Upper Paleocene-Lower Eocene Biostratigraphy of Darb Gaga , Southeastern Kharga Oasis Western Desert, Egypt

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Abstract

Paleontological studies on the Upper Paleocene-Lower Eocene succession at Darb Gaga, southeastern Kharga Oasis, Western Desert, Egypt document the changes associated with the Paleocene-Eocene Thermal Maximum (PETM), such as 1) a radical alteration of the relative and absolute abundance of planktonic foraminifera; 2) a massive occurrence of the excursion planktonic foraminiferal taxa; 3) a widespread deposition of calcarenite yielding atypical (extremely high) faunal abundance associated with the younger phase of warming; and 4) a concentration of coprolites associated with the middle phase of warming. We also document the Lowest Occurrence (LO) of dimorphic larger benthic and excursion foraminifera during the earlier phase of warming at Darb Gaga, as recorded in

Bed 1 of the Dababiya Quarry Member. The absence of these faunas in Bed 1 at Dababiya (the GSSP for the P/E Boundary) is likely to be due to both intense deficiency in dissolved oxygen and massive carbonate dissolution. Only remains (fish remains) of faunas that can tolerate the toxicity produced by low oxygen conditions are found in the stratigraphic record of this (oldest) phase at Dababiya.

The Dababiya Quarry Member (DQM) at Darb Gaga reflects the unfolding of the sedimentary and biotic changes associated with the PETM global warming at, and following, the Paleocene/Eocene boundary on the southern Tethys platform. The changes began with a rapid increase in bottom and "intermediate" water temperature. The temperature increase was accompanied by removal of oxygen during the early and middle stages of warming. This led to the absence of both subbotinids and calcareous benthic foraminifera in the early and second coprolite-bearing phases (Beds 2 and 3 of the DQM). Dissolution seems to have no role during these stages as shown by the unusual abundance and good preservation of the warm-tolerant *Ac. sibaiyaensis*. This species reaches its maximum abundance in Bed 2 where it exhibits a broad range of size (63-250 μm) and shape that probably reflect optimal growth under the warmest water conditions. Thus, we infer that temperature and dissolved oxygen content of the sea-water were the main factors controlling the distribution pattern(s) of the microplankton and microbenthos during the PETM.

Keywords: Paleocene/Eocene Boundary, Darb Gaga, Kharga Oasis, planktonic foraminiferal biostratigraphy, Dababiya Quarry Member

1 Introduction

Darb Gaga is situated East of the Esna-Kharga Road, ~40 Km before the end of this road and its intersection with Baris-Kharga road at latitude N 24° 54′ 48.2″ and longitude E 30° 56′ 58.5″ (Fig.1). The Upper Paleocene-Lower Eocene succession is well represented in the area by two main rock formations, the Tarawan Chalk and Esna Shale. The Tarawan Chalk/Formation (Awad and Ghobrial, 1965) outcrops west of the road, whereas the Esna Shale/Formation (Beadnell, 1905; Said, 1960) forms isolated hills east of it. The Esna Shale is represented by the lower member (El Hanadi Member, Abdel Razik, 1972, emended by Aubry et al. 2007) whose base is not exposed and the middle member (El Mahmiya Member of Aubry et al., 2007) whose top is not exposed. Both members are separated by a vertical cliff consisting of 5 beds made up successively of clay, phosphatic shale, coprolite-rich shale, marl and calcarenite. These form the Dababiya Quarry Member of Aubry et al. (2007= Dababiya Quarry Beds of Dupuis et al. 2003) which yields a notable, expanded record of the biotic and geochemical events that occurred during the PETM on the southern Tethys platform (Ouda and Aubry, eds.,2003).

Three sections were collected and investigated across the Paleocene/Eocene boundary interval in order to investigate the sedimentary and biotic changes associated with the global warming at, and following the P/E boundary, and to correlate the results with those of the GSSP of the P/E boundary at Dababiya, southern Nile Valley. The sections are: section DG1 , 5.5 m thick, includes the upper part of the El Hanadi Member (3.85 m thick) and the DQM (1.65 m thick); section DG2, 1.5 m thick, includes the uppermost levels of the El Hanadi Member (0.8 m thick) and the lower part of the DQM

(0.7 m thick); section DG3, 9.7 m thick, comprises the upper part of the DQM (1.7 m thick) and the lower part of the Mahmiya Member (8.0 m thick).

2 Material and methods

The samples were collected for paleontological studies with sampling intervals varying from 3 cm to 25 cm in the Dababiya Quarry Member (that member of the Esna Shale which reflects the major disruption of the Paleocene/Eocene boundary interval), from 10 cm to 25 cm in the underlying El Hanadi Member, and from 25 cm to 50 cm in the overlying El Mahmiya Member. The samples were numbered based on their position in the measured section, which ease the description of bioevents in individual beds.

Two hundred grams per sample were dried at 80^{o}C, and weighed. The dry samples were soaked in a 0.5 molar Na_2 CO_3 solution. Most samples disintegrated readily and after disintegration they were washed carefully over a 63 µm screen until the clay fractions washed completely. They were dried and sieved over 125, 250 and 500 µm screens. Samples from the hard limestone which forms a prominent constituent of the El Mahmiya Member were treated in a different manner. They were crushed into small fragments and heated to about 100^{o}C, then immediately soaked in kerosene for 24 hours until disaggregated. The fractions were weighed and preserved in glass vials. The foraminiferal faunas were concentrated in the size fractions of 125 and 250 µm from which the fossils were picked and then preserved on cardboard slides. Microphotographs of the index planktonic foraminiferal taxa of the Paleocene/Eocene boundary were taken by using the Scanning Electron Microscope (JEOL-JSM-5400LV) at Assiut University in

Egypt. The planktonic foraminiferal zonal scheme applied here is the tropical to subtropical Paleogene zonation of Berggren and Pearson (2005).

3 Litho- and Biostratigraphy:

3.1 Section DG1(Figs. 2-4):

3.1.1 The El Hanadi Member (Upper Paleocene, Subbiozone P4c and Biozone P5 of Berggren and Pearson, 2005):

This member (~3.85m thick, from level DG1 0.0 m to level DG1 3.85 m) consists of fossiliferous calcareous shale of more than 50% calcium carbonate, intercalated with thin limestone beds. The calcium carbonate content increases upward. The member contains a thin calcareous sandstone bed at the upper levels, and becomes a low-calcium shale in its uppermost 40 cm (Fig. 2).

The base of this member (level DG1 0.0 m) contains a mixed assemblage of benthic and planktonic foraminifera. The latter fauna form a subbotinid-rich assemblage with rare to common *Morozovella velascoensis, M. subbotinae, M. quadrata, M. angulata, M.aequa* together with *Acarinina soldadoensis, Ac. primitiva, Ac. tribulosa, Igorina lodoensis* and *Globanomalina luxorensis.* Such an association marks the higher levels of Subbiozone P4c despite the absence of the zonal marker *Globanomalina pseudomenardii.* The latter taxon has an erratic distribution in southern Egypt where its abundance is a function of the intensity carbonate dissolution. Evidence of partial to strong dissolution has been observed in samples of the lowermost Esna Shale Formation (El Hanadi Member) at Dababiya (Dupuis et al., 2003; Berggren and Ouda, 2003a, Aubry et al. 2007), Dababiya Corehole (Soliman, 2011, Ouda et al., 2013; Obaidallah, 2013) , Qrieya (Berggren and Ouda, 2003b; Knox et al. 2003) , Owaina and Kilabiya (Ouda and Aubry, 2003) where *Gl. pseudomenardii* is either completely absent or occurring very rarely and always sporadically. Other stratigraphic datums which can be useful indicators for approximating of the P4/P5 zonal boundary in the lower part of the Esna Shale (El Hanadi Member) include *Planorotalites pseudoscitula* and *Morozovella gracilis* (Berggren and Ouda, 2003a&b; Ouda et al., 2013). At Darb Gaga, the LO of *Pl. pseudoscitula* is recorded one meter above the base of the El Hanadi Member, (level DG1 1.0 m, Fig. 3) where *M. velascoensis* predominates the morozovellids and *Gl. chapmani* (morphotype *Gl. elongata*) attains its lowest common occurrence(LCO).

Morozovella gracilis, which is unknown below Biozone P5, has its LO at Darb Gaga, a short stratigraphic interval above the LO of *Pl. pseudoscitula* (level DG1 1.5 m), thus substantiating the placement of P4/P5 zonal boundary within the Hanadi Member at level DG1 1.0 m (Fig.3). Also, *Ac. angulosa* has its LO immediately above the LO of *M. gracilis* but never becomes common before the upper part of El Hanadi Member (level DG1 2.8 m). A similar occurrence has been reported by Ouda and Berggren (2003) in the upper part of the El Hanadi Member, corresponding to the lower part Biozone P5 at Dababiya.

In the upper part of El Hanadi Member (levels DG1 2.0 m-2.25 m) the planktonic foraminiferal assemblages are mainly composed of acarininids and subbotinids whereas morozovellids are subordinate and represented principally by the *M. subbotinae* Group (*M. subbotinae, M. qudrata, M. gracilis*) together with rare *M. velascoensis*. *Ac. esnaensis* and *Ac. wilcoxensis* have their LO at the same levels, but become common only in the upper level (level DG1 3.5 m) of the El Hanadi Member (=uppermost Biozone P5).

Morozovellids regain their predominance upward (level DG1 2.75 m) with *M. velascoensis* as the main taxon, accompanied by the LCO of *Ac. angulosa*. A thin limestone bed is recorded in the upper part of El Hanadi Member (levels DG1 3.0 m-3.25 m). It contains a mixed benthic and poorly preserved planktonic foraminiferal assemblage. The morozovellids predominate in the planktonic fauna and are composed mainly of *M. subbotinae M. velascoensis, M. acuta* and *M. gracilis* together with *Ac. angulosa , Ac.esnaensis and Gl. chapmani.* The LO *of Gl. planoconica* is at the base of this limestone bed.

