Lithologic symbols as for Text-fig. 6; S = Sudr Limestone. Bold line: correlation of the Paleocene/Eocene boundary (=NPa/b boundary).



TEXT-FIGURE 7, *continued*
Biozonal interpretation based on: St Paul: Faris, (1994), Scheibner et al. (2001); Wadi El Dakhl: Scheibner et al. (2001), Strougo and Faris (1993); Wadi Tarfa: Scheibner et al. (2001); Gebel Tarboul (Esh el Mellaha): El Dawoody (1990); Wasif area: Hewaidy and Faris (1989); Gebel Um El-Huetat: Faris (1988); Gebel Atshan: Faris et al. (1999b); Gebel Duwi: Bolle et al. (2000). El Dawoody et al. (1994). Abu Zenima: Bolle et al. (2000); Bir El Markha: Faris et al. (2005); Gebel Matulla: Abu Shama et al. (2007); Bolle et al. (2000), Faris et al. (2000); Gebel Nukhul: Monechi et al. 2000; Faris and Salem (2007); Gebel Mukattab: Faris et al. (2005); Wadi Feiran: Faris and Salem (2007); Gebel Belayim: El Dawoody (1992); Gebel Qabeliat: Marzouk and Abou-El-Enein (1997).

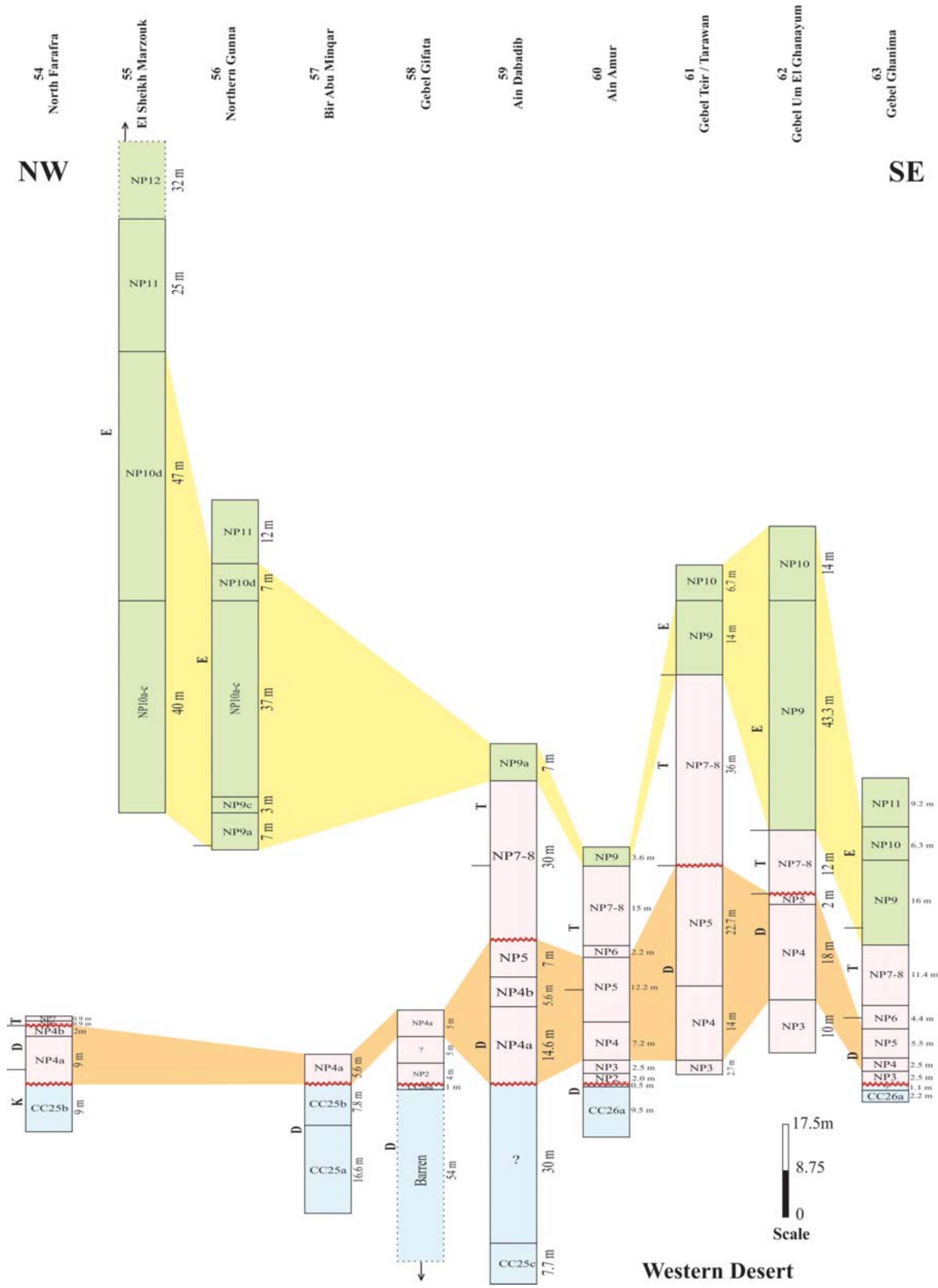


TEXT-FIGURE 8
Maastrichtian through Lower Ypresian stratigraphic successions in central and eastern Sinai, interpreted in terms of coccolith stratigraphy (see above for descriptions of zones and subzones). Locations of formational boundaries are shown where possible, as delineated in references used to construct figures. Lithologic symbols as for Text-figures 6 and 7. Bold line: Location of the Paleocene/Eocene boundary (=NPa/b boundary).

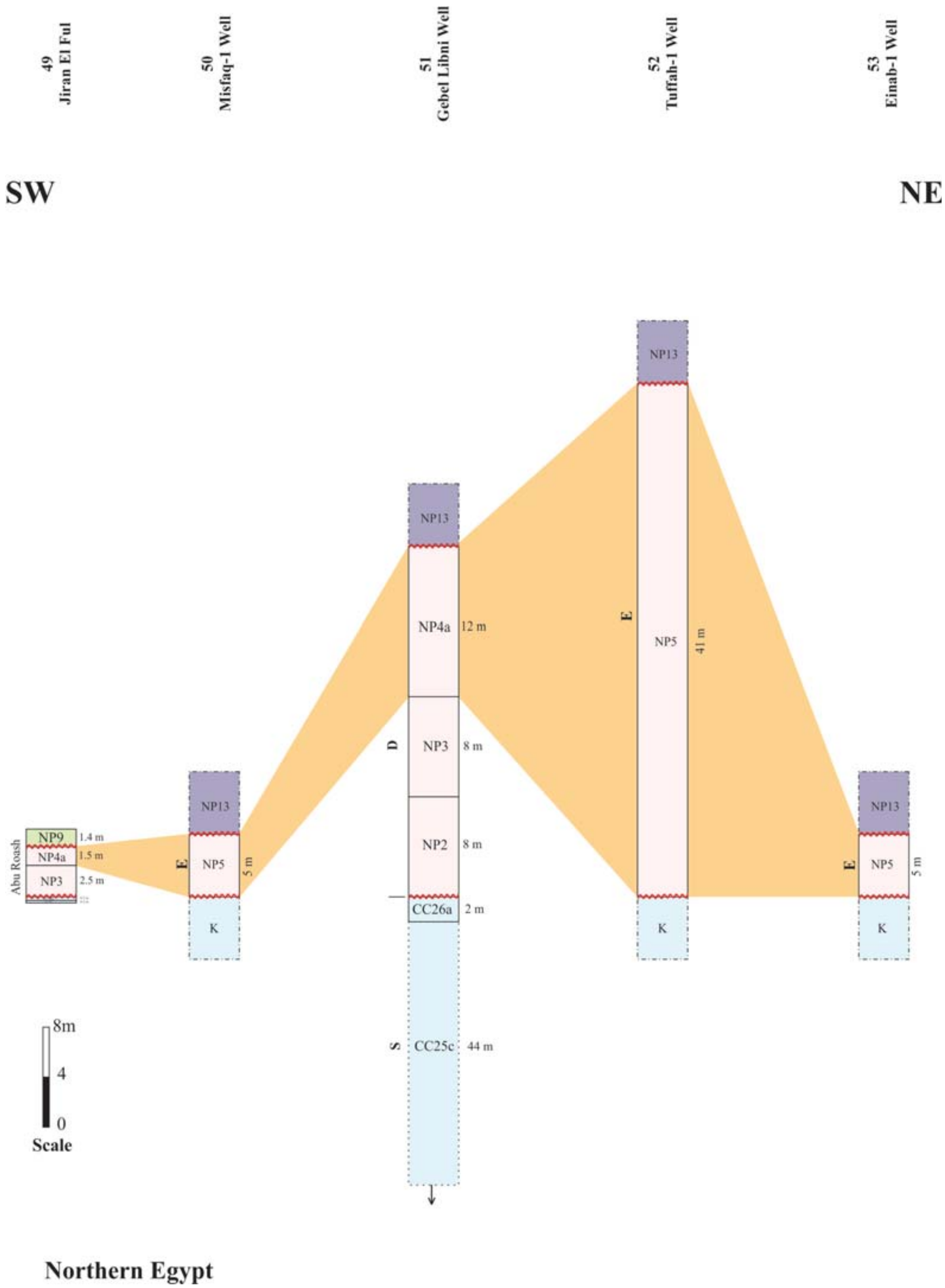


TEXT-FIGURE 8, *continued*

Biozonal interpretation based on: El Hassana: El Deeb et al. (2000); Gebel Yelleg: El Deeb et al. (2000); Gebel El Mishiti: Faris and Abu Shama (2007); West Themed: Marzouk and Luning (1998b); Gebel El Ghoriya: Swedan et al. (1995); Wadi Gurreis: Marzouk and Luning (1998b); Egma Plateau: Marzouk and Luning (1998b); Gebel El Heyala (Swedan et al. 1995); Gebel Umm Mafrud: Marzouk and Luning (1998), Amr: Ayyad et al. (2003); Muwaylih: Ayyad et al. (2003); El Falig: Faris (1998); Al Ain: Faris 1988; Gebel Areil El Naqa: Marzouk and Luning (1998); North El Kuntilla: Marzouk and Luning (1998); Taba: Marzouk and Luning (1998); North Nuweiba: Marzouk and Luning (1998); Sheik Attiya: Marzouk and Luning (1998).



TEXT-FIGURE 9
Maastrichtian through Lower Ypresian stratigraphic successions in the Western Desert, interpreted in terms of coccolith stratigraphy (see above for descriptions of zones and subzones). Locations of formational boundaries are shown where possible, as delineated in references used to construct figures. Lithologic symbols as for Text-figures 6 and 7. Bold line: Location of the Paleocene/Eocene boundary (=NPa/b boundary). Biozonal interpretation based on: North Farafra: Tantawy et al. (2001); El Sheik Marzouk: Faris and Strougo (1998); Northern Gunna: Faris and Strougo (1998); Bir Abu Minqar: Tantawy et al. (2001); Gebel Gifata: Tantawy et al. (2001); Ain Dabadib: Bassiouni et al. (1991); Ain Amur: Faris (1985); Gebel Teir/Tarawan: Ghandour et al. (2004); Gebel Um El-Ghanayum: Ghandour et al. (2004); Gebel Ghanima: Faris (1985).



TEXT-FIGURE 10
Maastrichtian through Lower Ypresian stratigraphic successions in Northern Egypt (unstable shelf) interpreted in terms of coccolith stratigraphy (see above for descriptions of zones and subzones). Bold line: Location of the Paleocene/Eocene boundary (=NPa/b boundary). Biozonal interpretation based on: Jiran El Ful: Faris and Abdel Hameed (1986); Misfaq 1 Well: Marzouk and Soliman (2004); Gebel Libni: Farouk and Faris (2008); Tuffah 1 Well: Marzouk and Soliman (2004); Einab 1 Well: Marzouk and Soliman (2004). Note that the ages of the Cretaceous sediments recovered from the Misfaq-1, Tuffah-1 and Einab-1 wells are unknown.

and LE units in the Paleocene-Lower Eocene successions, and this pattern is further enhanced when the UE is also considered (text-figs. 6–10, Table 5). Basically there is a contrast between 1) regions, such as the Nile Valley, where the LE and UE parts of the successions are unusually thick with respect to the DT, and 2) regions, such as eastern Sinai, where the opposite occurs. Because of the thickness variability discussed above and the numerous unconformities in some sections, the comparison between sedimentation rates may not be the best means to demonstrate the geographic contrast. We attempt to show this contrast by three means. One is graphical (text-figs. 6–10), and consists in comparing the thickness of two stratigraphic intervals representing similar durations. The LE represents a maximum duration of 3.15 Myr, (between the FAD of *H. multiradiatus* at 57.32 Ma and the LAD of *T. contortus* at 54.17 Ma). It would be difficult to consistently delineate a coeval Paleocene stratigraphic interval corresponding to 3.15 Myr, but the NP4-NP5 chronal interval is 3.71 Myr (between the FAD of *E. macellus* and the FAD of *H. kleinpelli*), its stratigraphic expression being Zones NP4 and NP5 (=UD, for "upper Dakhla" below). For our purpose a duration of 3.71 Myr is close enough to a duration of 3.15 Myr. Also, a longer Paleocene duration compensates somewhat for the stratigraphic gaps in the NP4-NP5 interval in some sections. Thickness (T) indices offer another means of comparison. The Rα index is the ratio T(LU)/T(DT). The Rδ index is the ratio T(LE+UE) /T(DT). Rα essentially accounts for the disparity in thickness between the Dakhla-Tarawan (also NP1-NP8) interval and the lower part of the Esna Shale. Rα = 1 when LE and DT are of the same thickness. Rα <1 indicates that DT is thicker than LE, and conversely DT is thinner than LE when Rα>1. Rδ accounts for the difference in thickness between the Dakhla-Tarawan interval and the Esna Shale. The greater the difference [Rδ-Rα] the more expanded UE is compared to LE (i.e., Zone NP11 vs. Zones NP9-NP10). A third means of comparing sections is to take into account their sedimentary history in terms of time represented by sediment accumulation. Differences in thickness between stratigraphic intervals of equal duration may reflect differences in sedimentation rates or stratigraphic truncations by stratigraphic gaps in the thinner sections. This approach is discussed above (text-figures 11-15; see methodology).

By using the three parameters explained above the following geographic pattern emerges:

1) In the Upper Nile Valley (text-figs. 6, 11; Table 5), the LE is thick and, with few exceptions, thicker than the UD. The Rα varies between 0.4 and 2.3, the Rδ 0.9 and 3.9. The DT contains multiple unconformities and long (several Myr) hiatuses; the LE and UE are essentially temporally continuous.

2) In the Galala Plateau–Red Sea Coast and western Sinai (text-figs. 7, 12; Table 5) the UD and LE are of comparable thickness (particularly in the Galala sections), and much thinner than in the Upper Nile Valley. The Rα varies between 0.20 and 1.2, the Rδ between 0.8 and 2.6. The DT contains numerous stratigraphic gaps some associated with long hiatus, as does the LE.

3) In central and eastern Sinai (text-figs. 8, 13; Table 5), the LE and UD are mostly thin, the LE being consistently thinner than the UD in the Eastern Sinai, as is also the case in most sections of the Central Sinai. The Rα varies between 0.10 and 0.3 in central Sinai but with two exceptions (1.1 and 1.7); it varies between 0.1 and 0.4 in eastern Sinai. The Rδ varies between 0.3 and 0.8. The DT contains some very long hiatuses (several Myr), particularly in central Sinai. The LE and UE also contain significant hiatuses (0.5 to >1 Myr).

4) In northern Egypt (text-figs. 10, 15; Table 5), the UD may be thicker than anywhere else in Egypt (Zone NP5 alone is 41 m thick in Tuffah-1 well), but the DT is highly discontinuous and no LE is preserved.

5) It is very difficult to determine a pattern in the Western Desert (text-figs. 9, 14; Table 5) because the NP10/NP11 zonal boundary was recovered in a few sections only. The Rα is meaningful in only two sections with values of 0.8 and 1.4. The Rδ cannot be established firmly in any section because the NP10/NP12 boundary was not recovered. The DT contains numerous stratigraphic gaps with long hiatuses, the LE and UE would appear to be essentially continuous.

Taking the UE into consideration only enhances the architectural patterns described above (Table 5). The UE is thick in the Nile Valley, Galala Plateau and western Sinai. It is very thin (a few meters) in the central and eastern Sinai (e.g., Gebel El Mishiti, Taba, North Nuweiba, Sheik Attiya).

