CLIMATE & BIOTA of the EARLY PALEOGENE

Austrian Journal of Earth Sciences | Volume 105/1 | 161 - 168 | Vienna | 2012

The Dababiya corehole, Upper Nile Valley, Egypt: Preliminary results

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KEYWORDS

Dakhla and Esna Shale Formations
Upper Cretaceous and Paleocene
Dababiya Quarry
Tarawan Chalk
stratigraphy

Abstract

The Dababiya corehole was drilled in the Dababiya Quarry (Upper Nile Valley, Egypt), adjacent to the GSSP for the Paleocene/Eocene boundary, to a total depth of 140 m and bottomed in the lower *Maastrichtian Globotruncana aegyptiaca* Zone of the Dakhla Shale Formation. Preliminary integrated studies on calcareous plankton (foraminifera, nannoplankton), benthic foraminifera, dinoflagellates, ammonites, geochemistry, clay mineralogy and geophysical logging indicate that: 1) The K/P boundary lies between 80.4 and 80.2 m, the Danian/Selandian boundary between ~ 41 and 43 m, the Selandian/Thanetian boundary at ~ 30 m (within the mid-part of the Tarawan Chalk) and the Paleocene/Eocene boundary at 11.75 m (base [planktonic foraminifera] Zone E1 and [calcareous nannoplankton] Zone NP9b); 2) the Dababiya Quarry Member (=Paleocene/Eocene Thermal Maximum interval) extends from 11.75 to 9.5 m, which is ~1 m less than in the adjacent GSSP outcrop.; 3) the Late Cretaceous (Maastrichtian) depositional environment was nearshore, tropical-sub tropical and nutrient rich; the latest Maastrichtian somewhat more restricted (coastal); and the early Danian cooler, low(er) salinity with increasing warmth and depth of water (i.e., more open water); 4) the Paleocene is further characterized by outer shelf (~ 200 m), warm water environments as supported by foraminifera P/B ratios > 85% (~79-28 m), whereas benthic foraminifera dominate (>70%) from ~27-12 m (Tarawan Chalk and Hanadi Member) due, perhaps, in part to increased dissolution (as observed in nearby outcrop samples over this interval); 5) during the PETM, enhanced hydrodynamic conditions are inferred to have occurred on the sea-floor with increased river discharge (in agreement with sedimentologic evidence), itself a likely cause for very high enhanced biological productivity on the epicontinental shelf of Egypt; 6) correlation of in situ measured geophysical logs of Natural Gamma Ray (GR), Single-Point Resistance (PR), Self-Potential (SP), magnetic susceptibility (MS), and Resistivity, and Short Normal (SN) and Long Normal (LN) showed correspondence to the lithologic units. The Dababiya Quarry Member, in particular, is characterized by very high Gamma Ray and Resistivity Short Normal values.

1. Introduction

The GSSP for the base of the Eocene Series is located at 1.58 m above the base of Section DBH in the Dababiya Quarry, on the east bank of the Nile River, about 35 km south of Luxor, Egypt (Aubry et al., 2007). It is the base of Bed 1 of the Dababyia Quarry Beds of the El Mahmiya Member of the Esna Shale Formation, interpreted as having recorded the basal inflection of the carbon isotope excursion (CIE), a prominent (3 to 5‰) geochemical signature which is recorded in marine (deep and shallow) and terrestrial settings around the world. The Paleocene/Eocene (P/E) boundary is thus truly a globally correlatable chronostratigraphic level. It may be correlated also on the basis of 1) the mass extinction of abyssal and bathyal benthic foraminifera (*Stensioeina beccariiformis* microfauna), and reflected at shallower depths by a minor benthic foraminiferal turnover event; 2) the transient occurrence of the excursion taxa among the planktonic foraminifera (*Acarinina africana*, *A. sibaiyaensis*, *Morozovella allisonensis*); 3) the transient occurrence of the *Rhomboaster* spp. – *Discoaster araneus* (RD) nannoplankton assemblage); 4) an acme of the dinoflagellate *Apectodinium* complex. The GSSP-defined Paleocene/Eocene boundary is approximately 0.8 Myr older than the base of the stratotypic Ypresian Stage in epicontinental northwestern Europe. We retain the term Sparnacian Stage for the interval separated by these two stratigraphic horizons.

Calcareous and organic-walled microfossils in Paleogene and Upper Cretaceous outcrops in most of Egypt are poorly to only moderately well preserved as a result of post-depositional carbonate recrystallization. The Dababiya Quarry microfossils are no exception and, indeed, both calcareous nannoplankton and planktonic foraminifera suffered from dissolution/recrystallization and no dinoflagellates were preserved. Benthic foraminifera fared somewhat better. Additionally, no paleomagnetic stratigraphy was possible in outcrop because 1) stable magnetizations are carried by hematite with no evidence of a primary magnetic mineral such as magnetite, 2) the magnetic polarity stratigraphy is inconsistent with patterns expected from the geomagnetic time scales, and 3) directions correspond to late Cenozoic directions and are far from those expected from early Cenozoic directions for Africa (Kent and Dupuis, 2003).