The less limy levels in the upper part of the El Hanadi Member (levels DG1 3.5 m-3.6 m) are relatively highly enriched in planktonic foraminifera. The fauna includes, among others, common to frequent specimens of *M. velascoensis, M. subbotinae, M. gracilis, Ac. angulosa, Ac. esnaensis, M. occulosa. M. apanthesma,* on the other hand, disappears in the same stratigraphic interval, whereas the benthic foraminifera exhibit a marked change leading to the occurrence of a rich assemblage characteristic of relatively deeper-water facies *(e.g. Gavellinella, Pseudoglandulina, Valvulinaria and Gyroidinoides)* including large *Gavellinella. cf. danica.*

In the uppermost levels of the El Hanadi Member, directly below the advent of the Lower Eocene warming episode (levels DG1 3.7 m- 3.8 m) the benthic foraminifera become more diversified and abundant than the planktonic ones which, in turn, become smaller and include mainly subbotinids and acarininids together with subordinate morozovellids (*M. velascoensis, M. subbotinae and M. gracilis*, arranged in order of abundance). On the other hand, *Ac. esnehensis* and *Ac. wilcoxensis* have their LCO together with rare to common representatives of *Igorina* (particularly *Ig*. *broadermanni*) at the top of the El Hanadi Member (levels DG1 3.7 m-3.8 m).

The benthic foraminifera in the El Hanadi member at Darb Gaga (Subbiozone P4c, partim and Biozone P5) are essentially characterized by the so-called “Midway” fauna, typical of shelf type (up to 200 m). *Anomalinoides midwayensis, An. umboniferous, Bulimina midwayensis, B. reussi, Cibicidoides alleni, Eponides lotus, E. plummerae, Frondicularia phosphatica, Gyroidinoides subangulata, Lenticulina midwayensis, Marginulinopsis tuberculata, Osangularia plummerae, Valvulineria scrobiculata.* The “Velasco” fauna which reflects an upper bathyal facies is only restricted to the low-calcium shale which constitutes the uppermost part of the El Hanadi Member (levels DG1 3.5 m-3.8 m). *Gyroidinoides giraradana* and *Gavelinella cf.danica* dominate this Velasco fauna. No *Angulogavelinella avnimelechi, A. beccarriformis, Tritaxia midwayensis or Neoflabellina jarvisi* were encountered at any level in the section, although they are common in the El Hanadi Member at Dababiya in the southern Nile Valley (Berggren and Ouda, 2003a).

The composition of planktonic foraminifera in the El Hanadi Member is a function of paleobathymetry. The predominance of subbotinids and acarininids in its lower part (Subbiozone P4c and Lower part of Biozone P5; (levels DG1 0.0 m- 2.5 m), together with the high benthic/planktonic foraminiferal ratio indicate the relatively shallower (middle-outer shelf) facies of this part of the El Hanadi Member at Darb Gaga. The morozovellids, on the other hand, show a marked increase in abundance in the middle-upper part of Biozone P5 (from level DG1 3.0 m to level DG1 3.6 m), accompanied by a decrease in benthic/planktonic ratio, thus suggest a relative deepening (outer-shelf/ bathyal). However, the shelf facies re-appears at the topmost Biozone P5 (levels DG1 3.7 m-3.8 m), directly below the DQM, as deduced from the high benthic/planktonic foraminiferal ratio and the predominance of subbotinids and acarininids, thus indicate a fluctuation of water depth around the outer shelf/bathyal interface a short time before the advent of the warming of the PETM.

The remarkable variations in the ratio of the (sub)tropical morozovellids of the *M. velascoensis* (Mv*)* group (levels DG1 0.0 m, 0.5 m, 1.0 m, 1.5 m, 3.5 m, 3.6 m, 3.7 m and 3.8 m) to the more broadly distributed morozovellids of the *M. subbotinae* (Ms) group (levels DG1 2.0 m, 2.25 m and 2.75 m) reflect temperature fluctuations. The members of the *M. velascoensis* group have a narrow biogeographic distribution within 45° North and 45° South, whereas the members of the *M. subbotinae* group are geographically widespread (see details in Ouda and Berggren, 2003). Thus, the variations of the Mv/Ms ratios seem to have been a function of temperature changes during Biozone P5. The high Mv/Ms ratio at the top of Biozone P5 (levels 3.5 m-3.8 m) indicates the prevalence of warm conditions immediately before the advent of the PETM.

The sequential LOs of *Ac. angulosa, Ac. esnaensis, Ac. wilcoxensis* and *Ac. esnehensis* in Biozone P5 (Fig.4) indicate that the third radiation of the acarininids occurred within a short stratigraphic interval in the mid-upper Biozone P5, directly before the onset of the PETM. The same sequence of bioevents was found in all sections studied in the southern Nile Valley, in either clastic (Esna Formation, Ouda and Berggren, 2003; Ouda et al., 2013) or calcareous (Garra Formation, Berggren et al.,

2003) facies. This implies that the radiation can reliably be used to approximate the P/E boundary and to predict the location of the stratigraphic interval that records the PETM.

3.1.2 The Dababiya Quarry Member (Lower Eocene, Biozone E1 of Berggren and Pearson, 2005):

This member is ~1.65 m thick (from level DG1 3.85 m to level DG1 5.5 m). It consists of a succession of five beds of different lithologies and varied foraminiferal contents overlying directly the El Hanadi Member. The succession is not covered by younger sediments in both sections DG1 and DG2. The member encompasses the PETM-interval and yields a record of the biotic changes induced by the Paleocene/Eocene boundary event. However, this record appears to be somewhat reduced at Darb gaga compared to those at Dababiya which contains the GSSP of the base of the Eocene Series (section DBH, Ouda and Aubry, eds, 2003; Aubry et al., 2007; Ouda et al., 2013).). The reduced thickness of the Dababiya Quarry Beds 1, 3 and 4 at Darb Gaga could simply have occurred by the action of bottom currents winnowing away some of the sediments. The foraminiferal content of this succession at Darb Gaga 1 has been critically investigated at higher resolution and the results can be summarized as follow:

3.1.2.1 Dababiya Quarry Bed 1

This bed is ~8 cm thick (from level DG1 3.85 m to level DG1 3.93 m). It is composed of a coprolite-free shale low carbonate content. The washing residues of this shale are made up of calcareous fragments associated with organic matter and fish remains, together with dispersed glauconite. The planktonic foraminifera are generally scarce while the benthic foraminifera are very rare, fragmented, and have almost deformed tests. The planktonic foraminiferal species are mainly composed of acarininids, morozovellids and globanomalinids together with subbotinids. The excursion faunas essentially *Acarinina sibaiyaensis* and *Morozovella. allisonensis* are recorded sparse in the medium-sized residual fractions with few deformed acarininids, but with no benthic foraminifera. The fine-grained residual fractions, however, is relatively enriched in dwarfed planktonic foraminifera belonging mainly acarininids and morozovellids, with subordinate subotinids and few sporadic *Ac. sibaiyaensis*. Surprisingly, the coarse fraction includes fragments of the oldest *Nummulites* sp. and *Discocyclina* sp. as well as fractions of species belonging to the genera *Lenticulina*, *Marginulinopsis* and *Frondicularia.* Evidence of partial dissolution at bottom water can be deduced from the etching of the test surface of the smaller benthic foraminifera.

Bed 1 was deposited under warm conditions of low dissolved oxygen in sea water as deduced from the general rarity and dwarfing of planktonic foraminifera, the marked impoverishment and deformation of foraminifera and the appearance of warm–tolerant excursion faunas *(A. sibaiyaensis, M. allisonensis)*. The presence of *Nummulites* and *Discocyclina* spp. together with excursion acarininids and morozovellids at the base of the DQM level at Darb Gaga (whereas the smaller benthic foraminifera occur only sporadically) can be interpreted as reflecting the presence of a restricted depositional basin (around a neritic carbonate shelf), in addition to the development of intense warming accompanied by a marked decrease in oxygen levels at the sea floor. These conditions may have led to exclusion of normal mature planktonic as well as smaller benthic foraminifera.

3.1.2.2 Dababiya Quarry Bed 2

This bed is 22 cm thick (from level DG1 3.93 m to level DG1 4.15 m). It is composed of phosphatic calcareous black shale. The coarse-grained fraction of the washing residues of all samples collected from this bed are rich in coprolites and fish remains with no foraminifera at level DG1 3.93 m , but with dispersed large-sized *Ac. sibaiyaensis* at level DG1 4.0 m. However, the medium- and fine-grained residual fractions are found to be either enriched or dominated by planktonic foraminifera together with fish remains. The planktonic foraminifera are predominantly represented by *Ac. sibaiyaensis together with subordinate M. allisonensis. Acarinina africana* becomes a constant constituent in the middle and upper levels of this bed (levels DG1 4.0 m- 4.07 m). Additional species of acarininid and globanomalinid (*Gl. imitata* and *Gl. pseudoimitata)* are restricted in very low numbers to the fine-grained fraction. The morozovellids (mainly *M.acuta*) occur sporadically in the lower part of this bed whereas upwards they are absent. No specimens referable to subbotinids are encountered among this faunal association. Benthic foraminifera are also entirely missing from all fractions in this bed.

The faunal content of this bed is that of the *Ac. sibaiyaensis* acme “zonule” of Berggren and Ouda (2003a) which marks Bed 2 of the DQM in the DBH section at Dababiya.