Discussion

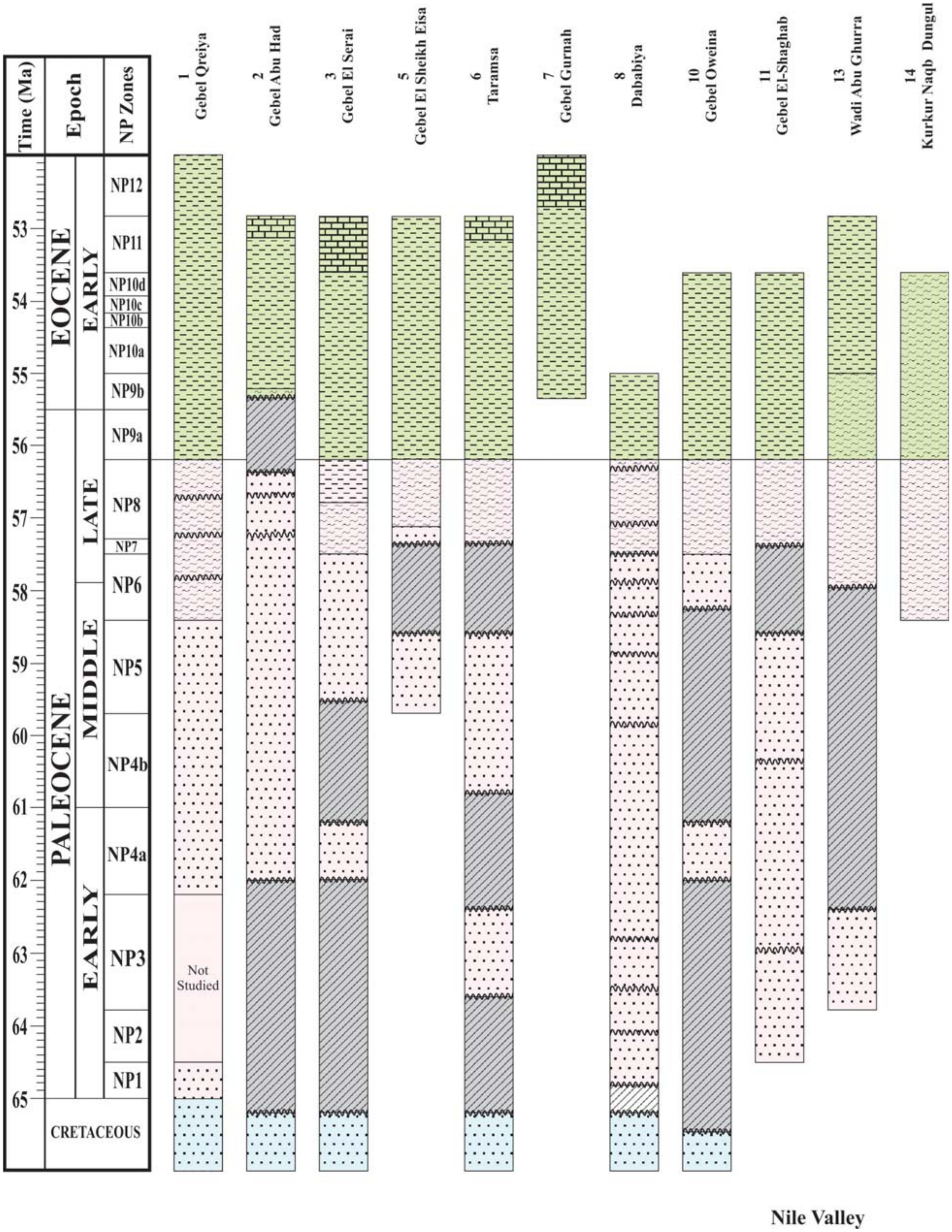
A regional stratigraphic pattern was expected/anticipated. First, the successions considered here are from different tectonic settings. The Nile Valley and Western Desert were part of the stable margin where deposition was less influenced by tectonics than on the unstable margin to which the Galala Plateau and Sinai belonged. Second, they represent a different sedimentary regime, with mostly siliciclastic deposits in the Nile Valley and Western Desert but hemipelagites in the Sinai. Further our regional differentiation corresponds well with prior works, such as the shared history of central and eastern Sinai (Luning et al. 1998b) and of the Galala Mountains and western Sinai (Scheibner et al. 2001a). However, the large regional differences, both in terms of thickness and stratigraphic continuity, that we document here were not expected.

The central and eastern Sinai clearly stands out as an area with 1) thinner Paleocene-Lower Eocene successions than elsewhere 2) a very thin Esna Shale equivalent interval (= LE + UE), and 3) abundant unconformities and significant hiatuses. Perhaps the most distinctive characteristic of this region is the thinness of the Lower Eocene succession, with the Esna only a few meters thick. The Nile Valley successions, particularly South of Luxor, exhibit characters opposite to those of eastern Sinai, with very thick Esna Shales reaching up to 120 m thick at Dababiya. For comparison, a composite of the Esna-Thebes succession in the Nile Valley (Dababiya + Gurnah) reaches a cumulative thickness of 460 m whereas the correlative interval in the Taba section (Eastern Sinai) is ~20 m thick!

Stratigraphic successions of the Galala Plateau–western Sinai region are more similar to those of the Nile Valley than further east in Sinai. Concerning the Esna Shale an interesting difference is that its thickness expands with Zone NP11, whereas in the Nile Valley the lower part of the Shales was deposited at high sedimentation rates. There is no clear difference between the successions of the Southern Galala Subbasin (Wadi El Dakhl, Wadi Tarfa) and those further south along the Red Sea Coast, except for the Duwi succession that would appear to include the most complete Paleocene section (probably due to its shallower setting; Speijer and Wagner 2002).

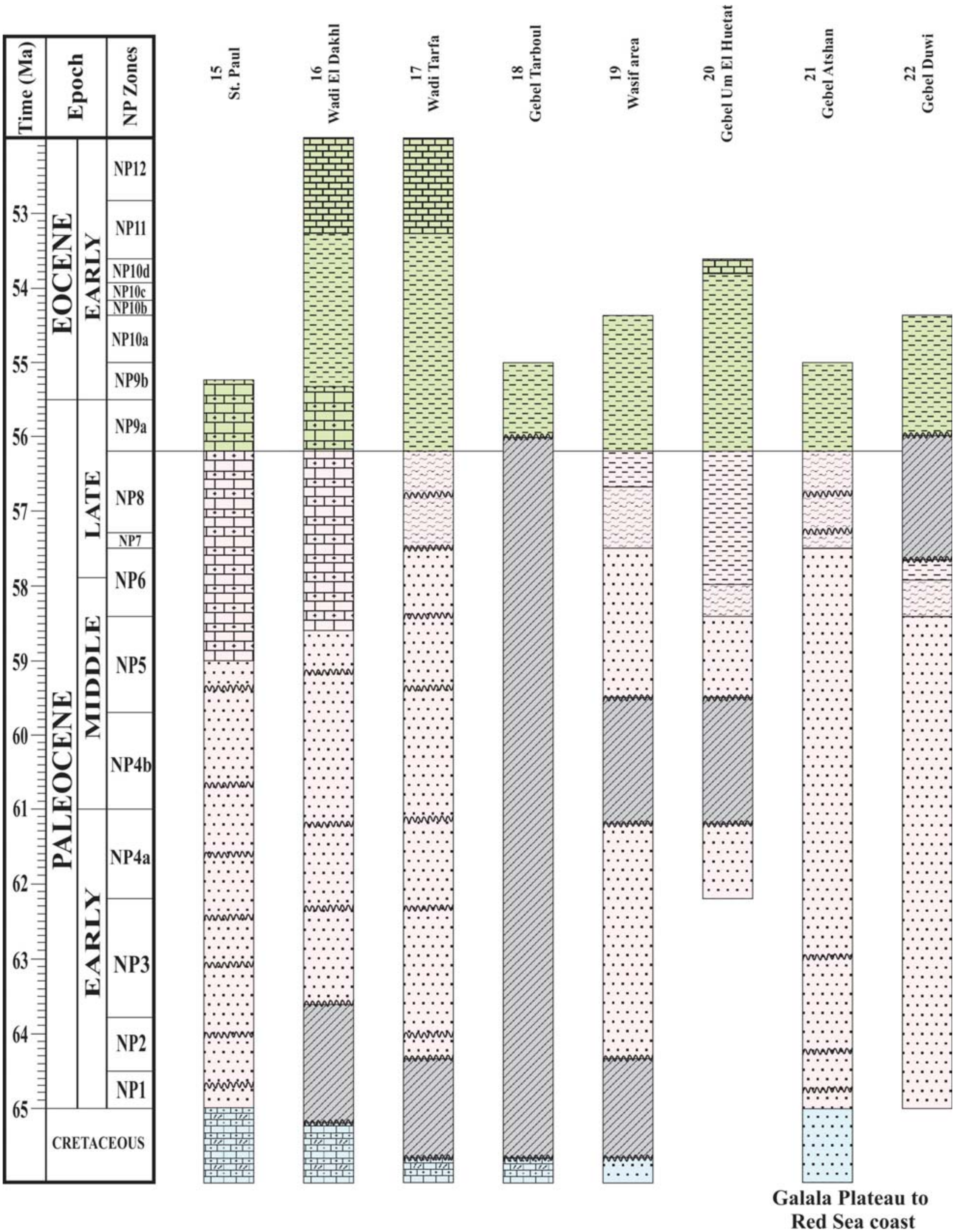
The successions from the Western Desert would seem similar to those of the Nile Valley, the biozones NP9 and NP10 being expanded in the lower part of the Esna Shale. However the data are presently inconclusive.

The architecture of the Paleocene-lower Eocene successions of Egypt has been interpreted as reflecting eustatic changes, based

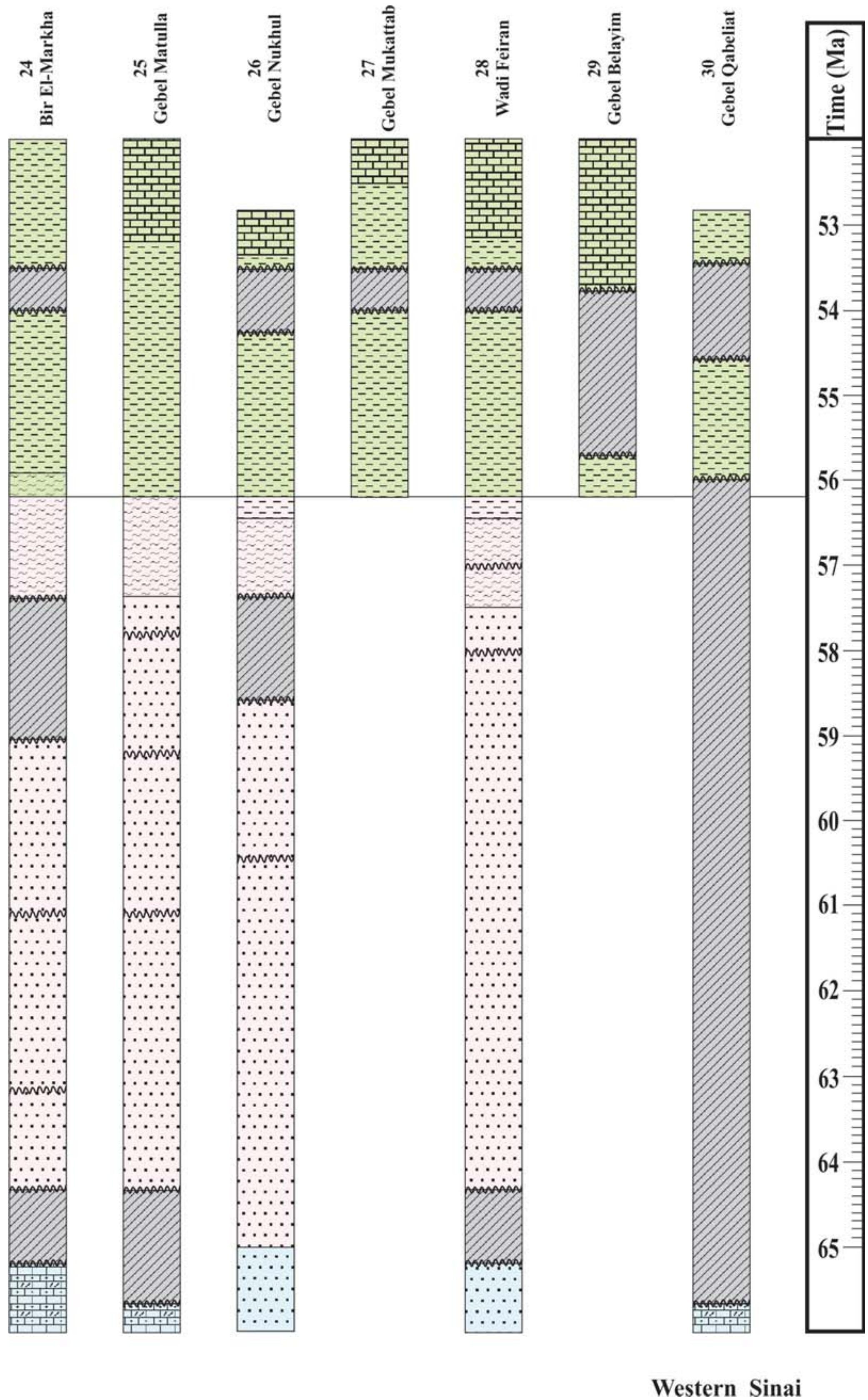


TEXT-FIGURE 11

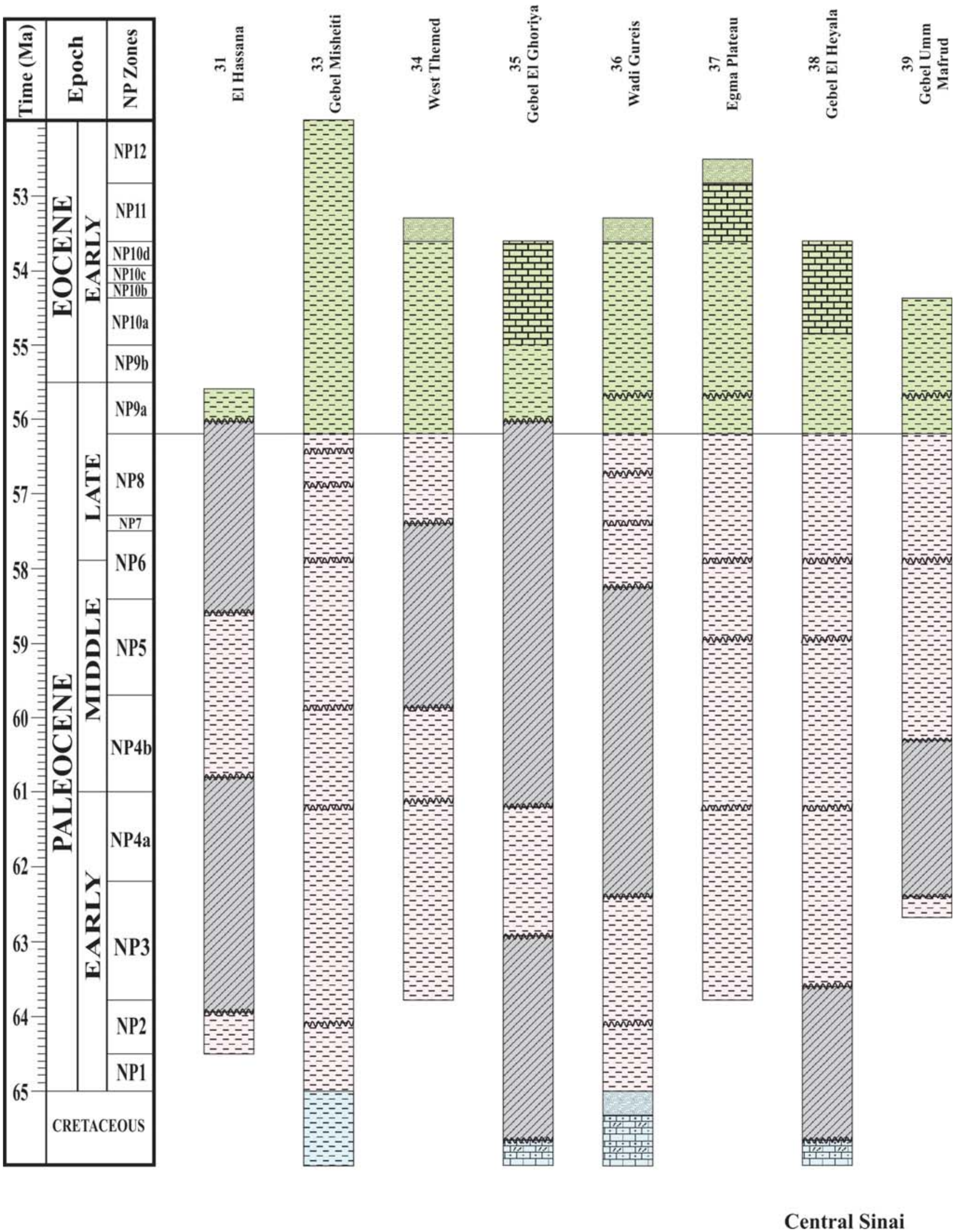
Depositional history of Maastrichtian through Lower Ypresian stratigraphic successions on the southern shelf (Egypt) of the Tethys Ocean: Edges of the Western and eastern Deserts along the Nile Valley. Lithologic symbols are given in Text-figure 16. Location of hiatuses based on the absence of biozones. Location of unconformities (without indication of hiatus) arbitrary for lack of sufficient data to allow precise determination. Biochronology from Berggren et al. (1995). For stratigraphic succession: see Text-figure 6. Cretaceous rocks shown to anchor the base of the Paleocene succession, but age of upper Cretaceous surface not tied to the time scale.



