The Dababiya Quarry Section: Lithostratigraphy, clay mineralogy, geochemistry and paleontology

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ABSTRACT: The Global Standard Stratotype-section (GSSP) for the Paleocene/Eocene (P/E) boundary has been selected in the Dababiya Quarry, near Luxor, at the base of a lithostratigraphic unit where the base of the so-called Carbon Isotope Excursion (CIE) is recorded. The Dababiya Quarry offers remarkable three-dimensional exposures of the Upper Paleocene-Lower Eocene succession in the Nile Valley which comprises the Tarawan Chalk, the Esna Shale and the Thebes Limestone. The horizon that constitutes the P/E GSSP is located in the lower part of the Esna Shale Formation. This formation, remarkably thick (~130m) at Dababiya, is largely of homogenous gray shales. Its lower part includes, however, a thin lithostratigraphic unit in a typical succession of five characteristic beds that can be followed throughout Upper Egypt, and at the base of which the GSSP is defined. We formally describe this unit as the Dababiya Quarry Beds at the same time as we subdivide the Esna Shale Formation into three formal lithostratigraphic units. The Dababiya Quarry Beds constitute the lower part of Unit Esna 2. While we place emphasis on the description of the lithology, mineralogy, carbon isotope stratigraphy and paleontology of the Dababiya Beds, we provide a mineralogic and biostratigraphic framework for the whole exposure of Esna Shale at Dababiya that constitutes essentially a complete record from the base of calcareous nannofossil Zone NP9 to Zone NP11 and planktonic foraminiferal Zone P4 to P8. The carbon isotopic excursion, measured on organic matter is ~3m thick and has an amplitude of ~4‰. The planktonic foraminiferal excursion taxa are sporadic and the distinct *Discoaster araneus-Rhomboaster* spp. association is persistent throughout the CIE-interval.


INTRODUCTION

In connection with the search for a GSSP for the Paleocene/Eocene boundary, extensive field collecting has been conducted in Egypt where some of the most spectacular lower Paleogene successions form a succession of high cliffs (or gebels) that dominate the Nile Valley. Whereas several upper Paleocene-lower Eocene sections, as for instance the Gebel Owaina section, have become well known to geologists, the remarkable exposures in the vast quarry at Dababiya, located in Central Egypt between Qena and Aswan, had not been investigated for stratigraphic purpose and remained essentially undiscovered by geologists. Research conducted in association with the Belgium Archeologic Mission established at Karnak with a view towards determining the origin of some of the limestones used in constructing the Temple of Amon, has led one of us (CD) to explore the quarry at Dababiya. This Quarry proves to offer a three dimensional approach to lower Paleogene stratigraphy, a remarkable advantage over other sections limited to two dimensional exposures on the gebel faces. Of exceptional interest is the fact that at Dababiya the Paleocene-Eocene inter-

val is expanded, providing a detailed record of the lithologic, mineralogic, biotic and geochemical events that were associated with the Paleocene/Eocene Thermal Maximum (PETM; formerly the Late Paleocene Thermal Maximum of LPTM; Zachos et al. 1993).

The quarry at Dababiya is in the process of becoming the stratotype for the Paleocene/Eocene boundary, formally defined by a lithostratigraphic horizon-the base of a clay layer at 1.56m in subsection DBH in the midst of the quarry. Our objective in this paper is to document the geology of the Dababiya quarry of which a brief discussion was first given by Aubry et al. (1999). We place particular emphasis on the Esna Shale Formation in the lower part of which the Paleocene/Eocene GSSP is located.

We first describe the lithostratigraphic framework that has provided the support to mineralogical, geochemical and biostratigraphic analysis. We introduce a new lithostratigraphic unit that we refer to as the Dababiya Quarry Beds whose base constitutes the lithostratigraphic horizon that defines the Paleocene/Eocene boundary. After explaining the procedure followed for sampling and establishing a composite section, we describe the clay mineralogy for the interval from the upper part of the Tarawan Formation to the base of the Thebes Limestone. We then de-

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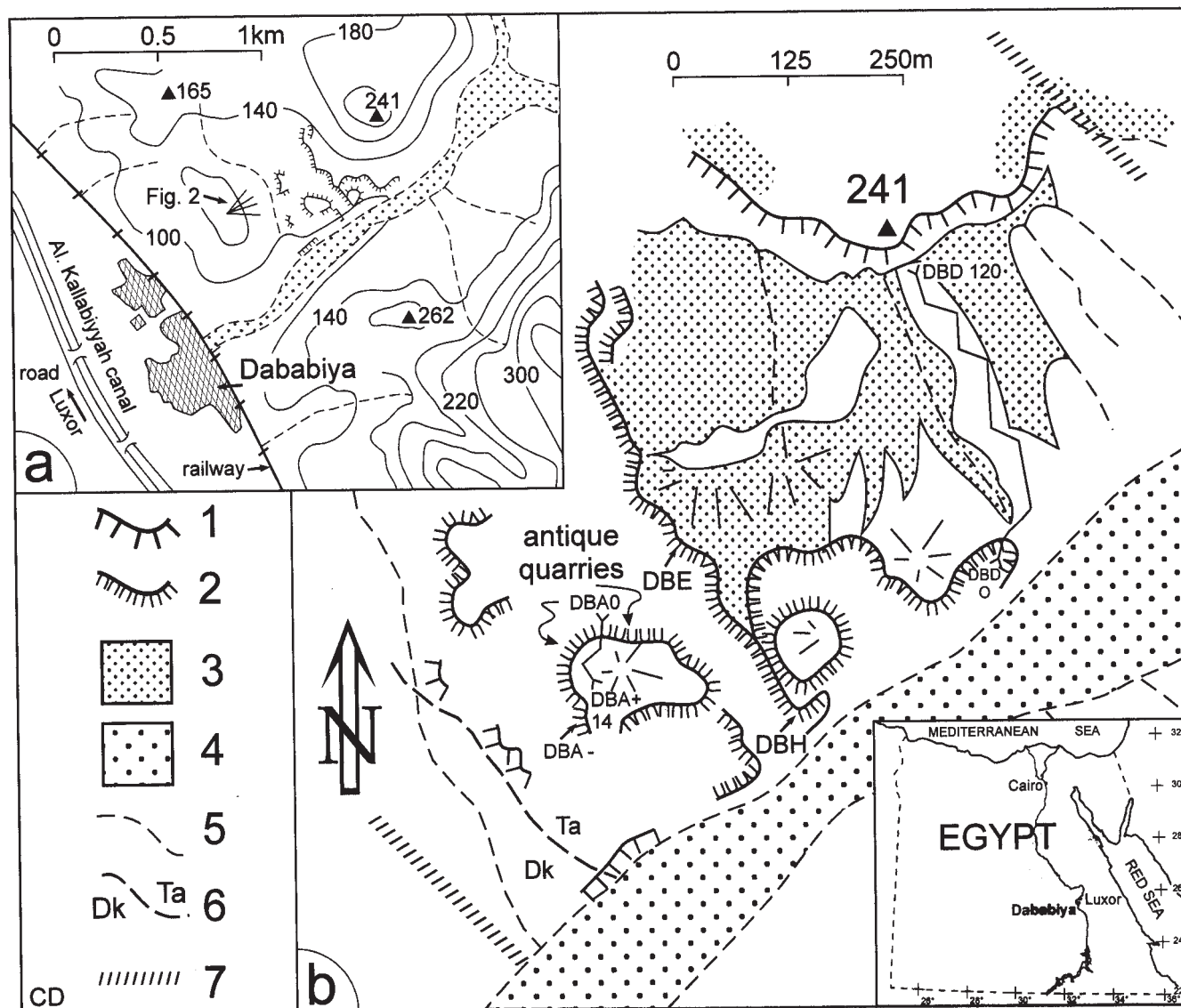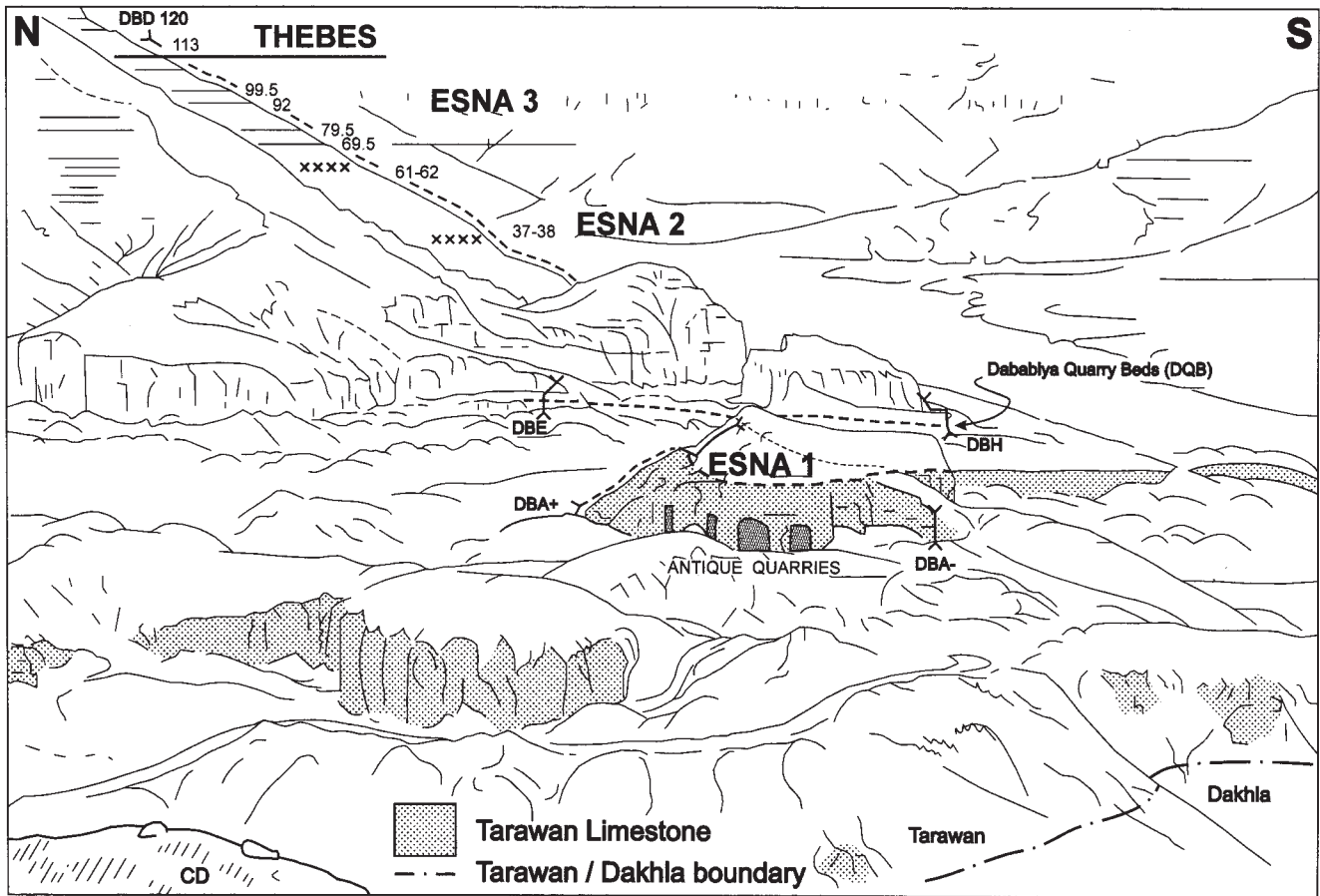
TEXT-FIGURE 1
Location maps redrawn from the 1/50000 topographic maps Al-Uqsur (Luxor) NG 36 F6a and Isna NG 36 F3c and aerial (a) and oblique photographs (a-b). a: outcrops studied near Dababiya on the east bank of the Nile River; b: detailed map of outcrops and quarries with the location of partial sections DBA, DBD, DBE and DBH, and of the antique quarries; legend: 1, natural cliffs; 2, quarry fronts; 3, screes; 4, wadi; 5, thalweg; 6, boundary between the Dakhla and the Tarawan Formations; 7, approximate location of faults.

scribe the carbon isotope stratigraphy of the Dababiya Quarry Beds. The last part of the paper describes the planktonic (foraminifera and nannoplankton) and benthic (foraminifera) calcareous microfossil stratigraphy of the Esna Shale Formation.