3.1.2.3 Dababiya Quarry Bed 3

This bed is ~35 cm thick (from level DG1 4.15 m to level DG1 4.5 m). It is a highly calcareous, coprolite-bearing marl. The coarse- and medium-grained residual fractions from this bed (levels DG1 4.15 m- 4.25 m) include coprolites with no faunas. However, the fine- grained residual fraction is highly fossiliferous and mainly contains small *Ac. sibaiyaensis* together with other subordinate acarininids and globanomalinids. Morozovellids are rare in the lower part of this bed (level DG1 4.15 m) while benthic foraminifera are recorded sporadically in minute specimens in the upper levels (eg. *Bulimina* sp. and *Siphogenerinoides* sp., level DG1 4.25 m). No specimens referable to genus *Subbotina* are encountered in this bed.

Beds 2 and 3 of the DQM were deposited under euxinic conditions with a marked deficiency in dissolved oxygen particularly in the bottom and “intermediate” water leading to mass mortality of bottom-living benthic foraminifera and the total exclusion of subbotinids. Both beds correspond to the second phosphatic phase of the P/E warming episode, deposited during the maximum warming when biostratigraphically compared to equivalent beds in the DBH section (Dupuis et al. 2003; Berggren and Ouda, 2003a; Aubry et al. 2007). Bed 2 differs from Bed 3 by the sole and abundant occurrence of the so-called excursion taxa (*Ac. sibaiyaensis, Ac. africana* and *M. allisonensis*), whereas in Bed 3 these taxa occur commonly among other planktonic foraminifera (morozovellids and acarininids).

3.1.2.4 Dababiya Quarry Bed 4

This bed is 25 cm thick, between levels DG1 4.5 m - DG1 4.75 m. It consists of marl with dispersed coprolites. The marl is highly fossiliferous, rich in *Ac. sibaiyaensis,* *Ac. africana, M. allisonensis*, *Gl.* sp. with few other acarininids and subordinate *M. velascoensis.* Subbotinids are absent. No benthic foraminifera were recorded in this bed which contained only dispersed and deformed ostracodes exist.

3.1.2.5 Dababiya Quarry Bed 5

This bed is ~75 cm thick (from level DG1 4.75 m to level DG1 5.5 m). It consists exclusively of detrital limestone (calcarenite) in which the grains are mostly of foraminiferal tests (pelagic ooze). Paleontologically, this bed shows unprecedented abundance of planktonic foraminifera reflecting a regional influx of warm low-oxygen Tethyan water masses, including .a flood of acarininids and morozovellids accompanied by a gradual vertical decrease in excursion faunas. At the lowermost part of this bed (level DG1 4.75 m) *Ac. sibaiyaensis, Ac. africana* and *M. allisonensis* are common among a rich acarininid-morozovellids assemblage with subordinate subbotinids, but these excursion taxa become smaller in the middle part of the bed (level DG1 5.0 m), then decrease in number of individuals until becoming entirely absent in the uppermost part of the bed (level DG1 5.5m). A gradual increase in the content of subbotinids occurs in this bed (from 2.0% at level DG1 4.75 m to 11.7% at level DG1 5.5 m). The benthic foraminifera reappear at the base of this bed (level DG1 4.75), but exhibit a very low diversity (mainly represented by *Siphogerinoides* sp. and *Lenticulina* spp. They are gradually increasing in both number of individuals and species until becoming common at top (level DG1 5.5 m). Ornamented ostracodes are also common. The (sub)tropical members of the *M. velascoensis* group constitute 70-75% of the total morozovellids in this bed (levels DG1 4.75 m- 5.25 m) decreasing to 56-61% at top (level DG1 5.5 m).

Bed 5 of the DQM reflects the progressive return to oxygenated conditions leading to the highly unusual planktonic microfossil assemblages, in which the ratio between various groups of planktonic foraminifera (among morozovellids, acarininids, subbotinids) return to values seen in immediately older (pre-PETM) assemblages of the El Hanadi Member. Evidence for marked fluctuations in sea level during the deposition of Bed 5 is indicated by the temporal decrease in abundance of faunas and size of both planktonic and benthic foraminifera at level DG1 5.0 m, but the faunal composition and pattern still reflects the intense warming of the PETM.

The upper limit of Bed 5 is not exposed in section DG1, but biostratigraphic correlation with comparable beds in section DG3 (see below) would suggest the placement of the top the PETM interval at or near the top of this bed (level DG1 5.5 m). Thus, Bed 5 in section DG1 should be considered equivalent to the lower (PETM) part of Bed 5 in the DBH section at Dababiya, corresponding to Bed 5a of Ouda et al. (2013) in the Dababiya Corehole.

3.2 Section DG2 (Fig.5)

3.2.1 The El Hanadi Member (Upper Paleocene, Biozone P5 of Berggren and Pearson, 2005):

This member is ~80 cm thick (from level DG2 0.0 m to level DG2 0.8 m). The base of this member is unexposed whereas the contact with the overlying DQM is seen at 0.8 m. The lower part of this member (levels DG2 0.0 m- DG2 0.35 m) contains common *M. velascoensis, M. acuta, M. apanthesma, M. subbotinae, M.aequa, Ac.*

soldadoensis and *S. velascoensis,* together with rare *M. gracilis, M. pasionensis, Ac. esnaensis, Ac.angulosa, Ac. primitiva, Gl. ovalis, Gl. imitata* and *Gl. chapmani.* This association belongs to Biozone P5. It does not occur below level 2.75 m in section DG1 (Fig.5). The middle part of this member (levels DG2 0.45 m- 0.55 m) is sparsely fossiliferous with dispersed subbotinids, *M. velascoensis* and *M. gracilis* as well as few poorly preserved benthic foraminifera. The uppermost part of the member (levels DG2 0.65 m- 0.75 m) is highly fossiliferous and contains a rich planktonic and benthic foraminiferal assemblage. The planktonic foraminiferal taxa include *M. subbotinae, M. gracilis, M. velascoensis, M. aequa, Gl. chapmani, Ac. soladodoensis, Ac. primitiva, S. velascoensis Ac. esnaensis,* listed here in order of decreasing abundance. M. gracilis, *Ac. wilcoxensis, Ac. esnaensis, Gl. imitata, Ac. angulosa and Gl. planoconica* exhibit a maximum abundance at the top level of this member (DG2 0.75 m) meanwhile *M. apanthesma* is still represented by rare, well-developed specimens at the same level. This would suggest correlation of the top of the El Hanadi Member in section DG2 with level 3.6 m in section DG1 (3.1.1).

3.2.2 The Dababiya Quarry Member (Lower Eocene, Biozone E1 of Berggren and Pearson, 2005):

This member is ~70 cm thick (from level DG2 0.8 m to level DG2 1.5 m). Only Dababiya Quarry Beds 1-3 are represented at Darb Gaga 2. The lithology and foraminiferal content of these beds have been critically investigated using high sampling resolution and the results can be summarized as follow:

3.2.2.1 Dababiya Quarry Bed 1

This bed has the same thickness (7 cm thick, from level DG2 0.8 m to level 0.87 m) and lithology as bed 1 in section DG1 (3.1.2.1) It is a low-calcium shale rich in organic matter, fish remains and with dispersed glauconite. The basal part of the bed (level DG2 0.8 m) contains few specimens of *Ac. sibaiyaensis* of medium to large size together with subordinate *M. allisonensis and* rare acarininids, subbotinids and globanomalinids. Benthic foraminifera are very rare and only sporadic at base where they include very few species of the pre-PETM Midway faunas. .However, 5 cm above, in the upper part of the bed (level DG2 0.85 m) *Ac. sibaiyaensis* is relatively common and associated with *Ac. africana* whereas benthic foraminifera are almost absent. The faunal composition in these levels mirrors those of level 3.9 m in section DG1 (Fig.4), although slightly enriched taxonomically and less affected by carbonate dissolution

3.2.2.2 Dababiya Quarry Bed 2

This bed is ~38 cm thick (from level DG2 0.87 m to level DG2 1.25 m). It is a coprolite-bearing, highly fossiliferous shale with abundant mature excursion planktonic foraminifera (*Ac. sibaiyaensis, Ac. africana and M. allisonensis*) together with fish remains but with no other significant planktonic foraminifera particularly subbotinids or benthic foraminifera. Both the lithology and faunal content of this bed mirror that of Bed 2 in section DG1 (levels DG1 3.93 m, 4.07 m) (3.1.2.2).

3.2.2.3 Dababiya Quarry Bed 3

This bed is 25 cm thick (from level DG2 1.25 m to level DG2 1.5 m, top level). It is a highly calcareous, coprolite-rich shale which shows a progressive increase in the content of the acarininid (mainly *Ac. sibaiyaensis*) upwards accompanied by a marked decrease in coprolite content. Neither subbotinids nor benthic foraminifera occur in this bed, but common *Globanomalina*. spp., as in the levels 4.15 m and 4.25 m in section DG1 (3.1.2.3).

3.3 Section DG3 (Fig.5)

3.3.1 The Dababiya Quarry Member (Lower Eocene, Biozone E1 of Berggren and Pearson, 2005)

This member is ~1.7 m thick (from level DG3 0.0 m to level DG3 1.7 m). Only Dababiya Quarry Beds by beds 3-5 are represented in section DG3. Representative samples have been collected from these beds in order to compare them with those of section DG1. Their lithology and foraminiferal content are summarized as follow:

3.3.1.1 Dababiya Quarry Bed 3

This bed is 20 cm thick (from level DG3 0.0 m to level DG3 0.2 m). It is a highly fossiliferous, coprolite-rich shale containing common acarininids of which *Ac. sibaiyaensis, Ac. africana*, *M. allisonensis together with Globanomalina* spp. are the main components. Morozovellids are very rare and occurring only sporadically. Neither subbotinids nor benthic foraminifera were recorded. The foraminiferal content of this bed mirrors those of levels 4.15m -4.25m in section DG1(3.1.2.3) and levels 1.25 m -1.5 m in section DG2 (3.2.2.3).