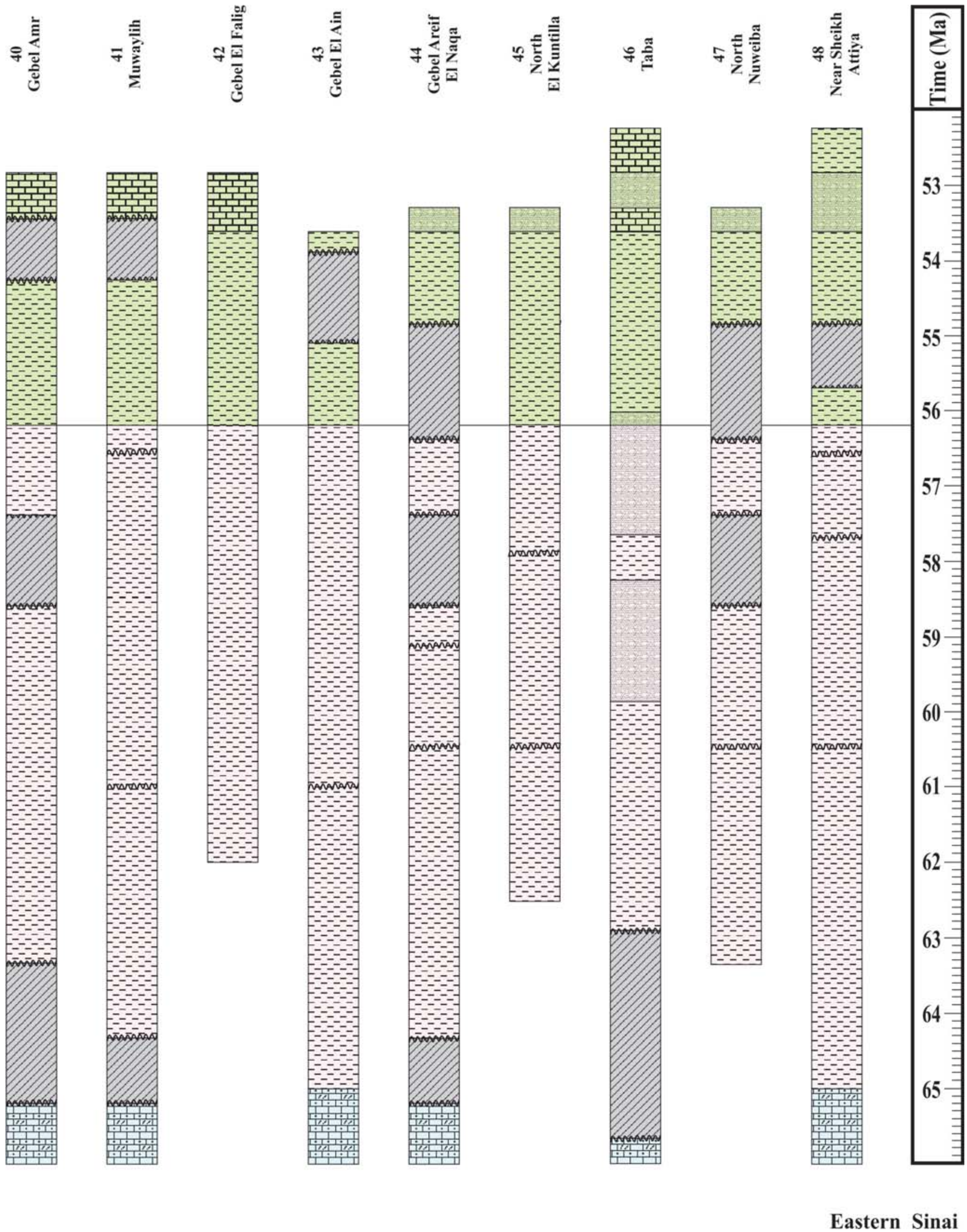
TEXT-FIGURE 12
Depositional history of Maastrichtian through Lower Ypresian stratigraphic successions on the southern shelf (Egypt) of the Tethys Ocean: Eastern Desert (Galala Plateau to Qusseir area, Red Sea Coast, and western Sinai) Lithologic symbols and biochronologic framework as in Text-figure 11.



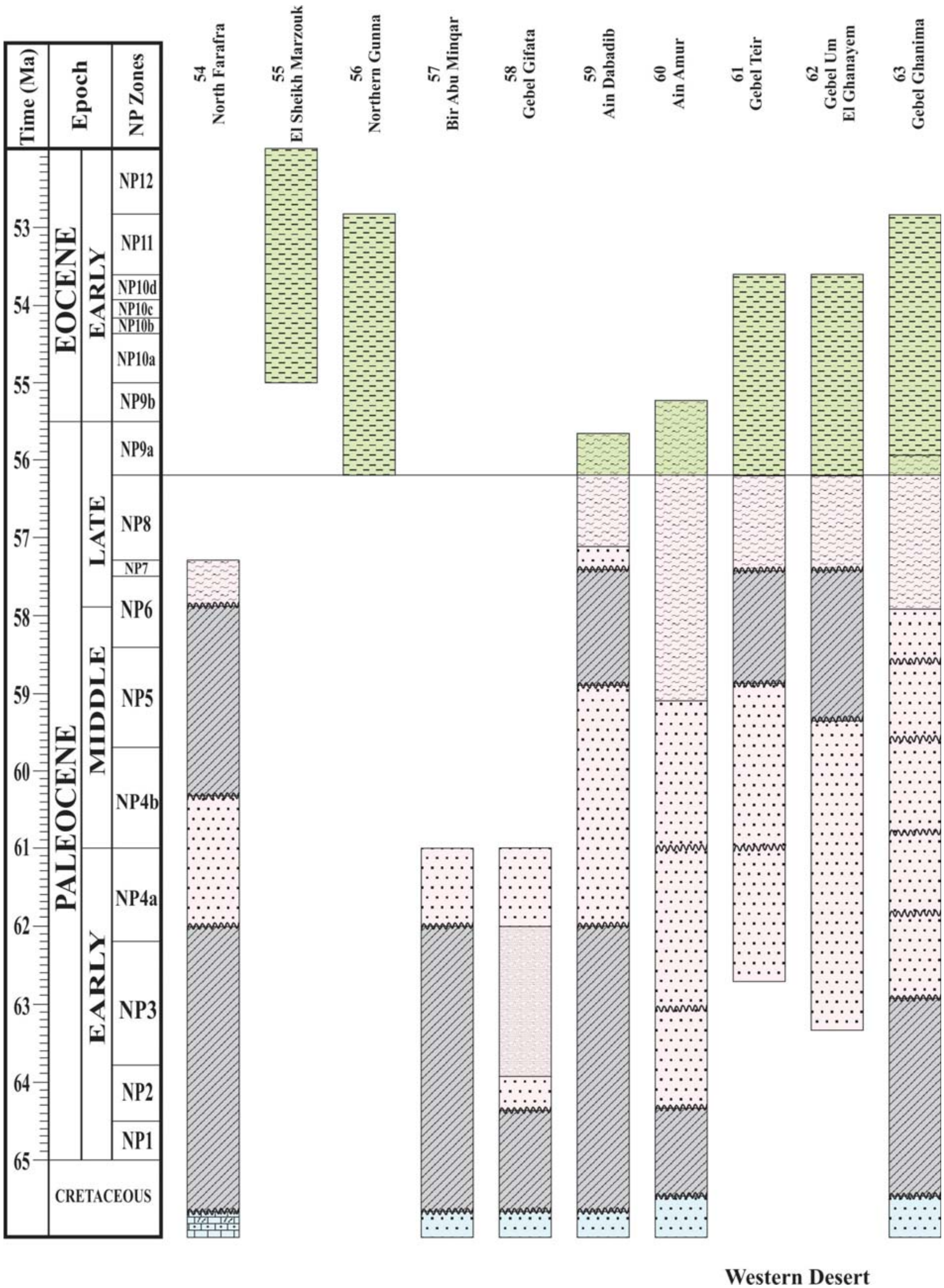
TEXT-FIGURE 12, *continued*
For stratigraphic succession: see Text-figure 7. Cretaceous rocks shown to anchor the base of the Paleocene succession, but age of upper Cretaceous surface not tied to the time scale.



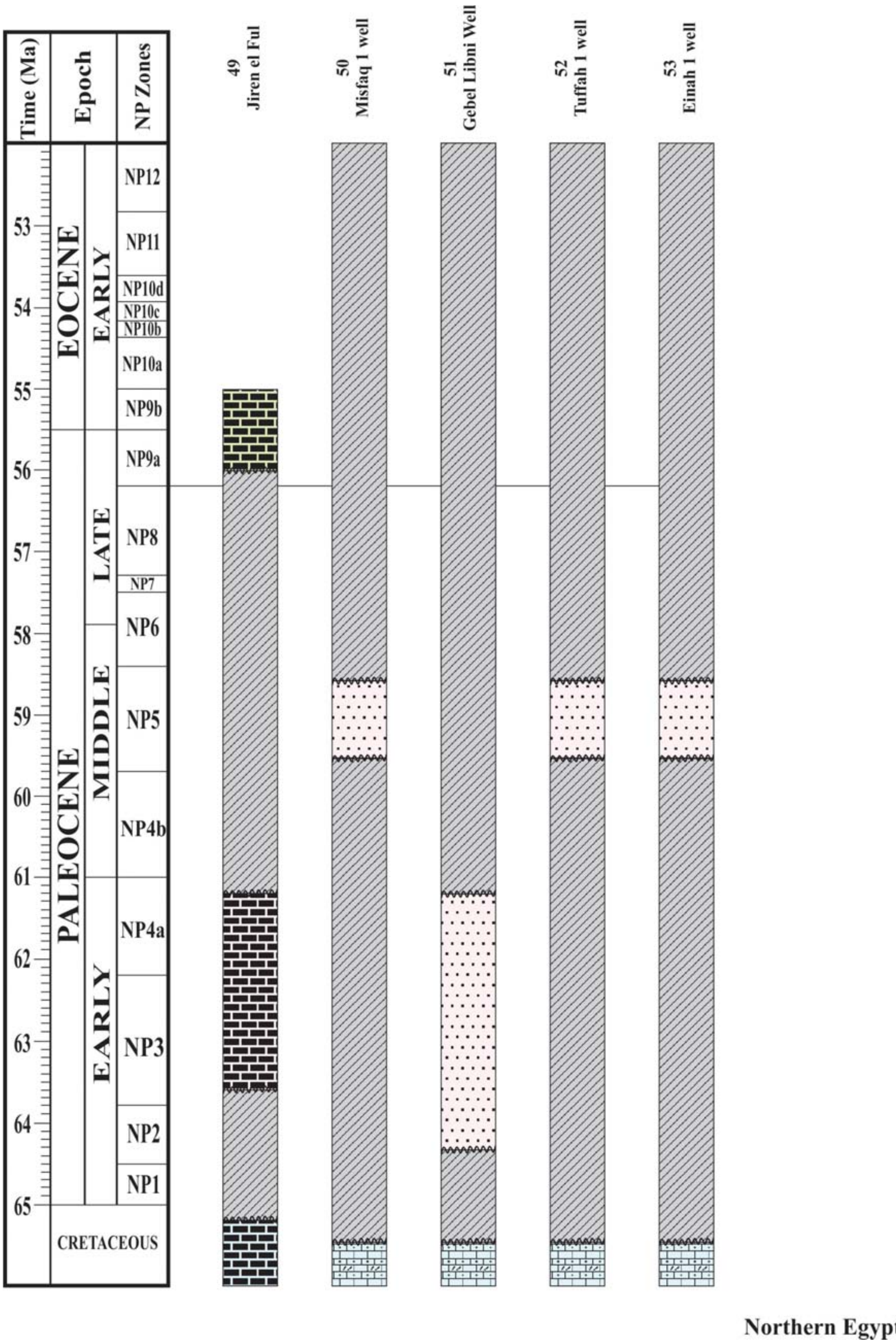
TEXT-FIGURE 13
Depositional history of Maastrichtian through Lower Ypresian stratigraphic successions on the southern shelf (Egypt) of the Tethys Ocean: central and eastern Sinai.



TEXT-FIGURE 13, *continued.*
Lithologic symbols and biochronologic framework as in Text-figure 15. For stratigraphic succession: see Text-figure 8. Cretaceous rocks shown to anchor the base of the Paleocene succession, but age of upper Cretaceous surface not tied to the time scale.



TEXT-FIGURE 14
Depositional history of Maastrichtian through Lower Ypresian stratigraphic successions on the southern shelf (Egypt) of the Tethys Ocean: Western Desert. Lithologic symbols and biochronologic framework as in Text-figure 11. For stratigraphic succession: see Text-figure 9. Cretaceous rocks shown to anchor the base of the Paleocene succession, but age of upper Cretaceous surface not tied to the time scale.



TEXT-FIGURE 15
Depositional history of Maastrichtian through Lower Ypresian stratigraphic successions on the southern shelf (Egypt) of the Tethys Ocean: Northern Sinai and Nile Delta. Lithologic symbols and biochronologic framework as in Text-figure 11. For stratigraphic succession: see Text-figure 10. Cretaceous rocks shown to anchor the base of the Paleocene succession, but age of upper Cretaceous surface not tied to the time scale.

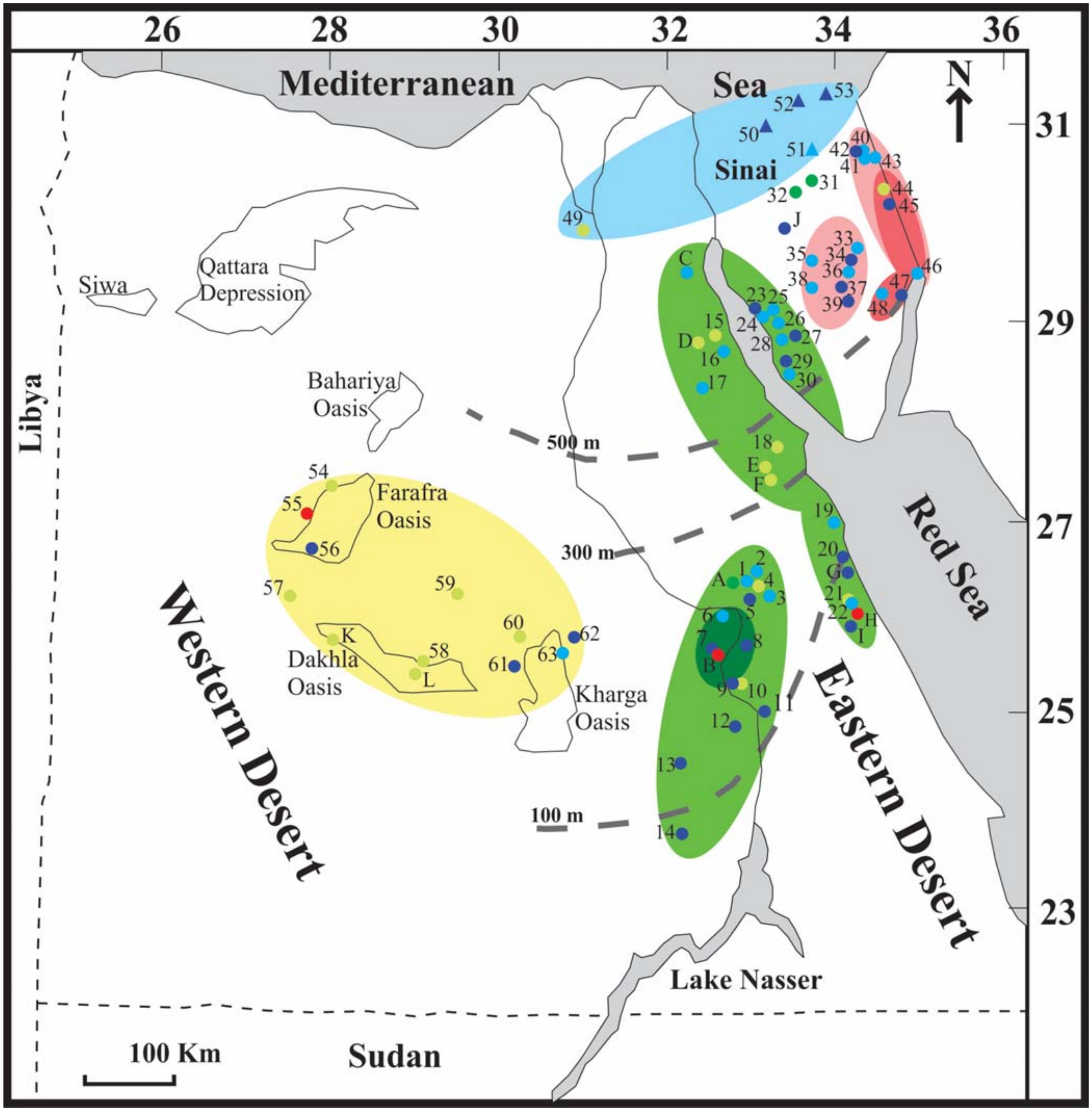
TEXT-FIGURE 16
Key to lithologic symbols in text-figures 11 to 15.

on the distribution of benthic foraminiferal assemblages (e.g., Speijer and Schmitz 1998) and sequence stratigraphy (e.g., Luning et al. 1998b). An important local tectonic component (uplift) was superimposed on eustasy to interpret the architecture of the Paleocene succession on the Galala platform (Scheibner et al. 2003b; Ayyat and Obaidalla 2013) and this was expanded to the Lower Eocene (Schiebner and Speijer 2008; Höntzsche et al. 2011).

Accommodation may not be sufficiently documented with regard to stratigraphic architecture, although it is a determinant factor. Benthic foraminiferal assemblages have made it possible to delineate 100 m, 300 m and 500 m isobaths on the stable shelf of Egypt (Speijer and Wagner 2002: Fig. 1). One of the shallowest localities was Duwi, (locality 22, text-figs. 4, 6, 12) whereas water depth increased northwards, with Dababiya at ~150 m (in agreement with Allegret and Ortiz, this volume) and Gebel Qreiya ~200 m. The DT interval at Dababiya is 60 m thick. If we apply a subsidence rate of 15 m/Myr as calculated by Speijer and Wagner (2002) for the Duwi locality, subsidence would have been amply sufficient to accommodate the input of 60 m of Paleocene [DT] sediments, even when sea level was low. However, this would have been highly insufficient for the input of 120 m of Esna Shales (let alone an additional 300 m of Thebes Limestone if this thickness was reached at Dababiya). Rates of subsidence would have had to be more than double to maintain the same water depth (as indicated by benthic foraminifera, W.A. Berggren, pers. Commun. August 2012) throughout deposition of the shales at Dababiya. Moreover, since this deposition occurred during a long-term regressive trend in the Middle East (Speijer and Wagner, 2002), rates of subsidence would have had to be even greater. We thus propose that the transition from the carbonate deposition of the Tarawan to the detrital/hemipelagic Esna Shales was accompanied by a marked increase in rates of subsidence in areas now occupied by the Nile Valley, and possibly the Western Desert. The completeness of the lower Eocene successions in these regions is likely explained by sustained, rapid subsidence. In contrast subsidence would have considerably slowed in the area now occupied by the eastern Sinai, resulting in thin, discontinuous, lower Eocene successions there (text-fig. 17).