GEOGRAPHIC AND GEOLOGIC SETTING

One of the most complete and expanded upper Paleocene to lower Eocene successions in the world outcrops at Dababiya, a small village on the east bank of the Nile River, ~35 km south of Luxor (text-fig. 1). This succession, in the Esna Shale Formation (Said 1960; Awad and Ghobrial 1965), is sandwiched between the upper Paleocene Tarawan Limestone Formation and the lower Eocene Thebes Limestone Formation (see Ouda 2003, chapter 2, this volume).

The section that we have studied is located 1 km to the northeast of the village of Dababiya. The limestone of the Tarawan Formation was quarried in Pharaonic times and used in the construction of the temples of Luxor and Karnak (in present day Luxor; Daressy 1888; text-figs. 1, 2). Until recently, shales and marls were extensively excavated from the lower part of the Esna Shale, probably for bricks. The quarries are now essentially abandoned, although the Tarawan Limestone is still sporadically excavated. Nearby outcrops, especially the south face of a 241m high hill, expose the bulk of the Esna Shale and the lower part of the Thebes Limestone (text-figs. 1, 2). The multiple orientations of the quarry faces allow a thorough 3-D investigation of lateral variations that typically occur throughout upper Egypt in the lower part of the Esna Shale. On this basis, we describe here a characteristic succession of beds that we define as the Dababiya Quarry Beds. These are extremely impor-

TEXT-FIGURE 2 ♣
Oblique east-facing view of the outcrops (see text-figure 1a) as seen from the hill immediately to the north of the village of Dababiya (fig. 2 on text-fig. 1a). Sketch outlining the exposures of the main lithologic units: Dakhla Shales, Tarawan Limestone, Esna Shale and its three Units: Esna 1 to Esna 3, Dababiya Quarry Beds and Thebes Limestone. The four partial sections DBA (as in text-fig. 1, subsection DBA- corresponds to part of the section below the flint marker), DBD, DBE and DBH are shown.

tant because they yield the lithological, paleontological and geochemical evidence of a major event at the Paleocene/Eocene boundary (Aubry et al. 1998; Katz et al. 1999, 2002; Kent et al. 2003) and because the GSSP for the Paleocene/Eocene boundary is located at their base (Aubry et al. 2002).

The Dababiya section exhibits a number of lithologic units that are parts of the formally defined formations of (in ascending order) the Dakhla Shale, the Tarawan Limestone, the Esna Shale and the Thebes Limestone. All these units dip gently (between 5° to 10°) eastwards. The sediments show more or less conspicuous weathering features such as nodules of iron oxides and jarosite and anhydrite veins. Faults are reported to be frequent along the River Nile (Youssef 2003, chapter 1, this volume). Such faults, that run more or less parallel to the Nile River with a NW-SE orientation, can be observed in the vicinity of Dababiya, although outside of the area of this study. A fault runs south of the exposure of Dakhla Shale and between the outcrop area and the Dababiya village (text-figure 1b) causing the (underlying) Dakhla Shale to rest in direct contact with the Esna Shale further to the SW. Another fault is responsible for the cliff that the Thebes Limestone forms NE of the major hill (241m), causing an unconformable contact between the Thebes Limestone and part of the Esna Shale.

In order to complement the field data, carbonate content of sample series from all sections was measured using standard techniques. The quartz and the apatite contents in sections DBE and DBH were measured using a combination of XRD and chemical methods; the clay content was determined by subtraction and controlled by XRD.

LITHOSTRATIGRAPHY

Lithostratigraphic framework

The Dababiya outcrops and quarry faces expose the upper part of the Dakhla Shale, Tarawan Limestone and Esna Shale Formations, and the lower part of the overlying Thebes Limestone Formation (text-figs. 1, 2).

The greenish calcareous shale (~10m; 60-80% carbonate content) that forms the uppermost part of the Dakhla Shale, crops out in the southwestern part of the quarry along the main wadi (river bed) (text-fig. 1). Its contact with the Tarawan limestone is exposed in a low cliff that extends from the wadi towards the southwest, (text-figs. 1, 2). The base of the Tarawan is marked by a slight increase in carbonate content (to 85%).
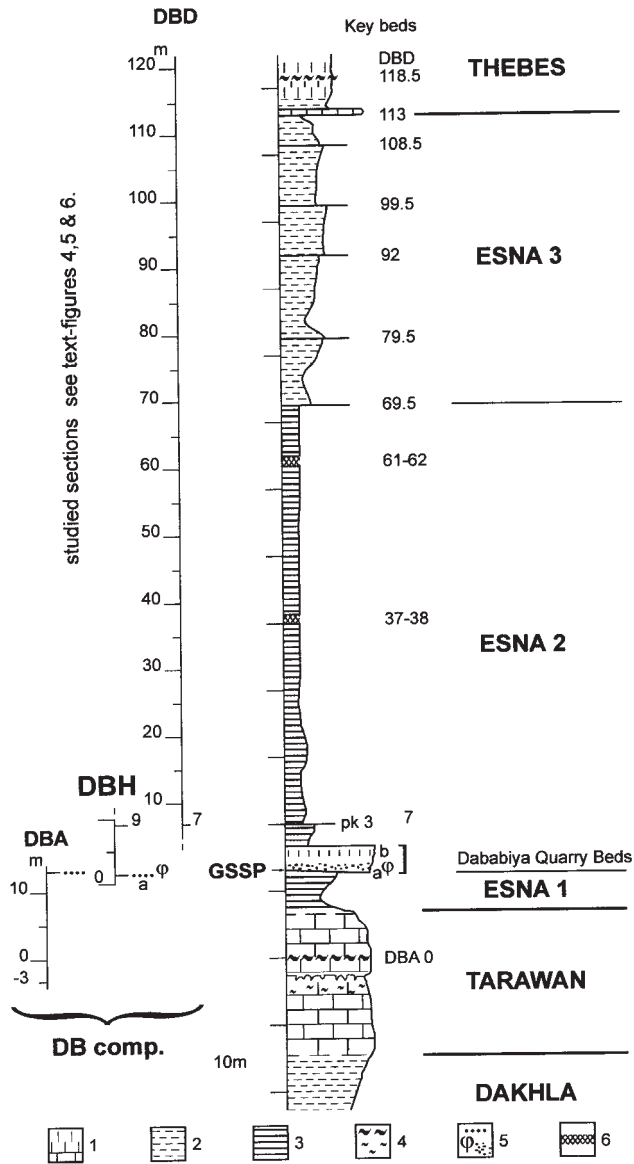
TEXT-FIGURE 3
Composite section of the formations and lithostratigraphic units at Dababiya, constructed on the basis of subsections DBA, DBH and DBD. Important lithological changes are used to delineate formations (see text). Legend: 1, limestones; 2, marls and shales; 3, shales; 4, flint concretions; 5, phosphates; 6, variegated shales.

The Tarawan Limestone is ~20m thick. It is more or less chalky and without visible stratification, except for its upper part. It is nearly white in color, becoming slightly greenish towards its top. A bioturbated surface, with brownish burrows, forms a clear lithologic reference. One to 2 meters below it, the limestone contains small, sparse, irregular flint concretions while ~4m above it grey flint concretions form a regular bed that is well exposed and easily traced throughout the antique quarries. We have used this bioturbated horizon as a marker bed (level/sample DBA0) to anchor our composite section (see below). The carbonate content is high (~85% average) in the lower part of the Tarawan Limestone. In the 7m above level DBA0, it ranges between 60% and 70%, and then decreases

drastically, thereby marking the transition to the Esna Shale. We place the formational boundary between the Tarawan Limestone and the Esna Shale, somewhat arbitrarily, at a level where the carbonate content falls below 50%. Macrofossils have not been found in the chalky limestone, but some iron oxide imprints (moulds of sponges and bryozoans) and burrows occur in the uppermost, somewhat shaly, 5 to 6 meters of the Tarawan.

The Esna Shale is ~130m thick at Dababiya. Its main development is exposed on the hills behind the Pharaonic quarries (partial section DBD, see below; text-figures 3, 4, 6 and 9). It can easily be divided into three units, that we formally designate here as Unit Esna 1, Unit Esna 2 and Unit Esna 3, on the basis of carbonate content (text-figs. 6 or 9). Unit Esna 1 is thin (7m) and sandwiched between the Tarawan Limestone and the Dababiya Quarry Beds at the base of Unit Esna 2 (text-figs. 3, 4). The Dababiya Quarry Beds consist in a singular, characteristic succession of five lithologies that occurs in the lower part of the Esna Formation throughout southern Egypt and marks the contact between Units Esna 1 and Esna 2. Characteristically they comprise a basal layer of dark gray clay (that constitutes the Paleocene/Eocene boundary throughout southern Egypt) overlain by phosphatic and calcareous shale and calcarenitic limestones (see below) but they vary laterally in thickness (between 1 and 5m) in the perimeter of the Dababiya quarry (text-figs. 4, 5, 7). The remaining Unit Esna 2 is ~65m thick and mainly clayey, rather dark in color and without prominent bedding. Its carbonate content never exceeds 50% (text-fig. 6). It exhibits marked cyclic variations that are locally visible in the field. Some useful lithologic marker beds have been identified in this monotonous upper Unit Esna 2. Slightly bioturbated (chondrites) surfaces have been recognized at levels DBD 26m, DBD 49m, DBD 51m and DBD 60.5m, suggesting short breaks in sedimentation. Oxidized pyrite concretions occur consistently between levels DBD 18 and DBD 24m, often as moulds of small macrofossils (e.g., solitary corals, gastropods, bivalves and brachiopods). Fibrous nodules of barite are rather common at ~DBD 35m. Near the top of Unit Esna 2, limestone beds become progressively more prominent. The base of the most conspicuous limestone bed at DBD 69.5m (carbonate content around 65%) is chosen to define the top of Unit Esna 2.

Compared to Unit Esna 2, Unit Esna 3, that extends between levels DBD 69.5m and DBD 113m, has a lighter color and a higher carbonate content. But its characteristic feature is a striking alternation of marls and limestone beds, including a few clay levels (text-fig. 6). Five limestone beds seem to have correlation potential, especially the lower, most prominent one at ~DBD 69.5m, at the base of Unit Esna 3, and the middle one at DBD 92m, which is thin and very hard, probably due to a high magnesium calcite content. The purple-colored bed at DBD 82m may also be useful for local/regional correlation.

There has been some controversy about the definition of the boundary between the Esna Shale and Thebes Limestone (Ouda 2003, chapter 2, this volume). Said (1960), who defined the Thebes Limestone, placed the boundary between both units at the base of the massive limestone cliff exposed along the Nile valley near Luxor. The break in slope is sharp and readily seen in outcrop. El Naggar (1966), on the other hand, placed this boundary at the level of the first, or lowest, limestone bed in the predominantly shaly to marly Esna Formation. At Dababiya this level lies around 45m to 50m below the base of the massive limestone package. Here we adopt the definition of Said (1960) by taking into account the specific features of the Dababiya sec-

tion, such as the first occurrence of black flints at level DBD 118.5m (text-figs. 3, 6), which regionally characterize the Thebes Limestone. Consequently, the base of the Thebes Formation is denoted here at level DBD 113m, using the base of a geomorphologically prominent 1-meter thick limestone (carbonate content around 90%), a few meters below the black flint level.

Stratigraphic section at Dababiya; subsection and composite section

To ensure a representative sampling of the stratigraphic succession at Dababiya and to account for the lateral variations observed at some levels, and in particular in the Dababiya Quarry Beds, we have constructed a composite stratigraphic section based on the careful survey and sampling of a series of overlapping subsections that, together, span from the upper part of the Tarawan Formation to the base of the Thebes Limestone, extending thus from upper Paleocene (Zone P4/ZoneNP8) to lower Eocene (Zone P8/ZoneNP11). We discuss four of these overlapping subsections (DBA, DBD, DBE and DBH) in this paper (text-figs. 3, 4, 6, 9). Although these subsections are close to one another, their physical correlation in homogenous lithologies (as in Unit Esna 2) is made difficult by the topography of the quarry and the multiple orientations of the faces of the outcrops. Thus we have sought use of various criteria to establish correlations even if only of very local usefulness.

We have mentioned above our use of the flint bed in the upper part of the Tarawan Limestone as our level 0 (DBA 0m) . The lowest criteria for physical correlation are offered by the Dababiya Quarry Beds (text-fig. 5) and consist in 1) the base (a) of a 1cm to 75cm thick black clay (Dababiya Quarry Bed 1, see below) containing sparse, ~0.5cm in diameter, phosphatic grains (coprolites), that rests on the light gray marls of Unit Esna 1 and constitutes the base of the Dababiya Quarry Beds, and 2) the base (b) of a light gray calcarenitic limestone (Dababiya Quarry Bed 5) with a carbonate content of ~ 60-65%. These criteria allow correlation of subsections DBA, DBE and DBH. The thickness of sediments comprised between these two markers varies, providing indirect information on the anatomy of the Dababiya Quarry Beds.