3.3.1.2 Dababiya Quarry Bed 4

This bed is 30 cm thick (from level DG3 0.2 m to level DG3 0.5 m). It is a marl with minute dispersed coprolites, very highly fossiliferous and containing a rich association of *Ac. sibaiyaensis*, *Ac. africana*, *M. allisonensis*, together with *Gl.* spp, among other acarininids and subordinate *M. velascoensis* and *M. acuta.* Subbotinids are still absent. The benthic foraminifera are mainly represented by small and dispersed *Siphogenerinoides* sp. The faunal content of this bed is also that of level 4.5m in section DG1 (3.1.2.4)

3.3.1.3 Dababiya Quarry Bed 5

This bed is about 1.2 m thick (from level DG3 0.5 m to level DG3 1.7 m). The lower part of the bed is a calcarenite, full of planktonic foraminifera containing very abundant acarininids and morozovellids together with subordinate subbotinids. It is 80 cm thick (from level DG3 0.5 m to level DG3 1.3 m) and contains rich excursion taxa (*Ac. sibaiyaensis, Ac. africana and M. allisonensis*) together with sub(tropical) morozovellids (e.g. *M. velascoensis, M. acuta).* Temperate morozovellids *(e.g. M. subbotinae, M. gracilis)* are also common but not as much as the sub(tropical) ones. The benthic foraminifera reappear in this calcarenite part, but they still very limited in diversity and mainly represented by *Siphogerinoides* sp*.* and *Lenticulina* spp. Ornamented ostracodes are also common.

The foraminiferal content of this calcarenitie part of Bed 5 mirrors those of levels 4.75 m- 5.5 m in section DG1(3.1.2.5). They are correlative with the lower (PETM) part of

Bed 5 of the DQM at Dababiya (Berggren and Ouda, 2003a = Bed 5a of Ouda et al., 2013).

The upper part of Bed 5 consists of unfossiliferous limestone changing upward into poorly fossiliferous limestone containing badly preserved planktonic and benthic foraminifera. It is 40 cm thick (from level DG3 1.3 m to level DG3 1.7 m). This limestone corresponds to the upper (post PETM) part of Bed 5 of the DQM at Dababiya (Berggren and Ouda, 2003a = Bed 5b of Ouda et al., 2013). Its top coincides with the lithological boundary between The Dababiya Quarry and El Mahmiya Members, whereas its base is more or less coincident with the top of the PETM, corresponding to the Bed 5a/5b lithological boundary in the Dababiya Corehole (Ouda et al., 2013).

3.3.2 The El Mahmiya Member (Lower Eocene, Biozone E2 of Berggren and Pearson, 2005)

This member is ~ 8.0 m thick (from level DG3 1.8 m to level DG3 9.8 m). The top of the member is uncovered at Darb Gaga. The member consists of gray fossiliferous shale intercalated with clays and hard yellowish marly shale, sometimes enclosing thin unfossiliferous flinty limestone (Fig.5). The foraminiferal content in the fossiliferous beds is marked by the abundance of *Ps. wilcoxensis* together with *Gl. luxorensis* and *Gl. chapmani*. The morozovellids are either subordinate (level DG3 2.9 m) or common to frequent and composed mainly of the sub(tropical) members *M. velascoensis* and *M. acuta* (level DG3 5.0 m). The subbotinids also fluctuates from rare (level DG3 5.0 m) to abundant and more diversified *(Subbotina patagonica, S. velascoensis, S. triangularis,* level DG3 2.9 m*)*. Benthic foraminifera are either absent (level DG3 5.0 m) or common and highly diversified although do not exhibit their pre PETM frequency. They include *Bulimina* sp., *Globobulimina* sp*., Praeglobobulimina quadrata, Siphogenerinoides* sp., *Cibicidoides* sp. and *Valvulineria* sp.

The upper part of this member (from level DG3 7.0 m to level DG3 9.8 m) is composed of intercalations of fossiliferous clays and unfossiliferous limestone. The fossiliferous horizons (levels DG3 7.0m, 9.5m and 9.6m) contain a rich planktonic foraminiferal assemblage including acarininids, subbotinids and *Ps. wilcoxensis*. The acarininids comprise *Acarinina angulosa, Ac.esnaensis*, *Ac. pseudotopilensis, Ac. soldadoensis* and *Ac. wilcoxensis*. The morozovellids, on the other hand, are generally subordinate and include *M. subbotinae, M. gracilis, M. acuta, M. aequa, M. occlusa* and *M. velascoensis.* Other planktonic foraminifera include *Igorina broedermanni, Gl. planoconica* and *Gl. pseudoimitata.* The benthic foraminifera are generally rare at these levels and they occur only sporadically such as minute specimens of *Siphogenerinoides* sp. Large ostracodes, on the other hand, are common.

The foraminiferal content leads to the assignment of this member to Biozone E2 which covers the stratigraphic interval from the LO of *Ps. wilcoxensis* (more or less synchronous with the HO of *Ac. sibaiyaensis*) to the HO of *M. velascoensis*. No sampling was taken above level 9.8 m.

The El Mahmiya member at Darb Gaga differs from that exposed along the southern Nile Valley (Aubry et al., 2007; Ouda et al., 2013) in being more calcareous and containing several unfossiliferous horizons of limestone. It is also marked by bathymetric fluctuation , variable climatic conditions and variations in the oxygen content of bottom waters, from warm moderate to deep temperate and from fairly oxygenated to very low-oxygenated bottom water masses. This is indicated by the fluctuation in the content of the bottom dwellers (benthic foraminifera), the deep dwellers (subbotinids), the sub(tropical)/temperate ratio of morozovellids, and the morozovellids/total planktonic foraminiferal ratio.

4 The Paleocene/Eocene Boundary at Darb Gaga

The stratigraphic horizon that denotes the base of the Eocene at Darb Gaga is the base of the Dababiya Quarry Member and is marked by a low-carbonate shale, 7-8 cm thick (Fig.5). This horizon yielded exclusively fish remains among which dispersed, excursion foraminifera (*Ac. sibaiyaensis, M. allisonensis*) were recorded together with a poor foraminiferal association including small acarininids , morozovellids (mainly *M. acuta*) and globanomalinids. The subbotinids are very rare and only sporadic. Very few deformed benthic foraminiferal specimens were recovered in the coarse-grained residual fraction in section DG1 (3.1.2.1) among which the oldest *Nummulites* sp. and *Discocyclina* sp. were found. The faunal content strongly supports the placement of the base of P/E boundary (Base Biozone E1) at the base of Bed 1 of the DQM at Darb Gaga.

The lithology and faunal content of this bed being almost/virtually identical to those in the uppermost horizons of Dababiya Quarry Bed 1 in the DBH section at Dababiya Village (Berggren and Ouda,.2003a; Dupuis et al., 2003; Aubry et al. 2007, Fig.6) although at the latter locality no *Nummulites* have been recorded below the Abu Had Member (upper part of the Esna Shale).

Berggren et al. (2003) recorded dimorphic larger foraminifera (*Discocyclina*, *Operculina*, primitive *Nummulites*) at the top of the inferred PETM-interval at a stratigraphic level equivalent to E1/E2 zonal boundary which coincides with the Garra/Dungul formational contact at Wadi Abu Ghurra in the southern upper Nile Valley. Upper Paleocene- Lower Eocene stratigraphic section exposed there represents a neritic/shelf carbonate setting. Based on our observations at Darb Gaga we can now state unequivocally that the oldest known *Nummulites* sp. occur at the base of the PETM interval (not at the top) i.e. at the base of Bed 1 of the DQM which is at the base of Biozone E1. The coexistence of older *Nummulites* sp. and *Ac. sibaiyaensis* at the same level in Bed 1 at Darb Gaga indicates that both dimorphic larger foraminifera and excursion faunas (particularly *Ac. sibaiyaensis*) appeared at the onset of the PETM interval. Orue-Etxebarria et al. (2001) pointed out that the larger foraminiferal turnover (LFT) which marks the base of the Ilerdian stage may be related to the PETM or be at least coeval with that climatic event. They postulated a synchrony or near synchrony between the LFT in shallow water carbonate successions, benthic foraminiferal extinction event (BFEE) in the bathyal and abyssal realms and carbon isotope excursion (CIE); all of them probably related to the PETM. Thus, the impact of the PETM seems to have been greater than previously thought, having also affected biota in shallow water carbonate successions of the Tethys domain.

5 Discussion and Conclusions

Our planktonic foraminiferal investigation of the Dababiya Quarry Member at Darb Gaga which reflects the unfolding of the sedimentary and biotic events associated with the PETM global warming has revealed the following succession of events:

1: Relative marine restriction around neritic carbonate shelf associated with oxygen deficiency during the early phase of the PETM through rapid and intense warming of bottom waters have resulted in the disappearance of both mature planktonic and smaller benthic foraminiferal faunas. However, the presence of lime (as precipitated carbonates) made it possible for dwarfing of shallow dwelling excursion foraminifera and the survival of some dimorphic larger benthic foraminifera (eg. *Nummulites*) which thrive on shallow carbonate shelf. This phase, which yields rich fish remains corresponds to the Dababiya Quarry Bed 1, the oldest known Eocene rock unit in southern Egypt.

The base of Bed 1 corresponds to a sharp decrease in the values of the CIE curve at Dababiya (Dupuis et al., 2003; Aubry et al. 2007, Fig.6). There the maximum negative shift of the CIE curve occurs at the top of this bed and continues upward in constant values to within bed 3 before increasing gradually until pre PETM values are reached near the top of Bed 5 (top of the DQM). At Darb Gaga, southern Western Desert, the Dababiya Quarry Bed 1 differs from that of Dababiya in being much reduced in thickness (7-8cm thick versus 70 cm thick at Dababiya), by having a noticeable content of calcium carbonate and in containing dispersed *Ac. sibaiyaensis* and *M. allisonensis* together with small-sized *M. acuta and* without smaller benthic foraminifera. A similar case was recorded in the Dababiya Corehole (Ouda et al. 2013) which is located 200 m east of the Dababiya GSSP (DBH section) where the Dababiya Quarry Bed 1 shows a marked reduction in thickness of 17cm thick. This reduction as well as that of the overlying Beds

2 and 3 in Darb Gaga may simply have resulted from the action of bottom currents winnowing away some of the sediments.