There is ample evidence of Paleocene and Early Eocene tectonic activity in the northern part of the Eastern Desert (Galala Mountains) and in northern Egypt (Cairo area) as a result of the closure of the Neo-Tethys and the growth of the Syrian Arc folds (Patton et al. 1994 and references therein; Shahar 1994). Scheibner et al. (2000, 2003) documented near the Monastery of Saint Paul (text-fig. 4, Locality 15) the occurrences in outcrops of glides, slumps and debris flows interspersed with discontinuous, Selandian and Thanetian hemipelagic deposits (they were interpreted by these authors as evidence of sea level changes). In the same area (southern Galala Plateau) Höntzsch et al. (2011) documented the late Paleocene reactivation of Cretaceous faults followed by Early Eocene deepening of the mid-carbonate ramp and coincident uplift of its inner part. Youssef (2003) discussed the gentle syn-sedimentary folding that took place on the southern platform in the area between Esna and Qena (Nile Valley) during the Cretaceous and Paleocene. Strougo (1986) dubbed the Middle and Late Paleocene tectonic unrest the "*Velascoensis* Event" whose evidence (faults, stratigraphic gaps, thin glauconitic levels in otherwise pure carbonate facies, hardgrounds, conglomeratic limestones) was recorded throughout Egypt, in the northern unstable shelf (e.g., Jiran el ful, Abu Roash area, text-fig. 4, Locality 49), and also on the stable shelf (e.g., Kharga Oasis). The massive Paleocene stratigraphic gaps recorded throughout Egypt may, in fact, reflect mass movements of sediments in a seismically active region, although their relationship with sea level history (Luning et al. 1998b; Scheibner et al. 2000; Höntzsch et al. 2011; King, this volume) remains to be clarified. We propose that enhanced subsidence in the Nile Valley during the latest Paleocene (early Magnetic Chron C24r; i.e., near the end of the "Velascoensis Event") resulted from far field tectonic relaxation after sustained Middle and Late Paleocene tectonic activity (Chron C26 and C25) in the Syrian Arc. Subsidence would have been facilitated by the numerous faults in the area where wrench faulting occurred during the Cretaceous and Paleocene (Youssef 2003).

Subsidence first increased markedly in the Nile Valley during the latest Paleocene, as indicated by the chalk to shale transition. Dupuis (this volume) interprets the latest Paleocene abrupt re-occurrence of detrital clay minerals (Hanadi Member of the Esna Shale) in the Dababiya Core as indicative of a sea-level induced resumption of continental erosion. In our view, the abrupt change in sedimentary regime following an episode of calcareous deposition (Tarawan Chalk) was not so much induced by a sea level fall as by the sudden subsidence of the sea floor and concomitant inshore uplift due to continental flexure. Subsidence would have remained high during the deposition of the Esna shales, and then would have decreased progressively during deposition of the Thebes Limestone that



TEXT-FIGURE 17
Map of Egypt showing areas of greater (intense blue for maximum) and lesser (intense red for minimum) subsidence during the Early Eocene (Biochrons NP9-NP 11).

represents an upward regressive sequence terminated by inner neritic, oyster-bearing limestones (Said 1962; Tawfik et al. 2011). Further to the northeast (Eastern Desert, western Sinai), subsidence also increased, but later (earliest Eocene; mid-Chron C24) than in the Nile Valley (as indicated by comparative thicknesses of biozones [see above] and sedimentologic features [Höntzsch et al. 2011]). The concomitant deepening of the mid-ramp and shallowing of the inner ramp (Höntzsch et al. 2011) seen in the Galala area represent a situation comparable to that in the Nile Valley. In contrast, further East, the central and eastern Sinai behaved differently. If anything, their stratigraphy indicates an Early Eocene shallowing, marked by very condensed sections and sedimentary instability resulting in stratigraphic gaps. To the North, continued tectonic activity is suggested by the lack of Upper Paleocene-Lower Eocene sequences between lower Selandian and upper Ypresian. Data are insufficient to reconstruct the tectonic history of the Western Desert at this time.

SUMMARY AND CONCLUSIONS

Biostratigraphic analysis of the Dababiya Core (Aubry and Salem, this volume) 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. To determine the significance of this contrast, we have conducted a review of calcareous nannofossil stratigraphic studies of Paleocene-Lower Eocene (Dakhla Shales – Esna Shales) sections throughout Egypt. This constitutes a database of stratigraphic successions deposited in different settings (e.g., stable/unstable shelf, primarily siliciclastic or hemipelagic sediments, neritic (<200 m) to bathyal (>200 m). We show that the architecture of the Paleocene–Lower Eocene stratigraphic record in Egypt exhibits a regional pattern, with extensive lower Eocene successions (representing ~ 3 Myr) present in the Nile Valley where they are significantly thicker than the Paleocene intervals (representing ~10 Myr), and extremely thin Lower Eocene successions present in central and eastern Sinai where they are consistently thinner than the Paleocene interval. Successions in the Eastern Desert and western Sinai exhibit a weaker lower Eocene/Paleocene contrast than in the Nile Valley. We explain these regional differences as reflecting differential tectonic regime (subsidence), suggesting that rates of subsidence 1) increased a) considerably in the latest Paleocene (Biochron NP9) along the Nile Valley where high rates were sustained during Biochrons NP10 and NP11, and b) to a lesser extent in the Eastern Desert and western Sinai beginning in the Early Eocene (Biochron NP10), but 2) decreased in central and eastern Sinai possibly as a result of uplift. Increase in subsidence is interpreted as resulting from tectonic relaxation following active Middle and Late Paleocene (Chron C26 and C25) tectonic activity along the Syrian Arc Folds in relation to the closure of the Neotethys Ocean.

This study shows that the Paleocene stratigraphic record of Egypt is highly discontinuous, confirming earlier regional reports (e.g., Awad and Ghobrial 1965; Anan 1992; Jenkyns 1990). We demonstrate the presence of numerous unconformities representing substantial hiatuses, i.e., longer than 1 Myr, but we are unable to compare the extent and overlap between hiatuses in adjacent sections for lack of sufficient data. We propose that these major hiatuses reflect mass-movements of sediments resulting from syn-sedimentary tectonic activity during the Paleocene. A test of this will be the re-examination in the framework of sequence stratigraphy of selected sections among those discussed here and their high-resolution sampling for comprehensive temporal analysis. The Paleocene-early Eocene Egyptian shelf of the Neotethys Ocean offers a great opportunity to separate the role of eustasy from that of tectonics in shaping the stratigraphic record.

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TABLE 1
Early development of coccoliths studies in Egypt (1968 to 1978; the late works by pioneering authors are also shown). Green indicates occurrence; gold indicates uncertain occurrence; red indicates stratigraphic gap. See explanatory notes below.

Authors & Sections		**Sadek, 1968**	**Sadek & Abd El Razik, 1970**	**Kerdany, 1970**	**Kerdany, 1970**	**Kerdany, 1970**	**Kerdany, 1970**
Series	**Zones**	**G. Homeira**	**G. Um El Huetat**	**El Guss Abu Said**	**G. Edmonstone**	**G. Ghanima**	**G.Oweina**
Middle Miocene		Helvetian					
Lower Miocene							
	NP25						
Upper Oligocene	**NP24**						
	NP23						
	NP22						
Lower Oligocene	**NP21**						
Upper Eocene	**NP19-20**						
	NP18						
Middle Eocene	**NP17**	Bartonian					
	NP16						
	NP15	Lutetian					
Lower Eocene	**NP14**						
	NP13						
	NP12						
	NP11		Esna Shale (30 m)	Upper ES ? L. Th	Upper ES ? L. Th	Upper ES ? L. Th	Upper ES ? L. Th
	NP10		Esna Shale (2.5 m)				
Upper Paleocene	**NP9**		Esna Shale (20 m)	Lowermost ES	Lowermost ES	Lowermost ES	Lowermost ES
	NP8						
	NP7						
Middle Paleocene	**NP6**						
	NP5						
Lower Paleocene	**NP4**						
	NP3						
	NP2			yes		yes	
Lower Paleocene	**NP1**			no	no	no	no
Maastrichtian	***M. prinsii***						
	N. frequens						
	M. murus						A. cymbiformis (9)
	L. quadratus			A. cymbiformis (9)	A. cymbiformis	A. cymbiformis (9)	A. cymbiformis (9)
	T. gothicus trifidus						A. cymbiformis (9)

TABLE 1
continued.

Authors & Sections		**Kerdany, 1970**	**Kerdany, 1970**	**Kerdany, 1970**	**Shafik, 1970 Shafik & Stradner, 1971**	**Shafik & Stradner, 1971**	**Shafik & Stradner, 1971**
Series	**Zones**	**G. Gurnah**	**G. Abu Had**	**Masak el Sharib**	**G. Tarbouli**	**Ash El-Mellaha**	**Hamadat**
Middle Miocene							
Lower Miocene							
	NP25						
Upper Oligocene	**NP24**						
	NP23						
	NP22						
Lower Oligocene	**NP21**						
Upper Eocene	**NP19-20**						
	NP18						
Middle Eocene	**NP17**						
	NP16						
	NP15						
Lower Eocene	**NP14**						
	NP13						
	NP12						
	NP11	Upper ES ? L. Th	Upper ES ? L. Th		Esna Shale (10 m)		
	NP10				Esna Shale		Esna Shale
Upper Paleocene	**NP9**	L most ES [5m] Sdaek & Teleb, 1978b	Lower most ES			Esna Shale	
	NP8						
	NP7						
Middle Paleocene	**NP6**						
	NP5						
Lower Paleocene	**NP4**						
	NP3						
	NP2		yes				
Lower Paleocene	**NP1**	no	yes	no			
Maastrichtian	***M. prinsii***						
	N. frequens						
	M. murus						
	L. quadratus		A. cymbiformis(9)	Khoman Chalk(9)	Tarawan Chalk (48 m)(9)		
	T. gothicus trifidus		A. cymbiformis(9)	Khoman Chalk(9)			

TABLE 1
continued.

Authors & Sections		Shafik & Stradner 1971	Shafik & Stradner 1971	Shafik & Stradner 1971	Sadek 1972	Sadek 1972	Sadek 1972
Series	**Zones**	**G. Duwi**	**Wadi Had**	**Haramween setion**	**Betty Well**	**Ghazalat Well**	**Burg el Arab Well**
Middle Miocene							
Lower Miocene							
	NP25						
Upper Oligocene	**NP24**						
	NP23						
	NP22						
Lower Oligocene	**NP21**						
Upper Eocene	**NP19-20**						
	NP18						
Middle Eocene	**NP17**						
	NP16						
	NP15						
Lower Eocene	**NP14**					1112-1132 ft	NP14a: 5020-5124 ft
	NP13						
	NP12						
	NP11	Esna Shale		Esna Shale			
	NP10	Esna Shale		Esna Shale			
Upper Paleocene	**NP9**	Esna Shale	Esna Shale	Esna Shale			
	NP8	Tarawan Chalk					
	NP7						
Middle Paleocene	**NP6**						
	NP5						
Lower Paleocene	**NP4**						
	NP3						
	NP2						
Lower Paleocene	**NP1**						
Maastrichtian	***M. prinsii***						
	N. frequens						
	M. murus						
	L. quadratus						
	T. gothicus trifidus						

TABLE 1
continued.

Authors & Sections		Sadek 1972	Sadek 1972	Sadek 1972	El Dawoody and Barakat 1972	El Dawoody and Barakat 1973	Sadek & Teleb 1973, 1974
Series	**Zones**	**Beni Suef**	**G. Mokattam**	**El Heit Ghorab**	**Duwi**	**Duwi**	**Betty Well**
Middle Miocene							
Lower Miocene							
	NP25						
Upper Oligocene	**NP24**						
	NP23						
	NP22						
Lower Oligocene	**NP21**						
Upper Eocene	**NP19-20**						
	NP18						
Middle Eocene	**NP17**		Maadi Fm	Maadi Fm			
	NP16	Mokkatam Fm	Mokkatam Fm				
	NP15						?Core 2
Lower Eocene	**NP14**						Core 3
	NP13						Core 4
	NP12						
	NP11				Thebes calcareous shale		
	NP10				Esna Shale (41 m)		
Upper Paleocene	**NP9**						
	NP8						
	NP7						
Middle Paleocene	**NP6**						
	NP5						
Lower Paleocene	**NP4**					samples 19D, 20D	
	NP3						
	NP2					Dakhla Shale (50 m)	
Lower Paleocene	**NP1**					Dakhla Shale (10 m)	
Maastrichtian	***M. prinsii***						
	N. frequens						
	M. murus					A. cymbiformis (9)	
	L. quadratus					A. cymbiformis Dakhla Sh 70 m (9)	
	T. gothicus trifidus						

TABLE 1
continued.

Authors & Sections		**El Dawoody and Zidan, 1976**	**El Dawoody, 1977**	**Perch-Nielsen et al., 1978**	**Perch-Nielsen et al., 1978**	**Sadek & Teleb, 1978a, b**	**Sadek & Teleb, 1978a, b**
Series	**Zones**	**West Mawhoob**	**G. El Teir(8)**	**G. Aweina**	**G. Gurnah**	**G. Owaina**	**G. Um El-Ghanayem**
Middle Miocene							
Lower Miocene							
	NP25						
Upper Oligocene	**NP24**						
	NP23						
	NP22						
Lower Oligocene	**NP21**						
Upper Eocene	**NP19-20**						
	NP18						
Middle Eocene	**NP17**						
	NP16						
	NP15						
Lower Eocene	**NP14**						
	NP13						
	NP12				Thebes Limestone		
	NP11		Thebes Calc. Sh. bed 2 (~15 m)		Gurnah Calc. Shale		
	NP10		Thebes Calc. Sh. bed 2 (~15 m)		Gurnah Calc. Shale	upper part Owaina Shale Member	
Upper Paleocene	**NP9**			Kilabiya Chalk	Upper Owaina Shale	Kilabiya Chalk Mb + Owaina Sh Mb (24m)	Tarawan Chalk+ U Owaina Sh Mb
	NP8		Tarawan Chalk (22m)			Kilabiya Chalk Mb	Tarawan Chalk
	NP7					Kilabiya Chalk Mb	Tarawan Chalk
Middle Paleocene	**NP6**		in Sadek and Teleb, 1978b				
	NP5						
Lower Paleocene	**NP4**			Lower Owaina Shale		Lower Owaina Shale Member	
	NP3						
	NP2						
Lower Paleocene	**NP1**						
Maastrichtian	***M. prinsii***						
	N. frequens						
	M. murus			Upper Sharawna Shale		Upper Sharawna Shale Membe	
	L. quadratus	A. cymbiformis M Sharawna Marl		Sharawna Shale and Marl		Middle Sharawna Marl Member	
	T. gothicus trifidus	base Upper Sharawna Sh Mb				Lower Sharawna Shale Member	correlative of LSSM

TABLE 1
continued.

Authors & Sections		Sadek & Teleb, 1978a, b	Sadek & Teleb, 1978b	Sadek & Teleb, 1978b	Sadek & Teleb, 1978b	Abdelmalik et al. 1978	Kerdany et al., 1980
Series	**Zones**	**Betty-1 Well**	**G. Ghamina**	**G. Abu Had**	**G. Duwi**	**Bir El-Markha**	**Wadi Nukhul**
Middle Miocene							
Lower Miocene							
	NP25						
Upper Oligocene	**NP24**						
	NP23						
	NP22						
Lower Oligocene	**NP21**						
Upper Eocene	**NP19-20**		19				
	NP18						Tanka Fm (56 m)
Middle Eocene	**NP17**						Darat+ Khaboba+ Tanka Fms (151 m)
	NP16						Darat Fm (76 m)
	NP15						Thebes Fm (50 m)
Lower Eocene	**NP14**						Thebes Fm (55 m)
	NP13						Thebes Fm (51 m)
	NP12						Thebes Fm (21 m)
	NP11					Esna Shale	Esna Shale (16.5 m)
	NP10					Esna Shale	
Upper Paleocene	**NP9**					Esna Shale, Tarawan Chalk	
	NP8						
	NP7						
Middle Paleocene	**NP6**					Dakhla Shale	
	NP5					Dakhla Shale	
Lower Paleocene	**NP4**						
	NP3					Dakhla Shale	
	NP2					Dakhla Shale	
Lower Paleocene	**NP1**						
Maastrichtian	***M. prinsii***						
	N. frequens						
	M. murus						
	L. quadratus					A. cymbiformis	
	T. gothicus trifidus	Khoman Chalk					

TABLE 1
continued.

Authors & Sections		Kerdany et al., 1980	Abdelmalik, 1982	Mohamed et al., 1982	El Dawoody 1984	El Dawoody 1984
Series	**Zones**	***Wadi El-Tayiba***	***Qusseir area***	***Taramsa***	***Owaina***	***Gurnah***
Middle Miocene						
Lower Miocene						
	NP25					
Upper Oligocene	**NP24**					
	NP23					
	NP22					
Lower Oligocene	**NP21**					
Upper Eocene	**NP19-20**					
	NP18					
Middle Eocene	**NP17**					
	NP16	Darat Fm (70.8 m)				
	NP15	Thebes Fm (204 m)				
Lower Eocene	**NP14**	Thebes Fm (32.4 m)				
	NP13					
	NP12					uppermost Thebes Calc. Sh. (30 m) + lowermost Thebes Limestone (20 m)
	NP11	Esna Shale (7 m)	Esna Shale	Thebes Formation		Thebes Calcareous Shale (16 m)
	NP10		Esna Shale+ Tarawan Chalk	Esna Shale	upper Upper Owaina Shale (~12 m)	Upper Owaina Shale+Thebes Calcareous Shale (30 m)
Upper Paleocene	**NP9**		Dakhla Shale	Esna Shale	Lower Upper Owaina Shale (30 m)	
	NP8					
	NP7			Tarawan Chalk +L most Esna Sh.	Middle Owaina Shale (22 m)	
Middle Paleocene	**NP6**		Dakhla Shale		uppermost Lower OS + L most Middle OS (8m)	
	NP5			Dakhla Shale		
Lower Paleocene	**NP4**			Dakhla Shale	Lower Owaina Shale (22 m)	
	NP3		Dakhla Shale	Dakhla Shale		
	NP2				Lower Owaina Shale (8 m)	
Lower Paleocene	**NP1**		Dakhla Shale			
Maastrichtian	***M. prinsii***					
	N. frequens					
	M. murus					
	L. quadratus					
	T. gothicus trifidus					

TABLE 1
Continued.