Three distinct pink layers (pk1, pk2, pk3) located in the lower part of Unit Esna 2 above the Dababiya Quarry Beds constitute a second set of criteria for physical correlation. Layers pk1 and pk2 lie immediately above the Dababiya Quarry Beds, passing laterally into grey layers. These are thus useful to trace the top of the Dababiya Quarry Beds throughout the quarry. The upper, 20 to 30cm thick layer pk3 was useful in helping us correlate Subsection DBD facing South with nearby subsection DBH oriented northwest (text-fig. 4).

Other marker beds allow correlation of section DBD throughout the hills that surround the quarry. These include the purple-colored bed at DBD 47m and the two mottled clay layers at respectively DBD 37-38m (ocher-purple) and DBD 61-62m (green-purple) (text-figs. 6, 9). The use of color as a means of correlation must be used with caution as color is believed to be weathering-dependent. The pink layers pass laterally into grey layers in less weathered rocks.

The composite section (DBcomp) studied here (text-fig. 3) is constructed using three partial sections: 1) the upper part of subsection DBA from 3m below (negative DBA) Level 0 (= the grey flint horizon; DBA 0) up to the base of the Dababiya

Quarry Beds (=Bed 1=link a), 2) the upper part of subsection DBH from Bed 1 (link a) to layer pk3 and 3) subsection DBD from layer pk3 up to the lowermost part of the Thebes Limestone (level DBD 120m) .

The Dababiya Quarry Beds

The Dababiya Quarry Beds constitute a complex lithologic succession at the base of Unit Esna 2. They are best observed in subsection DBH where they are 3.68m thick and among which 5 beds can be distinguished.

Bed 1 (0.63m thick, from DBH 1.57 to DBH 2.2m) is a dark laminated non-calcareous clay with at the base (= link a in text-figures 4 and 8) a few phosphatic coprolites, 0.5cm diameter (referred here as type 1). There is a substantial increase (from 7% to 11-14%) in quartz at the base of the Dababiya Quarry Beds at the interface with the underlying grey marls. The quartz content progressively increases upwards in Bed 1, from 21% up to 32.5% at its top.

Bed 2 (0.50m thick, from DBH 2.2 to DBH 2.70m)) is a phosphatic (~14% apatite) brown shale with numerous type-1 coprolites. It is characterized by an increase in carbonate content (up to 30%), coupled with a decrease in quartz content to about 18%.

Bed 3 (0.84m thick; from DBH 2.70 to DBH 3.54) is a cream-colored, laminated phosphatic shale with sparse type-1 coprolites and numerous, lens-like, pale, phosphate inclusions, 1cm in diameter (type-2 [compacted?] coprolites). The apatite content in this bed varies between 12% at the base and 8% near the top. As shown in figure 7, this relatively high apatite content does not result from the accumulation of type-1 coprolites, which are essentially absent in this unit. Consequently the type-1 coprolites are clearly not the only phosphorus bearer (see discussion in Mamdouh 2003, chapter 7, this volume). The carbonate content varies between 30% and 35%. The quartz content decreases upward in the bed from 18% to 12%. The base of the bed is locally marked by concretions of iron oxides, anhydrite and jarosite, interpreted as weathering products of pyrite nodules (Kent and Dupuis 2003, chapter 8, this volume).

Bed 4 (0.71m thick; from DBH 3.54 to DBH 4.25m) is a grey shale with an increasing carbonate content (from 40% to 50%) and decreasing contents of quartz (from 12% to 6%) and apatite (from ~6% to 3%).

Bed 5 (1.00m thick; from DBH 4.25 to DBF 5.25m) is a marly calcarenitic limestone, which, in outcrop, forms a conspicuous and continuous light grey bed, just below layers pk1 and pk2. The highest carbonate content (67%) of the Dababiya Quarry Beds is recorded at the base of this subunit (link b) whose contact with Bed 4 is unbioturbated. The high carbonate content coincides with low apatite and quartz contents, ~1% and 5%, respectively. Grey marls with variable carbonate content (40%-45% to ~30%) are interbedded with layers pk1 and pk2 and overlie them.

Field observations coupled with mineralogical analyses (e.g., carbonate content) show that the Dababiya Quarry Beds thicken laterally towards the south, as clearly seen by comparing the DBE and DBH subsections. This lateral thickening mostly affects Beds 1 to 4 (text-fig. 5). Bed 1 (dark clay) is only 5cm thick in subsection DBE compared to 63cm in subsection DBH. Its quartz content is ~10% in Subsection DBE, similar to the content at the base of the bed in Subsection DBH. However,
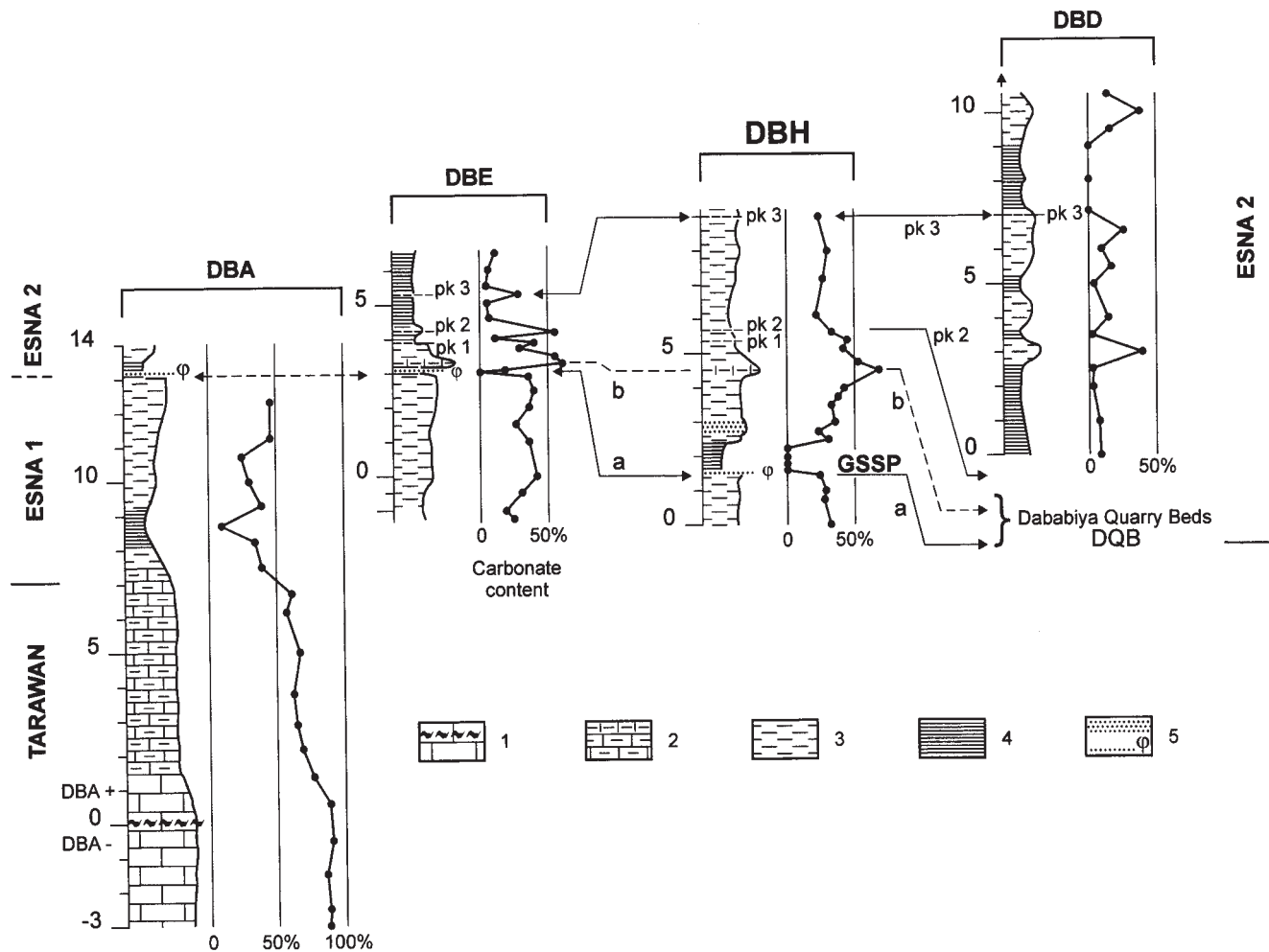
TEXT-FIGURE 4
Lithology and carbonate content in the upper part of the Tarawan Limestone, Unit Esna 1 and the Dabbabia Quarry Beds (DQB; shown between markers a [base of Dababiya Bed 1] and b [Dababiya Bed 5 = calcarenite]). Lithological correlations between subsections DBA, DBE, DBH and lowermost DBD. Legend: 1, limestones with DBA0 flint concretions; 2, marly limestone; 3, marls; 4, shales; 5, phosphatic shale and coprolites. The following horizons are used to correlate the subsections: 1) the base of the DQB (a); marker b in the calcarenite (~60% carbonate); 2) three pink layers in the lower part of Unit Esna 2, just above the DQB (pk1, pk2, pk3).

younger levels of Bed 1 in subsection DBH have a quartz content of ~30%, implying that these younger levels do not occur in subsection DBE. In subsection DBH Bed 2 yields only type 1-coprolites while Bed 3 contains coprolites of both type 1 and 2 (see above). In subsection DBE Bed 1 is overlain by a 3cm interval that consists in a thick accumulation of coprolites in which type 1 and type 2 are mixed, and characterized by an apatite content of up to 34%. We interpret this 3cm interval as a condensed interval equivalent to Beds 2 and 3 resulting in the mixing (winnowing?) of coprolites which otherwise would occur at distinct levels.

Because of its high carbonate content (with a peak of 67% at its base) Bed 5 is easily recognized and serves as a reliable means of correlation (link b; see above). Below it, Bed 4 is 71cm thick in subsection DBH, but may be reduced to a 1 to 2cm thin shaly layer in subsection DBE. Bed 5 is not as strongly affected as the other Dababiya Quarry Beds by southward thickening, al-

though it is twice as thick in subsection DBH (100cm) than in subsection DBE (45cm).

A similar degree of thickening affects the base of Unit Esna 2 above the Dababiya Quarry Beds, the distance between layers pk2 and pk3 being more than double in subsection DBH compared to subsection DBE and in subsection DBD compared to subsection DBH (text-figs. 4, 5), thus implying a thickening towards the south and the east. Only layer pk3 can be confidently correlated between subsections DBH and DBD. Layer pk2 is likely a few meters under the quarry floor, below the level DBD 0m.