2: The second phase of the warming episode produced a reducing environment marked by a continuous supply of coprolites and the deposition of carbonate-bearing, apatite–rich sediments which are, in part, highly fossiliferous and exhibit no evidence of $CaCO_3$ dissolution. This coprolite–bearing phase spans 57-63 cm at Darb Gaga and corresponds to Beds 2 and 3 of the DQM. Its stratigraphic record begins with highly fossiliferous, coprolite-bearing shale passing upward into poorly fossiliferous marly shale containing abundant coprolites.

The beginning of this phase is marked by the preponderance of mature specimens of *Ac. sibaiyaensis*, *Ac. africana*, and *M. allisonensis* without benthic or other stratigraphically significant planktonic foraminifera, so that it constitutes a true acme "zonule" corresponding to the Dababiya Quarry Bed 2 at Dababiya (Plate !). This is where, at Dababiya the CIE values attain their maximum negative shift (Fig. 6) . Bed 2 is 22-38 cm thick in Darb Gaga sections (DG1 and DG2) where it is overlain by a highly calcareous to marly shale bed, 25-35 cm thick (Bed 3) containing variable amounts of coprolites but with a lesser content of planktonic foraminifera than in the underlying beds. Excursion foraminifera are present in Bed 3 but they are generally small and commonly associated with other subordinate acarininids while morozovellids and subbotinids are absent. Minute rare specimens of *Siphogenerinoides* sp. and *Bulimina* sp. have also been found in the upper part of this bed. The faunal content of Bed 3 reflects strongly reduced/low oxygen conditions as suggested by the occurrence of excursion warmth-tolerant excursion faunas, the general impoverishment in shallow dwelling faunas (normal morozovellids and acarininds) and the entire absence of deep dwelling faunas (subbotinids) and bottom living forms (benthic foraminifera).

3: The younger phase of the PETM resulted in a weakly oxidizing, non-corrosive environment. Its stratigraphic record is marked by a progressive enrichment in the fossil content, corresponding to a continuous increase in the carbonate content and concomitant decrease in the coprolite content, passing upward into detrital calcarenite in which the lime fraction consists exclusively of foraminiferal tests.

The beginning of this phase at Darb Gaga is marked by an increase in abundance and diversity among the planktonic foraminifera The faunas are mainly represented by the excursion taxa (*Ac. sibaiyaensis, Ac, africana , M. allisonensis*) together with other acarininids and subordinate morozovellids. No subbotinids or benthic foraminifera were recorded at this level, except for a few deformed specimens of ostracodes. The foraminiferal content suggests correlation of this level to a level within Bed 4 of the DQM at Dababiya. It reflects weekly oxygenated surface waters but reducing conditions (with no oxygen) still predominated in the “intermediate” and deep waters as suggested by the absence of deep dwelling planktonic (subbotinids) and bottom dwelling foraminifera (benthic foraminifera).

Both abundance and diversity of planktonic foraminifera reach a maximum in the overlying calcarenite bed (bed 5) which is of similar thickness (75cm-80cm thick) in sections DG1 and DG3. This bed is marked by the reappearance of normal benthic foraminiferal assemblages, an increase of calcium carbonate content and the virtual absence of coprolites. The planktonic foraminifera (~95%) consist mainly of acarininids and morozovellids while subbotinids and benthic foraminifera are generally subordinate. The acarininids and morozovellids show a gradual decrease in relative frequency upward, whereas the subbotinids increase in abundance. The acarininids include *Ac. sibaiyaensis* and *Ac*. *africana* together with abundant pre-PETM species, particularly species with LOs slightly or immediately below the PETM-interval (*Ac. angulosa, Ac, esnaensis, Ac, wilcoxensis*). The morozovellids are comprised of members of both (sub)tropical *M. velascoensis* group and intermediate *M. subbotinae* group. *Morozovella allisonensis* is well represented and typical compared to those recorded in other Egyptian sections in the southern Nile Valley. The benthic foraminifera (~5%) are of low diversity and include a very low number of species of the “Midway”-type fauna belonging to the genera *Siphogenerinoides*, *Bulimina* and *Lenticulina* together with ornamented ostracodes. The faunal content indicates that this bed is equivalent to the lower (PETM) part of Bed 5 (Dupuis et al., 2003; Ouda and Berggren, 2003; Aubry et al. 2007), which was redefined as Bed 5a by Ouda et al. (2013) in the Dababiya Corehole.

No beds younger than Bed 5a are exposed in section DG1 (3.1.2.5). However in section DG3 (3.3.1.3) Bed 5a is overlain by an unfossiliferous limestone bed, 40 cm thick, equivalent to Bed 5b at Dababiya. The Top of this limestone coincides with the lithological boundary between the DQM and the El Mahmiya Member, whereas its base is more or less coincident with the top of the PETM, corresponding to the Bed 5a/5b lithological boundary at Dababiya (Ouda et al.2013).

The LO of *Peudohastigerina wilcoxensis* is located a very short stratigraphic interval above the base of the Mahmiya Member. Between the HO of *Ac. sibaiyaensis* and the LO of *Ps. wilcoxensis* it is difficult to locate the E1/E2 Zonal boundary due to the unfossiliferous nature of Bed 5b. At Dababiya, southern Nile Valley the LO of *Ps. wilcoxensis* is immediately or a very short stratigraphic interval above the HO of *Ac. sibaiyaensis* and other excursion planktonic foraminifera (Berggren and Ouda, 2003a, Ouda et al., 2013). Thus, the E1/E2 Zonal boundary at Darb Gaga should be provisionally placed along the lithological boundary between the DQM and the overlying Mahmiya Member as exemplified in section DG3. .

The upper levels of the El Mahmiya Member at Darb Gaga are marked by a general impoverishment of subbotinids and benthic foraminifera while acarininids and sub(tropical) morozovellids are common together with frequent *Ps. wilcoxensis*. This would suggest the re-establishment of warm environmental conditions, with a low content of dissolved oxygen in the "intermediate" and deep waters during a part of age of Biozone E2, but not as warm as during Biozone E1.

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Figure Captions

Fig.1 : SRTM Topographic Map of Egypt showing the location of Darb Gaga with respect to the GSSP of the P/E boundary at Dababiya

Fig.2: Lithology and calcium carbonate content throughout the Upper Paleocene-Lower Eocene succession at Darb Gaga, Section DG1, Southeastern Kharga Oasis, Western Desert, Egypt.

Fig.3: Lithology, biozones and characteristic bioevents of the Upper Paleocene-Lower Eocene succession at Darb Gaga, section DG1 Southeastern Kharga Oasis, Western Desert, Egypt.

Fig.4: Stratigraphic distribution of biostratigraphically important planktonic foraminifera in the Upper Paleocene-Lower Eocene succession at Darb Gaga, Section DG1, Southeastern Kharga Oasis, Western Desert, Egypt.

Fig.5: Litho- and biostratigraphy as well as characteristic bioevents of the Paleocene/Eocene boundary interval in different sections (DG1, DG2 and DG3) at Darb Gaga, Southeastern Kharga Oasis, Western Desert, Egypt

Fig.6 : Biostratigraphic correlation of the P/E boundary interval between the DBH section (the GSSP of the P/E boundary at Dababiya), South Luxor, Southern Nile Valley (Berggren and Ouda,2003a; Dupuis et al. 2003; Aubry et al, 2007), and the Darb Gaga (composite) section, Southeastern Kharga. Oasis, Western Desert (present study). Base line is the HO of *Ac. sibaiyaensis* (Top of the Paleocene–Eocene Thermal Maximum (PETM/CIE), equivalent to the top of the Planktonic Foraminiferal Excursion Fauna (PFEF). BFEE: Benthic Foraminifera Extinction Event

Plate 1:

(In all figures scale bar = 100 µm)

Figs.1-4 : *Acarinina africana* (El Naggar, 1966).

1. Umbilical view, level 4.07m., section DG1, Darb Gaga area.
2. Umbilical view, level 4.25m., section DG1, Darb Gaga area.
3. Umbilical view, level 4.15m., section DG1, Darb Gaga area.

4. Dorsal view, level 4.25m., section DG1, Darb Gaga area.

Figs. 5-14: *Acarinina sibaiyaensis* (El Naggar, 1966).

5- Umbilical view, level 4.07m., section DG1, Darb Gaga area.

6- Dorsal view, level 4.07m., section DG1, Darb Gaga area.

7- Umbilical view, level 4.15m., section DG1, Darb Gaga area.

8- Dorsal view, level 4.15m., section DG1, Darb Gaga area.

9- Umbilical view, level 4.25m., section DG1, Darb Gaga area.

10- Dorsal view, level 4.25m., section DG1, Darb Gaga area.

11- Dorsal view, level 4.07m., section DG1, Darb Gaga area.

12- Umbilical view, level 4.25m., section DG1, Darb Gaga area.

13- Umbilical view, level 4.15m., section DG1, Darb Gaga area.

14- Umbilical view, level 4.07m., section DG1, Darb Gaga area.