Authors & Sections		El Dawoody, 1992	El Dawoody, 1992	El Dawoody, 1992	El Dawoody, 1994
Series	**Zones**	***Wadi Belayim***	***Wadi Nukhul***	***Samalut***	***Duwi***
Middle Miocene					
Lower Miocene					
	NP25				
Upper Oligocene	**NP24**				
	NP23				
	NP22				
Lower Oligocene	**NP21**				
Upper Eocene	**NP19-20**				
	NP18				
Middle Eocene	**NP17**		Uppermost Tanka Fm		
	NP16		Darat Fm + Khaboba Fm + Tanka Fm	Mokattam Fm	
	NP15		Darat Formation		
Lower Eocene	**NP14**		Darat Formation		
	NP13		Thebes Formation		
	NP12	Thebes Formation			
	NP11	Thebes Formation			Esna Shale+Thebes Calc. Sh. (~20 m)
	NP10	Thebes Formation			Esna Shale (10 m)
Upper Paleocene	**NP9**	Esna Formation			Esna Shale (20 m)
	NP8				Tarawan Chalk
	NP7				Tarawan Chalk
Middle Paleocene	**NP6**				Tarawan Chalk+ lowermost ES (38m)
	NP5				Dakhla Shale (28m)
Lower Paleocene	**NP4**				Dakhla Shale (24m)
	NP3				
	NP2				Dakhla Shale (18m)
Lower Paleocene	**NP1**				Dakhla Shale (10m)
Maastrichtian	***M. prinsii***				
	N. frequens				
	M. murus				
	L. quadratus				
	T. gothicus trifidus				

EXPLANATORY NOTES FOR TABLE 1

(1) The section at Gebel Homeira provided evidence that coccolithophores were useful for biostratigraphic characterization of Middle Eocene, Upper Eocene and Middle Miocene strata in Egypt. Sadek (1968) identified and illustrated nine coccolith species (mostly discoasters).

(2) The section at Gebel Um El Huetat provided confirmation that ages assignments based on coccolithophores were in agreement with ages derived from fossil invertebrates and planktonic foraminifera. Lithologic determination based on comparison of the extent of nannofossil and planktonic foraminiferal zones with correlation of the latter with lithostratigraphy in Abd El-Razik et al. (1968; cited Abd El Razik, T. M., Razvaliaev, A. V., and Krasheninnikov, V. A. 1968. The Cretaceous — Paleogene, geological history of the Red Sea Coast and its comparison with the Nile Valley and Western Desert. Geological Society of Egypt (in press); probably published as Abd El Razik, T. M. 1972).

(3) Kerdany (1970) used the *Cruciplacolithus tenuis* Zone of Hay and Mohler (in Hay et al. 1967), which, as defined by these authors, encompasses Zone NP2 through NP4. He also grouped Zones NP5 through NP8 under a *Heliolithus kleinpelli* Zone, but acknowledged that Zone NP5 was not identified in the examined sections. Based on his table 2 (that shows co-occurrence of *H. kleinpelli* and *H. riedelii*), Zones NP6 and NP7 may not have been identified in the sections. Kerdany did not find *Tribrachiatus contortus* and he modified the definition of the "*Marthasterites contortus*" [=NP10] to represent the interval between the LOs of *T. bramlettei* and *T. orthostylus*. The extent of Zone NP 11 is unknown because the Thebes was found to be barren of coccolithophores.

(4) The nannofossil assemblages given by Sadek (1972) do not allow a precise biozonal assignment. Age of the Mokattam Fm is based on correlation with planktonic foraminifera. Age of the shallow water Maadi Formation is tentative.

(5) El Dawoody and Barakat (1972) used the full names of biozones described by diverse authors and subsequently integrated by Martini (1971) in a codified zonal scheme. They assigned the Esna Shale to Zone NP10 (lower 21 m) and Zone NP11 (overlying 20 m), and the "Thebes Calcareous Shale" (10+ m) to Zone NP12. However, El Dawoody and Barakat (1972) tinkered with the original zonal definitions. Thus, their *Discoaster binodosus* Zone (NP11) extends from the HO of *T. contortus* to the LO of *T. orthostylus*. In as much as the lower range of the latter species overlaps with the upper range of the former (Aubry 1996; Aubry et al. 1996), no such zone can be delineated in a normal stratigraphic succession. They delineated the *Marthasterites tribrachiatus* [vel. *Tribrachiatus orthostylus*] concurrent range Zone on the basis of the occurrence of the nominate species and regardless of the absence of the marker *H. lodoensis*. Clearly the "Thebes Calcareous Shale" belongs to Zone NP11. Although *T. contortus* evolved from *T. bramlettei* (as shown by morphometric analysis, Bord and Aubry, in press and in progress) co-occurrence of two species over a 20 m thick interval is highly unlikely. The stratigraphy of the NP10 interval is re-interpreted in Appendix 1.

The "Thebes calcareous shale" is equivalent to the Abu Had Member of the Esna Shale Formation (Aubry et al. 2007). It was assigned to Zone NP12 by El Dawoody and Barakat (1972) despite the absence of *Discoaster lodoensis*.

(6) Sadek and Teleb (1973) assigned Core 2 of the Betty Well to the *Discoaster saipanensis* Zone of the Upper Lutetian. They noted the absence of *Nannotetrina alata*, but their report of *Chiasmolithus gigas* (illustrated in Sadek and Teleb 1974) would imply Subzone NP15b. However no other diagnostic taxa support this age. The authors wisely concluded that Core 2 cannot be precisely located in the middle (< Zone NP14) and Upper Eocene (up to Zone NP19-20) stratigraphy.

(7) El Dawoody and Zidan (1976) intended an integrated biostratigraphic study, using planktonic foraminifera and nannofossils. However, nannofossils were present only in the Cretaceous part of the section.

EXPLANATORY NOTES FOR TABLE 1, *continued*

(8) El Dawoody (1977) identified three biozones in the stratigraphic succession at Gebel El Teir. The Tarawan was assigned to Zone NP8, the lower 7.5 of the Thebes Calcareous Shale to Zone NP10, and the overlying 27.50 m to Zone NP11. From the stratigraphic distribution of the nannofossils (op. cit, figure 3), the stratigraphic succession would appear to be more complex. The Tarawan Chalk belongs to Zone NP8 and is unconformable with the Thebes Calcareous Shale in agreement with El Dawoody. The lower part of Shale Bed 2 belongs to Zone NP10, also in agreement with the author. The co-occurrence of *T. bramlettei* and *T. contortus* suggests misidentification of the latter taxon (should be *T. digitalis*) and assignment to Subzone NP10b (see (5) above and Appendix 1). The occurrence of *T. bramlettei* without *T. digitalis* and *T. contortus* in the next 7.5 above denotes Subzone NP10c. The NP10/NP11 contact is marked by a sharp lithological change from calcareous shales below to marls interbedded with cherts (op. cit, Figure 2), possibly implying a stratigraphic gap (Subzone NP10d). (note the incorrect identification of *Chiasmolithus gigas*)

(9) An important contribution of Sadek and Teleb (1978a) was to re-evaluate the zonal age of the Cretaceous deposits of Egypt determined by earlier authors. They commented that the lower part of the Khoman Chalk in the Masak El Sharbi Section, assigned to an *Arhangelskiella cymbiformis* Zone by Kerdany (1969), may belong to the *Tetralithus gothicus trifidus* [*T. trifidus* Zone of Bukry 1973). They also tentatively assigned the upper part of the Khoman Chalk in this section to the *Lithraphidites quadratus* Zone, and determined the occurrence of the zone at Gebel Abu Had, Gebel Ghanima, and El Guss Abu Said. Sadek and Teleb (1978) also determined that the zone is present at Gebel Tarbouli and Gebel Duwi, based on Shafik and Stradner (1971) and El-Dawoody and Barakat (1972), respectively. They further assigned the youngest Maestrichtian strata at Gebel Duwi to the *Nephrolithus frequens* Zone, based on the latter work. Based on the absence of *M. murus* at all localities, they reasoned that the Maestrichtian record was incomplete in all sections studied to date.

In an equally important paper, Sadek and Teleb (1978b, text and unnumbered figure p. 445) re-valuated the biozonal subdivision of Paleocene sections studied earlier, in particular Gebel Abu Had and Gebel Ghanima sections (presumably based on Kerdany 1969) and the Duwi section (based on El Dawoody and Barakat 1973). They also added information on the local occurrence of zones, such as that of NP6 in the Gebel El Teir section.

(10) Abdelmalik et al. (1978) followed Kerdany (1970) in using a "*Cruciplacolithus tenuis* Concurrent-range zone" encompassing Zones NP2 to NP5. The range chart given by these authors (op. cit., Figure 3) would suggest that only Zone NP3 was identified in the section, but the text indicates that *C. danicus* was not found in the basal part of the Paleocene section. It is clear that Zone NP4 was not recorded (the absence of *Ellipsolithus macellus* is specified in the text), but it is unclear whether Zone NP5 is present or not, *Fasciculithus tympaniformis* being reported as scarce. *Tribrachiatus bramlettei* and *T. contortus* are shown to co-occur in the interval assigned to Zone NP10. As in other sections, this interval may well correspond to Zone NP10b, at least in part.

(11) Abdelmalik (1982) provided a composite stratigraphic section in the Qusseir area, based on the analysis of three sections (Gebel Duwi, Gebal Atshan, Gebel Hamadat) whose individual stratigraphy is not given. The composite range chart (op. cit.: figure 2) provides the basis for re-interpretating the "*Cruciplacolithus tenuis* Concurrent-range Zone". Note that the lithobiostratigraphic correlations differ markedly from those in other sections.

(12) El Dawoody (1994) reaffirmed the biozonal subdivision of the Duwi Section. His zonal subdivision of the Eocene part of the section is problematic for the reasons explained in (5).

(13) Kerdany et al. (1980) did not provide a range chart for each section. Their composite distribution chart of the coccoliths in the two sections shows overlap of the ranges of *D. lodoensis* and *D. sublodoensis* throughout the sections, suggesting the occurrence of Subzone NP14a, and a stratigraphic gap at the contact between this subzone and Zone NP15 (the markers of the subzones were not recovered according to the authors). The delineation of upper Middle and Upper Eocene NP zones in the Darat, Khaboba and Tanka Formations is difficult, but the *Reticulofenestra umbilica* and *Discoaster tani nodifer* Concurrent range Zones used by the authors corresponds to the NP16-NP17 zonal interval. Their *Discoaster saipanensis* Range (?) Zone is difficult to locate in the Eocene Series.

TABLE 2, part 1, Upper Nile Valley
Maastrichtian–Lower Eocene stratigraphic sections investigated for calcareous nannofossils in Egypt. Several sections may correspond to one locality. The latitude and longitude may be different for different sections (e.g., Gebel Duwi: Bolle et al. 2000). Several sections were sampled at Gebel Areif El Naqa with sections A1, A7, A5 studied by Luning et al. (1998,) and sections A8 and others by Marzouk and Luning (1998). At least four sections have been sampled at Gebel Qreiya. Section Qreiya 3 is the best known section, and this is the one studied in Aubry et al. (2012), not Qreiya 1 as incorrectly reported by these authors (R. Speijer, e-mail comm. to M-P. Aubry, June 2010. Section Qreiya 1 is also referred to as Wadi Qena).

Section	Location	latitude (N)	Longitude (E)	Age base	Age top	Authors
[1] Gebel Qreiya (composite Q1, Q2, Q3)	Eastern Desert	~26° 21'	33° 01'	U. Mastrichtian (*M. murus*)	L. Eocene	Bolle et al., 2000 Keller et al., 2002 Berggren & Ouda, 2003 Tantawy, 2003 Knox et al., 2003 Steurbaut & Sztrákos, 2008 Bornemann et al., 2009 Sprong et al., 2009, 2011, 2012 Youssef, 2009 Aubry et al., 2011, 2012 Monechi et al., 2013
[2] G. Abu Had	Mouth of Wadi Qena, Eastern Desert	—	—	U. Maastrichtian(*M. murus*)	L. Eocene (NP11)	Kerdany, 1970 Sadek & Teleb, 1978a, b Faris, 1997 Faris et al., 1989, 1999b
[3] El Serai	Eastern Desert	26° 14' 23"	33° 04' 50"	Maastrichtian(*L. quadratus*)	L. Eocene (NP11)	Faris, 1997 Faris et al., 1989 Tantawy, 2006
[4] Wadi Hamama	Central Eastern Desert	26° 18'	33° 02'	U. Maastrichtian(*M. murus*)	L. Paleocene (NP2)	Tantawy, 2003
[5] Gebel El Sheikh Eisa	Nile Valley	—	—	M. Paleocene (NP5)	L. Eocene (NP11)	Faris et al., 1999a Ghandour et al., 2004
[6] El Gir (Taramsa)	Eastern Desert	26° 05' 12"	32° 42' 25"	Maastrichtian(*M. murus*)	L. Eocene (NP11)	Mohammed et al., 1982 Faris, 1984a Faris et al., 1986, 1989, 1999b Tantawy, 2006
[7] Gebel Gurnah	Deir El Bahari	—	—	U. Paleocene (NP8)	L. Eocene (NP12)	Kerdany, 1970 El Dawoody, 1984, 1993 Perch-Nielsen et al., 1978 Sadek and Teleb, 1978a Faris 1991 Faris & Strougo, 1998 Aubry, 1996
[8] a- Dababiya Quarry (b- Gebel Nezzi)	Eastern Desert	25° 30' 18"	32° 31' 41"	U. Paleocene (NP7-8)	L. Eocene (NP11)	Dupuis et al., 2003 Aubry et al., 2007 Monechi et al., 2000
[9] Gebel Kilabiya	Eastern Desert	—	—	U. Paleocene (NP9)	L. Eocene (NP10)	Ouda et al., 2003
[10] G. Owaina	Nile Valley	25° 14.650'	32° 45.994'	U. Maastrichtian (*L. quadratus*)	U. Paleocene (NP9)	Kerdany, 1970 El Dawoody, 1984, 1993, 1994 Perch-Nielsen et al., 1978 Sadek & Teleb, 1978a, b Aubry, 1996 Schmitz et al., 1996 Speijer & Schmitz, 1998 Ouda et al., 2003 Steurbaut & Sztrákos, 2008 Bornemann et al., 2009 Sprong et al., 2009, 2012
[11] Gebel El-Shaghab	Nile Valley, Esna area	—	—	L. Paleocene (NP2)	L. Eocene (NP10)	Faris et al., 1999a Ghandour et al., 2004
[12] Gebel El-Homra El-Shanka		—	—	U. Paleocene (NP9)	L. Eocene (NP11)	Faris et al., 1999a
[13] Wadi Abu Ghurra	Nile Valley	—	—	M. Paleocene (NP6)	L. Eocene (NP10)	Youssef & Mutterlose, 2004
[14] Kurkur Naqb Dungul	Nile Valley	—	—	L. Paleocene (NP3)	L. Eocene (NP10)	Youssef & Mutterlose, 2004
[A] Gebel Araas	Eastern Desert	26° 22.436	32° 45.276	L. Paleocene (NP4)	L. Paleocene (NP4)	Youssef, 2009 Sprong et al., 2012
[B] Hills of Meretseger	Theban Hills, Nile Valley	—	—	L. Eocene	L. Eocene	Aubry et al., 2011b

TABLE 2, *continued*
Part 2, Eastern Desert.

Section	Location	latitude (N)	Longitude (E)	Age base	Age top	Authors
[15] St. Paul	West Gulf of Seuz,South Galala	—	—	U. Matesrichtian (*M. prinsii*)	U. Paleocene (NP9)	Faris, 1997; 1999 Scheibner et al., 2000; 2001a; b
[16] Wadi El Dakhl	Eastern Desert, South Galala Plateau	—	—	U. Maastrichtian(*M. murus*)	L. Eocene (NP14)	Strougo & Faris, 1993 Faris, 1997 Scheibner et al., 2001a; b Höntzsch et al., 2011
[17] Wadi Tarfa	Eastern Egypt, Gebel Galala	—	—	U. Maastrichtian(*M. murus*)	L. Eocene (NP12)	Scheibner et al., 2001a; b Höntzsch et al., 2011
[18] Gebel Tarboul	Ash Mellaha Range, Eastern Desert	—	—	Maastrichtian(*A. cymbiformis*)	U. Paleocene (NP9)	Shafik & Stradner, 1971 Sadek and Teleb, 1978a El Dawoody, 1990; 1992
[19] Wasif area	Red Sea Coast, Safaga area	~26° 30'	33° 51' 42"	U. Maastrichtian(*A. cymbiformis*)	L. Eoecene (NP10)	Hewaidy & Faris 1989 Faris, 1997
[20] Gebel Um El Huetat	Red Sea Coast	—	—	U. Paleocene (NP9)	L. Eocene (NP12)	Sadek & Abd El Razik, 1970 Faris 1988b
[21] Gebel Atshan	Red Sea Coast, Quseir Area	26° 4' 50"	34° 11' 30"	U. Maastrichtian(*M. murus*)	U. Paleocene (NP9)	Abdelmalik, 1982 Faris et al., 1999b
[22] G. Duwi	Red Sea Coast, Quseir Area	26° 8' 30"	34° 5' 5"	U. Maastrichtian(*A. cymbiformis*)	L. Eocene (NP11)	Shafik & Stradner, 1971 El Dawoody & Barakat, 1972, 1973 Sadek & Teleb 1978a, b Abdelmalik, 1982 El Dawoody, 1994 Schmitz et al., 1996 Faris, 1984 a; b, 1997; 1999 Bolle et al., 2000 Youssef, 2009 Bornemann et al., 2009 Sprong et al., 2009, 2012
[C] Wadi Nooz	West Gulf of Seuz, Gebel Galala	—	—	U. Maastrichtian (*L. quadratus*)	L. Eocene (NP12)	Scheibner et al., 2001a
[D] St. Anthony	West Gulf of Seuz, Gebel Galala	—	—	Campanian (CC22)	U. Paleocene (NP9)	Scheibner et al., 2001a; b Höntzsch et al., 2011
[E] Wadi El Mellaha	Ash Mellaha Range, Eastern Desert	—	—	Maastrichtian (*A. cymbiformis*)	U. Paleocene (NP9)	Shafik & Stradner, 1971 El Dawoody, 1990; 1992
[F] Wadi Um Derra	Ash Mellaha Range, Eastern Desert	—	—	Maastrichtian (*A. cymbiformis*)	U. Paleocene (NP9)	El Dawoody, 1990; 1992
[G] Haramween	Red Sea Coast, Safaga area	—	—	U. Paleocene (NP9)	L. Eocene (NP11)	Shafik & Stradner, 1971
[H] Wadi Had	Red Sea Coast, Qusseir area	—	—	L. Eocene (*M. spineus* Zone = NP9c)	L. Eocene (NP11)	Shafik & Stradner, 1971
[I] Gebel Hamadat	Qusseir area	25° 58' 20"	34° 10' 00"	U. Paleocene (NP9)	L. Eocene (NP10)	Shafik & Stradner, 1971 Abdelmalik, 1982

TABLE 2, *continued*
Part 3, western Sinai.