It is clear from the discussion above that subsection DBH constitutes the most expanded record (3.68m) of the Dababiya Beds and thus the CIE-interval available not only in the Dababiya quarry, but also in outcrop sections, throughout Egypt.
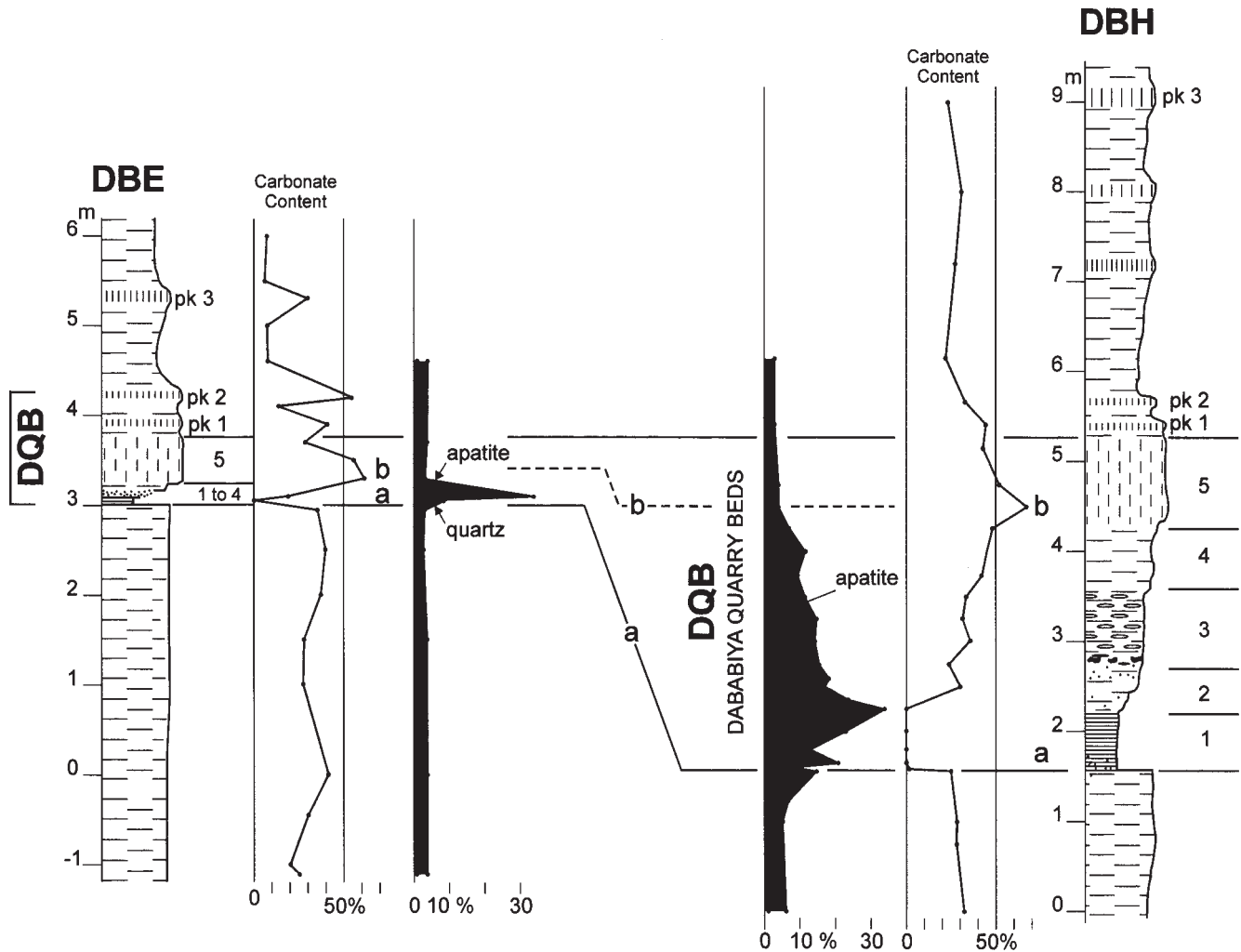
TEXT-FIGURE 5
Lateral variations in thickness, lithology and composition (carbonate, quartz and apatite contents) in the Dabbabia Quarry Beds between subsections DBE and DBH. Detailed description of DQB 1 to 5 in the text.

SEDIMENTOLOGY: CLAY MINERALOGY

Major trends

The clay fraction includes chlorite, illite, illite-smectite (R0 type-IS) mixed-layers (Inoue et al. 1989), irregular chlorite-smectite (14c-14s) mixed-layers, kaolinite, palygorskite and sepiolite, in variable proportions throughout the studied section (text-fig. 6).

Two superimposed patterns of clay mineral variations occur. One is a pattern of long-term progressive change that affects the whole succession; the other is a pattern of short-term abrupt changes restricted to specific levels. The contents of chlorite, kaolinite, palygorskite, sepiolite and R0 type-IS mixed layers exhibit long-term changes. However, there are some substantial fluctuations in these long-term changes, allowing recognition of three major intervals. The lower interval spans part of the Tarawan Chalk up to the top of Unit Esna 1. It is marked by relatively high content in detrital clay minerals, chlorite, illite, irregular chlorite-smectite mixed layer (14c-14s), and low content in kaolinite. The smectite proportion in R0-IS progressively increases in the Tarawan Limestone and reaches an almost stable value of 80% of smectite layers (saddle/I001~0.25) in Unit Esna 1. The middle interval, which coincides with Unit Esna 2, also contains detrital clay minerals, but no chlorite-smectite. The kaolinite content increases in the Dababiya Quarry Beds, and represents 15% to 30% of the clay fraction in the bulk of the unit. The smectite content of the R0-IS oscillates ~80% (saddle/I001~0.4). In the upper interval, which corresponds to Unit Esna 3, the detrital minerals and kaolinite are replaced by palygorskite and sepiolite. These two magnesian fibrous clays constitute the main components of the clay fraction in the Thebes Limestone. The smectite percentage in the R0-IS decreases upwards to reach 40% to 45% (saddle/I001~1). These long-term patterns are probably driven by paleogeographic (s.l.) constraints.

The short-term variations in mineral composition concern massive influxes of one or more clay minerals. These are probably related to a combination of eustatic, tectonic or/and climatic (?)

TABLE 1
Isotopic results for subsection DBH.

Sample	TOC(%)	$\delta^{13}C_{org}$ (‰)
DBH9	0.3503	-24.11
DBH8	0.3714	-24.18
DBH7.2	0.2924	-24.06
DBH5.65	0.3838	-24.26
DBH5.40	0.4088	-
DBH4.75	0.4766	-24.28
DBH4.50	0.6554	-25.05
DBH4.25	0.7872	-25.07
DBH4.00	0.9869	-25.59
DBH3.75	0.9481	-25.44
DBH3.50	1.1220	-25.90
DBH3.25	1.3850	-26.39
DBH3.00	2.0170	-27.18
DBH2.75	2.1880	-27.33
DBH2.50	2.9450	-27.35
DBH2.30	0.8894	-27.14
DBH2.25	0.8664	-26.98
DBH2.00	0.5558	-26.68
DBH1.80	0.2277	-25.82
DBH1.65	0.2995	-26.06
DBH1.60	0.4946	-25.38
DBH1.57	0.5649	-25.61
DBH1.56	0.3684	-24.39
DBH1.25	0.3256	-23.83
DBH1.00	0.3051	-24.22
DBH0.75	0.3018	-23.97
DBH0.50	0.3340	-23.56
DBH0.00	0.3353	-23.68

events. High resolution sampling allows us to describe accurately the short term pattern of mineralogical variations in the Dababiya Quarry Beds. Wide sample spacing (1 to 3m) in other parts of the Dababiya section precludes a thorough description of the frequency and magnitude of these events in the present study.

Clay mineralogy of the Dababiya Quarry Beds

The most prominent event in the clay mineralogy of the Dababiya Quarry Beds in the DBH partial section (text-figs. 6, 7) is the abrupt increase of the illite 14c-14s content (from ~0 to 15%) and the massive influx (from 4% to 32%) of the irregular chlorite-smectite mixed layer (14c-14s) that occurs in the middle of Bed 2. Sharp maxima of kaolinite (from ~0 to 14%) and illite (from almost ~0 to 10%) occur at the same level. This striking clay mineral pulse is associated with an important lithologic change from detrital (quartz + clays + organic matter (MO) + minor apatite) to more bio-derived material, as shown by the abrupt rise in carbonate and in apatite content (coprolites and fish debris) a few centimetres above the base of Bed 2, and

the simultaneous decrease in quartz content. All these changes are correlative with minimum $\delta^{13}C_{org}$ values.

Two other important short-term variations occur in the Dababiya Quarry Beds. Kaolinite, of which only traces are present at the top of Unit Esna 1, is absent just below the clay mineral influx at the base of Bed 2. Kaolinite progressively increases in abundance from the base of Bed 5 through Units Esna 2 and 3. The maximum abundance in kaolinite is clearly disconnected from the CIE interval (see Dupuis 2000). In Bed 1 of the Dababiya Quarry Beds, the smectite percentage in the R0-IS attains its highest value, indicating a nearly pure smectite. Above the clay mineral influx in Bed 2, the smectitisation of illite remains relatively low (65%) in phosphate Bed 3. This low smectitic R0-IS is associated with the persistence of relatively uniform 14c-14s (5-10%), a relatively high apatite content and significant amounts of quartz. The slow decrease in apatite (from 7 to 11%) and in quartz (from 15 to 11%) content coincides with the progressive return of the $\delta^{13}C_{org}$ values to pre-excursion values. Another maximum in smectite content of 90% in the R0-IS is recorded at the base of Bed 5 (marker b) where it coincides with the maximum carbonate content and with the youngest anomalous isotopic composition of the CIE. Above Bed 5 the smectite content decreases again to reach a percentage ~60% (saddle/ I001~0.55) in the remainder of the Esna Shales exposed in Subsection DBH.

GEOCHEMISTRY

Geochemical studies (e.g., Schmitz et al. 1996; Speijer et al.2000) have been successful in identifying the CIE in several upper Paleocene-lower Eocene stratigraphic sections in Egypt. However, these studies based on carbon isotope analysis of bulk carbonates and benthic foraminifera failed to produce the characteristic shape of the CIE as established from several ODP and land sections (e.g., Norris and Röhl 1999; Bowen et al. 2001) possibly due to fine recrystallisation of foraminiferal tests (Cramer et al. 1999). In an attempt to obtain a detailed and reliable record of the CIE at Dababiya, we have measured the carbonate isotopic content of organic matter. Because subsection DBH provides the most expanded record of the Dababiya Quarry Beds, we have limited our geochemical analysis to this section. The set of samples analyzed for isotopes is different from the set of samples analyzed for biostratigraphy and clay mineralogy, but both sets are perfectly integrated, based on field markers, and directly comparable.

Carbon isotope record of the Dababiya Quarry Beds

Carbon isotope analysis was performed exclusively on the DBH section. The carbon isotopes were measured at the Ecole polytechnique de Mons following the procedure described in Magioncalda et al. (2001) and Steurbaut et al. (2003). TOC was measured with a LECO device. Palynofacies tests were carried out in order to evaluate the suitability of the organic matter in recording the $\delta^{13}C$ variation.

The carbon isotopic composition of organic matter in section DBH varies between -23.5‰ and -27.5 ‰ PDB (Table 1). In the upper part of Unit Esna 1 (Samples DBH 0.00, 0.5, 0.75, 1.00, 1.25, 1.56), isotopic values are scattered around -24‰, although there seems to be a slight negative trend upward. The contact between Unit Esna 1 and Dababiya Quarry Bed 1 at the base of Unit Esna 2 (between samples DBH 1.56 and DBH 1.57) is marked by a negative $\delta^{13}C_{org}$ shift of -1.2‰. This is followed by a progressive and steady decrease in $\delta^{13}C_{org}$ through Bed 1 and the lower part of Bed 2 (levels DBH 1.57 to DBH
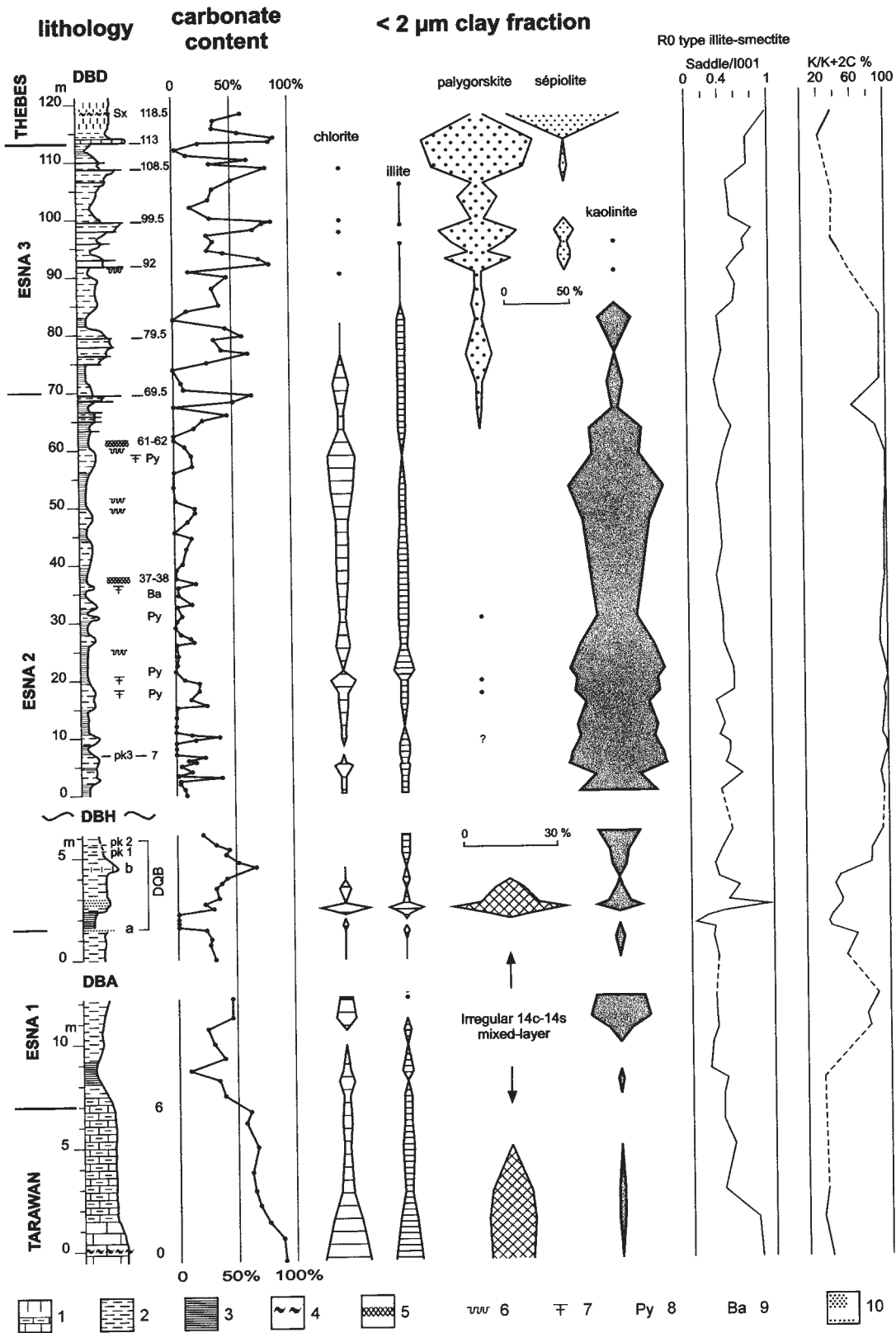
TEXT-FIGURE 6

