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Recalibration of the Tethyan shallow-benthic zonation across the Paleocene-Eocene boundary: the Egyptian record

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⊣ ABSTRACT ⊢

The Galala Mountains in Egypt provide an excellent platform-basin transect with deposits spanning the Paleocene/Eocene (P/E) boundary. These interfingering deposits enable a recalibration between platform and open marine biostratigraphic schemes. We investigated 18 sections from a shallow-water carbonate platform margin, dominated by larger benthic foraminifera, to basinal marls with pelagic and deep marine biota. The Late Paleocene to Early Eocene development of larger foraminifera is well recorded in the Galala transect, in particular the Tethyan evolutionary event known as the larger foraminifera turnover (LFT). This turnover distinguishes Paleocene assemblages dominated by glomalveolinids, miscellanids and ranikothalids typical for shallow benthic Zone 4 (SBZ4) from those of SBZ5, dominated by alveolinids, nummulitids, and orbitolitids. Our data agree with previous studies that suggested that the larger foraminifera turnover (LFT) coincides with the Paleocene/Eocene boundary, delineated by the carbon isotopic excursion (CIE) and that it correlates with the boundary between calcareous nannofossils subzones NP9a/b, the benthic extinction event in smaller benthic foraminifera and the boundary between planktic foraminifera Biozones P5/E1.

KEYWORDS | Paleocene. Eocene. Shallow-benthic zonation. Stratigraphy.

INTRODUCTION

Larger foraminifera are widely used as guide fossils in shallow carbonate platform sequences of various parts of the Phanerozoic. Fusulinids are adopted in Permo-Carboniferous sediments, orbitolinids in Cretaceous platform systems and a variety of larger foraminiferal groups in Cenozoic sequences (Forke, 2002; Schroeder and Neumann, 1985). Calibration of larger foraminiferal zonations to the more widely used pelagic zonation schemes (planktic foraminifera, calcareous nannofos-

sils) is generally a difficult task since these organisms generally occupy disparate habitats. Yet, calibration between these zonation schemes is of prime importance in order to evaluate the timing of ecosystem perturbations and revolutions. The Paleocene/Eocene (P/E) transition represents one of those intervals for which a reliable calibration between platform and pelagic zonations is needed. Serra-Kiel et al. (1998) proposed a correlation scheme of platform and pelagic sequences for the Paleocene-Eocene Tethys. This scheme is mainly based on the extensive works on alveolinids and nummulitids by

Hottinger (1960) and Schaub (1981). During the 1990's, the stratigraphy of the P/E boundary was intensively discussed and a global boundary stratotype section and point (GSSP) and a boundary criterion had yet to be established. During that time it was common practice to indicate a P/E boundary interval in anticipation of a formal decision on the criteria and position of the P/E boundary (e.g. Berggren et al., 1995). This interval covered most of planktic foraminifera Biozone P5, the upper part to lowermost part of calcareous nannofossil Biozones NP9 and NP10, and shallow-benthic Zones SBZ6 to lower part of SBZ7 (Serra-Kiel et al., 1998). Now, that the GSSP for the basal Eocene has been established in the Dababiya section in the Nile Valley in Egypt (Aubry and Ouda, 2003), there finally is general agreement on the stratigraphic position of the P/E boundary in marine and non-marine sequences: the onset of the carbon isotopic excursion (CIE) associated with the Paleocene/Eocene thermal maximum (PETM) acts as a prime criterion for delineating this boundary in sections around the world.

Detailed investigations of the P/E-boundary interval in pelagic sediments refined the position of the CIE to the boundary between planktic foraminiferal subzones P5a and P5b (Pardo et al., 1999; Speijer et al., 2000) or P5 and E1 (Berggren and Pearson, 2005) and between calcareous nannofossil subzones NP9a and NP9b (Aubry, 1995). In the correlation scheme of Serra-Kiel (1998) this boundary correlates with a level within Biozone P5 and within Biozone NP9 in deep marine successions and between shallow benthic Zones SBZ5 and SBZ6 in platform successions (Fig. 1).

Another important event that occurred within the P/E-boundary interval is the Larger Foraminifera Turnover (LFT after Orue-Etxebarria et al., 2001) that was first described from the Pyrenees by Hottinger and Schaub (1960). The LFT is characterized by the start of adult dimorphism and large shell size in larger foraminifera, especially the nummulitids and alveolinids, and marks the base of the Ilerdian, placed between SBZ4 and SBZ 5 (Hottinger and Schaub, 1960; Hottinger, 1998). The Ilerdian stage was introduced for marine deposits of the Tethyan realm for which no marine time equivalent in northern Europe exists (Hottinger and Schaub, 1960). Hottinger (1998) indicated that the LFT did not seem to correlate with any potential P/E-boundary marker based on planktic or deeper benthic organisms as outlined by Berggren and Aubry (1998). For practical reasons he proposed the base of the Ilerdian, the boundary between SBZ4 and SBZ5, as the P/E boundary in platform deposits, as this boundary can be easily recognized in the field by "hand lens" (Hottinger, 1998). Recently the Campo section and other platform to basin sections in Spain were re-examined by Orue-Etxebarria et al. (2001) and Pujalte et al. (2003) and synchronicity of the LFT and the CIE was proposed but the evidence was not unequivocal as the correlation with the calcareous nannofossil scheme is not straightforward. Investigations in Egypt show that the pragmatic placement of the P/E boundary of Hottinger (1998) in the shallow-water domain in fact does correlate with various pelagic and benthic boundary markers after all (Scheibner et al., 2005). It was also demonstrated that the LFT closely correlates with the CIE at the base of the Eocene (Fig. 1; see also Pujalte et al., a, this issue). In turn, this also means that the regional Ilerdian Stage only

	Series	Age			P Zone		NP Zone Martini (1971); Okada and Bukry (1980); Aubry (1995); Aubry et al. (2000)	B Zone Berggren and Miller (1989)	SB Zone		Platform stages
		Berggren et al. (1995/2000)	Serra-Kiel et al.(1998)	Scheibner et al. (2005)	Berggren and Pearson (2005)	Berggren et al. (1995)			Serra-Kiel et al.(1998)	Scheibner et al. (2005)	Scheibner et al. (2005)
LFT PETM CIE	Early Eocene / Ypresian	Ilerdian	Ilerdian	E4	P6b	NP10	d / c — b / a	BB2	SBZ8	SBZ8	
				E3	P6a				SBZ7	SBZ7	? / III
				E2	P5	NP9	b		SBZ6	6 5	
				E1							
				P5			a		SBZ5	SBZ4	II
	Late Paleocene / Thanetian			P4c	P4c			BB1	SBZ4		
				P4b	P4b	NP7/8			SBZ3	SBZ3	I
				P4a		NP6					
	Selandian										

FIGURE 1 | **Paleocene-Eocene correlation of deep- and shallow-water biostratigraphic schemes and platform stages in the Tethyan realm. Our study concerns the interval SBZ3 – SBZ5/6. Note the different position of the basal Ilerdian SBZ5 in the former and present calibration schemes.**

represents the lowermost Eocene and does not straddle the P/E boundary as considered previously (e.g., Serra-Kiel et al., 1998). Accordingly, the base of the Ilerdian Stage correlates with the base of the Ypresian Stage, which represents the Lower Eocene (Gradstein et al., 2004; Pujalte et al., b, this issue). In this context it should be noted that a drawing error occurred in figure 20.2 of the Paleogene chapter by Luterbacher et al. (2004): the P/E boundary was erroneously placed between the Ilerdian and the Cuisian Stages, i.e., between SBZ9 and SBZ10, a level way up into the Lower Eocene (Serra-Kiel et al., 1998).

In the present paper we present the details of the recalibration of the pelagic and shallow-benthic marine biostratigraphies across the P/E boundary based on a platform-basin transect in the Galala Mountains in Egypt. We demonstrate that the P/E boundary is located between SBZ4 and SBZ5, the biotic transition that represents the LFT.

MATERIAL AND METHODS

The study area of the Galala Mountains is located on the western side of the Gulf of Suez, 200 km southeast of Cairo (Fig. 2). The Galala Mountains are composed of the Northern Galala and the Southern Galala, which are separated by the 30 km wide Wadi Araba, where all Paleogene deposits were removed by Neogene erosion. The study area extends from the northern rim of the Northern Galala (sections N1, AS1 and AS2), approximately 140 km southwards to Wadi Tarfa with the main investigation area in the Southern Galala and the adjacent southern Bir Dakhl (Fig. 2). Eighteen sections were sampled in detail with a special focus on the Paleocene/Eocene transition. The sections in the north of the study area display platform deposits, whereas those in the south correspond to deep-water areas. All together about 800 marl and limestone samples were taken. The combination of paleontological (calcareous nannofossils, planktic foraminifera, small and larger benthic foraminifera), geochemical (δ^{13}C) and sedimentological data allows a precise correlation of the Paleocene and lowest Eocene deep- and shallow-water sections.

Eight sections were selected for lithostratigraphic correlation along a transect, running perpendicular to the former strike of the platform, from the platform in the north to the basin in the south (Fig. 3): Section A5 is located at the northern rim of the Southern Galala, sections K3 and K2 are located in the northern part of Wadi Askhar that runs perpendicular to the strike of the former platform. Sections D5, D6, D2 and D4 lie south of the Southern Galala. The other thirteen sections (B2, B3, A1, A1b, K4, K5, S9, S1-8, D7, D8, D3, T1, and T2) provide additional biostratigraphic and paleoenvironmental information.

Some of these sections (A1, S9, S1-8, D3, T1, and T2) have been described in detail in Scheibner et al. (2000, 2001a and 2001b).

Thin-section studies of Paleocene-Lower Eocene limestones are complemented by investigations on washed residues of marl samples. Sample spacing varied throughout the individual sections from 5 cm to 100 cm within shaley and marly sediments (Fig. 2) and from 50 cm to 5 m in more calcareous and chalky sediments. Thin sections of our study have dimensions of 7.5 cm x 10 cm and were cut vertical to the bedding plane. Within these thin sections, well-oriented larger foraminifera were identified; oriented thin sections for individual specimens were not prepared. For calcareous nannofossils, smear slides were prepared using techniques described in Bramlette and Sullivan (1961) and Hay (1961, 1964). In most of the studied samples, calcareous nannofossils are abundant to common and their preservation is generally good. Washed residues of foraminifera were prepared following standard procedures as outlined in Speijer et al. (1996).

GEOLOGICAL SETTING AND PLATFORM EVOLUTION

The Galala Mountains in the Eastern Desert, west of the Gulf of Suez, represent a southern branch of the Syrian Arc fold belt, called the Northern Galala/Wadi Araba High (NGWA High; Kuss et al., 2000a, fig. 2, lower inlay). The NGWA High is separated by east-northeast-trending faults (Bandel and Kuss, 1987) that run perpendicular to the younger Gulf of Suez faults that resulted from the Miocene opening of the Gulf. Similar to other Syrian Arc Highs on the Sinai Peninsula the Galala mountain range strikes in WSW-ENE direction (Kuss et al., 2000b).

On the NGWA High a carbonate platform evolved from the Late Campanian to early Paleogene (Kulbrok, 1996; Gietl, 1998; Scheibner et al., 2003). The evolution of the Paleocene carbonate platform margin and the variation of the biotic content along the Southern Galala Mountains (Egypt) depend on regional as well as on global factors. Regional tectonic activity (varying processes and amounts of uplift and subsidence) characterized the evolution of the Paleocene carbonate platform (Scheibner et al., 2003). The sedimentary consequences of mainly paleoclimatic changes associated with the evolution of larger foraminifera enabled a subdivision of the Upper Paleocene to Lower Eocene carbonate platform into three biotic platform stages (I-III; Scheibner et al., 2005).