In the hope of obtaining material of better preservation and reliable magnetostratigraphy we obtained funding to drill a corehole in the vicinity of the outcrop section(s). We describe below some of the preliminary results of our studies while noting that microfossil preservation has proved only marginally better, except for the dinoflagellates, and paleomagnetic measurements have again been found to be unreliable with occurrences of hematite remanence carriers, suggesting that chemical alteration and remagnetization are not simply due to surficial weathering.

2. Background

The Dababiya corehole (25° 30'09.9" N, 32° 31'27.1" E) was drilled in February 2004. It is located ~200 m east of the Eocene GSSP DBH section (Aubry et al., 2007; Fig. 1). It was spudded in the El Mahmiya Member of the Esna Shale Formation, ~9.5 m above the Dababiya Quarry Member. It penetrated to a total depth of 140.2 m, and bottomed in ammonite –nuculid–bearing phosphatic shales of the Dakhla Shale Formation in the lower Maastrichtian *Globotruncana aegyptiaca* Zone. Recovery was generally good but the upper/initial ~ 6 m of the corehole were poorly recovered.

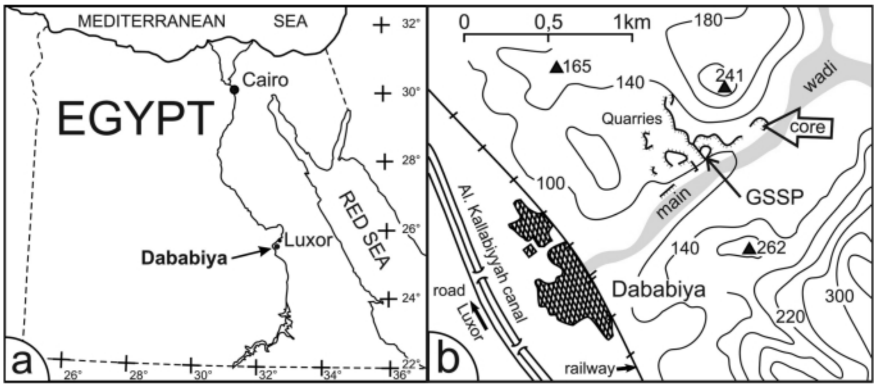

Figure 1: Geographic location of the Dababyia Corehole.

3. Lithostratigraphy and sedimentology

The core consists of, in stratigraphic order, the Dakhla Shale Formation (140 to 39 m), the Tarawan Chalk (39 to 22 m; Fig. 2), and the Hanadi (22 to 11.40 m), Dababiya Quarry (11.40 to 9.5 m) and El Mahmiya (9.5 to 0 m) members of the Esna Shale Formation. The Dakhla Shale Formation is provisionally divided into five informal lithologic units. A phosphate-rich bed at 136 m separates units 1 and 2. A strongly burrowed surface at 111 m separates units 2 and 3. The latter extends up to 83 m marked by a bioturbated surface at the base of a phosphatic bed. Unit 5 is thin (4 m) and topped by a pyritized horizon marking the K/P boundary. Unit 4 extends to the base of the Tarawan Chalk, marked by a sharp increase in $CaCO_3$ content. Bioturbation is conspicuous between ~73 and 78 m (Lower Danian) and between ~42 and 47 m (in the vicinity of the Danian/Selandian boundary). The interval from 9.4 m to 6.0 m in the corehole is readily correlated with the interval from 5.4 m to 9.0 m in the DBH (outcrop) subsection and the interval from 0.0 m to 3.5 m in the DBD subsection.

The clay mineral content (chlorite, illite, illite-smectite [R0 type], kaolinite) varies in the core. The interval from 140 to 80 m (unit 4) contains chlorite with illite and kaolinite, indicating detrital input. The interval from 80 m to 15/20 m is characterized by smectitic mixed layers with lesser amounts of illite and kaolinite. This may reflect reduced detrital input into the basin. From 15/20 m to the top of the core, kaolinite and illite are abundant, indicating continental erosion. The peak in kaolinite and illite at the P/E boundary likely reflects an episode of runoff associated with global warming, as supported by geochemical analysis (see below). Chlorite and illite are broadly regarded as anchimetamorphic minerals. However, considering the shallow burial depth (~350 to 500 m) of the lower Paleogene sediments at Dababyia, such an origin is not possible. As is often case in sedimentary successions, illite and chlorite are of detrital origin in the core. Kaolinite is typically a product of continental weathering associated with acidic leaching processes. Smectites and particularly the IS-mixed layers may form in sea water by aggradation, but they may also form in soils. Their detrital origin is thus blurred by marine aggradation processes, as might be the case here. For a comprehensive discussion on the origin of clays we refer the reader to Thiry and Jacquin (1993).

