

# *Globanomalina luxorensis*, a Tethyan biostratigraphic marker of latest Paleocene global events

Robert P. Speijer<sup>1,\*</sup> and Ashraf M. Samir<sup>2</sup>

<sup>1</sup>Department of Geology, Institute of Earth Sciences, Utrecht University,  
P. O. Box 80.021, 3508 TA, Utrecht, The Netherlands

<sup>2</sup>Geology Department, Faculty of Science, Alexandria University, Alexandria, Egypt

**ABSTRACT:** The lowest common occurrence (LCO) of the planktonic foraminifera *Globanomalina luxorensis* marks the level of the latest Paleocene global benthic extinction event (BEE) and associated negative  $\delta^{13}\text{C}$  excursion in various bathyal and neritic successions in the Mediterranean region. Below the BEE level, *G. luxorensis* is extremely rare and subordinate in abundance relative to its precursor *G. chapmani*. From this level onwards, *G. luxorensis* generally constitutes a large proportion of the planktonic assemblage (up to 10%). We propose to adopt the LCO of *G. luxorensis* as a marker for the level of the BEE in Tethyan continental margin deposits. It appears particularly useful for pinpointing the level of the BEE in neritic successions, where the benthic turnover is less pronounced. In combination, the BEE, the LCO of *G. luxorensis*, and the  $\delta^{13}\text{C}$  excursion, provide a powerful and accurate means of correlating a unique horizon through various marine environments. This makes this level very suitable to serve as a baseline for redefinition of the Paleocene/Eocene boundary.

## INTRODUCTION

The late Paleocene to early Eocene was a time of increased benthic and planktonic foraminiferal turnover. The latest Paleocene deep-sea benthic extinction event (BEE) concerns a well documented sharp faunal turnover, during which many long-ranging cosmopolitan calcareous deep-sea benthic foraminifera, such as *Gavelinella beccariiformis*, became extinct. This turnover has been observed in numerous sites in all oceanic basins (e.g. Tjalsma and Lohmann 1983; Nomura 1991; Pak and Miller 1992; Thomas 1992) and in many bathyal continental margin deposits (e.g. Von Hillebrandt 1962; Kaiho et al. 1993; Ortiz 1995; Speijer 1995). The BEE and associated excursions in carbon and oxygen isotopic records have been related to major climatic and oceanographic changes, in particular to high latitude warming, deep-sea circulation reversal, and carbon cycle perturbation (e.g. Kennett and Stott 1991; Bralower et al. 1995; Dickens et al. 1995; Thomas and Shackleton 1996). But not only deep-sea benthic ecosystems changed dramatically within a brief period of time; simultaneously, neritic benthic foraminifera faunas experienced a similar, though less dramatic turnover (Gibson et al. 1993; Speijer and Van der Zwaan 1994; Speijer et al. 1996a,b).

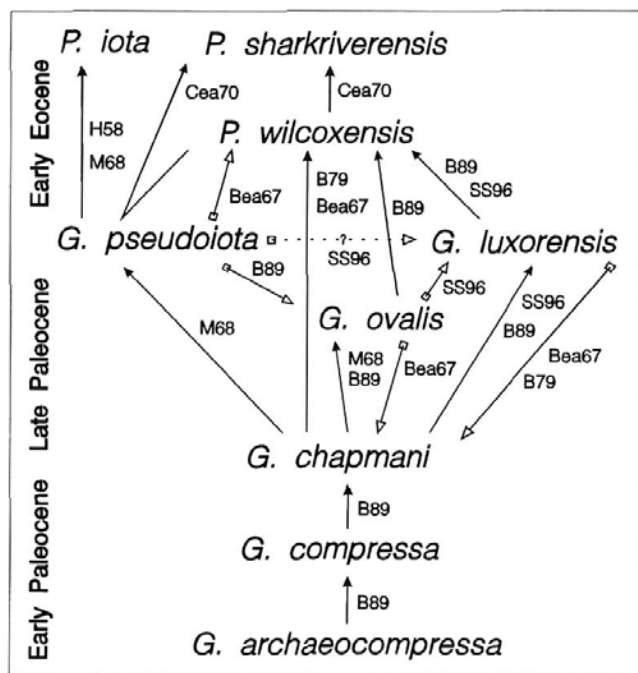
Pelagic ecosystems were only mildly perturbed during the latest Paleocene: Though the turnover in planktonic foraminifera within Zone P5 was punctuated, it was relatively minor and more gradual compared to the benthic turnover (Berggren et al. 1995; Canudo et al. 1995; Lu and Keller 1995). There is some documentation on planktonic foraminifera that have a regional highest or lowest occurrence (HO and LO, respectively) in close connection with the BEE. At southern high latitudes in the Southern Ocean, the LO of the planktonic foraminifera *Globanomalina australiformis* coincides with the BEE (Kennett and