Lithological description and beds in the main subsections (DBA, DBH and DBD) of the composite section. Clay mineralogy: semi-quantitative variations of chlorite, illite, kaolinite and irregular chlorite-smectite mixed-layer (14C-14s). Variations of palygorskite and sepiolite are shown at a different scale because of very high contents. R0 type-illite-smectite mixed layer is almost regularly present: the saddle/I001 ratio shows its smectite content. The K/K+2C parameter depicts the relative proportion of kaolinite and chlorite in the clay fraction. Legend: 1, limestones; 2, marls and marly limestones; 3, shales; 4, flint concretions; 5, variegated shale intervals; 6, bioturbated surfaces; 7, fossils; 8, main concentration of pyrite nodules; 9, barite nodules; 10, coprolite concentration and phosphate layers.

2.50) down to minimum values of ~-27.3‰. Minimum values of ~-27.3‰ also characterize the base of Bed 3 (samples DBH 2.75). Above this level, $\delta^{13}C_{org}$ values increase, first slightly in the lower part of Bed 3 (-27.18‰ at DBH 3.00), and then steadily and markedly (from ~-27.2‰ to ~-25.4‰ from the middle of the bed to the base of Bed 4. At the top of Bed 4 and the base of Bed 5 they reach plateau values of ~-25‰. A further $\delta^{13}C_{org}$ increase of ~0.7‰ in the lower part of Bed 5 results in a return to almost pre-excursion values of -24 to 25‰ in the middle of Bed 5 (DBH 4.75). Remarkably constant $\delta^{13}C_{org}$ values are maintained above this level throughout subsection DBH.

The occurrence of the so-called excursion taxa among the planktonic foraminifera and of the *Rhomboaster* spp.- *Discoaster araneus* assemblage (RD) among the calcareous nannoplankton (see below) in the Dababiya Quarry Beds permitted prediction of the recovery of anomalously low $\delta^{13}C$ values in these beds (Kelly et al. 1996; Aubry 1999; Cramer et al. 1999). There is thus no question that the carbon isotope record described above corresponds to the CIE. However because the structure of the CIE has been described from carbonate records (e.g., Norris and Röhl 1999; Bains et al. 1998; Bowen et al. 2001), not from organic matter records, we cannot exclude the possibility that the similarity in shape and amplitude between our record and the high resolution oceanic and terrestrial records of the CIE results from changes in composition of organic matter through the Dababiya Quarry Beds. We thus have performed palynologic tests to check the reliability of the isotopic record in these beds.

Palynological Test

Five samples (DBH 0.50, DBH 1.60, DBH 3.00, DBH 3.75 and DBH 4.75) taken at regular intervals through Units Esna 1 and Esna 2 were processed following standard palynological techniques. Except for DBH 3.00 all samples had very similar compositions of organic particle types, consisting almost exclusively (99%-100%) of black brown highly oxidized woody tissue fragments and some coal-particles. In sample DBH 3.00, black fragments dominate, but they are mixed with yellow AOM (amorphous organic matter) that constitutes up to 22% of the organic material. The $\delta^{13}C_{org}$ anomaly is possibly influenced by this change in organic particle composition. However, the $\delta^{13}C_{org}$ anomaly cannot be explained exclusively by an increased amount of the yellow AOM. This is clear from samples DBH 1.60 and DBH 3.75 that record, respectively, the onset and the decline of the CIE. These two samples have organic particle compositions identical to samples DBH 0.50 and 4.75 from respectively below and above the anomaly. The $\delta^{13}C_{org}$ values of these four samples fall in the range given for the woody and coaly organic matter by Tyson (1995) and probably reflect original variation of the isotopic composition in the environment.

Significance of the $\delta^{13}C_{org}$ in the Dababiya Quarry Beds

Based on the palynofacies test, we are confident that the $\delta^{13}C_{org}$ record of Esna Shale that outcrops in the DBH section is genuine, and that the carbon isotope signature of the Dababiya Quarry Beds is reliable. We thus interpret the -1‰ negative shift at the base of Dababiya Quarry Bed 1 as the base of the globally identified carbon isotope excursion or CIE and the -27.35‰ at DBH2.50m as its absolute minimum value. The total amplitude of the CIE at Dababiya is thus of -3‰, comparable to the amplitude measured in numerous other sections (e.g., Kennett and Stott 1991; Bowen et al. 2001; Katz et al. 1999; Stott et al. 1996). The Dababiya Quarry Beds thus record the full extent of the CIE. The lithologic interval from the base of Bed 1 (at DBH1.57m) to the middle of Bed 5 (at 4.75m) represents the stratigraphic interval now known as the CIE-interval.

PALEONTOLOGY AND BIOSTRATIGRAPHY

Planktonic foraminifera

Planktonic foraminifera are more or less discontinuously distributed throughout the Dababiya section because of the occurrence of non-calcareous intervals. As a whole microfossil recovery is excellent in the Tarawan Formation and in the main part of Units Esna 1 and Esna 3, but less consistent in Unit Esna 2, and preservation is very variable, from excellent to very poor. This does not hamper refined biostratigraphic interpretations (text-fig. 9). On the contrary, the overall cyclicity and the dominance of carbonate-rich levels throughout the section allow detailed records and ranges of the biostratigraphically determinant taxa and the generally precise location of the standard planktonic datum events of Berggren et al. (1995). Over a dozen lithic intervals scattered throughout the Esna Shale Formation and ranging in thickness from 10cm to ~1.5m (e.g. Dababiya Quarry Bed 5) are extremely rich in planktonic foraminifera (percentages ranging from 75% to nearly 100%), so that their residues mimic pelagic ooze residues.

The planktonic foraminiferal zonation and taxonomy adopted in our work are essentially based on Berggren et al. (1995), with modifications to Zone P5 (Berggren and Ouda 2003, chapter 4, this volume). The LOs of *Acarinina sibaiyaensis* and *Pseudohastigerina wilcoxensis* are used in this study to denote the boundaries between Subzones P5a/P5b and P5b/P5c, respectively. We have found that *Morozovella allisonensis* occurs too rarely and sporadically at Dababiya (and other sections studied as part of the current project) to be useful in defining a Subzone P5b (cf. Speijer et al. 2000). Subzones P4a and P4b (Berggren et al. 1995) are not differentiated here owing to the general rarity of *Acarinina subsphaerica* whose Highest Common Occurrence (HCO) is used to denote the boundary between the two subzones.

The ranges of commonly occurring and/or biostratigraphically important taxa in the overlapping Dababiya subsections and their biostratigraphical interpretation are displayed on text-fig. 9.

Tarawan and Unit Esna 1

The base of Subzone P4c, defined by the Lowest Occurrence (LO) of Acarinina soldadoensis, has been identified at DBA 6m, about 1m below the base of the Esna Shale Formation. This means that the topmost + 1m of the Tarawan Limestone Formation belongs to Subzone P4c and the underlying portion down to level DBA 0 to an undifferentiated P4a+b interval. The P4/P5 zonal boundary, denoted by the highest occurrence (HO) of *Globanomalina pseudomenardii,* is placed around level DBA 10m and DBE 0m, in the middle part of Unit Esna 1.

Planktonic foraminifera occur sporadically near the top of Unit Esna 1 in subsection DBH. Typical Subzone P5a assemblages include *Morozovella acuta, M. velascoensis, M. aequa, M. subbotinae, M. apanthesma, Acarinina soldadoensis, Ac. esnaensis* (=*Ac. intermedia*), *Subbotina patagonica, S. velascoensis* and *Igorina lodoensis.* The LO of *Ac. wilcoxensis* is recorded just below the Dababiya Quarry Beds (=CIE interval), at the extreme top of Unit Esna 1.
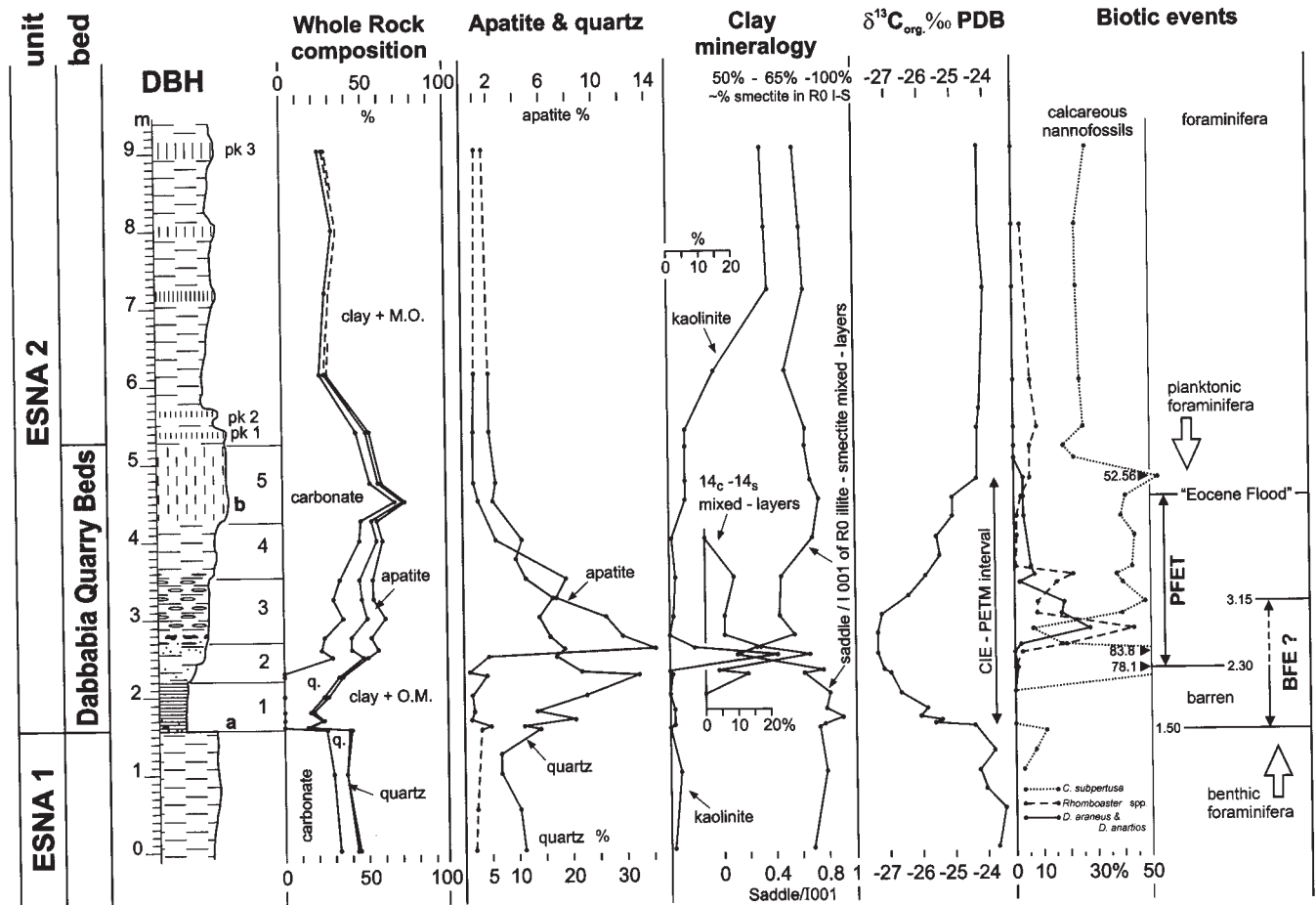
TEXT-FIGURE 7

The Dababiya Quarry Beds (DQB) in Subsection DBH. Lithology of the five beds of the DQB, whole rock composition, quartz and apatite contents, δ^{13}Corg. record, selected clay mineral variations (kaolinite, 14c-14s mixed layer, saddle/I001 and correlative proportion of smectite layer in R0 type IS mixed layers), and main biotic events. Base of Dababiya Quarry Bed 1 defines the Paleocene/Eocene GSSP.