15- Dorsal view, level 4.25m., section DG1, Darb Gaga area

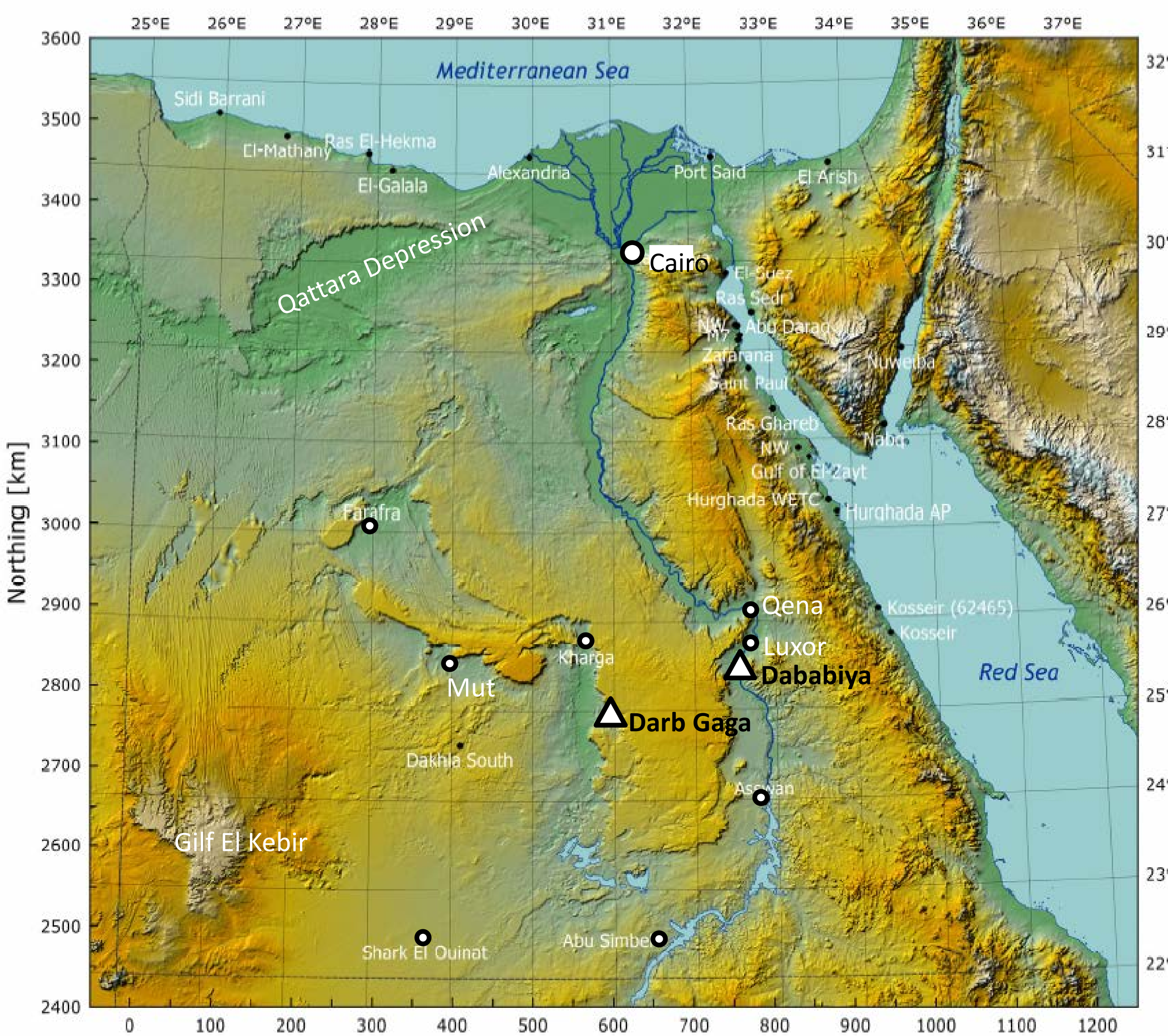

Fig.1: SRTM Topographic Map of Egypt showing the location of Darb Gaga with respect to the GSSP of the P/E boundary at Dababiya

single

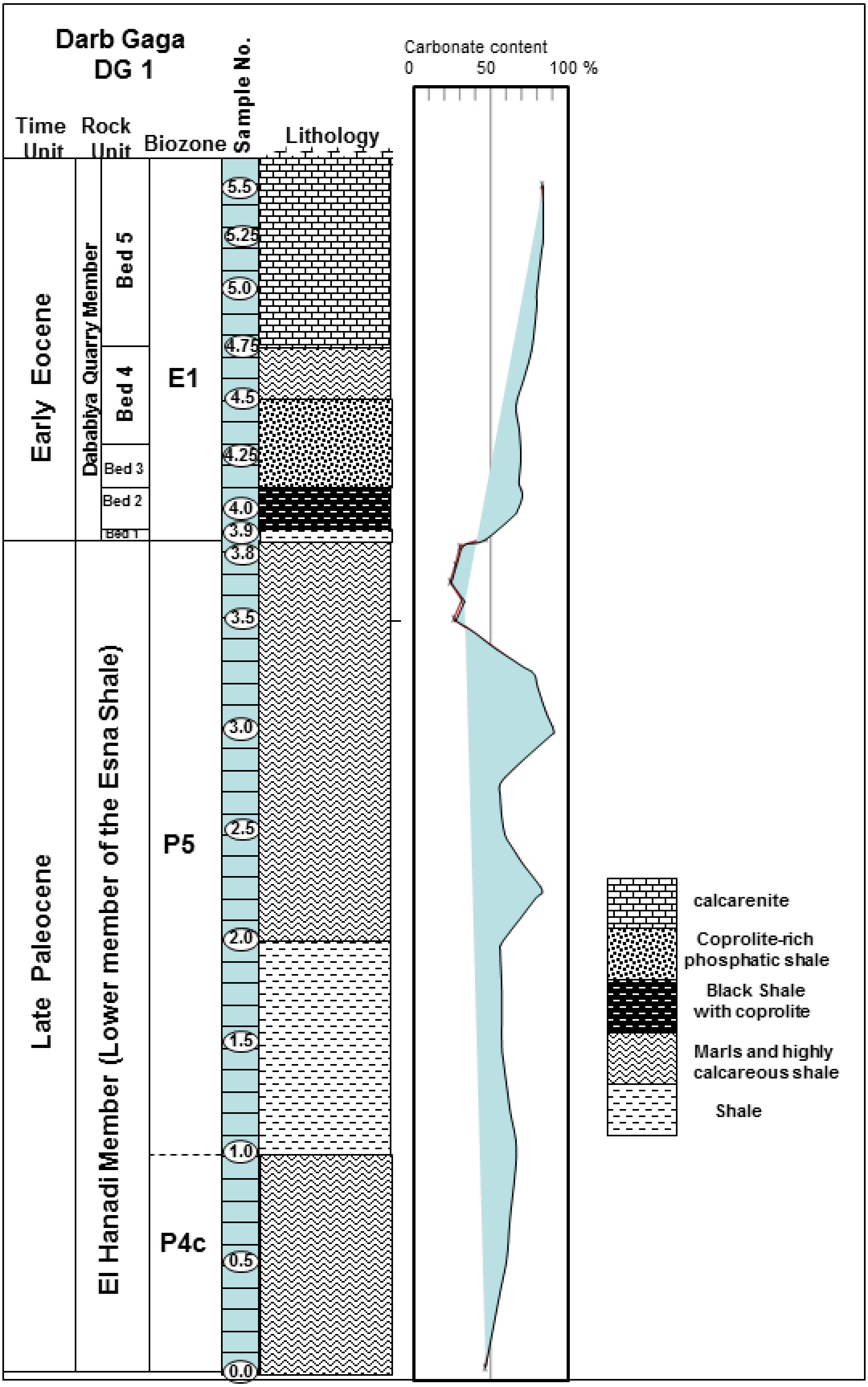

Fig.2: Lithology and calcium carbonate content throughout the Upper Paleocene-Lower Eocene succession at Darb Gaga, Section DG1 ,Southeastern Kharga Oasis, Western Desert