Stott 1991), whereas in northern mid latitudes in Spain, the HO of *Igorina laevigata* (virtually) coincides with the BEE (Canudo et al. 1995). Speijer (1995) found the LO of *Globanomalina luxorensis* (reported as *Pseudohastigerina wilcoxensis*) coinciding with the BEE in bathyal deposits from localities in Egypt and Israel, situated in the subtropical-tropical Tethyan region. Subsequent studies on the reflection of the BEE in neritic deposits from Egypt indicated that *G. luxorensis* can be employed as a marker species to locate the level of the BEE, even in neritic settings where deep-sea taxa, such as *G. beccariiformis*, are generally absent and the turnover in benthic foraminifera is expressed differently (Speijer et al. 1996a,b). In order to assess the merit of *G. luxorensis* as a marker species we studied taxonomy, phylogeny, and stratigraphic distribution of *G. luxorensis* and closely related taxa in material from many outcrops in Egypt and from some additional localities in the Mediterranean region. Furthermore, we discuss distribution patterns of *G. luxorensis* as documented from Pakistan and of *G. pseudoiota* reported from New Zealand.

## SUMMARY OF PROPOSED PHYLOGENIES OF THE *GLOBANOMALINA-PSEUDOHASTIGERINA* LINEAGE

Through the last 40 years, quite a few papers contributed to the discussion on the evolution from smooth-walled, trochospiral Paleocene planktonic foraminifera (herein referred to as *Globanomalina*) to the planispiral Eocene *Pseudohastigerina*. Pearson (1993) summarized these earlier proposed phylogenetic relationships in the Paleocene-Eocene *Globanomalina-Pseudohastigerina* lineage (text-fig. 1). For convenience, we only employ the generic names *Globanomalina* and *Pseudohastigerina* for all species mentioned below, in accordance with Banner (1989) and Pearson (1993); note, however, that other generic assignments (e.g. *Globigerina*, *Globorotalia* and *Planorotalites*) were employed by the various workers mentioned. Hornibrook (1958b) was the first to suggest that the low trochoid, asymmetric *G. pseudoiota* (Hornibrook) could be the ancestor of the

\*Current address: University of Bremen, FB5 Geosciences, P. O. Box 330440, 28334 Bremen, Germany.



TEXT-FIGURE 1  
 Summary of proposed phylogenetic relationships between the *Globanomalina* and *Pseudohastigerina* species discussed (modified from Pearson 1993). Solid arrows connect a species to its supposed descendant. Open arrows connect junior synonyms (square) to a species (arrow point). Time scale is merely approximate. Explanation of abbreviations: B79 = Blow 1979; B89 = Banner 1989; Bea67 = Berggren et al. 1967; Cea = Cordey et al. 1970; H58 = Hornibrook 1958b; M68 = McGowran 1968; SS96 = this paper.