The Maastrichtian to Selandian seabed bottom topography controlled the initial lateral facies distribution across the Paleocene platform-basin transect. The combi-

nation of a significant drop in sea level and tectonic uplift of the Northern Galala/Wadi Araba High initiated progradation of the Late Paleocene platform in the Selandian (59 Ma). During the progradation phases of the carbonate platform (59 Ma - 56.2 Ma and NP5 - NP8) the following facies belts developed: coral patch reefs, and reef debris were deposited at the platform margin, well-bedded limestones on the upper slope, slumps and debris flows on the lower slope, calciturbidites at the toe of slope and hemipelagic sediments in the basin (Scheibner et al., 2003). The occurrence of coralgal reefs characterizes biotic platform stage I (Fig. 4).

During the retrogradational phase (56.2 Ma - 55.5 Ma; base of NP9) a combination of sea-level rise and differentiated subsidence of various parts of the platform resulted in a decrease in slump and debris-flow activity on the lower slope, and a decrease in calciturbidite deposition at the toe of slope (Scheibner et al., 2003). During this time the change from coral patch reefs to larger foraminiferal shoals (miscellanids and ranikothalids) at the platform margin occurred, which mark biotic platform stage II (Fig. 4), possibly caused by an increase in water temperature as the main factor (Scheibner et al., 2005).

In the Early Eocene the platform again prograded (from 55.5 Ma onwards; middle to upper part of NP9 to NP11). The short-term effects of the PETM (temperature increase, eutrophication) resulted in a second organism change from the dominance of miscellanids and ranikothalids to the dominance of alveolinids and nummulitids and thus initiated the biotic platform stage III (Fig. 4).

CHEMO- AND BIOSTRATIGRAPHY

Isotope stratigraphy

The carbon isotopic excursion (CIE) has been accepted as marker criterion for the Paleocene/Eocene boundary (Aubry and Ouda, 2003), as it is detectable worldwide in marine and terrestrial records. In the GSSP section of Dababiya the CIE-interval comprises 3.18 m as revealed by $\delta^{13}C_{org}$ data (Dupuis et al., 2003). The base of the CIE is characterized by a negative $\delta^{13}C$ shift, which is followed by a steady decrease until it reaches its lowest values. From this lowest point, $\delta^{13}C$ values gradually increase, first slightly but then steadily, until they nearly reach pre-excursion values (Dupuis et al., 2003).

In this study, the $\delta^{13}C$ composition of bulk rock samples from 7 sections (B2, B3, A5, D2, D5, D6 and D8) was analyzed and, with the exception of section A5, measurements in all sections cover the Paleocene/Eocene interval. In some sections the sample distribution allows only the recognition of the CIE but do not display the varying gradients of the curve, like in Dababiya (Figs. 5, 6 and 7). The Paleocene part of the $\delta^{13}C$ curve in our sections is characterized by relatively high values around 3‰, while the CIE peak itself varies between -1‰ and 1‰ in the different sections. Lower Eocene values generally are 1‰ lower than the Upper Paleocene values. The CIE is best developed in the basinal to lower slope sections (D2, D6, D8 and D5; Figs. 6 and 7). In the more proximal settings at the platform margin the CIE is not (section B3) or only vaguely (section B2) detectable (Fig. 5). In some cases (sections B3 and D5) this absence can be related to a wider sample spacing (in section B3 the P/E boundary probably lies within an 8 m interval without samples). Another reason for an incomplete coverage of the PETM could be the presence of debris flow, slump and calciturbiditic deposits within this stratigraphic interval, which may have eroded PETM sediments higher upslope (e.g., section B2).

Calcareous nannofossils

The calcareous nannofossil (NP) zonation of Martini (1971) is applied here with modifications and subdivisions (Okada and Bukry, 1980; Aubry, 1995; Aubry et al., 2000). The calcareous nannofossil biostratigraphy and paleoenvironment of seven sections (T1, T2, D2, D3, S9, A1 and N1) of the Upper Cretaceous to Paleogene successions of the Galala Mountains was discussed in Marzouk and Scheibner (2003). Additional nannofossil data on sections D5 and D6 are presented here.

Calcareous Nannoplankton Biozone NP9

Aubry et al. (2000) delineated the NP9a/b boundary by the simultaneous lowest occurrences of several taxa, i.e. *Rhomboaster calcitrapa*, *R. spineus*, *Discoaster araneus*, and *D. anartios*. We follow Aubry et al. (2000) for the delineation of the NP9a/9b boundary, as all these taxa occur in our sections as well.

Paleocene/Eocene (P/E) boundary

The GSSP for the Paleocene/Eocene boundary is placed at the base of the CIE in the Dababiya Quarry section (Aubry and Ouda, 2003, Fig. 1), where an integrated

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FIGURE 2 | **Satellite image of the Southern Galala with all studied sections. In the upper left corner sections in the Northern Galala and Wadi Tarfa (T1 and T2) are plotted. In the lower left corner the Nile Valley sections of Dababiya and Qreiya are plotted. AB transect corresponds to Figures 3 and 4.**
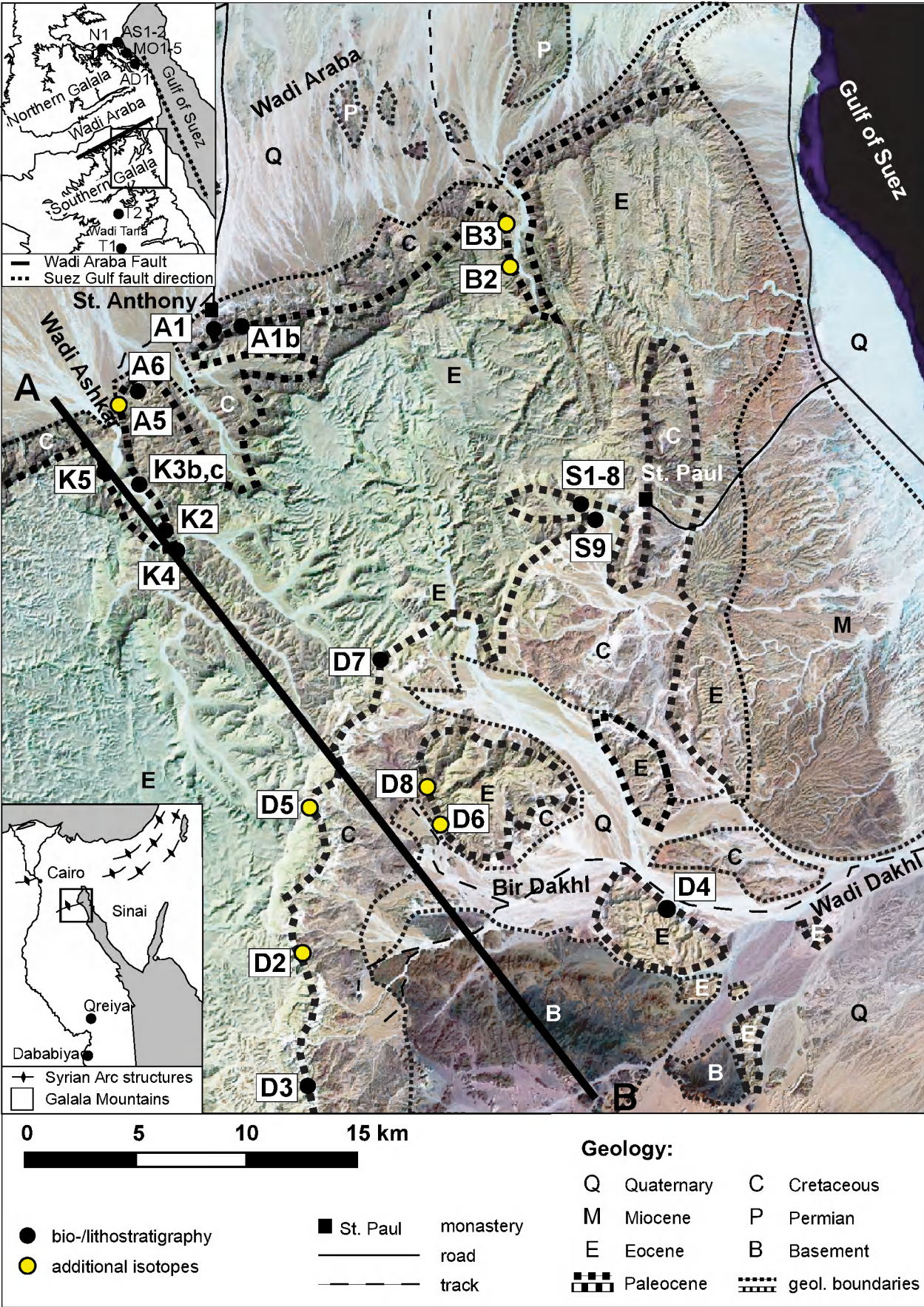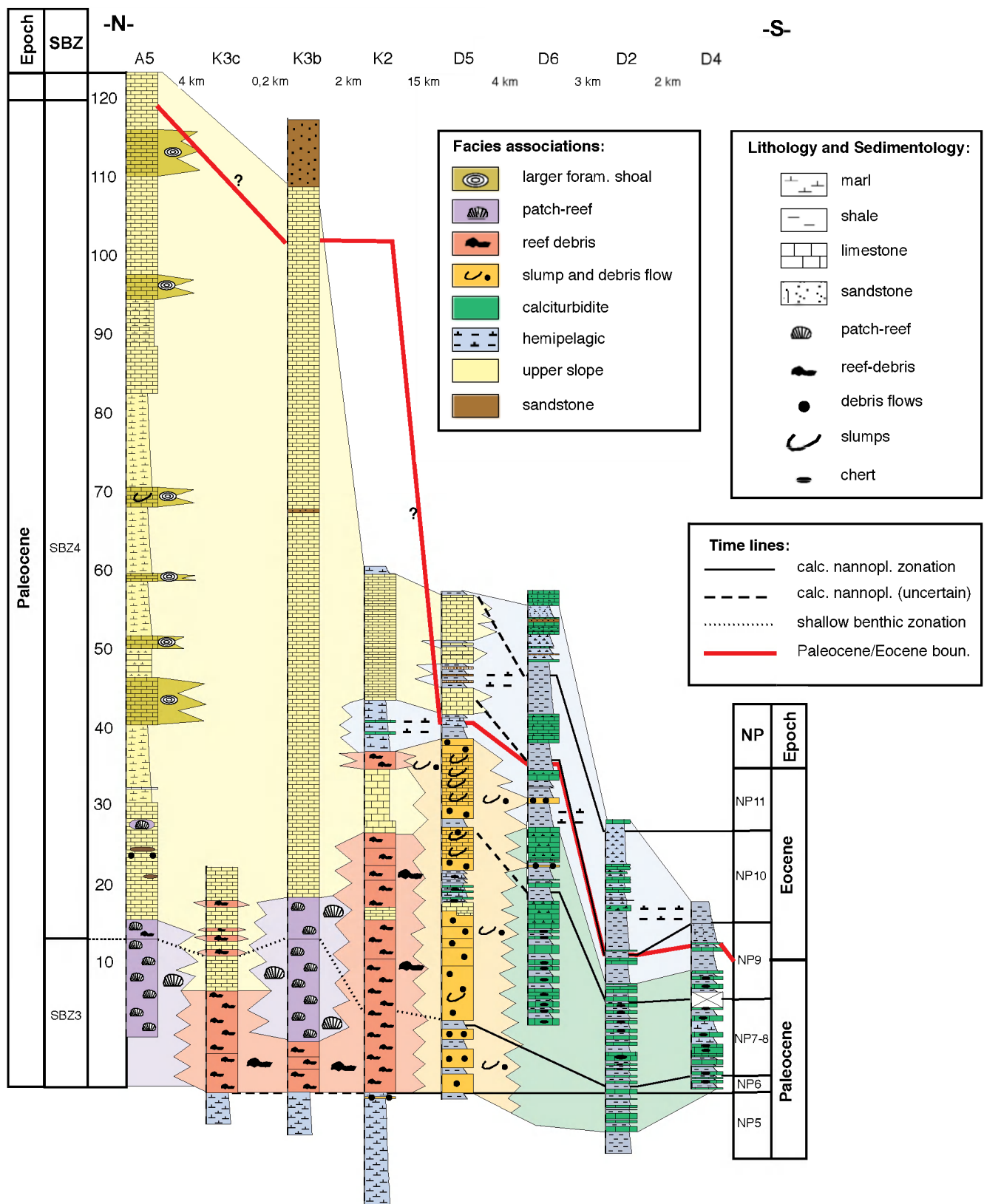
FIGURE 3 | Lithostratigraphic correlation and distribution of facies associations along the platform-basin transect. For location of the sections see Figure 2 (from Scheibner et al., 2003).
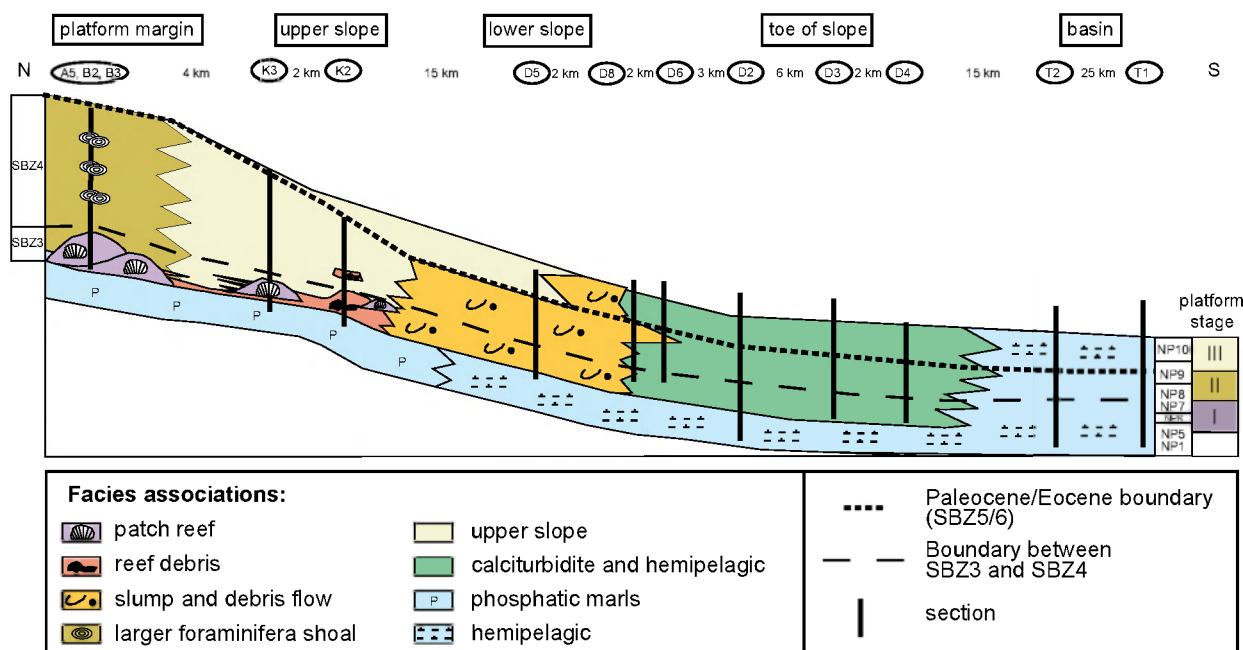
FIGURE 4 | Platform-basin transect of the Paleocene to Lower Eocene in the Galala Mountains (Egypt) with biostratigraphic zonations and platform stages.