single

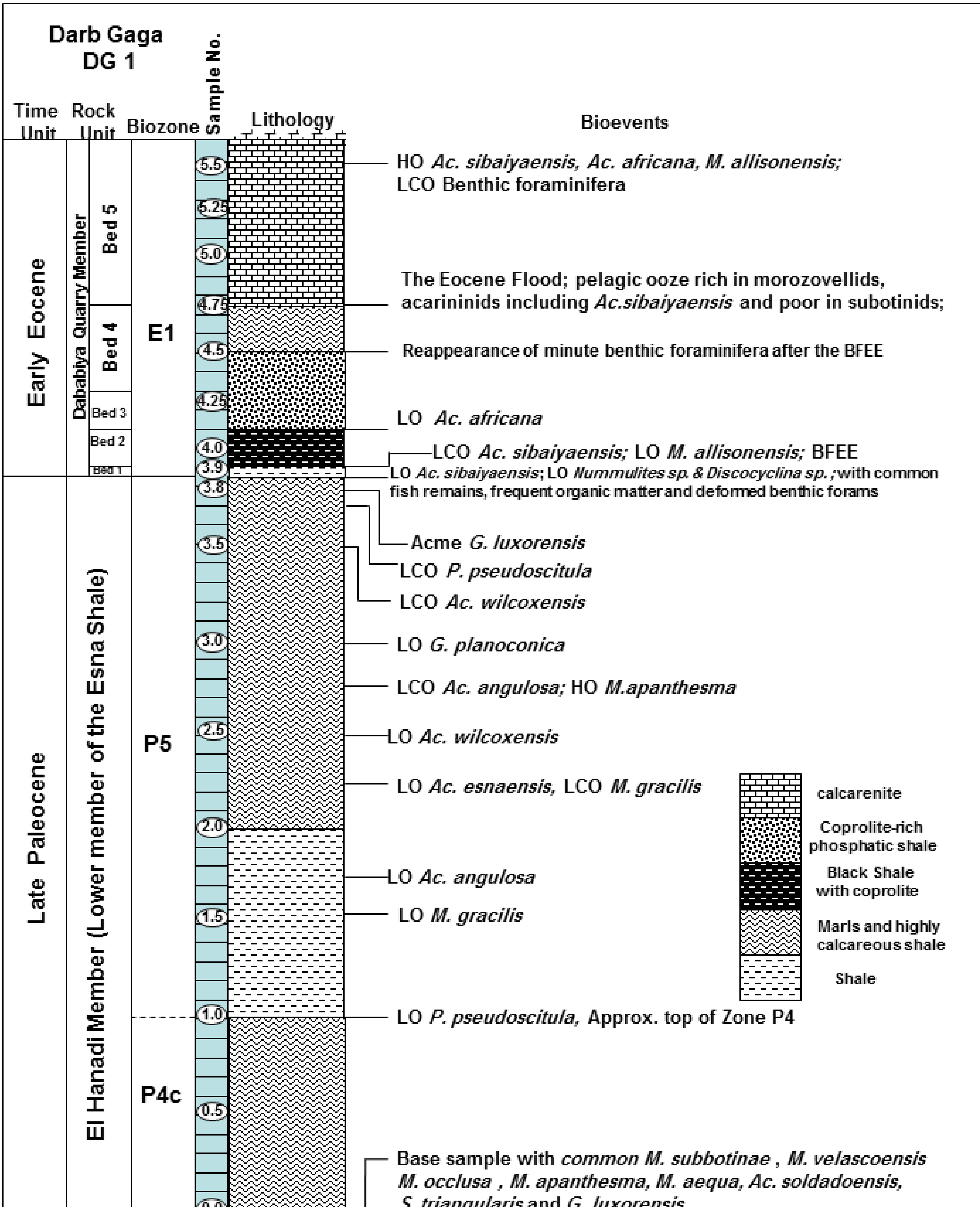

Fig. 3: Lithology, biozones and characteristic bioevents of the Upper Paleocene-Lower Eocene succession at Darb Gaga, Section DG1 ,Southeastern Kharga Oasis, Western Desert

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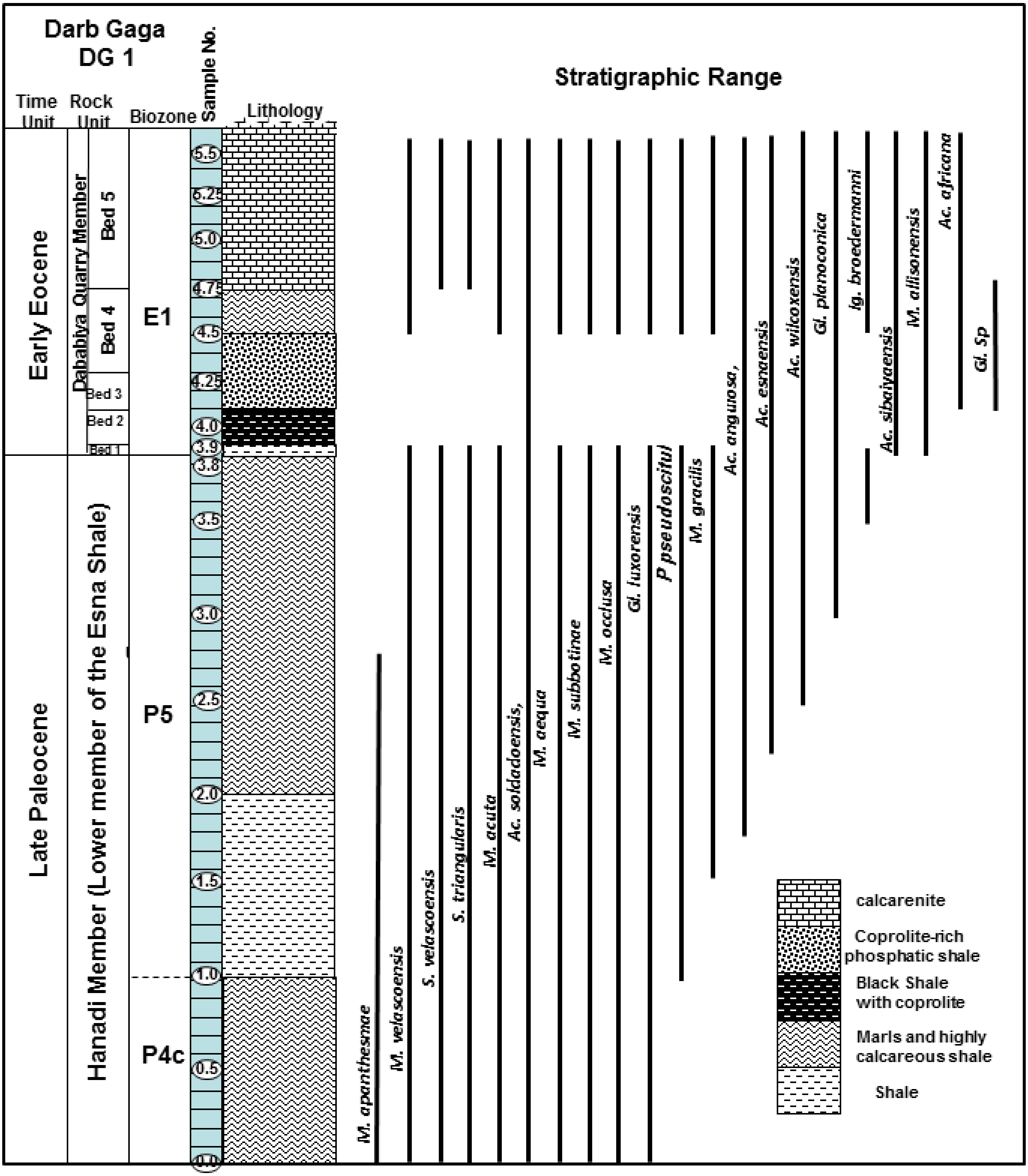

Fig. 4: Stratigraphic distribution of biostratigraphically important planktonic foraminifera in the Upper Paleocene-Lower Eocene succession at Darb Gaga, Section DG1,Southeastern Kharga Oasis, Western Desert

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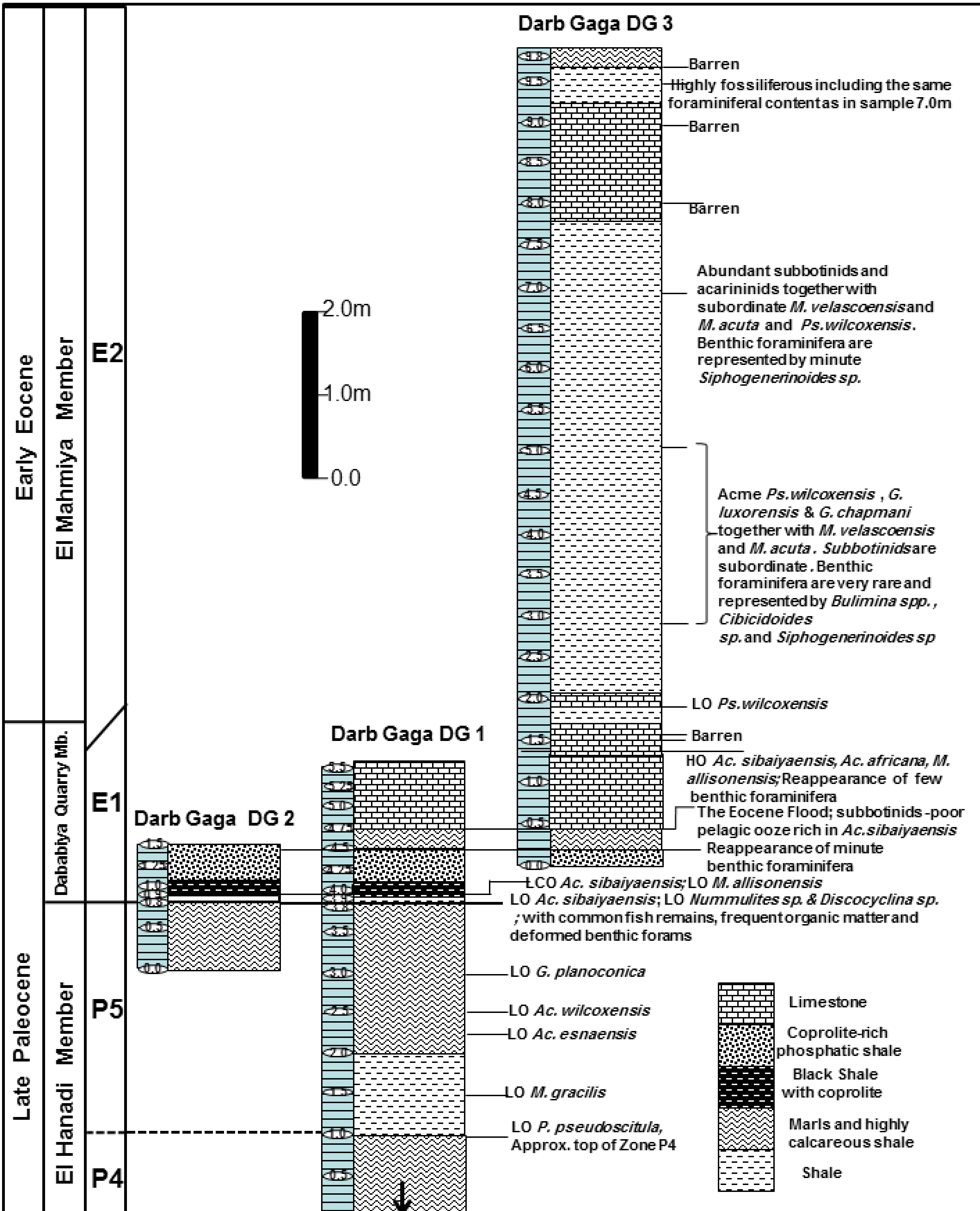

Fig. 5: Litho- and biostratigraphy as well as characteristic bioevents of the Paleocene/Eocene boundary interval in different sections (DG1, DG2 and DG3) at Darb Gaga, Southeastern Kharga Oasis, Western Desert