planispiral *P. iota* (Finlay). In a discussion on the origin and development of *Pseudohastigerina*, Berggren et al. (1967) considered the trochospiral *G. chapmani* (Parr) to be the direct precursor of the nearly planispiral *P. wilcoxensis* (Cushman and Ponton). Transitional forms, such as *G. luxorensis* (Nakkady) and *G. ovalis* Haque, were regarded as junior synonyms of *G. chapmani*; *G. pseudoiota*, however, was considered as a junior synonym of *P. wilcoxensis* (Berggren et al. 1967). McGowran (1968) did not elaborate on this lineage, but he briefly mentioned the possibility that *G. chapmani* could be ancestral to *G. pseudoiota* and *G. ovalis* and that in turn, the latter taxa could be precursors of *P. iota* as earlier suggested by Hornibrook (1958b). Cordey et al. (1970) reconsidered the evolution of *Pseudohastigerina* by means of a biometric analysis. They concluded that at least the younger specimens of *G. pseudoiota* (regarded as *Pseudohastigerina*) are transitional between *P. wilcoxensis* and *P. sharkriverensis* Berggren and Olsson. Blow (1979) essentially followed Berggren et al. (1967) as regards to the phylogeny of this lineage. The distinction between *G. chapmani* and *P. wilcoxensis* was defined in such a way that several primitive *P. wilcoxensis* of Berggren et al. (1967) were included within *G. chapmani* (Blow 1979). Finally, Banner (1989) proposed a lineage of *Globanomalina* starting with the early Paleocene *G. archaeocompressa* (Blow) and evolving through *G. compressa* (Plummer), *G. chapmani*, *G. ovalis* and *G. luxorensis* to *P. wilcoxensis* in the early Eocene. Only truly planispiral

specimens were assigned to *P. wilcoxensis*; all specimens with a clear low trochospiral tendency and an asymmetric aperture were regarded either as *G. ovalis* or *G. luxorensis* (see below). According to Banner (1989), *G. pseudoiota* should be regarded as a junior synonym of *G. ovalis*.

In summary, there appears to be considerable consensus on the phylogenetic linkage of *Globanomalina (chapmani)* to *Pseudohastigerina (wilcoxensis)*. The discussion mainly focused on the assignment of transitional types to *G. chapmani*, to *P. wilcoxensis*, or to one or more intermediate species, such as *G. luxorensis*, *G. ovalis*, and *G. pseudoiota*. A rather deviating view of the phylogeny of smooth-walled Paleocene planktonic foraminifera was recently expressed by Canudo (1994). Similar to the proposal by Banner (1989), this author suggested that many Paleocene species, amongst others *G. chapmani* and *G. luxorensis*, evolved from a mutual ancestor *G. compressa*. But, Canudo (1994) placed these species in the newly erected genus *Luterbacheria*, which would differ from *Globanomalina* in having an imperforate band or keel and less globose chambers. Moreover, he considered *Pseudohastigerina* to have evolved from (an unspecified) *Globanomalina* during the earliest Eocene. Consequently, *P. wilcoxensis* is thought to be unrelated to *G. chapmani* and *G. luxorensis*, despite the general consensus that exists on their phylogenetic linkage (e.g. Berggren et al. 1967; Blow 1979; Banner 1989; Pearson 1993).

**MATERIAL AND BIOSTRATIGRAPHIC TERMINOLOGY**

The late Paleocene to early Eocene *Globanomalina-Pseudohastigerina* lineage was studied by using samples from many localities in Egypt and from some additional sites in Israel, Spain and Tunisia (text-fig. 2). Most samples were collected during field trips conducted by teams from the Institute of Earth Sciences, Utrecht University, between 1974 and 1993. Additional samples from Egypt and Tunisia were supplied by various colleagues. Information on lithostratigraphy and biostratigraphy of the sections from which SEM-imaged specimens were derived (Plates 1 and 2) can be found in Luger (1985; Darb Gaga and Pyramidal Hill), Speijer and Van der Zwaan (1994; Wadi Nukhl), Speijer et al. (1996a; Gebel Aweina), and in Speijer et al. (1996b; Gebel Duwi). All figured specimens are stored in the private collection of the first author.