A high-resolution mineralogical and geochemical study of the Dababiya Quarry Member in the Dababiya core was carried out by Soliman et al. (2011) complementing the studies of Dupuis et al. (2003), Ernst et al. (2006), Soliman et al. (2006) and Schulte et al. (2011) on the adjacent Gabal Dababiya (Paleocene-Eocene GSSP) outcrop section. The sediments of the Dababiya Quarry Member are distinctive in containing relatively high amounts of phosphatic components (fish debris and coprolites), bacterial pyrite framboids and organic matter. Strong positive anomalies in the trace elements Zn, V, Mo, Ni, Cr, Cu, P and S are present at the top of Bed 1 (clay bed) and in Bed 2 (bone-bearing bed), corresponding to the core of the CIE. These geochemical and mineralogical signatures indicate deposition during a period of upwelling and high productivity, with the development of suboxic to anoxic conditions at or just above the sediment-water interface. High Ti/Al ratios indicate increased river discharge at this time, most probably in response to climatic warming. The sediments of the recovery phase of the CIE reflect a gradual return to open marine environments similar to those that prevailed during the Late Paleocene.

4. Biostratigraphy

4.1 Planktonic foraminifera

The core spans from lower Eocene (Zone E2) to lower Maastrichtian (*Globotruncana aegyptiaca* Zone) (Figure 2). Planktonic foraminifera are generally rare and moderately preserved. The biostratigraphy of the Tarawan Chalk to El-Mahmiya Member is the same as in the nearby GSSP section (see Berggren and Ouda, 2003; Chapter 4) with predominantly morozovellid and acarininid taxa and subordinate numbers of subbotinids. The Dababiya Quarry Member (11.75–9.5 m) contains a mixed acarininid-morozovellid assemblage with subordinate subbotinids and the excursion taxa (*Acarinina africana*, *A. sibaiyaensis* and *Morozovella allisonensis*). The greater part of the Hanadi Member corresponds to Subzone P4c (21.15–14.25 m) and Zone P5 (14.25–11.75 m). The P4a-b/P4c subzonal boundary is placed at the contact between the Tarawan Chalk and Hanadi Member (= lowest occurrence [LO] of *Acarinina soldadoensis* at ~21 m); the E1/E2 zonal boundary corresponds with the Dababiya Quarry/El Mahmiya boundary at 9.5 m.

The Cretaceous/Paleogene (K/P) boundary is located at ~ 80 m. Sediments between 81 and 80 m are characterized by, i.al., *Pseudotextularia deformis*, *Peudoguembelina costulata*, *P. kempensis*, *P. palpebra* and *Globigerinelloides aspera* denoting the uppermost Maastrichtian *P. palpebra* Zone. Zone Pα spans the interval between 80 and 79 m. Zone P1 extends from 79 to 68.35 m (~11 m) and can be divided into Subzones P1a (up to 76.4 m), P1b (to 72.40 m) and P1c (up to 68.35 m). Zone P2 extends from 68.35 m to 56.60 m (LO of *M. angulata*). Zone P3 extends from 56.60 m to 39.60 m. The LO of *Igorina albeari* (P3a/b subzonal boundary) occurs at 49.45 m below a black layer at 46.5 m. The highest occurrence (HO) of *Praemurica carinata* is at this level. The Danian/Selandian boundary is placed at ~46.5 m on this basis. Zone P4 is denoted by the LO of *Gl. pseudomenardii* just below the Tarawan Chalk/Dakhla Shale contact at ~ 39 m. The P4a/b boundary is denoted by the HO of *Parasubbotina variospira* at 34 m in the lower part of the Tarawan Chalk.

Assemblages from 137 to 140 m (base of the corehole) are characterized by *Globotruncana arca*, *G. aegyptiaca*, *G. lin-*