Section	Location	latitude (N)	Longitude (E)	Age base	Age top	Authors
[23] Abu Zenima	Western Sinai	29° 03'	33° 03'	U Paleocene (NP9a)	L. Eocene (NP9b)	Kerdany et al., 1974 Bolle et al., 2000
[24] Gebel Bir El Markha	West Central Sinai	33° 18'	29° 6'	Maastrichtian(*A. cymbiformis*)	L. Eocene (NP14)	Abdelmalik et al., 1978 Faris et al., 2005a; b
[25] Gebel Matulla	Western Sinai	29° 03'	33° 10'	Maastrichtian(CC24)	L. Eocene (NP12?)	Marzouk and Hussein, 1994 Bolle et al., 2000 Faris et al., 2000 Abu Shama et al., 2007
[26] Gebel Nukhul	Abu Zenima area, West Central Sinai	28° 40'	33° 10'	U. Maastrichtian(*M. murus*)	L. Eocene (NP11), M. Eocene (NP17?)	Kerdany et al., 1980 El Dawoody, 1992 Marzouk & Hussein, 1994 Faris & Salem, 2007 Faris et al., 2007a Morsi et al., 2008
[27] Gebel Mukattab	West Central Sinai	33° 25'	28° 49'	U. Paleocene (NP9)	L. Eocene (NP12)	Faris et al., 2005a; b
[28] Wadi Feiran	West central Sinai	29° 10'	33° 40'	Maastrichtian(CC24)	L. Eocene (NP12)	Marzouk & Abou-El-Enein, 1997 Faris et al., 2000 Faris & Salem, 2007 Morsi et al., 2008
[29] Gebel Belayim	West Central Sinai	—	—	U. Paleocene (NP9)	L. Eocene (NP13)	El Dawoody, 1992
[30] Gebel Qabeliat	West central Sinai	—	—	Maastrichtian(CC25a))	L. Eocene (NP11)	Marzouk & Abou-El-Enein, 1997

TABLE 2, *continued*
Part 4, central Sinai.

Section	Location	latitude (N)	Longitude (E)	Age base	Age top	Authors
[31] El Hassana	North Central Sinai	30° 30'	33° 45'	L. Paleocene (NP2)	U. Paleocene (NP9)	El Deeb et al., 2000
[32] Gebel Yelleg	North Central Sinai	30° 20'	33° 35'	L. Paleocene (NP2)	U. Paleocene (NP7-8)	El Deeb et al., 2000
[33] Gebel Misheiti	Themed area; East Central Sinai	—	—	U. Maastrichtian(*M. murus*)	L. Eocene (NP10)	Marzouk & Lüning, 1998 Lüning et al., 1998a; b; c Faris & Abu Shama, 2003; 2007 Faris et al., 2007
[34] West Themed	Central Sinai	—	—	L. Paleocene (NP3)	L. Eocene (NP10)	Marzouk & Lüning, 1998 Lüning et al., 1998b; c
[35] Gebel El-Ghoryia	Central Sinai	—	—	Maastrichtian(*A. cymbiformis*)	L. Eocene (NP10)	Sweden et al., 1995
[36] Wadi Gureis (Composite)	Central Sinai	29° 33'41.7"	34° 09'08.0"	U. Maastrichtian(*M. murus*)	L. Eocene (NP10)	Marzouk & Lüning, 1998 Lüning et al., 1998a; b; c
[37] Egma Plateau	Central Sinai	—	—	L. Paleocene (NP3)	L. Eocene (NP11)	Marzouk & Lüning, 1998 Luning et al., 1998b; c
[38] Gebel Heyala	Central Sinai	—	—	Campanian (*Quadrum trifidum*)	L. Eocene (NP10)	Sweden et al., 1995
[39] Gebel Umm Mafrud	Central Sinai	—	—	L. Paleocene (NP3)	L. Eocene (NP10)	Marzouk & Lüning, 1998 Lünning et al., 1998b
[J] Gebel El-Bruk	North central Sinai	—	—	M. Paleocene (NP5)	L. Eocene (NP12)	Faris & Zahran, 2002

TABLE 2, *continued*
Part 5, eastern Sinai.

Section	Location	latitude (N)	Longitude (E)	Age base	Age top	Authors
[40] Gebel Amr	Northeast Sinai	30° 42' 80"	44° 18' 25"	Maastrichtian(*L. quadratus*)	L. Eocene (NP11)	Ayyad et al., 2003 Faris et al., 2005a
[41] Gebel Muwaylih	Northeast Sinai	30° 39'	34° 20'	U. Mastrichtian (*M. murus*)	L. Eocene (NP11)	Ayyad et al., 2003 Faris et al., 2005a
[42] Gebel El Falig	El Qusaima, NE Sinai	—	—	L. Paleocene (NP4)	L. Eocene (NP11)	Faris, 1988a
[43] Gebel El Ain	El Qusaima, NE Sinai	—	—	Maastrichtian(*M. murus*)	L. Eocene (NP10)	Faris, 1988a; 1992; 1997; 1999
[44] G. Areif El Naqa (Composite)	Eastern Sinai	30° 24'31.1"	34° 29' 34.6"	Cenomanian (CC10)	L. Paleocene (NP2)	Marzouk & Lüning, 1998 Lüning et al., 1998a; b; c Bauer et al., 2001
[45] North El Kuntilla	Eastern Sinai	—	—	L. Paleocene (NP3)	L. Eocene (NP10)	Marzouk & Lüning, 1998
[46] Taba	Eastern Sinai	—	—	Turonian	L. Eocene (NP12)	Marzouk & Lüning, 1998 Lüning et al., 1998b; c
[47] North Nuweiba	Eastern Sinai	—	—	L. Paleocene (NP2)	L. Eocene (NP10)	Marzouk & Lüning, 1998 Lünning et al., 1998b
[48] Near Sheikh Attiya	Eastern Sinai	29° 16'13.1"	34° 30' 01.9"	Coniancian-Santonian	L. Eocene (NP12)	Marzouk & Lüning, 1998 Lüning et al., 1998a; b; c

TABLE 2, *continued*
Part 6, western desert.

Section	Location	latitude (N)	Longitude (E)	Age base	Age top	Authors
[54] North Farafra	Farafra Oasis, Western Desert	—	—	Maastrichtian(CC25a)	U. Paleocene (NP7)	Tantawy et al., 2001
[55] El Sheikh Marsouk= El Guss Abu Said	Farafra Oasis, Western Desert	—	—	L. Eocene (NP10)	L. Eocene (NP12)	Kerdany, 1970 Faris & Strougo 1998
[56] Northern Gunna	Farafra Oasis, Western Desert	—	—	U. Paleocene (NP9)	L. Eocene (NP11?)	Faris & Strougo 1998
[57] Bir Abu Minqar	Dakhla Oasis	—	—	Maastrichtian(CC25)	L. Paleocene (NP4)	Tantawy et al., 2001
[58] Gebel Gifata	Dakhla Oasis	—	—	CC23a	L. Paleocene (NP4)	Tantawy et al., 2001
[59] Ain Dabadib	NW Khaga Oasis	30° 26'	25° 44'	Maastrichtian(*M. murus*)	U. Paleocene (NP9)	Boussiani et al., 1991 Faris, 1997
[60] Ain Amur	Kharga Oasis	—	—	Maestrichtian (*A. cymbiformis*)	U. Paleocene (NP9)	Faris, 1984a; 1985; 1997
[61] Gebel El Teir	Kharga Oasis	~25° 33'	30° 33'	L. Paleocene (NP3)	L. Eocene (NP11)	El Dawoody, 1977 Faris et al., 1999a, b Ghandour et al., 2004
[62] Gebel Um el-Ghanayem	Kharga Oasis	—	—	L. Paleocene (NP3)	L. Eocene (NP10)	Sadek & Teleb, 1978a, b Faris et al., 1999a Ghandour et al, 2004
[63] Gebel Ghanima	Kharga Oasis	—	—	Maastrichtian(*A. cymbiformis*)	L. Eocene (NP11)	Kerdany, 1970 Sadek & Teleb, 1978a, b; Faris, 1984a, 1985; 1997
[K] West Mawhoob	Dakhla Oasis	—	—	U. Maastrichtian (*A. cymbiformis*)	U. Paleocene	El Dawoody & Zidan, 1976
[L] Mut	Dakhla area	—	—	Maastrichtian (*Q. trifidum*)	M. Paleocene (NP5)	Faris, 1984a; 1997

TABLE 2, *continued*
Part 7, northern Egypt.

Section	Location	latitude (N)	Longitude (E)	Age base	Age top	Authors
[49] Jiran El Ful	Abu Roash area	—	—	U. Mastrichtian (M. murus)	Paleocene (NP9)	Faris & Abd El-Hameed, 1986 Faris, 1997
[50] Misfaq-1 Well	onshore Mediterranean Coast	—	—	M. Paleocene (NP5)	U. Eocene -L. Oligocene (NP21)	Marzouk & Soliman, 2004
[51] Gebel Libni Well	North Sinai	30° 31' 48"	33° 49'16"	M. Campanian (CC22)	M. Eocene (NP17)	Farouk & Faris, 2008
[52] Tuffah-1 Well	Offshore northern Sinai	—	—	M. Paleocene (NP5)	U. Eocene -L. Oligocene (NP21)	Marzouk & Soliman, 2004
[53] Einab-1 Well	Offshore northern Sinai	—	—	M. Paleocene (NP5)	U. Eocene -L. Oligocene (NP21)	Marzouk & Soliman, 2004

TABLE 3, part 1, Cretaceous sections.
Stratigraphic sections other than Maastrichtian–Lower Eocene investigated for calcareous nannofossils in Egypt.

Section	Location	Latitude (N)	Longitude (E)	Age base	Age top	Authors
[C1] Masak el Sharib	mid Wadi Qena, eastern desert	27° 24' 04"	32° 27' 05"	U. Maastrichtian (*T. gothicus trifidus* ?)	U. Maastrichtian (*N. frequens*)	Kerdany, 1970 Sadek & Teleb, 1978b
[C2] Wadi Hamada	West Gulf of Seuz, Gebel Galala	—	—	U. Maastrichtian (*L. quadratus*)	U. Maastrichtian (*M. murus*)	Schneiber et al. 2001b
[C3] Wadi Miraf	West Gulf of Seuz, Gebel Galala	—	—	U. Maastrichtian (*M. murus*)	U. Maastrichtian (*M. murus*)	Schneiber et al. 2001b
[C4] Gebel El Risha	North Sinai	30° 41' 16"	34° 24' 58"	Turonian (CC11)	Campanian	Faris, 1992 Bauer et al. 2001
[C5] Gebel Minsherah	North Central Sinai	30° 17' 17"	33° 39' 50"	Cenomanian (CC10)	Turonian (CC12)	Bauer et al. 2001
[C6] Mitla Pass	West Central Sinai	30° 01'58"	32° 59' 15"	U. Coniacian (CC14)	M. Campanian (CC20)	Farouk & Faris, 2012
[C7] Nakhl Well 1	North central Sinai	—	—	Coniancian-Santonian	Santonian	Lüning et al., 1998c
[C8] Gebel Abu Zurub	Central Sinai	29° 22' 31"	33° 21' 07"	Cenomanian (CC10)	Turonian (CC12)	Bauer et al., 2001
[C9] G. Adamet El Amawy	Themed area; East Central Sinai	—	—	Coniancian-Santonian	U. Santonian	Faris & Abu Shama, 2003
[C10] W. Abu Suwan	Themed area; East Central Sinai	—	—	U. Santonian	U. Campanian (CC22)	Faris & Abu Shama, 2003
[C11] G. Abu Suwan	Themed area; East Central Sinai	—	—	U. Santonian (CC15)	U. Santonian (CC17)	Faris & Abu Shama, 2003
[C12] G. Khasm El Tarif	Themed area, East central Sinai	—	—	Cenomanian (CC10)	Cenomanian (CC10)?	Faris & Abu Shama, 2003
[C13] Wadi Taba	Southeastern Sinai, Gulf of Aqaba	29° 28' 30"	34° 52' 10"	Campanian (*Quadrum trifidum*)	U. Maastrichtian (*A. cymbiformis*)	El Sheikh, 1995
[C14] Wadi Gidira	East central Sinai	29° 23' 55"	34° 31' 28"	Coniacian (CC14)	Santonian (CC16)	Bauer et al. 2001
[C15] Gebel Um Alda	East central Sinai	29° 18' 50"	34° 31' 45"	Turonian (CC12)	Santonian (CC16)	Bauer et al. 2001
[C16] Ain Quseiyib	East central Sinai	29° 16' 47"	34° 43' 12"	Turonian (CC12)	Santonian (CC16)	Bauer et al. 2001
[C17] Gebel Gunna	Central Sinai	28° 56' 09"	34° 05' 48"	Cenomanian (CC10)	Turonian CC12	Bauer et al. 2001
[C18] Gebel Dhalal	Central Sinai	28° 53' 43"	33° 55' 46"	Cenomanian (CC10)	Turonian CC12	Bauer et al. 2001
[C19] G. Nazzazat	Southwest Sinai	~ 33° 15'	~28° 45'	Santonian (CC15)	U. Maastrichtian (*M. murus*)	Arafa 1991
[C20] Gebel Arabah	South west Sinai	28° 22' 25'	33° 30' 40"	Cenomanian (CC10)	Coniacian (CC14)	Bauer et al. 2001
[C21] East Mubarak-1 Well	North Western Desert	—	—	Coniacian	Maastrichtian (M. murus)	Andrawis et al., 1986
[C22] NW Qur El Malik	Western Desert	—	—	Maastrichtian (barren)	Maastrichtian (barren)	Tantawy et al., 2001
[C23] North El Qasr	Dakhla Oasis	—	—	Maastrichtian (CC25a)	Maastrichtian (CC26a)	Tantawy et al., 2001

TABLE 3, *Continued*
Part 2, post lower Eocene Paleogene sections.

Section	Location	Latitude (N)	Longitude (E)	Age base	Age top	Authors
[P1] Abu Roda-1 Well	onshore Mediterranean Coast	—	—	L. Eocene (NP13)	U. Eocene -L. Oligocene (NP21)	Marzouk & Soliman, 2004
[P2] Gebel Shabrawet	near Ismaelia	—	—	M. Eocene (NP14)	M. Eocene (NP14)	El Dawoody, 1992
[P3] Gebel Oweibid	Cairo - Suez District	—	—	M. Eocene	M. Eocene	El Dawoody, 1992
[P4] Gebel El Keeh	Themed area, East central Sinai	—	—	L. Eocene	L. Eocene	Faris & Abu Shama, 2007
[P5] Wadi El-Tayiba	West central Sinai	—	—	M. Eocene (NP17)	M. Eocene (NP18)	Kerdany et al., 1980 Faris & Strougo 1992 Strougo, 1992
[P6] Ezz El Orban Well	West Gulf of Seuz	—	—	M. Eocene	M. Eocene	Sadek, 1972
[P7] Gebel Mokattam	Cairo area	—	—	M. Eocene	U. Eocene	Sadek, 1972 El Dawoody, 1992 Strougo, 1992
[P8] El Helt Ghorab	Cairo area	—	—	U. Eocene	U. Eocene	Sadek, 1972
[P9] Gebel Gibli El Ahram	West Greater Cairo	—	—	M. Eocene (NP17)	U. Eocene (NP19-20)	Faris & Strougo, 1992 Strougo, 1992
[P10] Qattamia	Cairo - Suez District	—	—	M. Eocene (NP16	M. Eocene (NP17?)	El Dawoody, 1992
[P11] Wadi Gibbu	East Greater Cairo	—	—	M. Eocene (NP17)	U. Eocene (NP18)	Faris & Strougo, 1992
[P11] Naqb el Agel	East Greater Cairo	—	—	M. Eocene (NP17)	U. Eocene (NP18)	Faris & Strougo, 1992 Strougo, 1992
[P11] Gebel Tura	East Greater Cairo	—	—	M. Eocene (NP17)	U. Eocene (NP18)	Faris & Strougo, 1992
[P11] Wadi Degla	East Greater Cairo	—	—	M. Eocene (NP17)?	U. Eocene (NP19-20)	Faris & Strougo, 1992
[P11] Wadi Hof	East Greater Cairo	—	—	M. Eocene (NP17)?	U. Eocene (NP19-20)	Faris & Strougo, 1992
[P12] Qaret El Faras	Fayum Depression	—	—	U. Eocene (NP19-20)	U. Eocene (NP19-20)	Zalat, 1995
[P13] El Qurn Height	East Greater Cairo	—	—	M. Eocene?	U. Eocene (NP18)	Strougo, 1992
[P14] Siela	Fayum Depression	—	—	M. Eocene (NP16)	U. Eocene (NP18)	Zalat, 1995
[P15] Guta	Birket Qarun, Fayum Depression	—	—	M. Eocene (NP16-17)	U. Eocene (NP18)	Faris & Strougo, 1992 Strougo, 1992 Strougo & Faris, 2008
[P16] Gebel Na'alun	Fayum-Beni Suef divide	—	—	M. Eocene (NP16-17)	U. Eocene (NP18)	Faris & Strougo, 1992 Strougo, 1992 Strougo & Faris 2008
[P17] Shaqluf	Fayum depression	—	—	M. Eocene (NP16)	L. Pliocene (NN15)	Zalat, 1995
[P18] Beni Suef	Nile Valley	—	—			Sadek, 1972
[P19] Sinn Asfur	Beni Suef area	—	—	M. Eocene (NP16)	M. Eocene (NP16)	Strougo et al., 1983
[P20] Gebel Shaibun	Beni Suef area	—	—	M. Eocene (NP16)	M. Eocene (NP16)	Strougo et al., 1983
[P21] Wadi Bayad	Beni Suef area	—	—	M. Eocene (NP16)	M. Eocene (NP16)	Strougo et al., 1983
[P22] Warshet el Rokham	Beni Suef area	—	—	M. Eocene (NP16)	M. Eocene (NP18)	Strougo et al., 1983 Strougo & Faris, 2008

TABLE 3, *Continued*
Part 3, Post Lower Eocene Paleogene and Neogene sections.