In order to avoid confusion in terminology, the P-notation used for planktonic foraminiferal biozones in this paper refers to biozonal scheme of the revised Paleocene time scale (text-fig. 3; Berggren et al. 1995); this means that biozonal designations in some of the papers discussed are converted according to the criteria of the new biozonal scheme. Following the criteria of Martini (1971), we adopted the NP-notation for the calcareous nannoplankton biozonation, that was incorporated into the revised time scale (Berggren et al. 1995).

**TAXONOMY**

Genus *Globanomalina* Haque, 1956, emended Banner, 1989

The genus *Globanomalina* is applied to the smooth walled, finely perforate, non-spinose and low-trochoid lineage in Paleocene to early Eocene planktonic foraminifera (Banner 1989). In most *Globanomalina* species, such as *G. chapmani*, the aperture is confined to the umbilical side; however, in *G. luxorensis*, and *G. pseudoiota* it transgresses the periphery and opens at the spiral side. Earlier species in this lineage are not considered in this paper.

*Globanomalina chapmani* (Parr)

Plate 1, figures 1-3

*Globorotalia chapmani* PARR 1938, p. 87, pl. 3, figs. 8, 9 (Western Australia). — BERGGREN ET AL. 1967 (partim), p. 277, text-fig. 1; text-fig. 3, no. 1; text-fig. 4, no. 1; pl. 1, figs. 3-6; NOT pl. 1, figs. 1-3. — STAINFORTH ET AL. 1975, p. 176, fig. 42, Nos. 1-6. — HAIG ET AL. 1993, p. 276, pls. 1, 2

*Globorotalia membranacea* (Ehrenberg) in LEROY 1953, p. 32, pl. 3, figs. 13, 14

*Globorotalia elongata* Glaessner in BOLLI 1957, p. 77, pl. 20, figs. 11-13. — LOEBLICH AND TAPPAN 1957 (partim), p. 189, (?pl. 45, fig. 5); pl. 46, fig. 5; (?pl. 48, fig. 5); pl. 49, fig. 7; pl. 54, figs. 1-5; pl. 59, fig. 4; pl. 60, fig. 9; (?pl. 63, fig. 2)

*Globorotalia troelseni* LOEBLICH AND TAPPAN 1957, p. 196, pl. 60, fig. 4; pl. 63, fig. 5. — EL-NAGGAR 1966, p. 238, pl. 17, fig. 10. — sensu BLOW 1979, p. 899, pl. 89, figs. 6-10; pl. 90, figs. 1, 2; pl. 234, figs. 1-6

*Globorotalia emilei* EL-NAGGAR 1966, p. 208, pl. 17, fig. 9

*Globorotalia* (*Turborotalia*) *chapmani* Parr, sensu Berggren et al. 1967 in BLOW 1979 (partim), p. 1059, pl. 116, figs. 1, (?; ?pl. 106, fig. 1); NOT: pl. 116, figs. 3-5

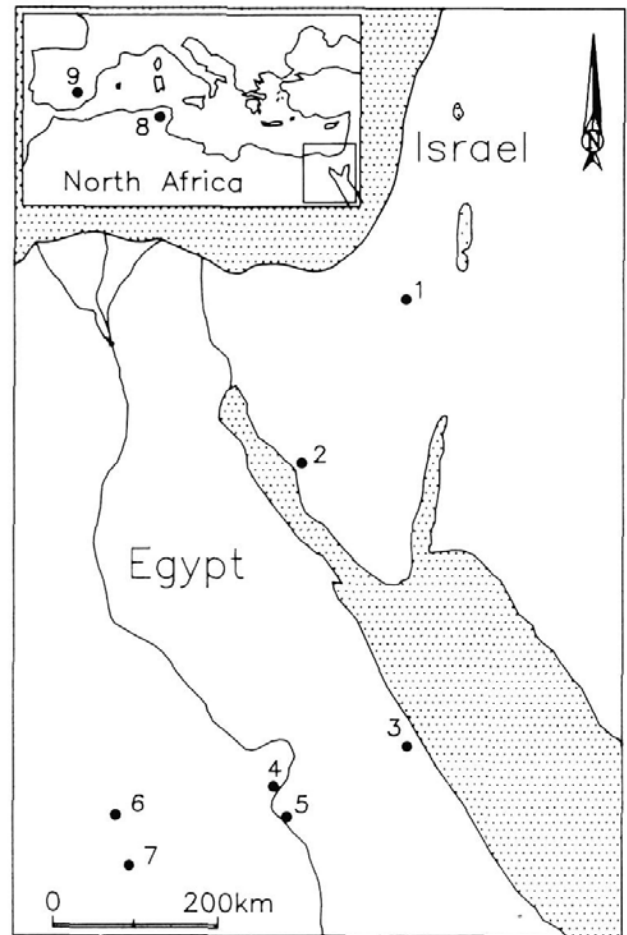
*Planorotalites chapmani* (Parr) in LUGER 1985, p. 102, pl. 20, figs. 8, 9. — TOUMARKINE and LUTERBACHER 1985, p. 108, fig. 12, nos. 5-8