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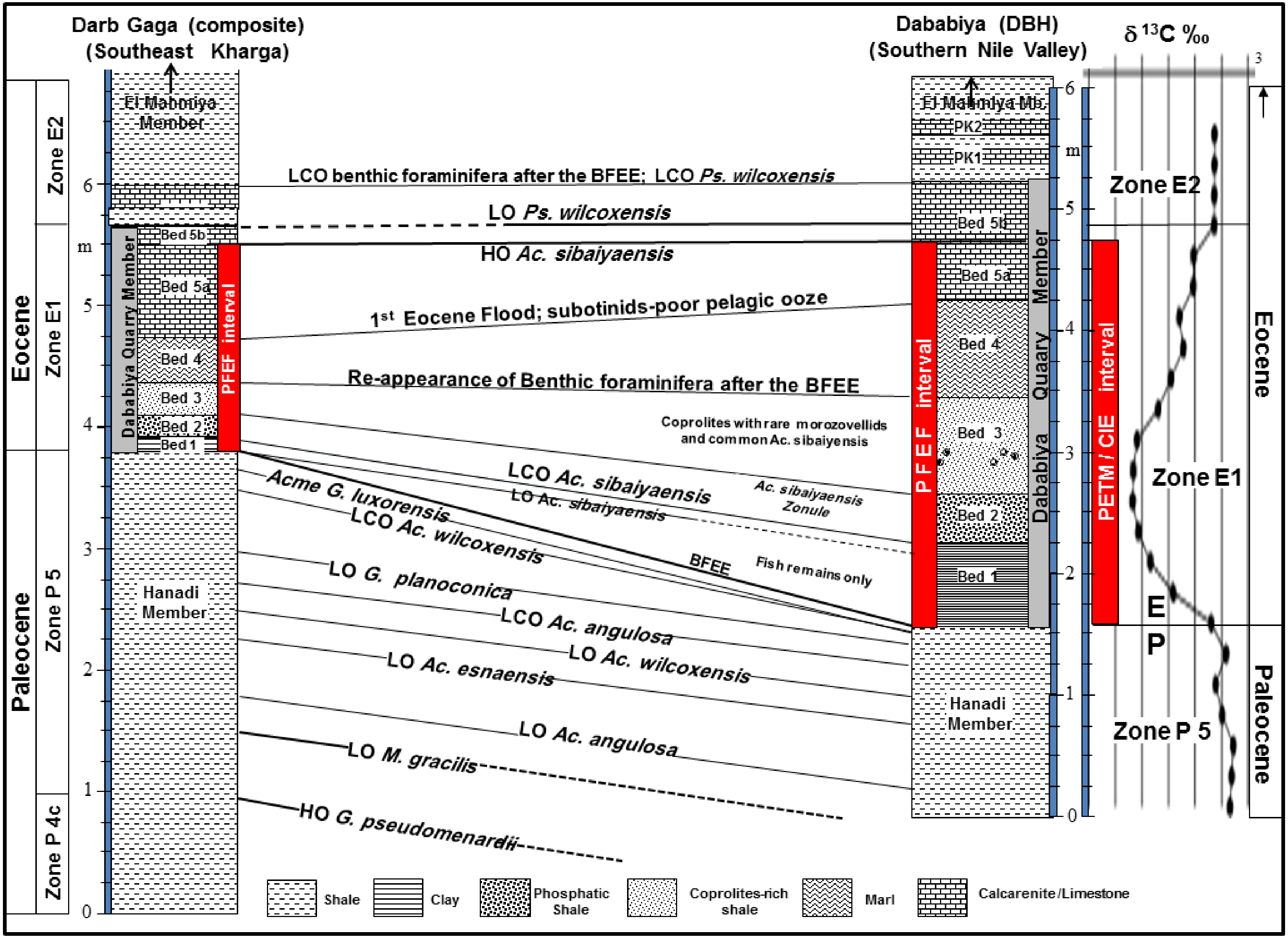


Fig.6 : Biostratigraphic correlation of the P/E boundary interval between the DBH section (the GSSP of the P/E boundary at Dababiya), South Luxor, Southern Nile Valley (Berggren and Ouda,2003a; Dupuis et al. 2003; Aubry et al, 2007), and the Darb Gaga (composite) section, Southeastern Kharga. Oasis, Western Desert (present study). Base line is the HO of Ac. sibaiyaensis (Top of the Paleocene–Eocene Thermal Maximum (PETM/CIE), equivalent to the top of the Planktonic Foraminiferal Excursion Fauna (PFEF). BFEE: Benthic Foraminifera Extinction Event

PLATE 1

(In all figures scale bar = 100 µm)

1-4 : *Acarinina africana* (El Naggar, 1966).

1- Umbilical view, sample 4.07m., section DG1, Darb Gaga area.

2- Umbilical view, sample 4.25m., section DG1, Darb Gaga area.

3- Umbilical view, sample 4.15m., section DG1, Darb Gaga area.

4- Dorsal view, sample 4.25m., section DG1, Darb Gaga area.

5-14: *Acarinina sibaiyaensis* (El Naggar, 1966).

5- Umbilical view, sample 4.07m., section DG1, Darb Gaga area.

6- Dorsal view, sample 4.07m., section DG1, Darb Gaga area.

7- Umbilical view, sample 4.15m., section DG1, Darb Gaga area.

8- Dorsal view, sample 4.15m., section DG1, Darb Gaga area.

9- Umbilical view, sample 4.25m., section DG1, Darb Gaga area.

10- Dorsal view, sample 4.25m., section DG1, Darb Gaga area.

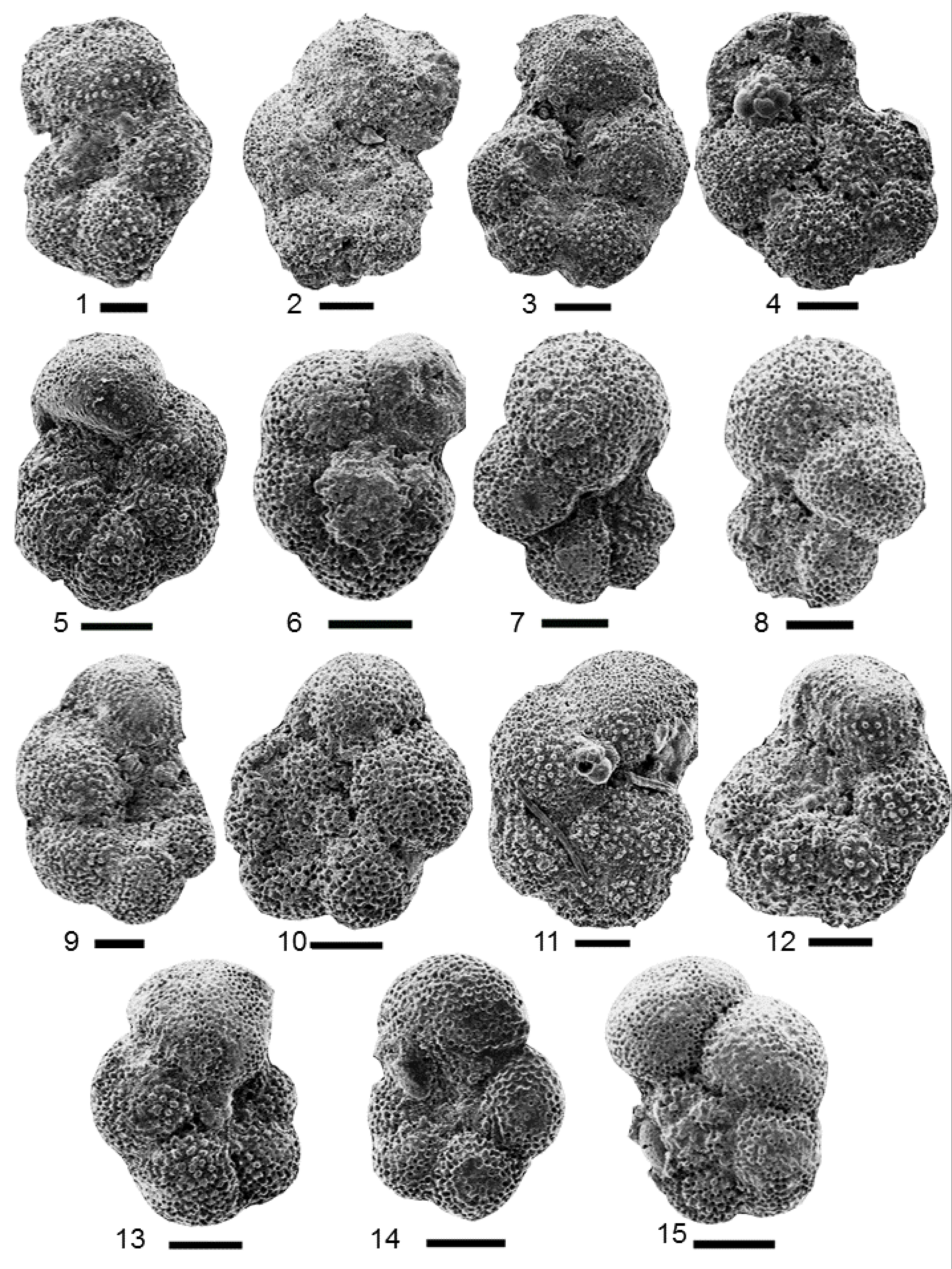
11- Dorsal view, sample 4.07m., section DG1, Darb Gaga area.

12- Umbilical view, sample 4.25m., section DG1, Darb Gaga area.

13- Umbilical view, sample 4.15m., section DG1, Darb Gaga area.

14- Umbilical view, sample 4.07m., section DG1, Darb Gaga area.

15- Dorsal view, sample 4.25m., section DG1, Darb Gaga area.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