Section	Location	Latitude (N)	Longitude (E)	Age base	Age top	Authors
[P23] Gebel Um Raqaba	Beni Suef area	—	—	M. Eocene (NP16)	M. Eocene (NP16)	Strougo et al., 1983
[P25] Um Arqub	Beni Suef area	—	—	M. Eocene (NP16)	M. Eocene (NP16)	Strougo et al., 1983
[P26] Samalut	Nile Valley	—	—	M. Eocene (NP16	M. Eocene (NP16)	El Dawoody, 1992
[P27] Sawada	Nile Valle, Lower Egypt	—	—	L/M Eocene B	L/M Eocene B	Janin et al., 1993
[P28] Wadi Daqer	Nile Valley, Lower Egypt	—	—	L/M Eocene B	L/M Eocene B	Janin et al., 1993
[P29] Beni Hassan	Nile Valley, Lower Egypt	—	—	L/M Eocene B	L/M Eocene B	Janin et al., 1993
[P30] Burg el Arab Well	North western Desert	—	—	U. Lower Eocene (NP14a)		Sadek, 1972
[P31] Ghazalat Well	Qattara Depression	—	—			Sadek, 1972
[P32] Betty Well	Qattara Depression	29° 40' 08"	27° 26' 45"	M. Eocene	U. Eocene	Sadek, 1972 Sadek & Teleb, 1973, 1974; 1978a; b
[P33] Edmonstone	Dakhla Oasis	—	—	no data	no data	Kerdany, 1970
[PN1] Rommana-IX Well	NE Nile Delta	31° 00'	32° 31'	U. Oligocene (NP25)	L. Pliocene (NN12)	Faris et al., 2007b
[PN2] G. Homeira	Cairo - Suez District	—	—	M. Eocene	M. Miocene	Sadek, 1968
[N1] Ras El Barr-1 Well	Mediterranean Sea	31° 40'	31° 51'	M. Miocene (NN6-7)	L. Pliocene (NN12)	Faris et al., 2007b
[N2] Bougaz E-1 Well	Mediterranean Sea	32° 48'	31° 10'	L. Miocene (NN2)	L. Pliocene (NN12)	Faris et al., 2007b

TABLE 4
Compared thickness of the NP1 to NP8, NP9 to NP10, and NP9 to NP11 zonal intervals in selected successions. [#]: section number as given in text-figs. 4, 5 and Table 2. CS: central Sinai; ES: eastern Sinai; GP: Galala Plateau; NU: Nile Valley; WD: Western Desert; WS: western Sinai.
(1)K/P contact unexposed. Oldest deposits are NP4; (2)the DT does not outcrop in this section

Sections	Location	DT (NP1-NP8)	LE (NP9-10)	DT +LE	UE	DT+LE +UE
G. Al Ain [43]	ES	154	60	**214**	—	
G. El Falig(1) [42]	ES	94.5	55.5	**150**	20	**170**
Dababiya [8]	NV	58	88	**146**	52	**198**
Taramsa [6]	-id-	70	45	**115**	77	**192**
G. Abu Had [2]	-id-	60	45	**105**	70	**175**
G. Owaina [10]	-id-	57	43	**100**	—	
El Sheikh Marzouk(2) [55]	WD	—	87		25	**112**
Bir El Markha [24]	WS	12	11	**23**	2.5	**25.5**
Wadi Tarfa [17]	GP	21.5	8.5	**30**	8	**38**
G. El Ghoriya [35]	CS	11	18.5	**29.5**	—	
Taba [46]	ES	22.5	6.5	**29**	1	**30**
G. Amr [40]	ES	22.5	10	**32.5**	2	**34.5**
G. Areif El Naqa [44]	ES	31	4	**35**	—	
Wadi Feiran [28]	WS	28	9	**37**	18.5	**55.5**
G. Nukhul [26]	WS	25.5	17	**42.5**	30	**72.5**
G. Ghanima [63]	WD	26.5	22.5	**49**	9	**58**

TABLE 5
Compared thickness of selected intervals in the Paleocene-Lower Eocene stratigraphic successions in Egypt. UD: Zone NP4+NP5 (maximum duration of 3.71 Myr); LE: Zone NP9+NP10 (maximum duration of 3.15 Myr); UE: Zone NP11 (maximum duration of 0.4 Myr).

Region	Unit	Qreiya	Abu Had	Serai	El Sheikh Eisa	Taramsa
Nile Valley	UE	5.4	70	2.6	9.5	76.8
	LE	39.8	45	25.2	43.2	44.8
	DT	29.8	59.8	59.9	41.5	69.6
	Rα	1.3	0.8	0.4	1.0	0.6
	Rδ	1.5	1.9	0.5	1.3	1.7
	UD	17	47	**36.3**	26.9	39.2
		G. Gurnah	**Dababiya**	**G. Owaina**	**G. El Shaghab**	**Wadi Abu Ghurra**
	UE	25.5	52	—	—	42.5
	LE	35.5	88	43	82.4	60
	DT	—	57.8	56.9	60	26.5
	Rα	—	1.5	0.8	1.4	2.3
	Rδ	—	2.4	—	—	3.9
	UD	—	44.75	35.4	25	—
		Kurkur Naqb Dungal				
	UE	—				
	LE	19				
	DT	34.2				
	Rα	0.6				
	Rδ	—				
	UD	—				
Galala – Red Sea		**St. Paul**	**Wadi El Dakhl**	**Wadi Tarfa**	**Wasif area**	**G. Um El Huetat**
	UE	—	25.6	8	—	—
	LE	—	22.8	8.5	38.75	14.5
	DT	45	18.55	21.6	40	25.5
	Rα	—	1.2	0.4	1.0	0.6
	Rδ	—	2.6	0.8	—	—
	UD	13.9	4.95	13.3	13.75	11.5
		G. Atshan	**G. Duwi**			
	UE	—	—			
	LE	15	17			
	DT	45	97			
	Rα	0.3	0.2			
	Rδ	—	—			
	UD	25	40			
Western Sinai		**Bir El Markha**	**G. Matulla**	**G. Nukhul**	**G. Mukattab**	**Wadi Feiran**
	UE	2.4	4.4	30	13.5	18.4
	LE	10.8	15.7	17	10	9.2
	DT	12.3	16.5	25.5	—	28
	Rα	0.9	1.0	0.7	—	0.3
	Rδ	1.1	1.2	1.8	—	1.0
	UD	5.6	6.9	8.5	—	15
		G. Belayim	**G. Qabeliat**			
	UE	10	16.5			
	LE	53	11			
	DT	—	—			
	Rα	—	—			
	Rδ	—	—			
	UD	—	—			

TABLE 5
Continued.

Region	Unit	G. El Mishiti	West Themed	G. El Ghoriya	Wadi Gureis	Egma Plateau
Central Sinai	UE	0.7	—	—	—	4
	LE	5.4	4.4	18.3	2.35	4.4
	DT	36.5	28.3	10.9	24.75	22
	Rα	0.1	0.2	1.7	0.1	0.2
	Rδ	0.2	—	—	—	0.4
	UD	8	3	7.5	—	7.3
		G. El Heyala	**G. Umm Mafrud**			
	UE	—	—			
	LE	37.3	5.75			
	DT	34.2	21			
	Rα	1.1	0.3			
	Rδ	—	—			
	UD	11.6	11			
Eastern Sinai		**G. Amr**	**Muwaylith**	**G. El Falig**	**G. Al Ain**	**G. Areif El Naqa**
	UE	2	3	20	—	—
	LE	10	9.7	55.5	59.5	3.8
	DT	22.6	46.2	94.5	153.4	31.25
	Rα	0.4	0.2	0.6	0.4	0.1
	Rδ	0.5	0.3	0.8	—	—
	UD	12.4	15.5	73.3	48.8	9.9
		North Kuntilla	**Taba**	**North Nuweiba**	**Near El Sheik Attiya**	
	UE	—	1.2	—	—	
	LE	4.4	6.4	1.8	3	
	DT	29.1	22.4	32.95	48.2	
	Rα	0.2	0.3	0.1	0.1	
	Rδ	—	0.3	—	—	
	UD	17.4	11.5 (+2.9?)	19.75	24	
Western Desert		**El Sheikh Marzouk**	**North Gunna**	**Ain Dabadib**	**Ain Amur**	**G. El Teir /Tarawan**
	UE	25	12	—	—	—
	LE	87	54	7	3.6	20.7
	DT	—	—	57.2	41.1	75.4
	Rα	—	—	0.1	0.1	0.3
	Rδ	—	—	—	—	—
	UD	—	—	27.2	19.4	36.7
		G. Um El Ghanayum	**G. Ghanima**			
	UE	—	9.2			
	LE	57.3	22.3			
	DT	42	26.3			
	Rα	1.4	0.8			
	Rδ	—	1.2			
	UD	20	8			

APPENDIX 1 (Marie-Pierre Aubry)
Cenozoic taxa described from the Paleogene of Egypt. The taxonomic classification used here is that of Aubry in Aubry and Bord (2009) and Stradner et al. (2010). Bold face numbers used for figuration of the holotypes.

Order **Biscutales** Aubry in press a

Family **Prinsiaceae** Hay and Mohler 1967

Genus **Toweius** Hay and Mohler 1967

Toweius rotundus Perch-Nielsen in Perch-Nielsen et al. 1978, Pl. 8, figs. 34, 35; pl. 18, figs. 4, **15**, 18, 19

Type locality: Gebel Gurnah, Egypt

Type level: lower Eocene, NP11

Occurrence: Paleocene-Eocene Owaina, Gurnah

Syracosphaera stradneri El-Dawoody 1975, p. 464, **Pl. 7**

Type locality: Gebel Duwi, Quseir District, Egypt

Type level: Upper Paleocene, Esna Shale

Occurrence: Rare occurrences at the base of Zone NP9 in the Duwi area.

Comments: This coccolith does not exhibit the morpho-structural characteristics of the genus *Syracosphaera*. It is a placolith and mostly likely a synonym of *Hornibrookina australis* Edwards and Perch-Nielsen 1975

Order **Coccosphaerales** Haeckel 1894 emend Young and BOWN 1997

Family **Coccolithaceae** Poche 1913, Young and Bown 1997

Genus **Chiasmolithus** Hay and Mohler 1967

Genus **Cruciplacolithus** Hay and Mohler in Hay, Mohler, Roth, Schmidt and Boudreaux 1967

Chiasmolithus spiralis El-Dawoody 1988, p. 551, pl. 1, figs. **1**, 2

Type locality: Gebel Duwi, Egypt

Type level: Tarawan Chalk

Occurrence: Zones NP5 and NP6

Comments: This taxon is synonymous with *Cruciplacolithus tenuis* (XXX).

Order **Discoasterales** Hay 1977, emend Aubry in press b

Family **Biantolithaceae** Aubry in press b

Genus **Diantholithus** Aubry in Aubry et al., 2011

Diantholitha mariposa RODRIGUEZ and AUBRY in AUBRY et al., 2011**,** Pl. 1, figs **1a-d**, 2a, b, 3a-f, 4a-d, 5a-d.

Type locality: Gebel Abu Had, Qreiya section, Upper Egypt.

Type level: Sample Q+8.6 (uppermost Danian).

Occurrence: This species occurs over a short stratigraphic interval in the Qreiya section, between level Q+7.2 to Q+9.9. It occurs between 47.05 m and 41 m in the DBQ core.

Diantholitha magnolia Aubry and Rodriguez in Aubry et al., 2011**,** Pl. 2, figs. **1a-d**, 2a-f, 3a, b, 4a-d, 5a-d.

***?Fasciculithus* sp. A** in Fuqua et al. 2008, Fig. 10

***Fasciculithus* sp. 1** Bernaola, Martín-Rubio and Baceta 2009, Figure 4/Q

Type locality: Gebel Abu Had, Qreiya section, Upper Egypt.

Type level: Sample Q+8.6 (uppermost Danian).

Occurrence: *D. magnolia* occurs over a short interval between levels Q+8.3 and Q+9.9 in the Qreiya section. It occurs between 43.15 m and 41 m in the DBQ core.

Diantholitha alata Aubry and Rodriguez in Aubry et al., 2011**,** Pl. 3, figs. 1a-d, 2a-d, 3a, b, 4a, b, 5a, b, 6a, b, 7a-d; PL. 8, figs. 5a-d.

***Fasciculithus* sp. 1** Bernaola, Martín-Rubio and Baceta 2009, figure 4/P

Type locality: Gebel Abu Had, Qreiya section, Upper Egypt.

Type-level: Sample Q+9.9 (lowermost Selandian).

Occurrence: Diantholitha alata occurs over a short interval between levels Q+8.3 and Q+9.9 in the Qreiya section. It occurs 41 m in the DBQ core.

Family **Sphenolithaceae** Deflandre 1952 orth. mut Vekshina 1959

Genus ***Sphenolithus*** Deflandre 1952

Sphenolithus editus Perch-Nielsen in Perch-Nielsen et al. 1978, Pl. 8, figs. 4, 5, 11-13, 16-18, 22-27, 43-45; pl. 20, figs. 5-11, **12**, 13-19

Type locality: Gebel Gurnah, Egypt

Type level: lower Eocene, NP11

Occurrence: Lower Eocene, Gurnah

Family Fasciculithaceae Hay and Mohler 1967

Genus ***Lithoptychius*** Aubry in Aubry et al., 2011.

Lithoptychius barakati (El-Dawoody) n. comb.

= *Fasciculithus barakati* El-Dawoody 1988, p. 555, 556, pl. 1, figs. **5a, b**, 6a, b, 7a, b

Type locality: Gebel Duwi, Egypt

Type level: Dakhla Shale

Occurrence: Abundant in the upper part of Zone NP5 and rare in Zone NP6.

Comments: The holotype of this taxon is a non-diagnostic distal view of a fasciculith. The side view of paratype 169 (Pl. 1, Figs. 7a, b) shows a fasciculith consisting of three superposed structural units and with a central body, characteristic of *Lithoptychius*. The calyptra is rather massive. In side view its distal periphery first curves gently inwards and then convexly towards the center of the fasciculith. It is expanded laterally so as to extend well beyond the thin collaret. The column is parallel-sided, with a deeply concave proximal face, a broad central canal and a small, but well delineated, triangular central body. Paratype 168 is also a *Lithoptychius*-fasciculith but poorly preserved, and uncharacteristic. Should the distal face of the holotype be associated with the side view of paratype 169, F. barakat is a legitimate species. For this reason it is recombined to *Lithoptychius*.

Lithoptychius collaris Aubry and Rodriguez, in Aubry et al., 2011**,** Pl. 4, figs. **1a-p**, 2a-d

Type locality: Gebel Abu Had, Qreiya section, Upper Egypt.

Type level: Level Q+8.6 (uppermost Danian).

Occurrence: *Lithoptychius collaris* has its LO at level Q+8.0 in the Qreiya section.

Lithoptychius felis Aubry and Bord in Aubry et al., 2011**,** Pl. 5, figs. **1a-d**, 2a-d, 3a-d, 4a-d, 5a-d

Type locality: Gebel Abu Had, Qreiya section, Upper Egypt.

Type level: Level Q+8.6 (uppermost Danian).

Occurrence: *Lithoptychius felis* has its LO at level Q+8.3 in the Qreiya section.

Lithoptychius stegastos Aubry and Bord in Aubry et al., 2011**,** Pl. 6, figs. **1a-d**, 2a-d, 3a, b, 4a-f, 5a-d.

Fasciculithus sp. 4 Bernaloa, Martín-Rubio and Baceta 2009, Pl. 5, figs. E-H

Type locality: Gebel Abu Had, Qreiya section, Upper Egypt.

Type level: Level Q+9.9.

Occurrence: *Lithoptychius stegastos* has its LO at level Q+8.3 in the Qreiya section.