stratigraphic study was carried out, including a detailed calcareous nannofossil analysis (Dupuis et al., 2003). The lower part of the CIE closely correlates with the NP9a/b boundary. Directly below the P/E boundary *Fasciculithus alanii* occurs, which is restricted to NP9a (Dupuis et al., 2003). This highest ocurrance (HO) close to the CIE was also encountered in other Egyptia sections such as Gebel Aweina, Gebel Duwi and Gebel Abu Had (Aubry, 1998; von Salis et al., 1998), in the Contessa section in Italy (Galeotti et al., 2000) and in the Zumaya and Alamedilla sections in Spain (Monechi et al., 2000). The basal 73 cm of Lower Eocene beds at Dababiya are carbonate free and thus barren of calcareous nannofossils (Dupuis et al., 2003). The beds directly above the barren interval contain *Discoaster araneus*, *Discoaster anartios*, *Rhomboaster spineus*, and *Rhomboaster* spp. *Discoaster mahmoudii* has its lowest occurrence (LO) at about 3.5 m above the P/E boundary, a level that correlates with the top of the CIE and is located in the lower third of NP9b (Dupuis et al., 2003). *Discoaster mahmoudii* has its HO within NP10a. A similar nannofossil distribution has been found in the Qreiya section, ~100 km northeast of the GSSP at Dababyia (Monechi et al., 2000; Knox et al., 2003, Fig. 1). In our sections, all above-mentioned species occur, albeit not consistently in all sections and thus suggesting a hiatus of variable length (Fig. 8). From the species that delineate the NP9a/b boundary (P/E boundary by means of calcareous nannofossils), *R. spineus* occurs in sections D3, D2, and D6, *D. anartios* and *D. araneus* in section D6. In sections D3 and D2, *Campylosphaera eodela* also

occurs directly at the P/E boundary, whereas in section T2 *C. eodela* occurs within NP9a (Fig. 8). In section D8 the calcareous nannofossil distribution clearly suggests a stratigraphic gap shortly above a well-defined CIE, ranging from NP10a up to NP11, as no marker species for NP10 occur (Fig. 8). *Discoaster mahmoudii* is present in section D5, suggesting no or only a small hiatus in upper NP9b and lower NP10a, but this section lacks the presence of any of the marker species of the boundary of NP9a/b. This probably results from a wider sampling interval across the P/E boundary or from the poor preservation of calcareous nannofossils.

Calcareous Nannoplankton Biozone NP10

This biozone defined by Martini (1971) can be subdivided following Aubry (1995) into four subzones (NP10a-d), based on the *Tribrachiatus* lineage. NP10a is defined by the first occurrence of *T. bramlettei* (= *T. nunnii*), NP10b is defined by the total range of *T. digitalis*, NP10c is defined by the absence of *T. digitalis* and *T. contortus* and the presence of *T. bramlettei* (*T. nunnii*). *T. contortus* is the marker species of NP10d. Dupuis et al. (2003) used the same criteria for their subdivision of the succession at Dababiya. Aubry et al. (1999) also used this subdivision in their description of the Esna shales of Egypt (Gebel Qreiya, Gebel Kilabiya). Similar to Faris (1997) and Aubry and Sanfilippo (1999), we found the HO of *Tribrachiatus bramlettei* (*T. nunnii*) within NP10d, slightly above the LO of *Tribrachiatus contortus* and slightly
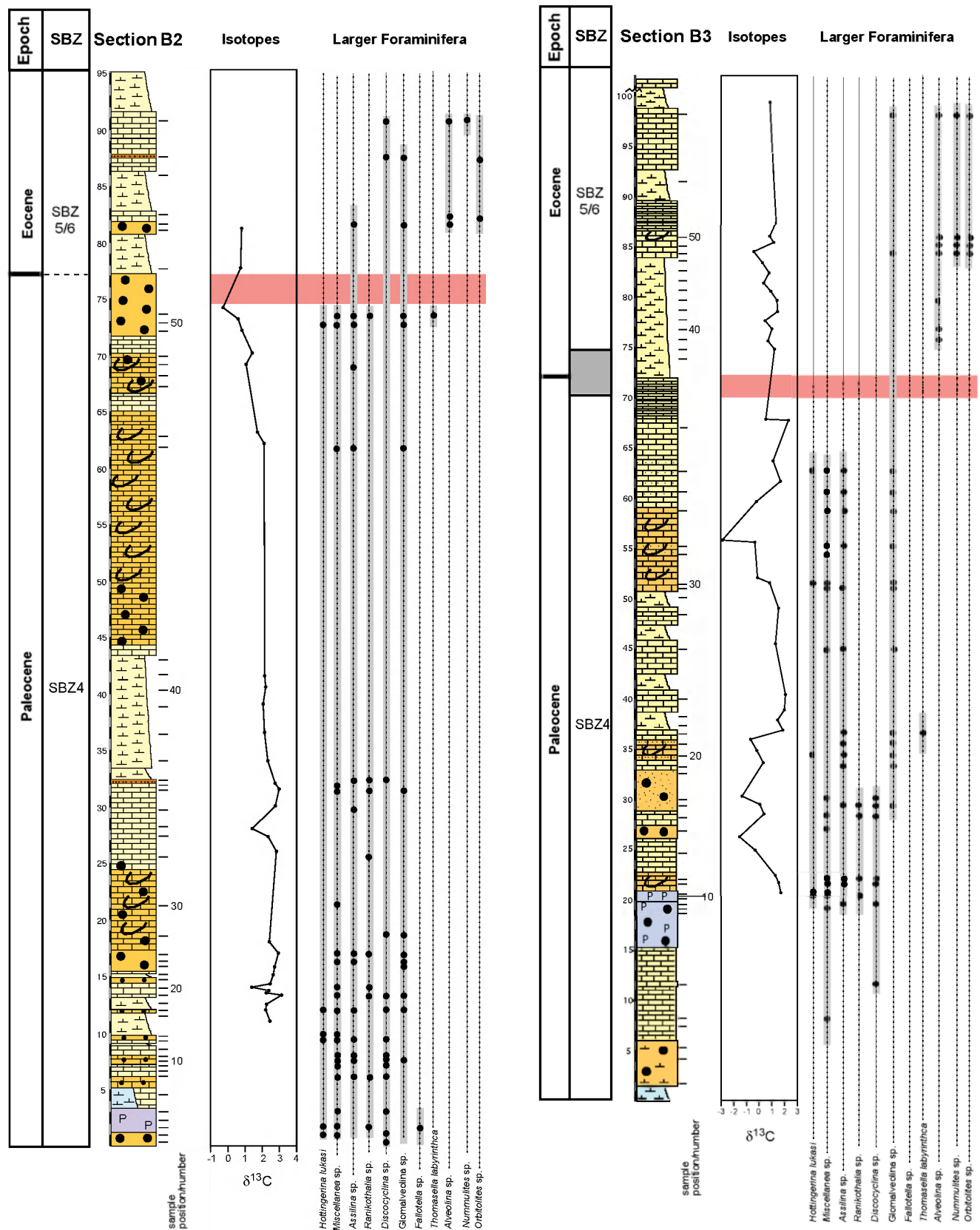
FIGURE 5 | Lithology, δ¹³C isotopes and stratigraphic range of larger foraminifera in the two platform sections B2 and B3. The highlighted area marks the CIE. See Figures 2 and 4 for location of the sections. For legend see Figure 3.
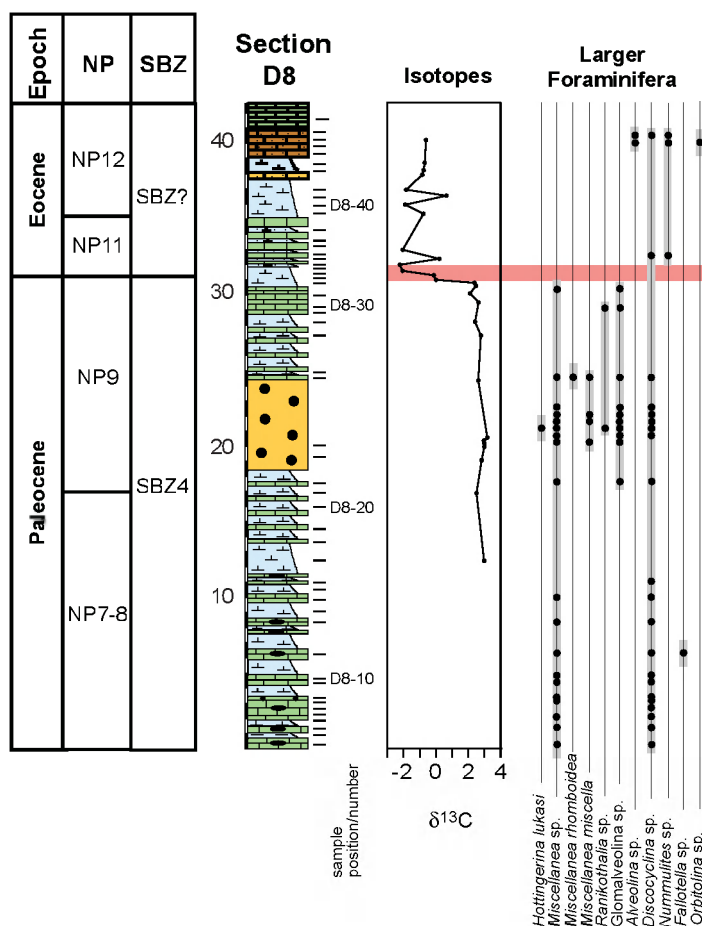
FIGURE 6 | Lithology, $\delta^{13}C$ isotopes and stratigraphic range of larger foraminifera in the lower slope section D8. The highlighted area marks the CIE. See Figures 2 and 4 for location of the sections and Figure 3 for legend.

below the LO of *Tribrachiatus orthostylus*, with the exception of section T1, where *T. bramlettei* continues up to the NP10/11 boundary (Marzouk and Scheibner, 2003). NP10 is present – at least in part – in all deep-water sections with the exception of section D8 (Fig. 8).