Dababiya Quarry Beds

The CIE-interval (that encompasses the greater part of the Dababiya Quarry Beds, from Bed 1 to lower Bed 5) is bracketed (below) by the sequential LOs of *Acarinina esnaensis* and *Igorina broedermanni* (sample DBH 0.25m), *Acarinina angulosa* (DBH 1.0m) and *Acarinina wilcoxensis* (DBH 1.4m) and (above) of *Pseudohastigerina wilcoxensis,* at the top of the CIE-interval.

The black, quartz-rich Dababiya Quarry Bed 1 and Bed 2 are barren, except for a sample at DBH 2.5m in the middle of Bed 2. The phosphate rich layer (Bed 3) is essentially barren in its lower part (DBH 2.8m, DBH 3.15m). Planktonic foraminifera reoccur at level DBH 3.25m.

In its slightly modified form Subzone P5b is recorded in section DBH from 2.5m up to 4.5m, thus encompassing most of the Dababiya Quarry Beds (up to the middle of Bed 5). The so-called Planktonic Foraminiferal Excursion Taxa (PFET), consisting of common *Acarinina sibaiyaensis* and rare *Ac. africana,* appear uniquely at DBH 2.5m and from DBH 3.25 to DBH 4.5m. *Morozovella allisonensis* is a rarely occurring form

at Dababiya, as well as at other sections we have studied. Other events in the Dababiya CIE-interval, which may have a certain correlation potential, are the LO of *Ac. pseudotopilensis* coincident with HO of the benthic *Angulogavelinella avnimelechi,* both located at ~DBH 3.4m (but see below).

At the top of Dababiya Quarry Bed 4, between samples DBH 4.0m and DBH 4.25m there is a major increase in abundance and taxonomic diversity. This abundance peak continues up to ~5.3m at the top of Bed 5, of which the sample residues resemble pelagic ooze residues.

A rich, diverse planktonic foraminiferal fauna and large, robust Midway-type benthic foraminiferal taxa (LO at ~DBH 4m) characterize the upper part of the Dababiya Quarry Beds (upper Bed 4 and Bed 5) 1.2 m-thick interval, which spans, essentially, the upper half of the ascending limb of the CIE. Characteristic faunal elements include *Morozovella acuta, M. velascoensis, M. subbotinae, M. gracilis, Acarinina soldadoensis, Igorina lodoensis, Subbotina patagonica* and *S. velascoensis.* The distinctive planispiral taxon *Pseudohastigerina wilcoxensis* has its LO in sample DBH 4.75m (confirming its stratigraphic usefulness in denoting the Paleocene/Eocene boundary).

In contrast to the situation in subsection DBH, Beds 1-4 are essentially absent or extremely condensed in the nearby section DBE (See Berggren and Ouda 2003, chapter 4, this volume) that illustrates the common situation of the lateral equivalents of the Dababiya Quarry Beds in Egypt. A few planktonic foraminifera (including *Morozovella acuta, M. velascoensis,* subbotinids; and a few Midway-type benthic foraminifera) occur in samples DBE 2.90m and DBE 2.95m in the top of Unit Esna 1, below the Dababiya Quarry Beds. They are essentially absent at the base of the Dababiya Quarry Beds (samples DBE 3.03m and DBE 3.07m). A few benthic foraminifera (including the HO of *Angulogavelinella avnimelechi*) are found at DBE 3.2m. At this level coprolites are abundant. The rare benthic and planktonic foraminifera show chalky preservation and sometimes occur as internal, phosphatic moulds, suggesting reworking. Extremely rich associations occur from level DBE 3.3m to 3.5m (with a rich planktonic foraminiferal fauna, including *Ac. sibaiyaensis* and *Ac. africana* and a Midway-type benthic fauna comparable to that seen in subsection DBH). The 1.2m foraminifera-rich marly limestone of subsection DBH is reduced to half of its thickness in subsection DBE. The interval above this limestone (level DBE 4m to DBE 6.5m) consists of essentially barren shale with a few preserved foraminifera at 6m.

The relatively sudden abundance of planktonic foraminifera at 4.25m in subsection DBH, near link b at the base of Dababiya Quarry Bed 5 (and at comparable levels in other sections) is termed here "The Eocene Flood", in order to denote a distinct biostratigraphic event, that may serve as a useful regional correlation level within the lower part of the Esna Shale Formation (text-figs 7, 9).

Unit Esna 2 above the Dababiya Quarry Beds and Unit Esna 3

The upper (post-Dababiya Quarry Beds/post-CIE interval) of the Esna Shale Formation is exposed in the upper ~5m of subsection DBH (from 4.75 to 9m) and in subsection DBD from level DBD 7 at the base (= top of nearby section DBH 9.0) up to ~DBD 114 at which level it is overlain by the massive Thebes Limestone Formation. Subzone P5c is denoted by the LO of *Pseudohastigerina wilcoxensis* and its concurrent range with *Morozovella velascoensis*. It extends to DBD 18 (HO of *Morozovella velascoensis*). Typical Subzone P5c faunal elements include: *Subbotina patagonica, S. velascoensis, Acarinina esnaensis, Ac. pseudotopilensis, Morozovella acuta, M. aequa, M. apanthesma, M. gracilis, M. subbotinae, Igorina broedermanni* (with well defined, incised umbilical sutures), *Ig. lodoensis* and *Pseudohastigerina wilcoxensis*.

Zone P6 extends from samples DBD 18 to DBD 83.5 (from 24m to 89.5m above the base of the Esna Shale) and is ~65.5m thick. It is divided into two subzones based on the LO of *Morozovella formosa* in sample DBD 48. Subzone P6a is ~30m thick and Subzone P6b ~36.5m thick. Faunas of Subzone P6a are essentially similar to those of Subzone P5c with several notable exceptions:
 a. absence of several morozovellids (*M. acuta, M. apanthesma, M. velascoensis*);
 b. addition of *M. edgari* over the stratigraphic interval of samples DBD18 to 37;
 c. sporadic occurrences of *M. marginodentata;*
 d. more common occurrence of *Ac. pseudotopilensis, Ac. wilcoxensis* and *M. gracilis* than in Subzone P5c.
Subzone P6b faunas are similar to those in Subzone P6a with several exceptions:

 a. *Subbotina velascoensis* has its HO in sample DBD 48 (i.e., at the P6a/P6b boundary);
 b. *Morozovella lensiformis,* joint nominate form for Subzone P6b, occurs rarely, and sporadically at Dababiya, its LO being in sample DBD 57;
 c. *Acarinina appressocamerata, Ac. quetra, Ac. interposita* and *M. crater* have their LOs at DBD63.7, DBD 64.5, DBD 68.2 and DBD 75, respectively;
 d. *Subbotina inaequispira* has its LO at DBD81, essentially coincident with the P6/P7 boundary.

The P6/P7 boundary, in Unit Esna 3, is denoted by the L0 of *Morozovella aragonensis* at DBD 83.5 (89.5m above the base of the Esna Shale). Typical faunal components include *Subbotina patagonica, Morozovella aragonensis, M. formosa, M. lensiformis, M. subbotinae, Acarinina angulosa, Ac. appressocamerata, Ac. interposita, Ac. pseudotopilensis, Ac. quetra, Ac. pentacamerata* (LO at DBD 84), *Ac. wilcoxensis, Igorina broedermanni* and *Pseudohastigerina wilcoxensis.*

Alternating shales/marls and indurated limestone stringers above DBD 97 render positive identification of taxa difficult in some instances. However, the HO of *Morozovella formosa* (P7/P8 boundary) and the LO of *Acarinina bullbrooki* at level DBD 105 (9m below the Esna Shale/Thebes Limestone contact at ~DBD 114) lead us to place the P7/P8 boundary at DBD 105 (111m above the base of the Esna Shale). Zone P7 is thus ~21.5m thick. Planktonic foraminiferal faunas are essentially the same as those in Zone P7 below, with the following additions: LO of *S. frontosa* (DBD 109.5) and LO of *Ac. cuneicamerata* (DBD 108).

Planktonic foraminiferal faunas continue into the basal levels of the Thebes Limestone and we find no definitive evidence in the benthic foraminiferal faunas for significant shallowing across the Esna/Thebes contact.

Calcareous nannofossils

The composite Dababiya section constitutes an extended (150m thick) and essentially complete record of the interval from Biozone NP8 to NP 11 (combined biozonal schemes of Martini 1971; Aubry 1996 and Aubry 1999), with the Esna Shales extending from the NP8/NP9 zonal boundary to Zone NP11. Its stratigraphic significance lies in the facts that it provides 1) a remarkable, expanded record of the events that occurred in Tethys-Atlantic realm during the CIE, and 2) an excellent record of Zone NP10 and its subzones, similar to DSDP Hole 550 (Aubry et al. 1996) but twice as thick.

We first discuss below the general calcareous nannofossil stratigraphy of the section. We then document the main events that can serve for fine biostratigraphic resolution across the Paleocene/Eocene boundary.

Biozonal subdivision

Calcareous nannofossils are abundant to common at most levels in the Dababiya section, and preservation varies from good to poor. There are barren intervals, particularly in Units Esna 2 and Esna 3 that potentially could hamper biostratigraphic resolution. We have found however that close sampling generally alleviates this problem. For instance, our resampling (subsection 02DBE) at a spacing of 20cm of the interval from DBD 36 to DBD 48 that appeared to be largely barren on the basis of a 1.5m sampling interval has resulted in recovery of nannofossils from the greater part of the interval.
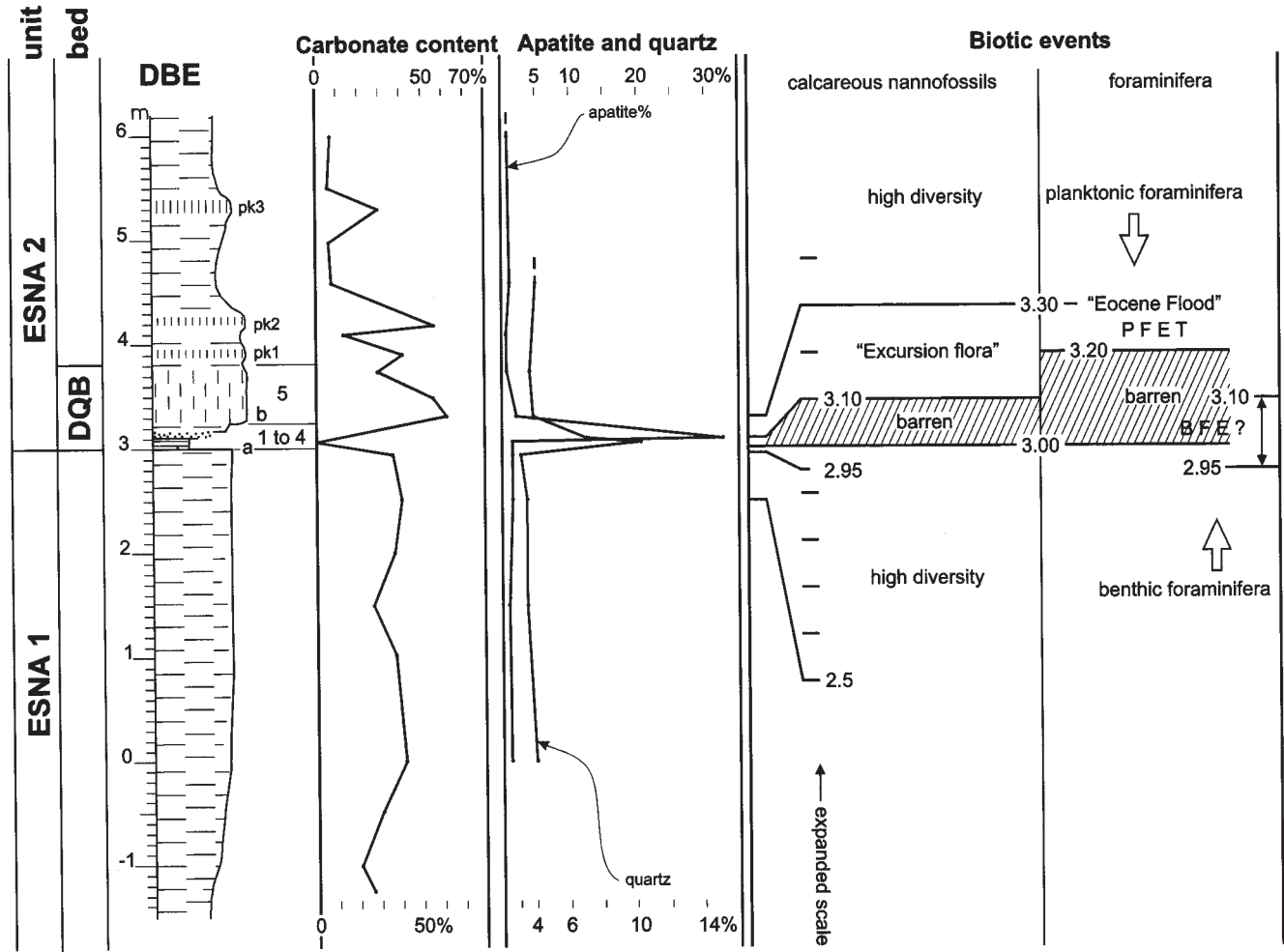
TEXT-FIGURE 8
Subsection DBE. Note that the Dababiya Quarry Beds are significantly reduced in thickness (m) compared to subsection DBH.