*Luterbacheria troelseni* (Loeblich and Tappan) in CANUDO 1994, p. 32, pl. 1, figs. 6, 7; pl. 3, figs. 4, 5.

**Morphological characteristics:** The test consists of 11-15 chambers, that increase rapidly in size, with generally 4.5-6 chambers in the final whorl. Some specimens have up to seven chambers in the last whorl (pl. 1, figs. 2a-c). The sutures are depressed, radial and straight to slightly curved on the umbilical side, and more curved on the spiral side. The lobate periphery usually shows an imperforate band, which may develop into an indistinct keel on the earlier chambers of the last whorl ("*troelseni*" morphology; pl. 1, figs. 1a-c). Lateral compression of the test varies considerably; early specimens are usually more compressed and generally have fewer chambers than later ones. The aperture is moderately to highly arched and bordered by a distinct lip, extending from the umbilicus to the peripheral margin. The aperture does not transgress the peripheral margin onto the spiral side.

**Remarks:** Haig et al. (1993) show some of the variation in *G. chapmani* by SEM and ESEM (Environmental Scanning Electron Microscopy) images of the holotype and topotypes from the upper Paleocene (Zone P4) of Perth, Australia. All specimens from the type locality clearly show the imperforate peripheral band. In our material, however, not all specimens have this feature well developed; even on the earlier chambers of the last whorl some scattered pores may be present on the periphery (pl. 1, figs. 3a-c).

**Synonymy:** The taxa recorded as *Globorotalia emilei* El-Naggar and *Globorotalia troelseni* Loeblich and Tappan have previously been put in synonymy with *G. chapmani* by various authors (see e.g. Berggren et al. 1967; Stainforth et al. 1975; Blow 1979; Toumarkine and Luterbacher 1985). *Globorotalia elongata* Glaessner is not conspecific with *G. chapmani* (Berggren et al. 1967; Stainforth et al. 1975; Blow 1979; Toumarkine and Luterbacher 1985); in some early works (Bolli 1957; Loeblich and Tappan 1957), however, this species name was employed erroneously for specimens referable to *G. chapmani*. In Egypt, *G. chapmani* has been recorded under its proper name (Luger 1985), as *Globorotalia membranacea* (Ehrenberg) (Leroy 1953), and as *G. emilei* and *G. troelseni* (El-Naggar 1966).



TEXT-FIGURE 2

Provenance of the investigated late Paleocene-earliest Eocene material: 1 Nahal Avdat (Israel); 2 Wadi Nukhl; 3 Gebel Duwi; 4 Gebel Gurnah; 5 Gebel Aweina; 6 Pyramidal Hill; 7 Darb Gaga (2-7 in Egypt); 8 Bou Dabbous (Tunisia); 9 Caravaca (Spain).

**Differential diagnosis from *G. luxorensis*:** In *G. chapmani* the aperture does not extend to the spiral side as in *G. luxorensis*.