Aubry (1995) and Berggren and Aubry (1998) showed that in virtually all oceanic deep sea sites the middle or upper part of NP10 lies unconformably on top of the lower part of NP9. In our samples, this hiatus also appears to be present, ranging in some sections at least from middle NP9b to upper NP10a (Fig. 7). In sections T1 and T2 the hiatus starts in upper NP9a, where the zone-indicative calcareous nannofossils of NP9b are absent. The missing lower part of NP10a is indicated in sections T1 and T2, by the absence of *Discoaster mahmoudii*. With the exception of section T2, *T. digitalis* is absent in all our sections (Marzouk and Scheibner, 2003). This may be the result of a hiatus covering at least NP10b, poor preservation and taxonomic problems of this taxon as suggested also by Monechi et al. (2000), or perhaps also a consequence of insufficient sample resolution in this interval.

Planktic foraminifera

Hemipelagic marls dominate in the southernmost sequences of Wadi Tarfa (sections T1 and T2) and decrease towards the platform margin (Fig. 4). These sediments generally contain rich foraminiferal assemblages with large numbers of planktic specimens (commonly >95% planktics). This enables – with some limitations – the application of the standard tropical biozonation of Berggren et al. (1995) as well as the recently proposed modification by Berggren and Pearson (2005).

With respect to the P/E transition, Berggren and Pearson (2005) modified the zonal scheme of Berggren et al. (1995) as depicted in figure 1. In the new scheme all Paleocene zones retained the formerly used P-notation, whereas all Eocene zones received a new E-notation. The most prominent change is the subdivision of the former Upper Paleocene to Lower Eocene Zone P5 into the new Zones P5 (uppermost Paleocene only), E1 and E2, based on the presence of unique stratigraphic marker species associated with the PETM (Molina et al., 1999; Pardo et al., 1999; Speijer et al., 2000).

In the following, we essentially adopt the nomenclature of the new zonal scheme, but retain some reservations with respect to the definitions and applicability of Zones E1 and E2. The base of Zone E1 is defined by the first appearance of *Acarinina sibaiyaensis* (Berggren and Pearson, 2005). This definition, however, appears seriously flawed as El-Naggar (1966), who first described this species, observed it in the lower part of the Esna Formation at Aweina, Egypt. This interval is now generally accepted to belong to the Upper Paleocene (Speijer et al., 2000; Ouda et al., 2003) and thus the first appearance of *A. sibaiyaensis* cannot serve to delineate the base of the lowermost Eocene Zone E1 (Guasti and Speijer, 2005).

Berggren and Pearson (2005) furthermore proposed to define the base of Zone E2 on the first appearance of *Pseudohastigerina wilcoxensis*. This taxon has a long history in delineating the position of the P/E boundary going back to the studies by Berggren et al. (1967). We agree that this taxon first appears during or just after the PETM, but note that it can be very difficult to distinguish from its precursor *Globanomalina luxorensis*, which is abundant in Lower Eocene Tethyan deposits (Speijer and Samir, 1997). This is particularly true for poorly to moderately preserved basal Eocene foraminiferal assemblages in the present study. Zone E3 is equivalent to the former Zone P6a and its base is defined by the last appearance of *M.*
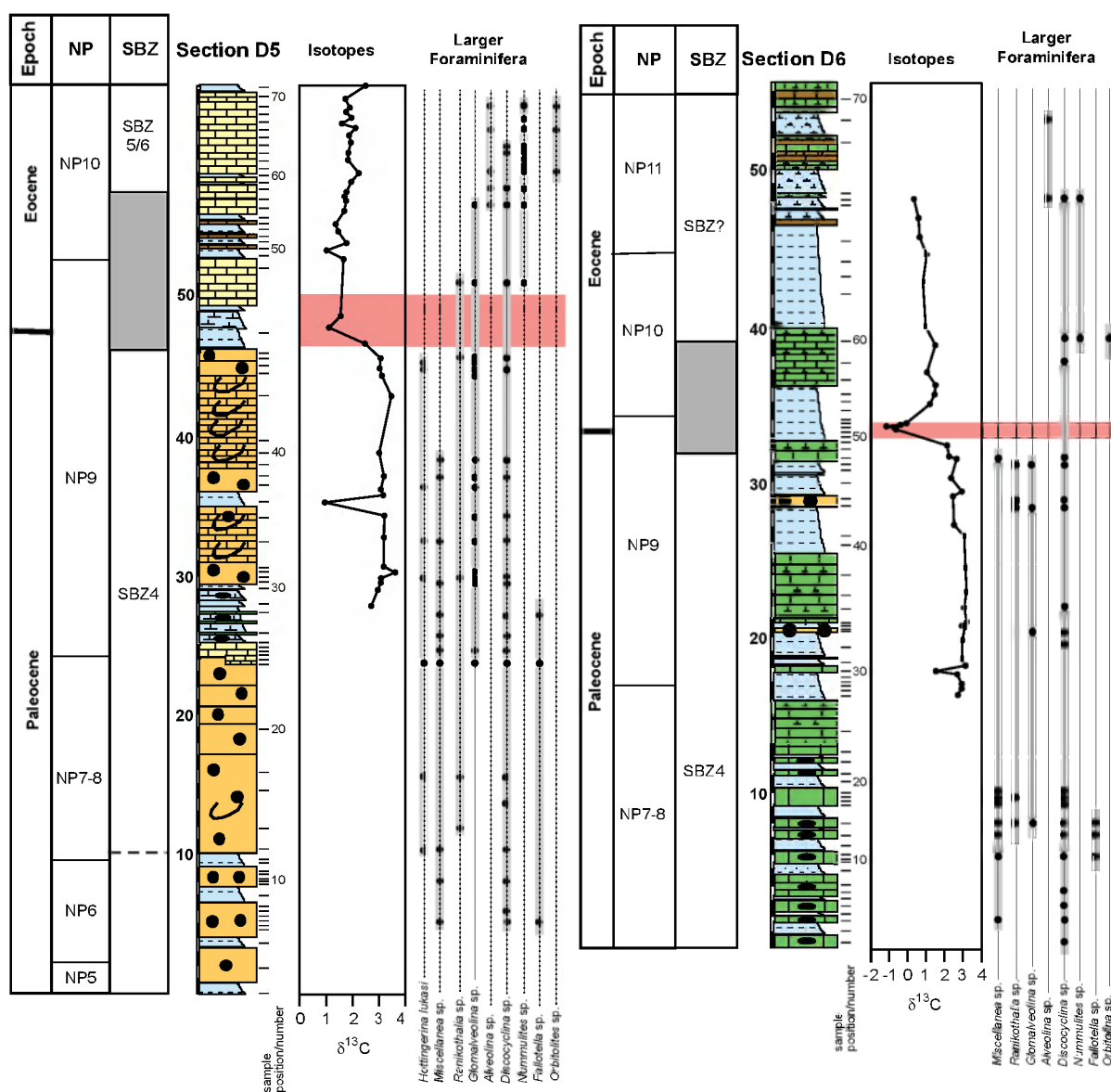

FIGURE 7 | Lithology, δ¹³C isotopes and stratigraphic range of larger foraminifera in the lower slope section D5 and in the toe of slope section D6. The highlighted area marks the CIE. See Figures 2 and 4 for location of the sections and Figure 3 for legend.

velascoensis. This event can usually be easily pinpointed in Eocene deposits of Egypt, although reworking and redeposition may artificially extend the range of *M. velascoensis* upwards (e.g., Wielandt, 1996).

The lower part of the investigated Galala sequences corresponds to Zones P4-P5. As pointed out earlier (Speijer et al., 2000) it is generally not possible in Upper Paleocene Egyptian sequences to reliably differentiate between Zones P4 and P5 on the basis of the disappearance of *G. pseudomenardii*. Typical *G. pseudomenardii* with a distinct keel and a large enveloping last chamber - as it is common in many open ocean records - is rare in Egypt. Consequently, we refrain from pinpointing the P4/P5 zonal boundary in the Upper Paleocene sequences. In addition, the base of Zone P4, formally defined by the first appearance of *G. pseudomenardii*, is approximated by the lowest occurrence of *M. velascoensis*, which in contrast is a very common species in the Upper Paleocene of Egypt (Speijer, 2003).

Planktic foraminiferal assemblages dominated by flat-spired *Acarinina*, including *A. sibaiyaensis* and related taxa typical of the PETM have been observed in the D2, D3, D4 and D6 sections in the Bir Dakhl area. These occurrences enable a tentative positioning of this interval to Zone E1. Although the exact positioning of the E1/E2 zonal boundary is problematic as indicated, Zone E2 (the interval between the lowest occurrence of *P. wilcoxensis* and the highest occurrence of *M. velascoensis*) is well represented in most sections studied. Some sections (T1, T2, D3, D2, D6, and D8) continue higher up into Zone E3 and even into Zone E4. The details of this, however, are beyond the scope of the present study.

Smaller benthic foraminifera

Smaller benthic foraminifera are a key tool in identifying the position of the P/E boundary in open marine sequences. The extinctions of *Gavelinella beccariiformis* and associated deep-sea taxa have since long been recognized as a major event in biotic evolution (benthic extinction event; BEE) of the deep-sea (Beckmann, 1960; von Hillebrandt, 1962; Tjalsma and Lohmann, 1983; Thomas, 1998). This extinction has been correlated with the onset of the PETM worldwide (Kennett and Stott, 1991; Thomas, 1998). Based on this extinction level, Berggren and Miller (1989) defined a zonal boundary between benthic foraminiferal bathyal Zones BB1 and BB2 for deep-sea sequences. Bathyal benthic foraminiferal Zone BB1 spans the entire Paleocene and is characterized by the presence of deep-sea taxa such as *G. beccariiformis*, *Neoflabellina jarvisi*, *N. semireticulata*, *Bulimina velascoensis*, *Bolivinoides delicatulus* and numerous other Velasco-type taxa. BB1 is distinguished from BB2 (Lower

Eocene) through the extinction of *Angulogavelinella avnimelechi*, *G. beccariiformis* and *N. jarvisi*. Characte ristic BB2 taxa are *Turrilina brevispira*, *Bulimina callahani*, *B. trinitatensis*, and *Nuttallides truempyi* (Berggren and Miller, 1989).

Also in continental margin deposits in the Middle East this extinction event is well defined, both in bathyal and outer neritic deposits (Speijer, 1994; Speijer et al., 1995, 1997). In P/E boundary sequences in southern Israel and Sinai (Egypt), *G. beccariiformis* is the most common Paleocene benthic species, becoming extinct at the P/E boundary together with taxa such as *A. avnimelechi*, *Pullenia coryelli*, *Gyroidinoides globosus* and *Cibicidoides hyphalus* (Speijer, 1994). Further south, towards the shallower parts of the Egyptian basin in central Egypt, most deep-sea taxa (e.g., *G. beccariiformis*) are rare in uppermost Paleocene deposits. Nevertheless the P/E boundary can easily be delineated by the sudden extinction of *A. avnimelechi*, which is most common in outer neritic deposits in Egypt (Speijer et al., 1995; Speijer and Schmitz, 1998; Dupuis et al., 2003; Alegret et al., 2005; Ernst et al., 2006).