The upper part of the Tarawan Limestone (DBA 0 to DBA 7) belongs to the upper part of Zone NP8 as indicated by the co-occurrence of *Heliolithus riedelii* and *Discoaster okadai* (levels DBA 0.5 to DBA 1). Preservation is poor in these chalky sediments resulting in uncertain determination at species level. In particular, the LO of *Discoaster nobilis* difficult to determine because of overgrowth, may be as low as level DBA 1.0. Typical specimens of this species occur at level DBA 3.0. Transitional forms between *Discoaster drieveri* and *D. multiradiatus* occur between DBA 5.5 and DBA 6.5 at which level the LO of *D. multiradiatus* is placed. The lithologic transition from the Tarawan Limestone to the Esna Shale is thus mirrored by a paleontologic transition, implying sedimentary continuity between the two formations. As delineated by carbonate content, the boundary between the Tarawan and Esna Formations, sampled in subsection DBA, thus essentially corresponds to the NP8/NP9 biozonal boundary. As in all other sections in the Upper Egypt, Unit Esna 1 at Dababiya belongs to Subzone NP9a that extends up level DBA 13, characterized by the common occurrence of *Fasciculithus alanii* between DBA 9 and DBA 13. In subsections DBE and DBH Subzone NP9a extends up to samples DBE 2.95 and DBH 1.5 both taken just below Bed 1 of the Dababiya Quarry Beds (= base of Unit Esna 2). *Fasciculithus alanii* occurs throughout Unit Esna 1 in subsections DBE and DBH.

Bed 1 (samples DBE 3.03 to 3.09 and DBH 1.6, 2.0) of the Dababiya Quarry Bed is barren in both subsections DBE and DBH (the upper one meter of section DBA is stratigraphically complex and is not discussed herein). However, calcareous nannofossils occur just at the base of Bed 2 (levels DBE 3.10 and DBH 2.3). Sample DBE 3.10 contains few calcareous nannofossils most of which occurred in Unit Esna 1. However, it also contains *Discoaster* araneus and *Rhomboaster* spp. whose cooccurrence characterizes the base of the Subzone NP9b. All of Unit Esna 2 that outcrops in subsection DBE belongs to Subzone NP9b. Of particular interest is the LO of *D. mahmoudii* at DBE 4.5. A few specimens of *F. alanii* occur in the Dababiya Quarry Beds, which suggests reworking from Unit Esna 1, thus supporting the interpretation that the occurrence in these beds of *Angulogavelinella avnimelechi* and other pre-latest Paleocene extinction benthic foraminiferal species reflect reworking (see below).

Samples DBH 2.3 and 2.5 yield common but poorly preserved discoasters, among which *Discoaster* sp. cf *D. anartios* and *D.*

sp. cf. *D. araneus*. On this basis they are assigned to Zone NP9b. Sample DBH 2.6 to 4.25 (Beds 2 to base of Bed 5) typically belong to the lower part of Subzone NP9b characterized by the co-occurrence of *Rhomboaster* spp. and *Discoaster araneus* (whose abundances vary in a specific pattern (see below). Of stratigraphic interest in subsection DBH above level 4.24 are the LOs of *D. mahmoudii* at DBH 5.00 and the LO of *D. diastypus* between DBH 8.00 and DBH 9.00.

Section DBD exposes the greater part of the Esna Shale Formation (110m compared to ~11m exposed in combined subsections DBA and DBH). The lower 9m of subsection DBD belong to Zone NP9b. The large overlap of the upper parts of subsections DBH and DBE with the lower part of subsection DBD is indicated by the occurrence of early morphotypes (with the characteristic 5 rays but a low knob that is weakly stellate) of *D. mahmoudii* at level DBD 0.50 similar to morphotypes that occur in DBH 5.00 and DBH 5.15. The LO of *T. bramlettei* is difficult to delineate. The scarcity of specimens of 6-rayed single-crystal asteroliths below level DBD 18 combined with generally poor preservation renders it difficult to identify the first asteroliths with an hexaradiate symmetry (In the late Paleocene-early Eocene genus *Rhomboaster* the nannoliths have a rhomboidal structure; the evolution from *Rhomboaster* to *Tribrachiatus* involves a change in symmetry from rhomboidal to hexaradial; see Aubry et al.2000 contra Von Salis et al. 2000). Morphometric analysis in progress will help in confirming our provisional location of the LO of T. bramlettei at DBD 9.0.

Subzone NP10a extends up to DBD 41.50. The total range of *Tribrachiatus digitalis* between DBD 41.75 and DBD 45.5 characterizes Subzone NP10b and that of *T. contortus* between DBD 56.25 and DBD 66.8 characterizes Subzone NP10d. The NP10c/d subzonal boundary is well constrained between DBD 56.25 and DBD 56.00, but the NP10b/c zonal boundary is imprecise because of a 1m barren interval above DBD 45.5. Stratigraphic completeness is shown by the short (~1 to 1.50m) overlap of the uppermost range of *T. bramlettei* and the lower range of *T. contortus* in lowermost Subzone NP10d and the short (~1 to 1.50m) overlap of the lowermost range of T. orthostylus and the upper range of *T. contortus* in uppermost Subzone NP10d. Similar stratigraphic overlaps accompanied by the occurrence of morphotypes transitional between *T. bramlettei* and *T. contortus* on the one hand, and between *T. contortus* and *T. orthostylus* on the other were reported from DSDP Site 550 (Aubry et al. 1996).

The NP10/NP11 zonal boundary is almost correlative with the boundary between Units Esna 2 and Esna 3. Numerous samples from Unit Esna 3 were barren. Others yielded poorly preserved calcareous nannofossils with only rare and strongly overgrown discoasters. *Tribrachiatus orthostylus* is rare at most levels and no typical specimens of *D. lodoensis* were encountered. For this reason Unit Esna 3 is here broadly assigned to the NP11-NP12 zonal interval.

Biostratigraphy of the Dababiya Quarry Beds

The Dababiya Quarry Beds constitute a lithologic unit that is mappable throughout southern Egypt, so that the Paleocene boundary, marked by their base, is easily traceable. Outside of the geographic area they cover, the Dababiya Quarry Beds can be finely correlated using the combined ranges and acmes of several calcareous nannoplankton species (text-fig. 7). These help in characterizing the Paleocene/Eocene boundary in sec-

tions removed from the stratotypic area and in evaluating the completeness of lowermost Eocene sections, in particular in the absence of carbon isotopic data. This also help determining the completeness of the Dababiya Quarry Beds in southern Egypt.

The Dababiya Quarry Beds are most expanded in subsection DBH that we describe here. Their fine biostratigraphy as established in other subsections sampled in the Dababiya quarry will be discussed elsewhere. The base of the Eocene is defined at level 1.57m in Subsection DBH. This is the base of Bed 1, a 63cm-thick, calcium carbonate free clay. Whereas the lowest 73cm of the lower Eocene is barren of calcareous nannofossils, the next 3.00m of differentiated lithologies provide a succession of marked events, both in terms of LOs and HOs and in term of acmes. The datum events were determined after extensive inventory using smear slides prepared directly from raw sediment (as for the datums given above). The acmes described below were determined from counts using the same smear slides. The first 300+ specimens occurring in successive fields of view at magnification ×1200 were recorded using both Bright Field and Crossed Nicols for any given field. The results are shown as percentage of the total number of specimens counted.

The oldest Eocene nannoplankton events, as seen in the DBH section, are 1) an acme of *Coccolithus subpertusus* and 2) the LO of *Discoaster anartios.* The acme of *C. subpertusus is* a striking event that characterizes the lowest 20cm of Bed 2 with percentages of 78% and 84% at DBH 2.3 and DBH 2.5, respectively. This acme is followed by a sharp drop in the abundance of the species (17% at DBH 2.6). Although *C. subpertusus* may be abundant at other levels in the Dababiya Quarry Beds it does not exceed ~50% of the assemblages at any level. This acme is associated with extremely low diversity, particularly in sample DBH 2.3. Preservation is very poor at level DBH 2.3 but this does not explain the low diversity and the acme because discoasters are as resistant as placoliths to solution and overgrowth, as are the placoliths of species of *Toweius* (a major component of late Paleocene and early Eocene assemblages) compared to those of *C. subpertusus*. In addition, *C. subpertusa* is in low abundance in the assemblages of Unit Esna 1. Our data indicate that the acme of *C. subpertusus* is a primary event.

Coincident with the acme of *C. subpertusus* are the LOs of *D. anartios* and long-armed species of *Rhomboaster* (text-fig. 9). *Discoasters* are very poorly preserved at DBH 2.3, but good morphotypes of *D. anartios* were encountered together with *D. multiradiatus*. *Discoaster anartios* is rare throughout the Dababiya Quarry Beds, except at DBH 3.15. *Rhomboaster* spp. are rare at DBH 2.5. This is a complex of forms with extended arms and distinct asymmetry that are usually referred to as R. calcitrapa.