**Biostratigraphic distribution of *G. chapmani* in Egypt:** Zones P3-P6

*Globanomalina luxorensis* (Nakkady)

Plate 1, figures 4-6; plate 2, figures 1-4

*Anomalina luxorensis* NAKKADY 1950, p. 691, pl. 90, figs. 39-41 (western Sinai, Egypt). — LEROY 1953, p. 18, pl. 18, figs. 5-7. — NAKKADY 1959 pl. 5, fig. 1

*Globanomalina ovalis* HAQUE 1956, p. 148, pl. 14, fig. 3. — BANNER 1989 (partim): p. 175, pl. 1, figs. 1, 4 (?fig. 3); pl. 2, fig. 1, (?fig. 2); NOT pl. 3, figs. 1, 2

*Globigerina pseudoiota* HORNIBROOK ?1958a, p. 34, pl. 1, figs. 16-18. — HORNIBROOK ?1958b: p. 665, figs. 23, 26-28

*Globorotalia chapmani* Parr in BERGGREN ET AL. 1967 (partim), pl. 1, figs. 1-3; NOT: p. 277, text-fig. 1; text-fig. 3, no. 1; text-fig. 4, no. 1; pl. 1, figs. 3-6

*Pseudohastigerina wilcoxensis* (Cushman and Ponton) in BERGGREN ET AL. 1967, (partim), p. 278, text-fig. 2, d-f, m-r. NOT: text-fig. 2, (?a-c, ?g-l), s-v; text-fig. 3, 2-5; text-fig. 4, 2-5; (?text-fig. 5, 1-9); text-fig. 6, 1-6 — STOTT AND KENNETT 1990, p. 560, pl. 5, figs. 5, 6

*Pseudohastigerina wilcoxensis* (Cushman and Ponton) in STAINFORTH ET AL. 1975, p. 243, fig. 99, no. 6 ("transitional to *G. chapmani*")

*Globorotalia (Turborotalia) chapmani* Parr, sensu Berggren et al. 1967 in BLOW 1979 (partim), p. 1059, pl. 116, figs. 3-5; pl. 111, fig. 5 (recorded as "ex interc. *G. (T.) chapmani* and *P. wilcoxensis*"). NOT pl. 106, fig. 1; pl. 116, figs. 1, 2

**Morphological characteristics:** The test consists of about 13-15 chambers, increasing rapidly in size as added, with five to seven (generally six) chambers in the last whorl. Most specimens are rather inflated and have a circular last chamber in apertural view. However, lateral compression strongly varies, resulting in more flattened specimens with an oval last chamber in apertural view (pl. 1, figs. 4a-c; pl. 2, figs. 3a-c). The sutures are strongly depressed, radial and nearly straight on the umbilical side and more curved on the spiral side. The spiral side is almost entirely evolute in some specimens (pl. 1, figs. 5a-c), but generally it is semi-involute; some specimens are semi-involute on both sides (pl. 2, figs. 1a-c). The shape of the aperture ranges from high-arched and strongly asymmetric equatorially (pl. 1, figs. 6a-c; pl. 2, figs. 1a-c), to low-arched and almost symmetric equatorially (pl. 2, figs. 4a-c). The aperture is bordered by a distinct lip, forming a small umbilical flap, partly covering the umbilicus. The aperture transgresses the peripheral margin, but it does not open in the trace of the spiral suture. The test is finely perforate, although pore-pits on the earlier chambers may suggest the presence of larger pores (pl. 1, figs. 5a-c; figs. 6a-c). Some specimens show a distinct imperforate marginal band (pl. 1, figs. 6a-c), but mostly just less dense pore distribution at the periphery of the earlier chambers of the last whorl (pl. 1, figs. 5a-c; pl. 2, figs. 2a-c).