The P/E boundary can be pinpointed accurately by means of faunal turnover of the benthic foraminiferal assemblages and allowing us to identify bathyal fora-
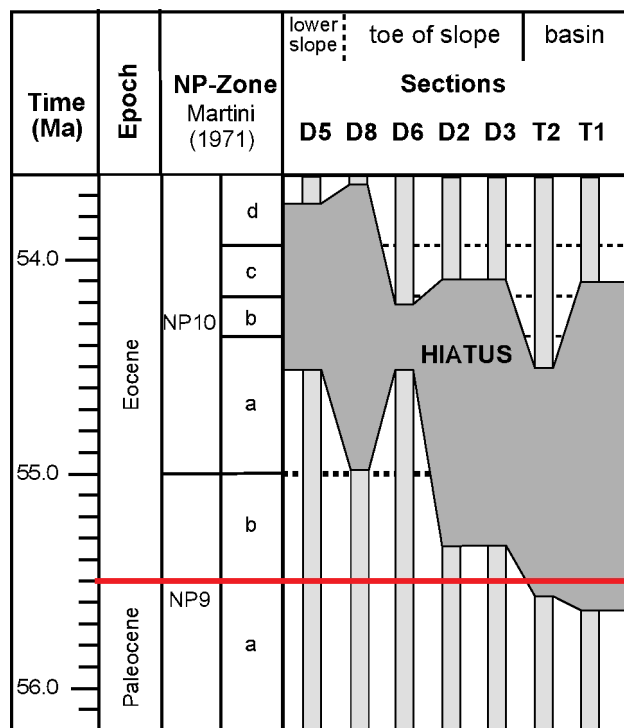

FIGURE 8 | **Stratigraphic range of the hiatus in selected sections across the P/E interval, based on calcareous nannofossils.**

miniferal Zones BB1 and BB2 (Fig. 1). Hemipelagic sediments are encountered in all sections from section T1 in the south to section B3 in the north of the southern Galalas. Generally these sediments yield a mixture of neritic and bathyal benthic foraminiferal taxa, similar to mixed Midway/Velasco type assemblages described from Sinai and southern Israel (Speijer, 1994). The common presence of *G. beccariiformis*, *A. avnimelechi* and other Velasco type taxa points to Zone BB1 in the lower reaches of all these sections. The level of extinction of these taxa delineates the base of Zone BB2. Hemipelagic sediments encountered in the upper parts of most sections studied yield typical Lower Eocene benthic assemblages characterized by numerous neritic taxa and with varying amounts of the bathyal taxa *N. truempyi* and *B. trinitatensis* (particularly in the southernmost sections). In some sections, however, anomalous benthic assemblages without any deep-sea taxa characterize the transition from Zone BB1 to Zone BB2, i.e. the interval spanning the PETM. Anomalous assemblages composed of large numbers of buliminids or *Anomalinoides* were observed in the more downslope sections of the Bir Dakhl area (sections D2, D3, D4 and D6). Similar anomalous assemblages were also observed by Obaidalla (2004) in the Wadi Tarfa region. The resolution of our Wadi Tarfa (sections T1 and T2) samples was apparently too low to observe this feature. It is not surprising that the more proximal sections (D5, D8, B2, and B3) do not show any anomalous assemblages in between the typical bathyal assemblages of Zones BB1-BB2. The carbon isotope profiles clearly indicate that the $\delta^{13}C$ excursion is absent (section B3) or not well developed (sections B2 and D5), pointing to an incomplete coverage of the PETM. Apparently, either the sampling interval was too large or the erosion through debris flows, slumps and calciturbiditic flows was too intensive to preserve PETM sediments higher upslope.

Larger benthic foraminifera

According to Hottinger (2001), the Upper Paleocene to Lower Eocene interval includes two important phases in a global community maturation cycle, which consists of five phases of continuous, gradual biotic change. The Upper Paleocene represents phase 2 of the maturation cycle, in which an increase in generic diversity occurred. The Lower Eocene represents phase 3, which is characterized by an abrupt diversification of different species and marks the full recovery after the collapse at the Cretaceous/Paleogene (K/P) boundary (Hottinger, 2001). Apart from the reorganization of larger foraminifera after the K/P boundary, long-term and short-term paleoenvironmental trends were responsible for the success of larger foraminifera within this time interval (Scheibner et al., 2005). These trends include increasing oligotrophy and higher sea-surface temperatures, which led to the demise

of corals in low latitudes and created new niches for larger foraminifera (Scheibner et al., 2005). In this study we focus mainly on alveolinids and some other shallow benthic foraminifera, whereas nummulitids are only treated subordinately. In the following, we present a characterization of larger foraminifera assemblages encountered in SBZ3, SBZ4 and SBZ5/6.

Shallow Benthic Zone 3 (SBZ 3)

Prior to the revision of the shallow-benthic foraminiferal biozonation (Serra-Kiel et al., 1998) SBZ3 was established by Hottinger (1960) as the *G. primaeva* Biozone, defined by the total range of *Glomalveolina primaeva*. In the Galala Mountains we identified *G. primaeva* (Fig. 9) as well as small *Miscellanea* sp. and *Discocyclina* sp. Agglutinated forms, like *Fallotella alavensis* or *Coskinon rajkae*, which are indicative of very shallow waters, have not been found or were too poorly preserved. The base of SBZ3 is not well defined in our sections, because of the absence of shallow-water limestones at the base of the stratigraphic sequences. Furthermore, shallow-platform strata worldwide lack a clearly expressed SBZ2/SBZ3 boundary because of the scarcity of index taxa (Serra-Kiel et al., 1998). In contrast to this, the transition from SBZ3 to SBZ4 in most sections is straightforward.

1. *Glomalveolina primaeva*: According to Hottinger (1960) and Serra-Kiel et al. (1998), the range of *G. primaeva* is restricted to SBZ3. In contrast to this narrow assignment, White (1992) gives a longer range, from SBZ3 up to SBZ6. In our samples *G. primaeva* is restricted to SBZ3. In one section (K2) it occurs together with younger species typical of SBZ4. Possibly these species are reworked from older strata, as they were found in debris-flow deposits.

Shallow Benthic Zone 4 (SBZ4)

The precursor of SBZ4 was established by Hottinger (1960) as the *G. levis* Biozone, defined by the total range of *Glomalveolina levis*. Several index taxa were identified in thin sections from the Upper Paleocene of Bir Dakhl and the Southern Galala: *Hottingerina lukasi*, *Glomalveolina* spp., *Miscellanea* spp., *Ranikothalia* spp., *Dictyokathina simplex*, and *Thomasella labyrintica* (Fig. 9).

1. *Hottingerina lukasi*: In Slovenia *H. lukasi* ranges exclusively within the *G. levis* Biozone (Drobne, 1975). However, White (1992) demonstrated this species ranging throughout the *G. primaeva* to *A. ellipsoidalis* Biozones in Oman. Yet, Serra-Kiel et al. (1998) described it as index fossil of shallow benthic Zone SBZ4. Gietl (1998)
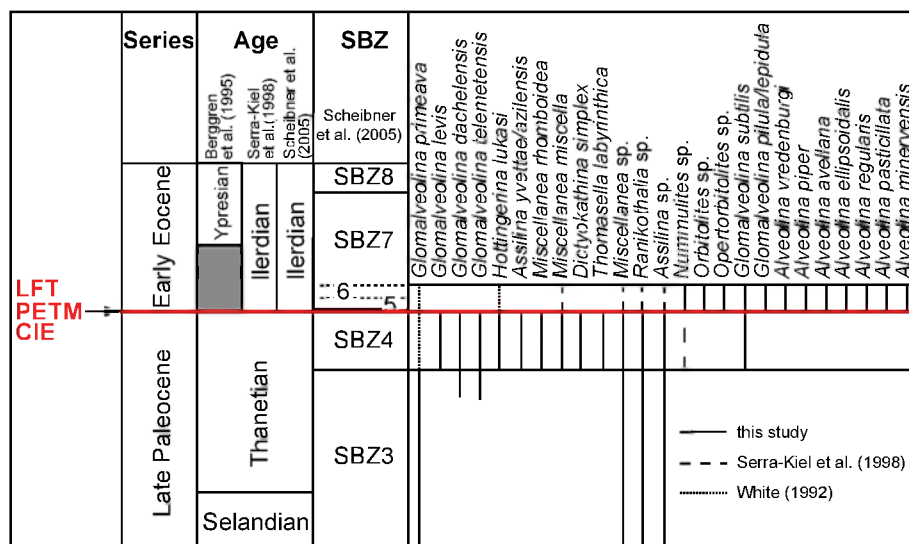
FIGURE 9 | **Stratigraphic ranges of representative shallow-water benthic foraminifera.**

and Kuss and Leppig (1989) described *H. lukasi* in the Galala Mountains also from the *G. levis* Biozone (SBZ4). *Hottingerina lukasi* is characteristic of very shallow parts of the platform, which is probably the reason why we do not find it in the most distal toe of slope sections. Because of the very characteristic internal structures, *H. lukasi* is easily recognized in thin sections, even if specimens are not orientated properly. This easy recognition leads to a relatively high number of identifications, in contrast to the glomalveolinids, which can only be identified in correctly oriented specimens. Therefore, *H. lukasi* is considered in this study to be an index fossil for SBZ4 (Fig.10).

2. *Glomalveolina* spp.: In SBZ4 we found *G. telemetensis* and *G. dachelensis*, which first appear within SBZ3 and disappear within or at the top of SBZ4 (Hottinger, 1960; Serra-Kiel et al., 1998), while *G. levis* has a total range of SBZ4 (Hottinger, 1960; Serra-Kiel et al., 1998; Fig. 11).

3. *Miscellanea* spp.: *M. rhomboidea*, *M. miscella* and other species are recorded within SBZ4. According to Serra-Kiel et al. (1998) *M. miscella* ranges from SBZ4 to SBZ5. In our sections we did not find any miscellanids above SBZ4. *Miscellanea rhomboidea* was described for the first time by Kuss and Leppig (1989) in their section "X" close to the monastery of St. Anthony (Fig. 10).

4. *Assilina* spp.: Within this biozone *Assilina* spp. (probably *A. azilensis* or *A. yvettae*) occur frequently in some sections (A5, B2 and B3; Fig. 10).

5. *Ranikothalia* spp.: various species (*R. nuttalli*, *Ranikothalia* sp.) are recorded within SBZ4 (Fig. 10).

Shallow Benthic Zones 5/6 (SBZ5/6)

According to Hottinger (1960) the precursor biozones of SBZ5 and SBZ6 are the *A. cucumiformis* and *A. ellipsoidalis* Biozones, identified by the total ranges of *Alveolina cucumiformis* (junior synonym of *A. vredenburgi*, Hottinger et al., 1998) and *Alveolina ellipsoidales*, respectively. SBZ5 and SBZ6 in this study are combined and not separated, because index species of both biozones co-occur. Larger foraminifera of this biozone are very easily recognized, because of the first appearance of true alveolinids, which are characterized by an increase in size, flosculinisation, axial thickening and adult dimorphism (Hottinger, 1960). The base of this zone marks the LFT and the carbon isotopic excursion and hence the Paleocene/Eocene boundary.

The following taxa are considered index fossils for the Lower Eocene: *Alveolina* spp., *Nummulites* spp., *Orbitolites* spp., *Cuvillierina* spp. (Fig. 9).

1. *Alveolina* spp.: From the P/E boundary upwards the following *Alveolina* species are recorded: *A. vredenburgi*, *A. avellana*, *A. piper*, *A. regularis*, which belong to SBZ5 and *A. ellipsoidalis*, *A. pasticillata*, *A. minervensis*, which belong to SBZ6 (Hottinger, 1960; Serra-Kiel et al., 1998; Fig. 5; Figs. 10 and 11).