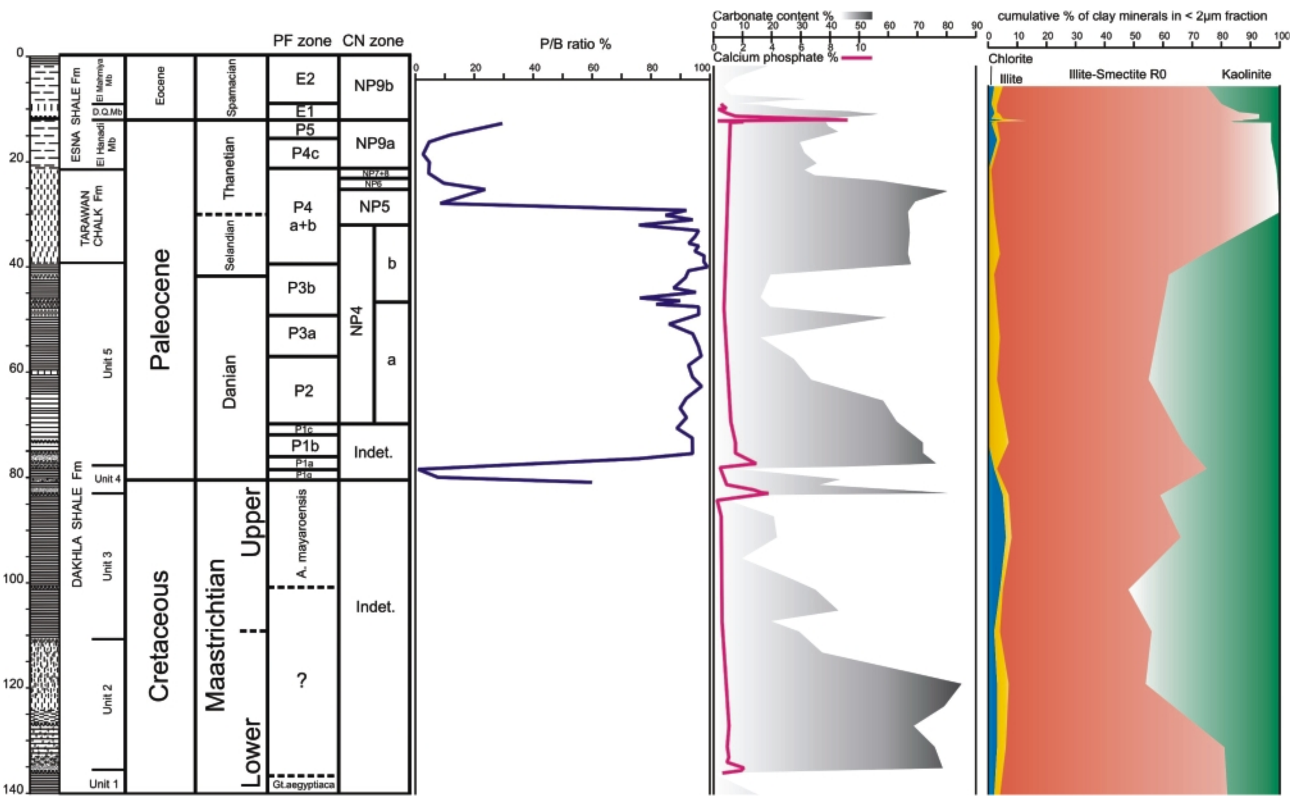

Figure 2: Lithology, biostratigraphy, geochemistry and mineralogy of Dababya Corehole. Formation and Member names shown in left column. Cretaceous/Paleogene (K/P) boundary lies at ~80 m; Paleocene/Eocene (=Thanetian/Sparnacian) boundary lies at 11.75 m (= [PF] P5/E1 and [CN] NP9a/b) zonal boundaries). PETM=11.75–9.5 m. See text for discussion/explanation of P/B ratios, carbonate and clay mineralogy data; DBM: Dababiya Quarry Member.

neiana, *G. ventricosa*, *Archeoglobigerina cretacea*, *Heterohelix globulosa*, *H. moremani* and *H. reussi* indicative of the lower Maastrichtian *G. aegyptiaca* Zone. Maastrichtian samples between 137 and 81 m were not examined with few exceptions and will form the subject of future studies.

4.2 Calcareous Nannoplankton

Coccoliths are common to abundant at most levels throughout the section, but preservation varies greatly. Assemblages are of rather low diversity, and some markers are unexpectedly rare. Species of *Heliodiscoaster* and *Heliolithus* were generally rare, causing difficulties in determining the presence and /or extent of Zones NP6, NP7 and NP8 (Figure 2). For this preliminary study only the zonal markers of Martini (1971) and Sissingh (1977) are considered.

The Paleocene/Eocene boundary lies at the base of Bed 1 of the Dababyia Quarry Member, with the upper part of the Hanadi Member belonging to Subzone NP9a, and the Dababyia Quarry Member Bed 2 belonging to the older part of Subzone NP9b as characterized by the so-called RD assemblage (which consists of *Rhomboaster* spp., *Helio-discoaster araneus* and *H. anartios*). The youngest beds belong to Zone NP9b, and lie very close to the NP9/NP10 zonal boundary. The Tarawan Chalk is extremely difficult to date, encompassing Zone NP5 to NP9a (39 to 22 m).

The bulk of the Dakhla Shale belongs to Zone NP4 (69 m to 33 m). The Neo-Duwi beds (see Aubry et al., this volume) are predicted to occur in the interval between 43.15 and 41 m. The LO of *Diantholitha mariposa* at 47.05 m, those of *D. alata*, *D. magnolia*, *Lithoptychius collaris* and *L. felis* at 43.15 m, and the HO of *Diantholithus* spp. at 41 m constitute a characteristic sequence in the vicinity of the Neo-Duwi beds at Gebel Qreyia (Aubry et al., this volume). The radiation of *Lithoptychius* (first radiation of the fasciculiths, Romein, 1979; second radiation of the fasciculiths, Bernaola et al., 2009) that marks the Danian/Selandian boundary begins at 43.15 m. The LO of *Sphenolithus primus* was noted at 35 m. The Selandian/Thanetian boundary is extremely difficult to delineate. It possibly corresponds to a burrowed surface between 23 and 24 m, and a substantial stratigraphic gap is inferred. Zonal boundaries are difficult to delineate below 69 m because of the scarcity of the marker species. The NP3/NP4 zonal boundary lies