***Lithoptychius* sp. 1** Aubry, Rodriguez and Bord, 2011, Pl. 7, figs. 1a-d, 2a-d, 3a-d, 4a, b, 5a-c, 6a-c.

***?Fasciculithus* sp. 3** Bernaola, Martín-Rubio and Baceta 2009, Figure 5/A-D

***Lithoptychius* sp. 2** Aubry et al., 2011**,** Pl. 8, figs.1a-d.

Family **Heliodiscoasteraceae** Aubry in press b

Genus ***Helio-discoaster*** Theodoridis 1984

Helio-discoaster aegyptiacus (El-Dawoody) n. comb.

= *Discoaster aegyptiacus eagyptiacus* El-Dawoody 1988, p. 556, 557, pl. 2, figs. **1**, 2-4

Type locality: Gebel Duwi, Egypt

Type level: Esna Shale

Occurrence: Frequent but restricted to a horizon in the top part of Zone NP9 at Gebel Duwi.

Comments: Although not highlighted in the original description a distinctive character of this taxon is the asymmetry of the discoaster, with inter-ray areas of variable width and rays projecting in different planes. These forms are part of the *Discoaster araneus* taxonomic complex itself part of the RD whose occurrence is restricted to the PETM. Whether it represents a discrete taxon or not is undecided, and will depend ultimately on the biologic interpretation of the complex, which is seen by some to represent malformed discoasters. Because this species is cited in the literature (e.g., Tantawy, 2006) the name is formally recombined here.

Discoaster aegyptiacus duwiensis El-Dawoody 1988, p. 557, pl. 2, figs. **5**, 6-8

Type locality: Gebel Duwi, Egypt

Type level: Esna Shale

Occurrence: Occurs together with *Discoaster aegyptiacus eagyptiacus* at Gebel Duwi, being restricted to a horizon in the top part of Zone NP9.

Comments: El-Dawoody's illustrations of this taxon are directly comparable with Bukry's illustrations of *Discoaster araneus* Bukry 1971, and the two names are regarded synonyms.

Heliodiscoaster mahmoudii (Perch-Nielsen) n. comb.

= *Discoaster mahmoudii* Perch-Nielsen 1981, p. 836, pl. 4, figs. 1–4, **5**, 6, **7**, 8–10

Type locality: Gebel Taramsa, Nile Valley, Egypt

Type level: Late Paleocene, *Discoaster multiradiatus* Zone

Occurrence: Found in several samles from the Taramsa section. "Romein (personal communication 1980) has been observed in the Upper Paleocene of the Caravaca section" (Perch-Nielsen 1981, p. 836).

Discoasteroides multiradiatus El-Dawoody 1988, p. 557, pl. 2, figs. **10**, 11

= *Discoasteroides* cf. *megastypus* Bramlette and Sullivan in El-Dawoody 1984, p. 271, pl. 1, figs. 9, 10

Type locality: Gebel Owaina, Egypt

Type level: Esna Shale

Occurrence: Frequent in upper part of the Esna Shale at Gebel Owaina.

Discoaster niloticum Sadek 1972, p. 110. nomen nudum

Taxon introduced without description or figuration

Order **Pontosphaearales** Aubry in press c

Family **Pontosphaeraceae** Lemmermann 1908

Genus **Pontosphaera** Lohmann 1902

Pontosphaera minuta El-Dawoody 1988, p. 554, pl. 2, fig. 9

Type locality: Gebel Duwi, Egypt

Type level: Esna Shale

Occurrence: Common throughout the upper part of Zone NP9, but rare Zone NP10 at Gebel Duwi

Comments: This taxon is the oldest representative of the genus *Pontosphaera*. Its LO is slightly younger than the RD. It is found in sections in Egypt as well as New Jersey.

Order **Syracosphaerales** Hay 1977, emended Young et al., 2003

Scapholithus solidus El-Dawoody 1975, p. 467, Pl. 12, Fig. 4

Type locality: Gebel Duwi, Quseir District, Egypt

Type level: Upper Paleocene, Esna Shale

Occurrence: Restricted to the base of the Esna Shale unit (NP9) at Gebel Duwi

Order **Zygosdiscales** Young and Bown 1997 emend Aubry in press d

Family **Zygodiscaceae** Hay and Mohler 1967

Zygodiscus kuepperi El-Dawoody 1988, p. 554, 555, pl. 1, figs. 3, 4

Type locality: Gebel Duwi, Egypt

Type level: Tarawan Chalk

Occurrence: Common in the upper part of Zone NP5 and very common in Zone NP6.

Incertae sedis

Cyclolithella esnaensis El-Dawoody 1988, p. 553, pl. 2, fig. 12

Type locality: Gebel Owaina, Egypt

Type level: Dakhla Shale

Occurrence: Throughout the Dakhla Shale of Gebel Owaina

Family **Rhomboasteraceae** Aubry in press e

Genus ***Rhomboaster*** Bramlette and Sullivan 1961

Marthasterites spineus Shafik and Stradner 1971, p. 93, tfs. 6, 7a, **7b, 7c**, 7d

Type locality: Ash El-Mellaha Range, Egypt

Type level: Paleocene

= *Rhomboaster spineus* (Shafik and Stradner) Perch-Nielsen 1984

Comments: This coccolith is easily identified by the presence of tiny, irregularly spaced, spines on its delicate arms. The species is restricted to Subzone NP9c.

Genus ***Tribrachiatus*** Shamray 1963 emended Romein 1979

Marthasterites bramlettei subbramlettei El-Dawoody in El-Dawoody and Barakat 1972, p. 25, Pl. 6, Fig. **9**

= *Tribrachiatus bramlettei* Bronniman and Stradner, subsp. *subbramlettei* (El-Dawoody 1972) Aubry 1988, p. 24, 25 (*bramelettei* in original description of the subspecies corrected to *bramlettei*)

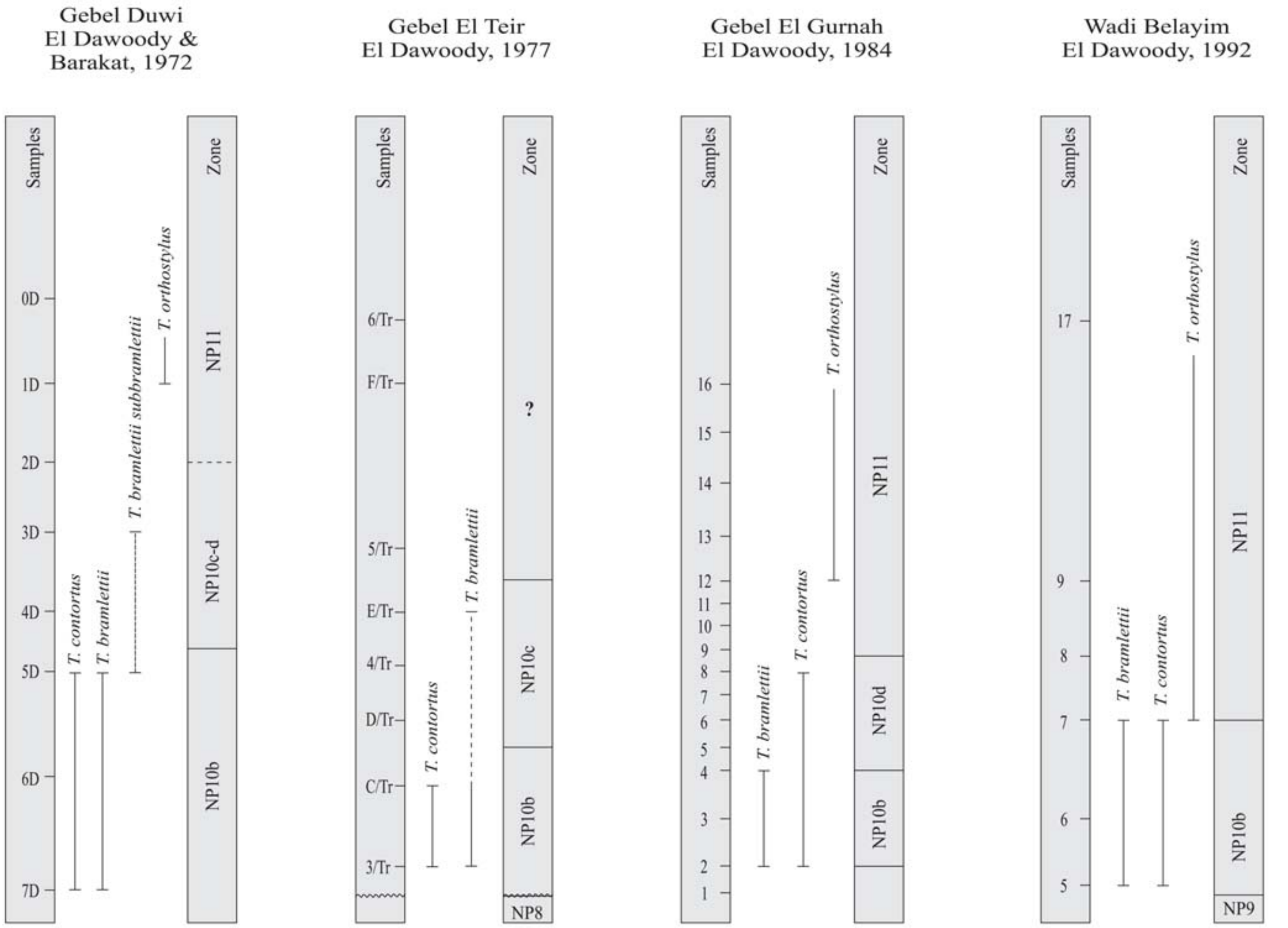
= *Tribrachiatus contortus* (Stradner) Bukry 1972

Type locality: Gebel Duwi, Quseir District, Egypt

Type level: Topmost part of the Esna Shale unit

Occurrence: Common in the basal part of the *Discoaster binodosus* Zone. Also occurs at the top of the underlying zone.

Comments. A single, broken specimen (holotype from Level 5D, see below) was figured by El-Dawoody (in El Dawoody and Barakat 1972) to illustrate his concept of *M. bramlettei subbramlettei*. It would seem that there was no subsequent use of the name *subbramlettei*, including in synonymy lists by El-Dawoody (1977: p. 852; 1984: p. 271, 278). Two exceptions were the reassignment of the taxon to the genus *Tribrachiatus* (Aubry 1988, p. 24, 25) and the remark by Aubry (1996, p. 246) that it was morphologically reminiscent of *T. digitalis*. Relying on El-Dawoody's biozonal assignments in the Duwi section, she provisionally concluded that *T. bramlettei subbramlettei* is a morphologic variant of *T. orthostylus*. Nevertheless the question remained whether *T. digitalis* could be a synonym of *T. bramlettei subbramlettei*. *Tribrachiatus digitalis* is similar to *T. contortus* in having arms arranged in two triplets asymmetrically arranged. However, whereas the tips of adjacent arms of *T.*



APPENDIX FIGURE
Distribution of *Tribrachiatus* species in selected sections of the Nile Valley and subzonal interpretation.

contortus lie in different planes because of an offset between the triplets of *T. contortus*, the arms of *T. digitalis* lie in the same plane. The two taxa may difficult to distinguish in poorly preserved material, and there has been reluctance in accepting the distinction (Raffi et al., 2005). Aubry (1996) has shown that *T. bramlettei* and *T. contortus* do not co-occur except for a very thin stratigraphic interval in which the latter species is seen to evolve from the former (see also Bord and Aubry, 2013). On the other hand, the range of *T. digitalis* is entirely comprised within the range of *T. bramlettei* and the co-occurrence of the two taxa defines Subzone NP10b. These relationships first established at DSDP Site 550 (Aubry et al. 1996) have since been verified in Egyptian sections (e.g., Tantawy 1998).

The stratigraphic ranges of *Tribrachiatus* species in the Duwi section as shown by El-Dawoody and Barakat (1972, p. 7, Fig. 3; Fig. A) is revealing of the taxonomic status of *T. bramlettei subbramlettei* that can be safely interpreted as a synonym of *T. contortus* (Stradner). *Tribrachiatus contortus* (sensus El-Dawoody 1972) and *T. bramlettei* co-occur in the interval between Levels 7/C and 5/D, which was assigned to the "*Marthasterites contortus* Zone" (= Zone NP10); the subspecies *subbramlettei* also occurs at Level 5/D and it is present, alone, at Level 3/D; the LO of *T. orthostylus* is at Level 1D. The interval between level 4/D (thus above the HO of *T. contortus* sensu El-Dawoody) and just below Level 1D (LO *T. orthostylus*) was assigned to the *Discoaster binodosus* Zone (= Zone NP11) whereas the section above Level 1D was assigned to the concurrent range "*Marthasterites tribrachiatus* Zone" (= Zone NP12), despite the absence of *Heliodiscoaster lodoensis*. Based on Aubry (1996) the biozonal subdivision of the Lower Eocene section at Gebel Duwi is reinterpreted, the interval between Level 7/C to 5/D being assigned to Subzone NP10b, that above level 1/D to Zone NP11, the intervening interval (Levels 3/D and 2/D) belonging to Subzones NP10c and NP10d or to Subzone NP10d. This reinterpretation implies that 1) *Tribrachiatus contortus* sensu El Dawoody 1972 is in fact *Tribrachiatus digitalis* Aubry 1996, and 2) *Tribrachiatus bramlettei subbramlettei* (El-Dawoody) Aubry 1988 is a synonym of *Tribrachiatus contortus* (Stradner 1958) Bukry 1972. Other studies also show that El Dawoody indifferently assigned to *T. contortus* specimens that co-occur with *T. bramlettei* or range above it. At Gebel El Teir (El-Dawoody 1977, p. 832, fig. 3; Fig. A) the range of *T. contortus* (sensu El Dawoody) is restricted to the lower range of *T. bramlettei*. At Gebel Gurnah (El-Dawoody 1984, p. 265, Fig. 3), the range of *T. bramlettei* is restricted to the lower range of *T. contortus*. At Wadi Belayim (El-Dawoody 1992, p. 417, Fig. 3) the ranges of the two taxa overlap.

My interpretation of synonymy between *T. bramlettei subbramlettei* and *T. contortus* is supported by El-Dawoody's figurations of the species. The holotype of the former taxon was chosen from Level 5D where *T. contortus* sensu El-Dawoody was also shown to occur (see Fig. A). No illustrations of this latter taxon were given, neither from this level nor from Levels 7C or 6C in the interval of Subzone NP10b (these would have been the first illustrations of the taxon now called *T. digitalis*). El-Dawoody (1992) did not illustrate specimens of *Tribrachiatus* from the Sinai section, but he (1984, pl. 3, figs. 17a, b) illustrated one specimen assigned to *T. contortus* from Level 8/Gh at Gebel Gurnah. He (1977, fig. 9a, b) also illustrated a specimen assigned to *T. contortus* in his work on the Upper Paleocene-Lower Eocene stratigraphy at Gebel El Teir, this without information on its stratigraphic occurrence. Specimens from Gebel El Teir assigned by El-Dawoody to *T. contortus* would be of *T. digitalis* (see Fig. 3 and above). A brief comparison shows that the latter illustration is the same as the 1984 illustration of *T. contortus* (Stradner). Thus *T. digitalis* was not illustrated by El-Dawoody, even though he recognized in 1972 that there were two distinct asymmetrical six-rayed morphotypes of *Tribrachiatus*.

Mesozoic taxa described from the Paleogene of Egypt

The classification used here follows work in progress by Aubry. Bold numbers indicate holotypes

Order **Coccosphaerales** Haeckel 1894 emend Young and Bown 1997

Family **Markaliaceae** Aubry in press a

Markalius perforatus PERCH-NIELSEN 1973, p. 317, 318, pl. 1, figs. 9, 10; pl. 10, figs. 13, 14: Maestrichtian (*N. frequens* Zone) of Egypt

Order **Discoasterales** Hay 1977, Aubry in press b

Pseudomicula quadrata Perch-Nielsen in Perch-Nielsen et al. 1978, Pl. 1, figs. 43, 44; pl. 7, figs. 3, **6, 9**

Type locality: Gebel Owaina, Egypt

Type level: Upper Maestrichtian, *N. frequens* Zone

Occurrence: rare Gebel Owaina

Order **Syracosphaerales** Hay 1977 emended Young et al., 2003

Family **Predicosphaeraceae** Rood, Hay and Barnard 1971

Genus **Predicosphaera** Vekshina 1959

Predicosphaera bukryi Perch-Nielsen 1973, p. 320, Pl. 7, figs., 6, 7; pl. 10, figs. 4, 5

= *Predicosphaera honjoi* Bukry 1969, Pl. 18, fig. 4, NON Pl. 18, fig. 6

Type locality: Oweina, Egypt

Type level: Maestrichtian, *N. frequens* Zone

Predicosphaera majungae Perch-Nielsen 1973, p. 321. Pl. 8, figs. 1-6; pl. 10, figs. 37, 38

Maestrichtian (*N. frequens* Zone) of Egypt

Genus ***Polypodorhabdus***

Polypodorhabdus pienaari Shafik and Stradner 1971, p. 86, tf. 4, pl. 14, figs. 1-3, **4**

= *Cretarhabdus decorus* Pienaar, p. 92, pl. 8, fig. 8

Type locality: Gebel Tarbouli, Egypt

Type level: Upper Maestrichtian

Unclassified

Cribrocorona gallica (Stradner 1963) Perch-Nielsen 1973, p. 312, pl. 4, figs. 1-4, pl. 10, figs. 25-28: Maestrichtian of Egypt

Cylindralithus oweinae Perch-Nielsen 1973, p. 314, 315, Pl. 4, figs. 7, **8**; pl. 5, fig. 1:

Type locality: Oweina, Egypt

Type level: Maestrichtian, *N. frequens* Zone

Zygolithus tarboulensis Shafik and Stradner 1971, p. 91, pl. 37, figs. 1, **2**, 3, 4, tf. 5

Type locality: Gebel Tarbouli, Egypt

Type level: Upper Maestrichtian