2. *Nummulites* spp. first appear within SBZ5 and above (Fig. 10).

3. *Orbitolites* spp. and *Opertorbitolites* spp. first appear in this biozone, Serra-Kiel et al. (1998) also reported the first occurrence of these genera in this biozone (Fig. 10).

4. *Cuvillierina* spp.: According to Loeblich and Tappan (1988), *Cuvillierina* is restricted to the Lower Eocene.

INTEGRATED STRATIGRAPHY

The sediments from the northern rim of the southern Galala Mountains southwards to the Bir Dakhl and the Wadi Tarfa areas were deposited on a platform margin to basin transect during the Late Paleocene and Early Eocene. The platform margin in the north was characterized by patch reefs and larger foraminifera shoals, while the lower slope and the toe of slope were respectively characterized by debrites intercalated with hemipelagic marls and by calciturbidites intercalated within hemipelagic marls. In the Wadi Tarfa area in the south, the basinal marls show no evidence of the presence of the carbonate platform in the north (Fig. 4). This paleobathymetric transect provides the opportunity to calibrate the various deep- to shallow-water biostratigraphic schemes. The crucial area for the recalibration of the different biostratigraphies is the Bir Dakhl area, where debris flow deposits, calciturbidites and hemipelagic marls of the lower slope and toe of slope crop out, as in these sections all biostratigraphic schemes can be compared directly. In the following, we discuss the different biostratigraphic schemes together with the litho- and chemostratigraphy with respect to the shallow benthic zonation to strengthen the correlation of the SBZ4/SBZ5 boundary with the newly established Paleocene/Eocene boundary.

Paleocene

The Upper Paleocene can be separated into SBZ3 and SBZ4. SBZ3 is characterized in our sections by the presence of *G. primaeva* and the absence of *H. lukasi*. At that time coral patch reefs thrived at the platform margin (sections A5, B2 and B3), while fragments of corals can be found in the debris flows of the lower slope sediments of section D5. In the intercalating hemipelagic marls of section D5 mainly calcareous nannofossils of NP6 were found, planktic foraminifera assemblages of Zones P4-P5 (undivided) and smaller benthic foraminifera typical of BB1. The presence of corals in this time interval characterizes biotic platform stage I (Fig. 4; Scheibner et al., 2005).

SBZ4 in our sections is characterized by the occurrence of *H. lukasi*, *G. levis*, *M. rhomboidea*, *M. miscella*,

and *A. yvettae/azilensis*. Additionally *G. dachelensis* and *G. telemetensis*, which have their first appearance in SBZ3, are also present, while true alveolinids or other markers of SBZ5 are absent in all sections. Within this time interval the coral patch reefs declined and were succeeded by larger foraminifera-bearing shoals, dominated by miscellanids and subordinately by ranikothalids (section A5; biotic platform stage II, Fig. 4). The accompanying hemipelagic marls in the lower slope to toe of slope sections yield calcareous nannofossils from NP7/8 to NP9a, planktic foraminifera assemblages of Zones P4-P5 and smaller benthic foraminifera typical of BB1.

Paleocene/Eocene boundary

The level, now delineated by the base of the CIE (Aubry and Ouda, 2003) as P/E boundary, correlates with the boundary between SBZ5 and SBZ6 in the shallow-benthic zonation of Serra-Kiel et al. (1998). Our data demonstrate an unambiguous correlation between the P/E boundary and the SBZ4/SBZ5 boundary. In our sections SBZ5 is characterized by the presence of *Alveolina* spp., *Nummulites* spp., *Orbitolites* sp., *Opertorbitolites* sp. and the absence of *H. lukasi*, *Miscellanea* spp., and *Ranikothalia* spp. The lowermost Eocene is characterized by a decrease of debris flow and calciturbiditic deposits in the lower slope to toe of slope sections and a southward shift of upper slope facies to section D5. Dominant organisms are alveolinids and nummulitids (biotic platform stage III). The hemipelagic marls in the lower slope to toe of slope sections yield calcareous nannofossils from NP9b to NP10, planktic foraminifera assemblages of Zones E1-E3 and smaller benthic foraminifera typical of BB2.

In all our sections, the base of the CIE is located below the lowest occurrence of any of the marker species for SBZ5. An uncertainty may arise on the question of the precise correlation of the CIE with the shallow benthic zonation, as we do not have a continuous record of larger foraminifera across the CIE. In the lower slope section D5 and the toe of slope section D6 the well-preserved CIE is lying within a marly interval without larger foraminifera (Fig. 6). Whereas the limestone directly below the marly interval represents SBZ4, the lowest occurrence of marker species of SBZ5 is somewhat above the P/E boundary. However, despite this larger foraminifera gap, and regardless of the processes of rede-

FIGURE 10 | **Larger foraminifera of SBZ 4 – SBZ5/6. A)** *Ranikothalia nuttalli* middle; *Miscellanea* cf. *rhomboidea* top left; SBZ4; sample A5-44c; magnification 20x. **B)** *Assilina azilensis* and *Miscellanea* sp.; SBZ4; sample A5-44d; magnification 20x. **C)** *Nummulites* sp.; SBZ8; sample K1-1; magnification 20x. **D)** *Hottingerina lukasi*; SBZ4; sample B2-3a; magnification 40x. **E)** *Hottingerina lukasi*; SBZ4; sample K2-12; magnification 40x. **F)** *Hottingerina lukasi*; SBZ4; sample D5-23; magnification 40x. **G)** *Hottingerina lukasi*; SBZ4; sample D5-16b; magnification 40x. **H)** *Dictyokathina* sp.; SBZ4; sample A5-63; magnification 40x. **I)** *Orbitolites* sp.; SBZ5/6; sample B3-49; magnification 40x. **J)** *Alveolina vredenburgi*; SBZ5; sample D5-57; magnification 20x. **K)** *Alveolina piper*; SBZ5; sample B2-54; magnification 20x. **L)** *Alveolina ellipsoidalis* top; *A. regularis* bottom; SBZ5/6; sample AS1-1; magnification 20x.
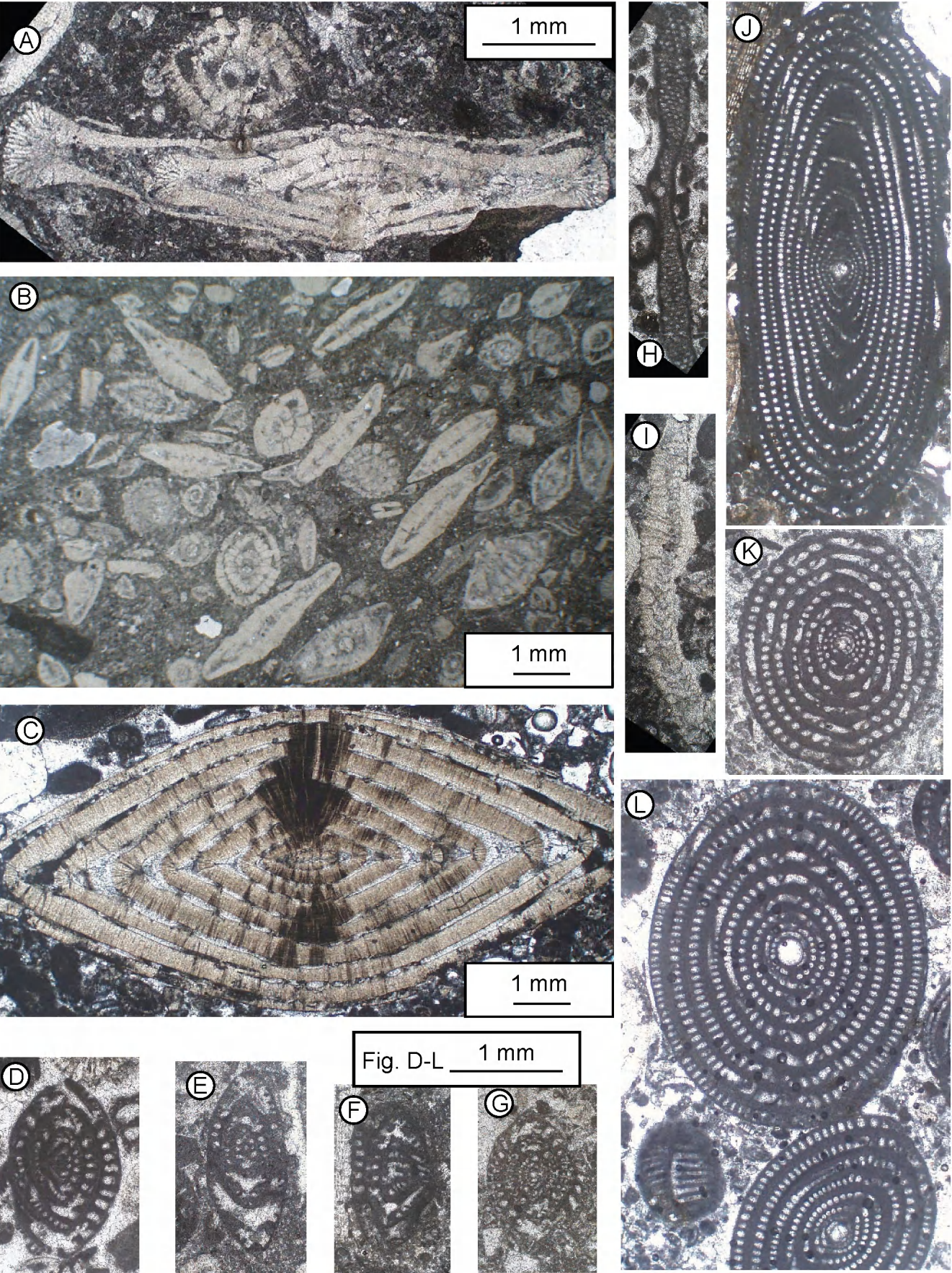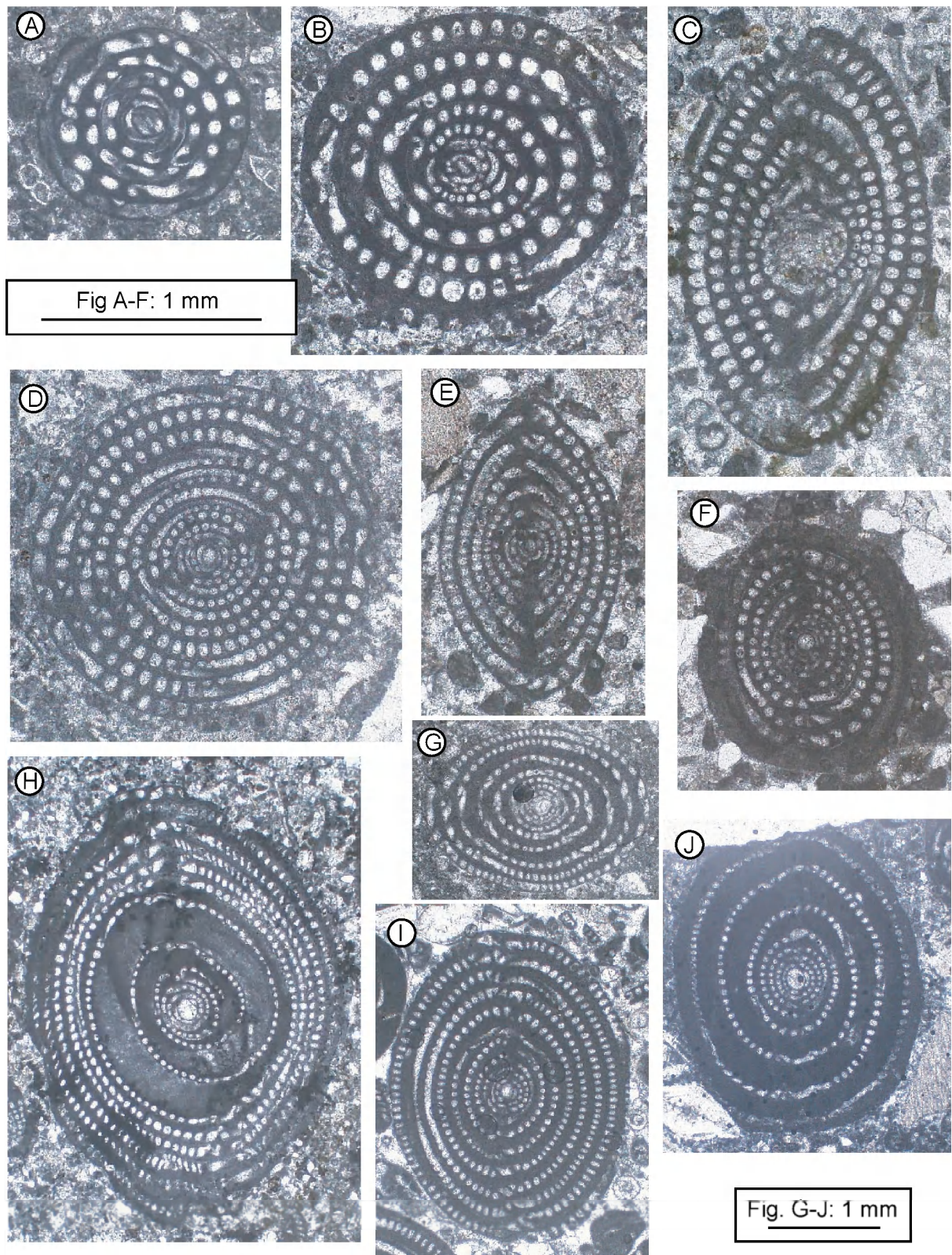
FIGURE 11 | **Glomalveolinids of SBZ3 and SBZ4. A)** *Glomalveolina primaeva*; SBZ3; sample B2-10; magnification 40x. **B)** *Glomalveolina dachelensis*; SBZ3-SBZ4; sample D8-24b; magnification 40x. **C)** *Glomalveolina levis*; SBZ4; sample K3b-30; magnification 40x. **D)** *Glomalveolina telemetensis*; SBZ3-SBZ4; sample B2-51; magnification 40x. Glomalveolinids and alveolinids from SBZ5/6. **E)** *Glomalveolina subtilis*; SBZ5; sample D5-61a; magnification 40x. **F)** *Glomalveolina pilula/lepidula*; SBZ5/6; sample D5-53a; magnification 40x. **G)** *Alveolina avellana*; SBZ5; sample AS2-2; magnification 20x. **H)** *Alveolina pasticillata*; SBZ5/6; sample AS2-1; magnification 20x. **I)** *Alveolina regularis*; SBZ5/6; sample AS1-1; magnification 20x. **J)** *Alveolina minervensis*; SBZ5/6; sample AS2-4; magnification 20x.