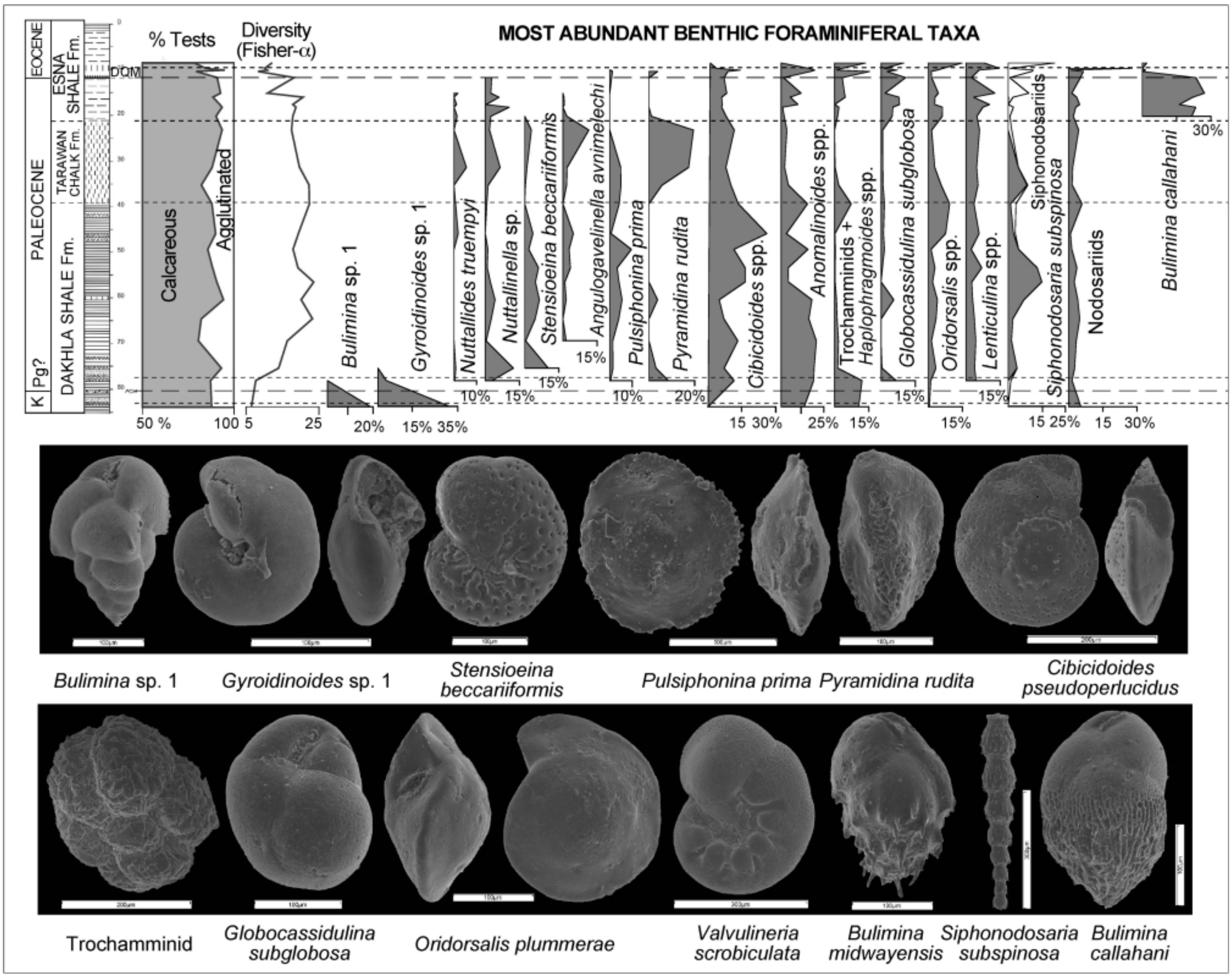

Figure 3: Benthic foraminiferal assemblages in the Cretaceous Dakhla Shales Formation through lowermost Eocene Esna Shales Formation. DQM: Dababiya Quarry Member.

between 70.5 m and 72.5 m. The base of Zone NP2 occurs between 77.85 and 78.40 m. The K/P boundary is denoted by the LO of *B. sparsus* at 80.20 m. The interval between 80.40 m and 84 m is characterized by the occurrence of *Nephrolithus frequens* and belongs to Zone CC26. The occurrence of *Micula prinsii* at 80.40 and 80.60 characterizes Subzone CC26b. No samples were studied between 84 m and 139.90 m. A sample from 139.90 m belongs to Zone CC24 or older.