The datums events subsequent to the LOs of *D. anartios* and *Rhomboaster* spp. are, sequentially:

In Bed 2: the LO of *D. araneus* (DBH 2.6; upper Bed 2);

In Bed 3: the LCO of *Rhomboaster spineus* (DBH 2.8) and the LO of *Pontosphaera inconspicua* at DBH 3.4. This latter event is extremely difficult to determine because of the great rarity of the taxon up to level DBH 4.25;

In Bed 4: the HCO of *D. araneus* in DBH 3.5 (text-fig. 7);

In Bed 5: the LO of *Blackites solus* at DBH 4.50 in the lower part of the bed and the LOs of *P. plana* and *Discoaster*
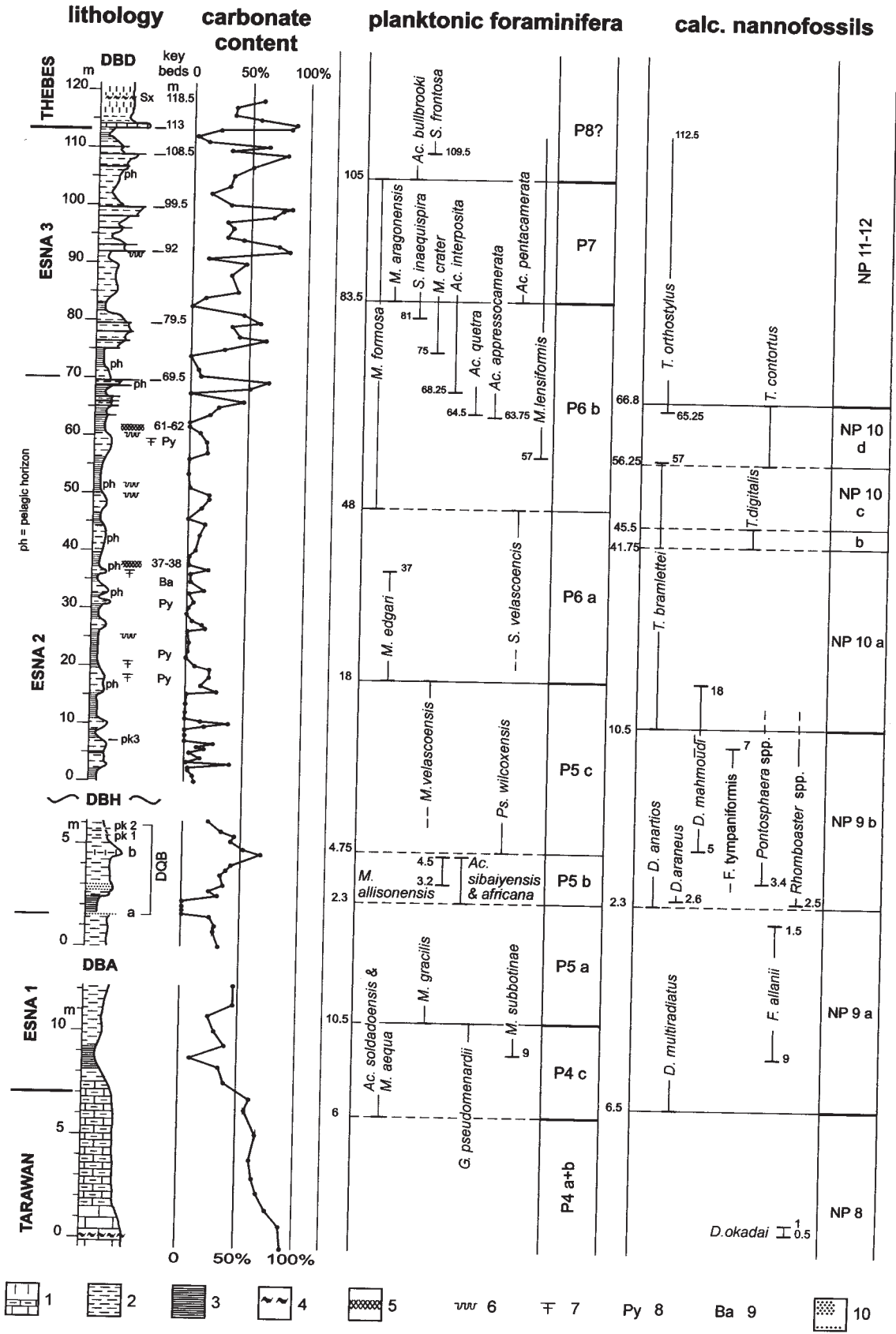
TEXT-FIGURE 9

Composite section (Dbcomp): Lithology marker beds and carbonate content in subsections DBA, DBH and DBD. Biostratigraphy and lowest and highest occurrences of selected planktonic and calcareous nannofossil taxa. Legend as in text-figure 6.

mahmoudii (DBH 5.00) and the HO of *D. araneus* (DBH5.15) in its upper part.

Whereas the above datum events may be difficult to use because of the scarcity of the nominative taxa, another means of stratigraphic correlation is provided by successive acmes (text-fig. 7). The acme of *C. subpertusus* at the base of Bed 2 is followed by a first acme of *Rhomboaster* spp. (DBH 2.60 and 2.80) in the upper part of the bed and the base of Bed 3. The lower part of Bed 3 is characterized by an acme of *D. araneus* (DBH 2.80 to DBH 3.15) while the upper part of the bed (DBH 3.40) and the base of Bed 4 (DBH 3.50) are characterized by a second acme of *Rhomboaster* spp. It is remarkable that the acme of C. *subpertusus* and the LO of *D. anartios* and *Rhomboaster* spp. coincide with the minimum (negative) δ^{13}C values of the CIE. It is also remarkable that the acme of *D. araneus* and the two acmes of *Rhomboaster* spp. are restricted to the CIE well within the interval with minimal δ^{13}C values.

Coccolithus subpertusus is a long ranging taxon but *D. araneus, D. anartios* and the long-armed *Rhomboaster* species are short-lived, being essentially restricted to the CIE (this is particularly clear for *D. araneus;* the HO of *D. anartios is* difficult to determine because of the scarcity of the species). The acme of *C. subpertusus* in subsection DBH may correlate with the acme of this species at Equatorial Pacific Ocean Drilling Site 865 (Kelly et al. 1996), in which case this is a global acme possibly in response to global warming. The acmes of *D. araneus* and *Rhomboaster* spp. are essentially restricted to the Atlantic-Tethyan realm, and their ecologic significance remains indeterminate (Aubry 1999; Cramer et al. 1999; Aubry2001). The challenge is now to determine whether the acmes of *D. araneus* and *Rhomboaster* spp. described in Atlantic and Tethyan sections (Khan and Aubry, unpublished data) correlate with the acmes at Dababiya.

Benthic foraminifera

Nineteen samples (excluding barren samples) were examined for a semi-quantitative survey of the benthic foraminiferal assemblages from the Dababiya subsections DBA, DBD, DBE and DBH. Generally the benthic assemblages are moderately well preserved and highly diverse, yielding up to 30 taxa (species and genera) amongst 200 specimens per sample. In total over sixty taxa, mostly well-known, were encountered. In many samples, however, benthic foraminifera are nearly absent, and occur mostly as broken (thick-shelled) tests of *Lenticulina*, *Cibicidoides*, and nodosariids. This together with the large numbers of limonitic/hematitic burrows and concretions, the low numbers of planktonic foraminifera and the occasional abundance of agglutinated foraminifera provide evidence of severe dissolution of the primary assemblages.

Throughout the section, the assemblages are largely composed of Midway-type species, i.e. taxa commonly found in Paleocene neritic deposits worldwide (Berggren and Aubert 1975). Most common taxa observed are various *Cibicidoides* (*C. pseudoacutus, C.* cf. *C. hyphalus, C. alleni. C.* cf. *C. pseudoperlucidus*), *Lenticulina* spp., *Anomalinoides* (*A.* cf. *A. midwayensis, A. aegyptiacus, A. zitteli), Loxostomoides applinae, Oridorsalis plummerae, Valvulineria scrobiculata,* and *Tritaxia* spp. (see Speijer 1994 for taxonomic concepts).

Of particular interest is the common occurrence in the lower part of the section of *Angulogavelinella avnimelechi.* This species is common in Paleocene outer neritic to upper bathyal deposits in Tethyan and European basins (Speijer et al. 1995; Weidich 1995). Exclusively bathyal (Velasco-type) taxa, such as *Gavelinella beccariiformis, Nuttallides truempyi, Pullenia coryelli* and *Bulimina trinidadensis* (Berggren and Aubert 1975; Tjalsma and Lohmann 1983; Speijer 1995) were not found in our analysis of the samples from Dababiya. Consequently, the benthic foraminiferal assemblages suggest deposition at depths of 150-175m, which is slightly shallower than at nearby Gebel Owaina, where low numbers of Velasco-type taxa were encountered (Speijer et al. 1995; Speijer and Schmitz 1998; Ouda et al. 2003, Chapter 9, this volume). The current data set does not allow for any indications of changes in water depth within the succession.

The most prominent change observed in the benthic assemblage occurs in the CIE interval between samples DBE 2.95m and DBE 3.6m. Samples below these levels (in Zone P5a) are dominated by *Cibicidoides* spp, *A.* cf. *A. midwayensis, Lenticulina* spp., *A. avnimelechi,* and *Tritaxia* spp. Except for *Lenticulina* spp. the HOs of these taxa are within Zone P5b, i.e. within the CIE interval, and correspond to local extinctions. Assemblages in the interval representing the CIE and Zone P5b include (as common occurrences) species that are abundant in pre-CIE intervals (unit Esna 1) and a few new taxa, such as *A. aegyptiacus* and *A. zitteli.* Above the Dababiya Quarry Beds the most common taxa are *A. zitteli, Lenticulina* spp., *Valvulineria scrobiculata, Oridorsalis plummerae,* and occasionally *L. applinae, Bulimina farafraensis* and *Gaudryina* cf. *G. ellisorae.* The level marked by local extinction of many taxa correlates with the prominent benthic foraminiferal extinction event in bathyal and abyssal sections (Beckmann 1960; Tjalsma and Lohmann 1983; Thomas 1998). The extinction of *A. avnimelechi* has proven to be a useful marker for delineating the deep-sea extinction event in shallower successions such as those of central Egypt, where the otherwise common deep-sea taxon *G. beccariiformis* is rare or absent (Speijer et al. 1995). In the DBE and DBH sections, this event seems to be recorded just above the carbonate free Dababiya Quarry Bed 1 (text-figures 7 and 8). No benthic foraminifera were found in samples DBE 3.03m and DBE 3.07m, nor in samples DBH 1.6m to DBH 2.8m and only very few, dissolution resistant specimens (nodosariids and *Lenticulina*) were found in sample DBH 3.15m. *Angulogavelinella avnimelechi* occurs up to samples DBE 3.2m and DBH 3.4m.

It is likely that most of the benthic foraminifera that occur just above the barren interval (i.e., in Dababiya Quarry Bed 3) were redeposited, in which case the benthic extinction event should be situated in Bed 1. Evidence from other sections in the region indeed imply that the assemblages in samples DBE 3.1m and DBE 3.2m and DBH 3.4m result from the mixing of relatively rare in situ specimens with abundant reworked material. In Gebel Qreiya, Gebel Nezzi and Gebel Owaina a succession of three distinct benthic assemblages was observed: the *Angulogavelinella avnimelechi* assemblage below the CIE, the A. aegyptiacus assemblage within the lower part of the CIE (absent at G. Owaina because of a stratigraphic gap; see also Ouda et al. 2003, chapter 9, this volume) and the *Bulimina callahani* assemblage in the upper part of the CIE (Dababiya Quarry Bed 5 = calcarenitic bed) and above. (Speijer et al. 2000; Speijer and Wagner 2002). In none of these sections have more than a few single specimens of the taxa dominating the *A. avnimelechi* assemblage been observed in the phosphatic beds or the overlying calcarenitic bed (i.e., Dababiya Quarry Beds 3 to 5). From this we infer that the occurrences of *A. avnimelechi, Cibicidoides* spp, *A.c*f. *A. midwayensis* and *Tritaxia* spp. in these beds result

from reworking. The benthic foraminiferal turnover thus proba- bly occurred between levels DBE 2.95m and DBE 3.1m and levels DBH 1.5m and DBH 3.15m. In various deep-sea sections reworking has been demonstrated by means of stable isotopes analyses (e.g. Kelley et al 1996; Thomas and Shackleton 1996). However, because of recrystallization and calcite infilling of the benthic foraminifera preserved in the Dababiya section (as in other Egyptian sections Charisi and Schmitz 1995; Schmitz et al. 1996) samples are generally not suitable for such analyses.

CONCLUSIONS

The Dababiya section, a composite of a series of adjacent over- lapping sections (DBA, DBE, DBH and DBD), on the east bank of the Nile River, 25 km south of Luxor, exposes one of the world's most complete and most expanded Upper Paleocene to Lower Eocene sequences. Its detailed logging and mapping has led to the description of new formal subdivisions of the Esna Shale Formation, divided into three units, the base of the middle one being marked by a characteristic succession of five distinct beds that can be traced throughout a large area in Egypt and probably to neighboring countries (e.g., Speijer et al. 2000). We describe this succession as the Dababiya Quarry Beds. Their significance lies in the fact that they record the geochemical, mineralogical and biotic events that occurred in the earliest Eocene. Their base records the base of the CIE with an initial decrease of ~1.2‰ in the carbon isotopic composition of or- ganic matter. The extent of the CIE essentially encompasses the Dababiya Quarry Beds which also record the extinction of *Angulogavelinella avnimelechi,* the influx of the planktonic foraminiferal taxa *Acarinina sibaiyaensis* (abundant), *Ac. africana* (rare) and *Morozovella allisonensis* (extremely rare) and that of the *Discoaster araneus-Rhomboaster* spp. assem- blage. The Dababiya Quarry Beds thus provide the elements for long distance correlation of the Paleocene/Eocene boundary, defined at their base in subsection DBH. Of equal importance, the Dababiya section constitutes a complete and expanded stratigraphic succession from upper Paleocene to lower Eocene, encompassing the stratigraphic interval from the NP8/NP9 zonal boundary to Zone NP11 and from Zone P4 to Zone P8. We have highlighted here the essential biostratigraphic ele- ments in this succession.

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