position on the southern Galala slope, the larger foraminiferal distribution is very consistent: typical SBZ4 taxa are present only below the P/E boundary and SBZ5 taxa exclusively above it. This pattern is consistent with the Pyrenean records (Orue-Etxebarria et al., 2001; Pujalte et al., 2003; Pujalte et al. 2009 a and b, this issue) and thus the proposition that the SBZ4/SBZ5 boundary correlates with the P/E boundary is tenable. Only a - yet undiscovered - continuous succession of larger foraminifera together with a well-defined CIE can further improve this correlation.

CONCLUSIONS

The Upper Paleocene-Lower Eocene platform-basin transect of the Galala Mountains has provided an excellent opportunity for calibrating platform and pelagic stratigraphic schemes. Our data show that the Paleocene/Eocene boundary, as delineated by the base of the CIE, not only correlates with various evolutionary events in pelagic and deep marine microbiota, but also with a turnover in shallow platform biota. The larger foraminiferal turnover (LFT), located between shallow benthic Zones 4 and 5 is not a Late Paleocene event, as proposed in previous correlation schemes, but rather one that occurred at the onset of the Eocene. Consequently, in Tethyan platform successions, the P/E boundary can be identified in the field by means of a hand lens. For the purpose of mapping the P/E boundary in platform deposits, the choice for the CIE as P/E boundary criterion was a fortunate one after all.

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REFERENCES |

Alegret, L., Ortiz, S., Arenillas, I., Molina, E., 2005. Palaeoenvironmental turnover across the Palaeocene/Eocene boundary at the Stratotype section in Dababiya (Egypt) based on benthic foraminifera. Terra Nova, 17, 526-536.

Aubry, M.P., 1995. Towards an upper Paleocene-lower Eocene high resolution stratigraphy based on calcareous nannofossil stratigraphy. Israel Journal of Earth Sciences, 44, 239-253.

Aubry, M.P., 1998. Early Paleogene calcareous nannoplankton evolution, a tale of climatic amelioration. In: Aubry, M.P., Lucas, S.G., Berggren, W.A. (eds.). Late Paleocene-early

Eocene climatic and biotic events in the marine and terrestrial records. New York, Columbia University Press, 158-203.

Aubry, M.P., Sanfilippo, A., 1999. Late Paleocene-Early Eocene sedimentary history in western Cuba: Implications for the LPTM and for regional tectonic history. Micropaleontology, 45, Suppl. 2, 5-18.

Aubry, M.P., Berggren, W.A., Cramer, B., Dupuis, C., Kent, D.V., Ouda, K., Schmitz, B., Steurbaut, E., 1999. Paleocene/Eocene boundary sections in Egypt. In: Soliman, H.A., Ouda, K.A.K. (eds.). Symposium on Late Paleocene-Early Eocene Events from North Africa to the Middle East within The First International Conference on the Geology of Africa, Assiut, Egypt, The Faculty of Science, University of Assiut, 1-11.

Aubry, M.P., Cramer, B.S., Miller, K.G., Wright, J.D., Kent, D.V., Olsson, R.K., 2000. Late Paleocene event chronology: unconformities, not diachrony. Bulletin de la Societé Géologique de France, 171, 367-378.

Aubry, M.P., Ouda, K., 2003. Introduction to the upper Paleocene-Lower Eocene of the Upper Nile Valley: Part I Stratigraphy. Micropaleontology, 49, Suppl. 1, ii-iv.

Bandel, K., Kuss, J., 1987. Depositional environment of the pre-rift sediments - Galala Heights (Gulf of Suez, Egypt). Berliner geowissenschaftliche Abhandlungen A, 78, 1-48.

Beckmann, J.P., 1960. Distribution of benthonic foraminifera at the Cretaceous-Tertiary boundary of Trinidad (West-Indies). In: Rosenkrantz, A., Brotzen, F. (eds.). International Geological Congress. Report of the Twenty-First Session Norden. Part V: the Cretaceous-Tertiary Boundary. Copenhagen, Det Berlingske Bogtrykkeri, 57-69.

Berggren, W.A., Aubry, M.P., 1998. The Paleocene/Eocene epoch/series boundary: chronostratigraphic framework and estimated geochronology. In: Aubry, M.P., Lucas, S.G., Berggren, W.A. (eds.). Late Paleocene-early Eocene climatic and biotic events in the marine and terrestrial records, New York, Columbia University Press, 18-36.

Berggren, W.A., Miller, K.G., 1989. Cenozoic bathyal and abyssal calcareous benthic foraminiferal zonation. Micropaleontology, 35, 308-320.

Berggren, W.A., Pearson, P.N., 2005. A revised tropical to subtropical Paleogene planktonic foraminiferal zonation. Journal of Foraminiferal Research, 35, 279-298.

Berggren, W.A., Olsson, R.K., Reyment, R.A., 1967. Origin and development of the foraminiferal genus *Pseudohastigerina* Banner and Blow, 1959. Micropaleontology, 13, 265-288.

Berggren, W.A., Kent, D.V., Swisher III, C.C., Aubry, M.P., 1995. A revised Cenozoic geochronology and chronostratigraphy. In: Berggren, W.A., Kent, D.V., Aubry, M.P., Hardenbol, J. (eds.). Tulsa, Geochronology, time scales, and global stratigraphic correlation, SEPM Spec. Publ. 54, 129-212.

Berggren, W.A., Aubry, M.P., van Fossen, M., Kent, D.V., Norris, R.D., Quillévéré, F., 2000. Integrated Paleocene calcareous plankton magnetobiochronology and stable isotope stratigraphy: DSDP Site 384 (NW Atlantic Ocean). Palaeogeography, Palaeoclimatology, Palaeoecology, 159, 1-51.

Bramlette, M.N., Sullivan, F.R., 1961. Coccolithophorids and related nannoplankton of the early Tertiary in California. Micropaleontology, 7, 129-174.

Drobne, K., 1975. *Hottingerina lukasi* n.gen., n.sp. (Foraminiferida) iz srednjega paleocena v severozahodni jugoslaviji. Radzprave, 18, 242-253.

Dupuis, C., Aubry, M.P., Steurbaut, E., Berggren, W.A., Ouda, K., Magioncalda, R., Cramer, B.S., Kent, D.V., Speijer, R.P., Heilmann-Clausen, C., 2003. The Dababiya Quarry Section: Lithostratigraphy, clay mineralogy, geochemistry and paleontology. Micropaleontology, 49, Suppl. 1, 41-59.

El-Naggar, Z.R., 1966. Stratigraphy and planktonic foraminifera of the upper Cretaceous-lower Tertriary succession in the Esna-Idfu region, Nile Valley, Egypt, U.A.R. London, Bulletin of the British Museum (natural history) Geology, 291.

Ernst, S.R., Guasti, E., Dupuis, C., Speijer, R.P., 2006. Environmental perturbation in the southern Tethys across the Paleocene/Eocene boundary (Dababiya, Egypt): Foraminiferal and clay mineral records. Marine Micropaleontology, 60, 89-111.

Faris, M., 1997. Stratigraphic distribution, paleocologic implications and evolutionary lineages of the *Rhomboaster* and *Tribrachatus* Taxa in the late Paleocene/early Eocene in Egypt. Assiut University, Bulletin Faculty of Science, 26 (3-F9), 1-11.

Forke, H.C., 2002. Biostratigraphic subdivision and correlation of Uppermost Carboniferous/Lower Permian sediments in the Southern Alps: fusulinoidean and conodont faunas from the Carnic Alps (Austria/Italy), Karavanke Mountains (Slovenia), and Southern Urals (Russia). Facies, 47, 201-276.

Galeotti, S., Angori, E., Coccioni, R., Ferrari, G., Galbrun, B., Monechi, S., Premoli Silva, I., Speijer, R., Turf, B., 2000, Integrated stratigraphy across the Paleocene/Eocene boundary in the Contessa Road section, Gubbio (central Italy). Bulletin de la Societé Géologique de France, 171, 355-365.

Gietl, R., 1998. Biostratigraphie und Sedimentationsmuster einer nordostägyptischen Karbonatrampe unter Berücksichtigung der Alveolinen-Faunen. Universität Bremen, Berichte aus dem Fachbereich Geowissenschaften, 112, 1-135.

Gradstein, F., Ogg, J., Smith, A., 2004. A geologic time scale 2004. Cambridge, Cambridge University Press, 1-589.

Guasti, E., Speijer, R.P., 2005. The Paleocene-Eocene thermal maximum in Egypt and Jordan: an overview of the planktic foraminiferal record. In: Guasti, E. (ed.). Early Paleogene environmental turnover in the southern Tethys as recorded by foraminiferal and organic-walled dinoflagellate cysts assemblages. Universität Bremen, Berichte aus dem Fachbereich Geowissenschaften, 241, 113-145.

Hay, W.W., 1961. Note on the preparation of samples of discoasterids. Journal of Paleontology, 35, 873.

Hay, W.W., 1964. The use of the electron microscope in the study of fossils. Annual Report Smithsonian Institution, 1963, 409-415.

Hottinger, L., 2001. Learning from the past? In: Box, E., Pignatti, J. (eds.). Volume IV: The living world. Part Two: Discov-

ery and Spoliation of the Biosphere. San Diego, Academic Press, 449-477.