4.3 Dinoflagellates

Diverse and well-preserved dinoflagellate cyst assemblages were recovered from the Dakhla Formation. The interval between 70 and 140 m is Upper Cretaceous–Lower Paleocene, but there is no sharp qualitative changes in the dinoflagellate cyst associations that would help in precisely delineating the K/P boundary. The LOs of *Damassadinium californicum* and *Carpatella coronata* (80.25 m), *Senoniasphaera inornata* (81 m), *Membranilarnacia?*, *Tenella* and *Kallosphaeridium yorubaense* (80.75 m), *Palynodinium grallator* (80.75 m) and *Kenleyia leptocerata* (81 m) and the HOs of *Dinogymnium* spp. (80.75 m), *Damassadinium fibrosum* (82.1 m) and *Alisogymnium euclaense* (84 m) are significant markers around the Maastrichtian/Danian boundary (e.g., Slimani et al., 2010). Thus the K/P boundary is between 80 m and 81 m or, possibly, at 81.75 m.

4.4 Ammonites

In the Cretaceous part of the core, ammonites are observed at several levels between 80.42 and 139.27 m. They are almost all heteromorph ammonites such as scaphitids and baculitids. The presence of the stratigraphically restricted scaphitid species *Indoscaphites pavana* (Forbes, 1846), previously only known from southern India, Algeria and Tunisia (Goolaerts et al., 2004; Goolaerts, 2010), suggests that the interval from ~100 to 80 m represents the latest 420 kyr of the Maastrichtian. This is supported by the presence of the latest Maastrichtian planktonic foraminifer *Abathomphalus mayaroensis* in the same interval.

5. Paleoenvironments

5.1 Benthic foraminifera

Benthic foraminiferal assemblages are dominated by taxa typical of the Midway-type fauna and of outer shelf environments, and indicate deposition at about 200 m depth for most part of the studied section (Fig. 3).

Significant changes in composition have been observed, with very low diversity assemblages characteristic of low-oxygen environments in the Cretaceous dark-colored levels of the Dakhla Shale Formation, followed by the typical Paleocene assemblages dominated by the Midway–type fauna (e.g., *Angulogavelinella avnimelechi*, *Bulimina midwayensis*, *Cibicidoides alleni*, *Cibicidoides succeedens*, *Loxostomoides applinae*, *Osangularia plummerae*, *Siphogenerinoides eleganta*; Berggren and Aubert, 1975) in the Dakhla Shale and Tarawan Formations.

The uppermost Paleocene assemblages from the El Hanadi Member of the Esna Shale Formation contain abundant buliminids (*Bulimina callahani*), which may indicate an abundant flux of food to the seafloor and partially dissolved tests that may be indicative of corrosive bottom waters.

The HOs of species such as *Anomalinoides rubiginosus*, *Cibicidoides hyphalus* and *Gyroidinoides globosus* in the Dababiya Corehole can be correlated with the Benthic Foraminiferal Extinction Event (BEE) that occurred in deep-water settings during the PETM. Less than 10% of the benthic foraminiferal species disappeared at the Paleocene/Eocene boundary in the section, confirming that the BEE was less prominent in shallow epicontinental environments compared to the deep sea (Alegret and Ortiz, 2006).

Lowermost Eocene assemblages (Dababiya Quarry Member) contain abundant pyritized molds and dissolved tests. Low diversity assemblages are mainly dominated by uniserial taxa, trochamminids, *Lenticulina*, *Anomalinoides* cf. *zitteli*, *C. pseudoperludicus*, *Globocassidulina subglobosa* and *Oridorsalis umbonatus*. Samples available from the Dababiya Quarry Member were insufficient to assess in detail the paleoenvironmental turnover across the PETM in comparison to earlier high resolution studies (e.g., Alegret and Ortiz, 2006). Available data confirm the previous pattern of recovery documented by these authors. In particular, the presence of abundant pyritzed moulds of benthic foraminifera and dissolved tests in the Dababiya Quarry Beds suggest carbonate dissolution during the PETM.

5.2 Ratio planktonic/benthic foraminifera

The ratio of planktonic to benthic foraminifera in the 125-250 µm size fraction varies considerably in the interval 81 m–12 m and characterizes three markedly different intervals. Between 81 and 80 m the planktonic foraminifera are in very low proportions (< 10% compared with 60% at 82 m). This prominent event between 81 and 82 m is latest Maastrichtian. Between 79 and 28.5 m the planktonic foraminifera occur in very high proportions (mostly > 85%). This is typical for outer neritic to upper bathyal open marine environments. Between 28.0 and 12.0 m the benthic foraminifera dominate (>70%). This abrupt drop in the abundance of the planktonic foraminifera occurs in the upper part of the Tarawan Chalk and low abundances persist through the Hanadi Member.

These abrupt changes clearly indicate major oceanographic events and need to be calibrated with other environmental parameters.

5.3 Dinoflagellates

Dinoflagellate assemblages indicate that environmental changes occurred through the Maastrichtian and Danian. The interval between 140 and 86 m is marked by the abundance of peridinioid cysts such as *Palaeocystodinium*, *Phelodinium*, *Cerodinium* and *Deflandrea*. This is indicative of near-shore, tropical-subtropical and nutrient-rich environments (Lentin and Williams, 1980). Based on the abundance of *Manumiella* the interval between 86 and 80 m corresponds to a restricted, low salinity and cold environment (Habib and Saeedi, 2007). A gradual increase in water depth from a near shore to open marine (warm) environment is inferred for the interval between 80 and 70 m based on the abundance of gonyaulacoid cysts such as *Glaphyrocysta*, *Areoligera*, *Operculodinium* and *Spiniferites* (Brinkhuis and Zachariasse, 1988).