Hottinger, L., 1960. Recherches sur les Alvéolines du Paléocène et de l'Eocène. Schweizerische Palaeontologische Abhandlungen, 75/76, 1-243.

Hottinger, L., 1998. Shallow benthic foraminifera at the Paleocene-Eocene boundary. Strata, Serie 1, 9, 61-64.

Hottinger, L., Schaub, H., 1960. Zur Stufeneinteilung des Paleocaens und des Eocaens. Eclogae Geologicae Helvetiae, 53, 453-479.

Hottinger, L., Smeeni, S.J., Butt, A.A., 1998. Emendation of *Alveolina vredenburgi* Davies and Pinfold, 1937 from the Surghar Range, Pakistan. In: Hottinger, L., Drobne, K. (eds.). Paleogene shallow benthos of the Tethys, 2. Ljubljana, Dela-Opera SAZU, 155-163.

Kennett, J.P., Stott, L.D., 1991. Abrupt deep-sea warming, palaeoceanographic changes and benthic extinctions at the end of the Palaeocene. Nature, 353, 225-229.

Kulbrok, F., 1996. Biostratigraphie, Fazies und Sequenzstratigraphie einer Karbonatrampe in den Schichten der Oberkreide und des Alttertiärs Nordost-Ägyptens (Eastern Desert, N'Golf von Suez, Sinai). Universität Bremen, Berichte aus dem Fachbereich Geowissenschaften, 81, 1-216.

Kuss, J., Leppig, U., 1989. The early Tertiary (middle-late Paleocene) limestones from the western Gulf of Suez, Egypt. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, 177, 289-332.

Kuss, J., Scheibner, C., Gietl, R., 2000a. Carbonate Platform to Basin Transition along an Upper Cretaceous to Lower Tertiary Syrian Arc Uplift, Galala Plateaus, Eastern Desert, Egypt. GeoArabia, 5, 405-424.

Kuss, J., Westerhold, T., Groß, U., Bauer, J., Lüning, S., 2000b. Mapping of Late Cretaceous stratigraphic sequences along a Syrian Arc Uplift - examples from the Areif el Naqa/Eastern Sinai. Middle East Research Center, Ain Shams University, Earth Science Services, 14, 171-191.

Knox, R.W.O.B., Aubry, M.P., Berggren, W.A., Dupuis, C., Ouda, K., Magioncalda, R., Soliman, M., 2003. The Qreiya Section at Gebel Abu Had: Lithostratigraphy, clay mineralogy, geochemistry and biostratigraphy. Micropaleontology, 49, Suppl. 1, 93-104.

Loeblich, A.R., Tappan, H., 1988. Foraminiferal genera and their classification. New York, Van Nostrand Reinhold Company, 970 pp.

Luterbacher, H.P., Ali, J.R., Brinkhuis, H., Gradstein, F.M., Hooker, J.J., Monechi, S., Ogg, J.G., Powell, J., Röhl, U., Sanfilippo, A., Schmitz, B., 2004. The Paleogene period. In: Gradstein, F., Ogg, J., Smith, A. (eds.). A geologic time scale 2004, Cambridge, Cambridge University Press, 384-408.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci A. (ed.). Proceedings of the II Plankton Conference, Roma, Edizioni Tecnoscienza Rome, 739-785.

Marzouk, A.M., Scheibner, C., 2003. Calcareous nannoplankton biostratigraphy and paleoenvironment of the late Creta-

ceous-Paleogene of the Galala Mountains, Eastern Desert, Egypt. Courier Forschungsinstitut Senckenberg, 244, 11-35.

Molina, E., Arenillas, I., Pardo, A., 1999. High resolution planktic foraminiferal biostratigraphy and correlation across the Palaeocene/Eocene boundary in the Tethys. Bulletin de la Societé Géologique de France, 170, 521-530.

Monechi, S., Angori, E., Speijer, R.P., 2000. Upper Paleocene biostratigraphy in the Mediterranean region: Zonal markers, diachronism, and preservational problems. GFF. Geologiska Föreningens i Stockholm Förhandligar, 122, 108-110.

Obaidalla, N., 2004. The Paleocene/Eocene boundary foraminiferal events at Wadi Tarfa, northern Eastern Desert. In: Bice, K., Aubry, M., Ouda, K. (eds.). Climate and biota of the Early Paleogene, CBEP V, Assiut, Department of Geology, Faculty of Science, B-21.

Okada, H., Bukry, D., 1980. Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). Marine Micropaleontology, 5, 321-325.

Orue-Etxebarria, X., Pujalte, V., Bernaola, G., Apellaniz, E., Baceta, J.I., Payros, A., Nunez-Betelu, K., Serra-Kiel, J., Tosquella, J., 2001. Did the Late Paleocene thermal maximum affect the evolution of larger foraminifers? Evidence from calcareous plankton of the Campo Section (Pyrenees, Spain). Marine Micropaleontology, 41, 45-71.

Ouda, K., Berggren, W.A., Saad, K., 2003. The Gebel Oweina and Kilabiya sections in the Idfu-Esna area, Upper Nile Valley (Egypt). Micropaleontology, 49, Suppl. 1, 147-166.

Pardo, A., Keller, G., Oberhänsli, H., 1999. Paleoecologic and paleoceanographic evolution of the Tethyan realm during the Paleocene-Eocene transition. Journal of Foraminiferal Research, 29, 37-57.

Pujalte, V., Orue-Etxebarria, X., Schmitz, B., Tosquella, J., Baceta, J.I., Payros, A., Bernaola, G., Caballero, F., Apellaniz, E., 2003. Basal Ilerdian (earliest Eocene) turnover of larger foraminifera: Age constraints based on calcareous plankton and $\delta^{13}C$ isotopic profiles from new southern Pyrenean sections (Spain). In: Wing, S.L., Gingerich, P.D., Schmitz, B., Thomas, E. (eds.). Causes and consequences of globally warm climates in the early Paleogene. Boulder, Geological Society of America, Special Paper, 369, 205-221.

Pujalte, V., Schmitz, B., Baceta, J.I., Orue-Etxebarria, X., Bernaola, G., Dinarès-Turell, J., Payros, A., Apellaniz, E., Caballero, F., 2009a. Correlation of the Thanetian-Ilerdian turnover of larger foraminifera and the Paleocene-Eocene thermal maximum: confirming evidence from the Campo area (Pyrenees, Spain). Geologica Acta, 7(1-2), 161-175.

Pujalte, V., Baceta, J.I., Schmitz, B., Orue-Etxebarria, X., Payros, A., Bernaola, G., Apellaniz, E., Caballero, F., Robador, A., Serra-Kiel, J., Tosquella , J., 2009b. Redefiniton of the Ilerdian Stage (early Eocene). Geologica Acta, 7(1-2), 177-194.

Schaub, H., 1981. Nummulites et Assilines de la Téthys paléogène. Taxinomie, phylogenèse et biostratigraphie. Schweizerische Palaeontologische Abhandlungen, 104/105/106, 1-238.

Scheibner, C., Kuss, J., Marzouk, A.M., 2000. Slope sediments of a Paleocene ramp-to-basin transition in NE Egypt. International Journal of Earth Sciences, 88, 708-724.

Scheibner, C., Marzouk, A.M., Kuss, J., 2001a. Shelf architectures of an isolated Late Cretaceous carbonate platform margin, Galala Mountains (Eastern Desert, Egypt). Sedimentary Geology, 145, 23-43.

Scheibner, C., Marzouk, A.M., Kuss, J., 2001b. Maastrichtian-Early Eocene litho- biostratigraphy and Palaeogeography of the northern Gulf of Suez region, Egypt. Journal of African Earth Sciences, 32, 223-255.

Scheibner, C., Reijmer, J.J.G., Marzouk, A.M., Speijer, R.P., Kuss, J., 2003. From platform to basin: The evolution of a Paleocene carbonate margin (Eastern Desert, Egypt). International Journal of Earth Sciences, 92, 624-640.

Scheibner, C., Speijer, R.P., Marzouk, A., 2005. Larger foraminiferal turnover during the Paleocene/Eocene thermal maximum and paleoclimatic control on the evolution of platform ecosystems. Geology, 33, 493-496.

Schroeder, R., Neumann, M., 1985. Les grands foraminifères du Crétacé moyen de la Région Méditerranéenne. Geobios, Mem. spec., 7, 1-161.

Serra-Kiel, J., Hottinger, L., Caus, E., Drobne, K., Ferrandez, C., Jauhri, A.K., Less, G., Pavlovec, R., Pignatti, J., Samso, J.M., Schaub, H., Sirel, E., Strougo, A., Tambareau, Y., Tosquella, J., Zakrevskaya, E., 1998. Larger foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene. Bulletin de la Société Géologique de France, 169, 281-299.

Speijer, R.P., 1994. The late Paleocene benthic foraminiferal extinction as observed in the Middle East. Bulletin de la Société Belge de Géologie, 103, 267-280.

Speijer, R.P., Schmitz, B., Aubry, M.-P., Charisi, S.D., 1995. The latest Paleocene benthic extinction event: Punctuated turnover in outer neritic foraminiferal faunas from Gebel Aweina, Egypt. Israel Journal of Earth Sciences, 44, 207-222.

Speijer, R.P., van der Zwaan, G.J., Schmitz, B., 1996. The impact of Paleocene/Eocene boundary events on middle neritic benthic foraminiferal assemblages from Egypt. Marine Micropaleontology, 28, 99-132.

Speijer, R.P., Schmitz, B., van der Zwaan, G.J., 1997. Benthic foraminiferal extinction and repopulation in response to latest Paleocene Tethyan anoxia. Geology, 25, 683-686.

Speijer, R.P., Samir, A.M., 1997. *Globanomalina luxorensis*, a Tethyan biostratigraphic marker of latest Paleocene global events. Micropaleontology, 43, 51-62.

Speijer, R.P., Schmitz, B., 1998. A benthic foraminiferal record of Paleocene sea level and trophic/redox conditions at Gebel Aweina, Egypt. Palaeogeography, Palaeoclimatology, Palaeoecology, 137, 79-101.

Speijer, R.P., Schmitz, B., Luger, P., 2000. Stratigraphy of late Palaeocene events in the Middle East: Implications for low- to middle-latitude successions and correlations. Journal of the Geological Society, London, 157, 37-47.

Speijer, R.P., 2003. Danian-Selandian sea-level change and biotic excursion on the southern Tethyan margin (Egypt). In: Wing,

S.L., Gingerich, P.D., Schmitz, B., Thomas, E. (ed.). Causes and consequences of globally warm climates in the Early Paleogene. Boulder, Geological Society of America, 275-290.

Tjalsma, R.C., Lohmann, G.P., 1983. Paleocene-Eocene bathyal and abyssal benthic foraminifera from the Atlantic Ocean. Micropaleontology, Spec. publ. 4, 1-90.

Thomas, E., 1998. Biogeography of the Late Paleocene benthic foraminiferal extinction. In: Aubry, M.P., Lucas, S., Berggren, W.A. (eds.). Late Paleocene-Early Eocene climatic and biotic events in the marine and terrestrial records, New York, Columbia University Press, 214-243.

von Hillebrandt, A., 1962. Das Paläozän und seine Foraminiferenfauna im Becken von Reichenhall und Salzburg. Bayer. Akad. Wiss., Math.-Naturw. Kl., Abh., 108, 1-182.

von Salis, K., Ouda, K., Saad, E.D.M., Tantawy, A.A., Bernasconi, S., 1998. Calcareous nannofossils, foraminifera and stable isotope studies from the P/E boundary sections in Egypt. Strata, 9, 113-115.

White, M.R., 1992. On species identification in the foraminiferal genus Alveolina (Late Paleocene-Middle Eocene). Journal of Foraminiferal Research, 22, 52-70.

Wielandt, U., 1996. Benthic foraminiferal paleoecology and microfacies investigations of Paleogene sediments from the Farafra Oasis, Western Desert, Egypt. Tübinger Mikropaläontologische Mitteilungen, 13, 1-78.