6. Geophysical logging

The geophysical logging was carried out by the Egyptian Geological Survey and Mining Authority (EGSMA). It included Natural Gamma Ray (GR), Single-Point Resistance (PR), Self-Potential (SP), and Resistivity, Short Normal (SN) and Long Normal (LN). The magnetic susceptibility of the core was measured in Assiut University.

The geophysical logs were correlated with each other as well as the magnetic susceptibility. From this correlation it was easy to separate five geophysical zones. These zones are described from top to bottom as follows (Figure 4). The first geophysical zone extends from the ground surface to 9.7 m. This zone is characterized by high to moderate MS values (2.0-7.0 CGS units), GR values (72-101 API), PR (51-53 Ohm), SN (75-80 Ohm-m), and SP values (-2328 to -2082 mV), while LN values are high (49-50 Ohm.m). This geophysical zone corresponds to the El-Mahmiya Member. The second geophysical zone extends from 9.7 to 11.75 m and has moderate to low MS (1.0-4.0 CGS units) while characterized by very high values of GR (79-460 API) and SN (72-87 Ohm.m). The PR values change from 51-53 Ohm and the SP values from -2536 to -2262 mV; LN is high (50-52 Ohm-m). This zone corresponds to the Dababyia Quarry Member. The third geophysical zone extends from 11.75 to 21.35 m. It is characterized by moderate to very low values of MS (0.4-4.0 CGS units) and moderate to low values of GR (52-94 API), SN (50-77 Ohm-m) and SP from -2282 to -1784 mV. PR values change from 49 to 53 Ohm and the LN from 2 to 52 Ohm-m. This zone corresponds to the El-Hanadi Member. The fourth geophysical zone extends from 21.35 to 39 m, and is characterized by moderate to very low values of MS (0.7-5 CGS units), with high GR (24-101 API) and SP values (-2499-1740 mV). The PR ranges between 49 and 57 Ohm, the SN values be-

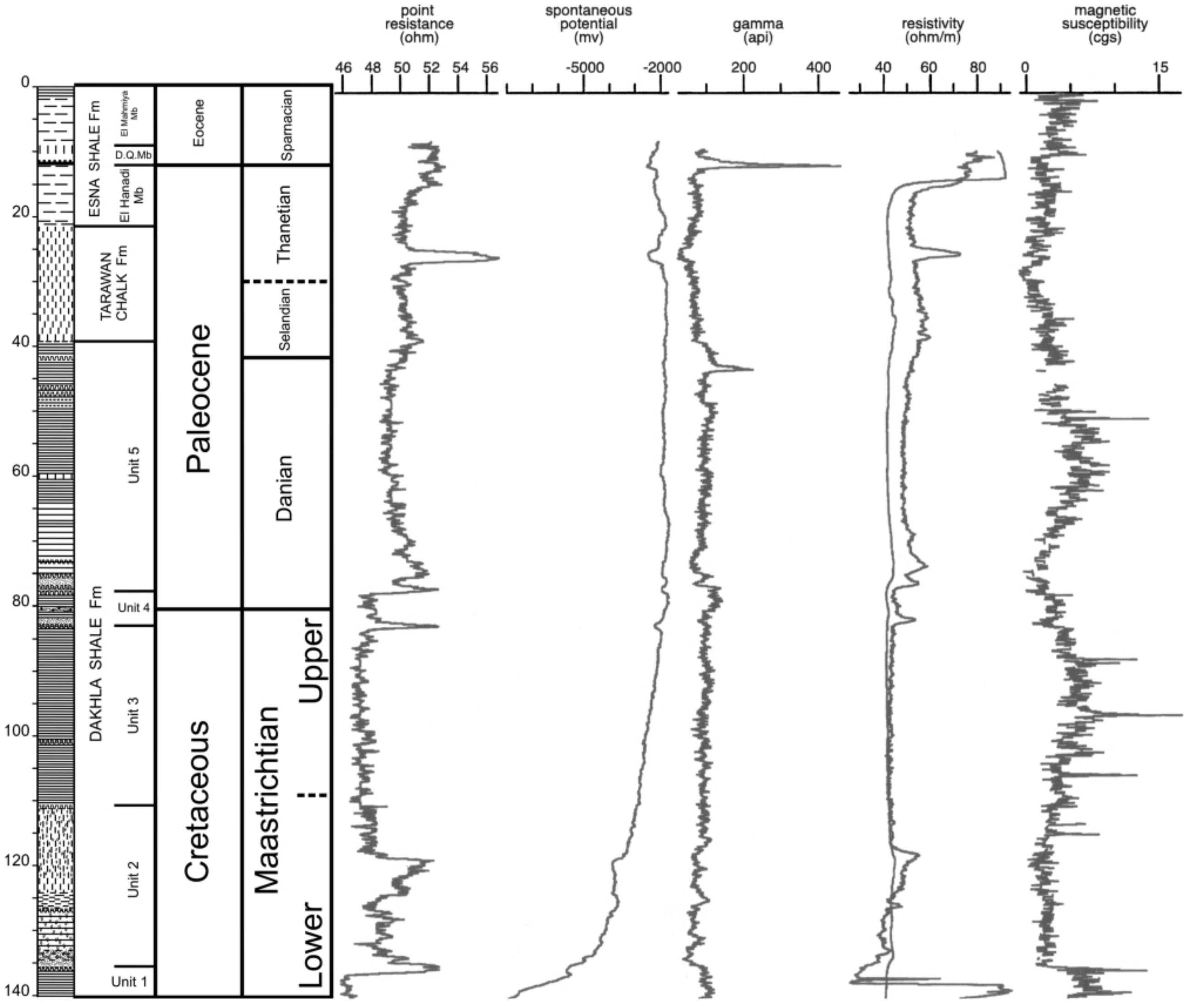

Figure 4: Geophysical logging of Dababiya corehole. See text for further explanation.

tween 50 and 73 Ohm-m, and the LN between 2 and 5 Ohm-m). This zone is encountered in the Tarawan Chalk Formation. The fifth geophysical zone extends from 39 m to the bottom of the well. It has very high to very low values of MS (0.1-11 CGS units) and SN (25-94 Ohm-m) and high to low values of GR (34-224 API) and PR (46-53 Ohm). The SP values range between -5748 and -1676 mV, and the LN values between 0.4-5 Ohm-m). This zone encompasses the Dakhla Shale Formation.

The geophysical zones clearly reflect different lithologies. In addition, the biostratigraphically identified P/E and K/P boundaries are marked by sharp peaks in all logs particularly in the GR and PR as well as in the magnetic susceptibility. Of special interest are the major GR peaks associated with the Dababiya Quarry Member and the Neo-Duwi beds. These peaks are associated with relatively high concentrations of phosphate and organic matter, both of which are commonly enriched in uranium and other radioactive elements.

7. Conclusions

The Dababiya Corehole provides basic information on the litho-, bio- and chemostratigraphy of the Late Cretaceous-earliest Eocene (~70-56 Ma) of the Upper Nile Valley. This will be expanded in a more thorough analysis as a monograph in the near future.

At this stage of our work we can cite the following (preliminary) conclusions:

1) The Dababiya corehole recovered ~ 80 m of lower Eocene-Paleocene shales and chalk, and ~60 m of Upper Cretaceous (Maastrichtian) black shales.
2) The Dababiya corehole recovered a relatively complete succession of Paleocene and lowermost Eocene planktonic foraminiferal and calcareous nannoplankton zones. The hole terminated in the Lower Cretaceous *Globotruncana aegyptiaca* Zone.
3) Assemblages characteristic of low-oxygen environments in the Cretaceous dark levels of the Dakhla Shale Formation are followed by typical Midway-type Paleocene assemblages. The latter suggests deposition at upper bathyal to outer neritic depths (~200 m) which is supported by P:B ratio studies.
4) The presence of the stratigraphically restricted scaphitid species *Indoscaphites pavana* suggests that the interval from 100 to 80 m represents the latest 420 kyr of the Maestrichtin. This is supported by the presence of the latest Maestrichtian planktonic foraminifera *Abathomphalus mayorensis* in the same interval.
5) Dinoflagellate assemblages indicate notable environmental changes from Late Maestrichtian to earliest Paleocene. An abundance of peridinoid cysts indicates a near-shore, (sub)tropical, nutrient-rich environment during the Late Cretaceous; the presence of *Manumiella* indicates a cold, restricted, low salinity environment in the latest Maestrichtian, and an abundance of Gonyaulacoid cysts indicates a gradual increase in water depth from a nearshore to open marine (warm) environment.
6) Five geophysical zones were identified, which clearly reflect different lithologies. The main chronostratigraphic boundaries were also marked by sharp peaks in the GR. PR and MS.

Acknowledgements

This paper is an outgrowth of a poster presented at the Climate and Biota of the Early Paleogene Conference (CBEP 8) held in Salzburg, June 5-8, 2011. We are grateful to Hans Egger (Geological Survey of Austria) for organizing the conference and to Michael Wagreich (University of Vienna) for his editing the proceedings volume of the conference. We thank the many colleagues who were kind enough to offer comments on the poster during the course of the meeting, and to Werner Piller and Peter Schulte for reviewing the paper. We are grateful to Dave Bord for assistance with the preparation of the figures. The Dababiya corehole was made possible by the financial support of the National Geographic Society. RK publishes with the approval of the Executive Director, British Geological Survey (NERC).

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Received: 21 October 2011
Accepted: 15 March 2012

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