**Remarks:** Nakkady (1950) first described *G. ("Anomalina") luxorensis* from the uppermost shale bed of the Esna Formation (latest Paleocene or earliest Eocene) at Abu Durba, western Sinai, Egypt. Unfortunately, the quality of the drawing of the holotype (umbilical view) and paratypes (other views) is very poor and the description rather brief, though they are not in conflict with our species concept of *G. luxorensis*. Morphological features of the specimen from central Egypt, figured in Nakkady (1959) also correspond well with the description given above. This species has often been treated as a junior synonym of *G. chapmani* (Berggren et al. 1967, Blow 1979). However, *G. luxorensis* can easily be distinguished from *G. chapmani* on its apertural features and this also appears very useful for biostratigraphic purposes (see below). Blow (1979) proposed to include many specimens of *P. wilcoxensis* as figured by Berggren et al. (1967) into the concept of *G. chapmani*. Both these specimens as well as several specimens figured in Blow (1979) are included in the concept of *G. luxorensis* in this paper.

**Synonymy:** The holotype figure and description of *G. ovalis* from Nammal Gorge, Salt Range, Pakistan (Haque 1956) strongly suggest that this specimen falls within the range of variation of *G. luxorensis* as outlined above. Yet, Banner (1989) compared holotypes and paratypes of *G. ovalis* and *G. luxorensis* and concluded that the taxa are very closely related, but not conspecific, basically differing in the number of chambers per whorl, inflation of the chambers, and lateral compression. However, this conclusion was reached at on the basis of only five specimens of *G. luxorensis*, that were deposited in the British Museum of Natural History (BMNH). During our study we examined hundreds of specimens in the *G. chapmani*-*P. wilcoxensis* lineage from various localities, largely in Egypt (text-fig. 2) and allow for a greater intraspecific variation within *G.*

*luxorensis*, than indicated by Banner (1989). Consequently, we consider *G. ovalis* as a junior synonym and, as far as can be determined at the moment, *G. ovalis* also seems to have the same stratigraphic range in Pakistan as *G. luxorensis* in Egypt (see below).

Type figures and descriptions of *G. ("Globigerina") pseudoiota* from Waipawa, New Zealand (Hornibrook 1958a,b) strongly suggest a close affinity to *G. luxorensis*. Hornibrook donated ideotypes of *G. pseudoiota* from another outcrop (Birch Stream) to the BMNH. These specimens were studied and figured by Banner (1989), who concluded that *G. pseudoiota* is conspecific with *G. ovalis* and therefore should be considered as junior synonym. From the discussion above, it could be concluded that *G. pseudoiota* is actually a junior synonym of *G. luxorensis*. However, the morphology of the specimens shown by Banner (1989) does not fall within the range of variation as we observed it in our assemblages from Egypt. Although this may partly be explained by the poorer preservation of the New Zealand specimens, they appear more robust and tightly coiled, and also more quadrate in outline, due to the lower height-width ratio of the chambers. Moreover, two specimens figured by Banner (1989; his plate 3, figs. 1, 2) also lack the characteristic apertural features of *G. pseudoiota*, as shown in all five specimens figured by Hornibrook (1958a,b), and which enables distinction of *G. luxorensis* from *G. chapmani*. Without further detailed comparison of populations of *G. luxorensis* and *G. pseudoiota*, we cannot be conclusive on the proper taxonomic status of *G. pseudoiota*. Therefore, we only tentatively treat this species as a junior synonym.

**Differential diagnosis from *P. wilcoxensis*:** In *G. luxorensis* the aperture extends to the dorsal side, but it does not open in the trace of the spiral suture as in *P. wilcoxensis*.

**Biostratigraphic distribution of *G. luxorensis* in Egypt:** Zones P4-P6 (extending possibly higher).

Genus *Pseudohastigerina* Banner and Blow, 1959, emended Blow, 1979

The genus *Pseudohastigerina* is applied to the smooth walled, finely perforate, non-spinose, (nearly) planispiral lineage in Eocene planktonic foraminifera. All species have a (nearly) symmetric equatorial aperture opening in the trace of the spiral suture (cf. Blow 1979).

***Pseudohastigerina wilcoxensis* (Cushman and Ponton)**  
Plate 1, figure 5

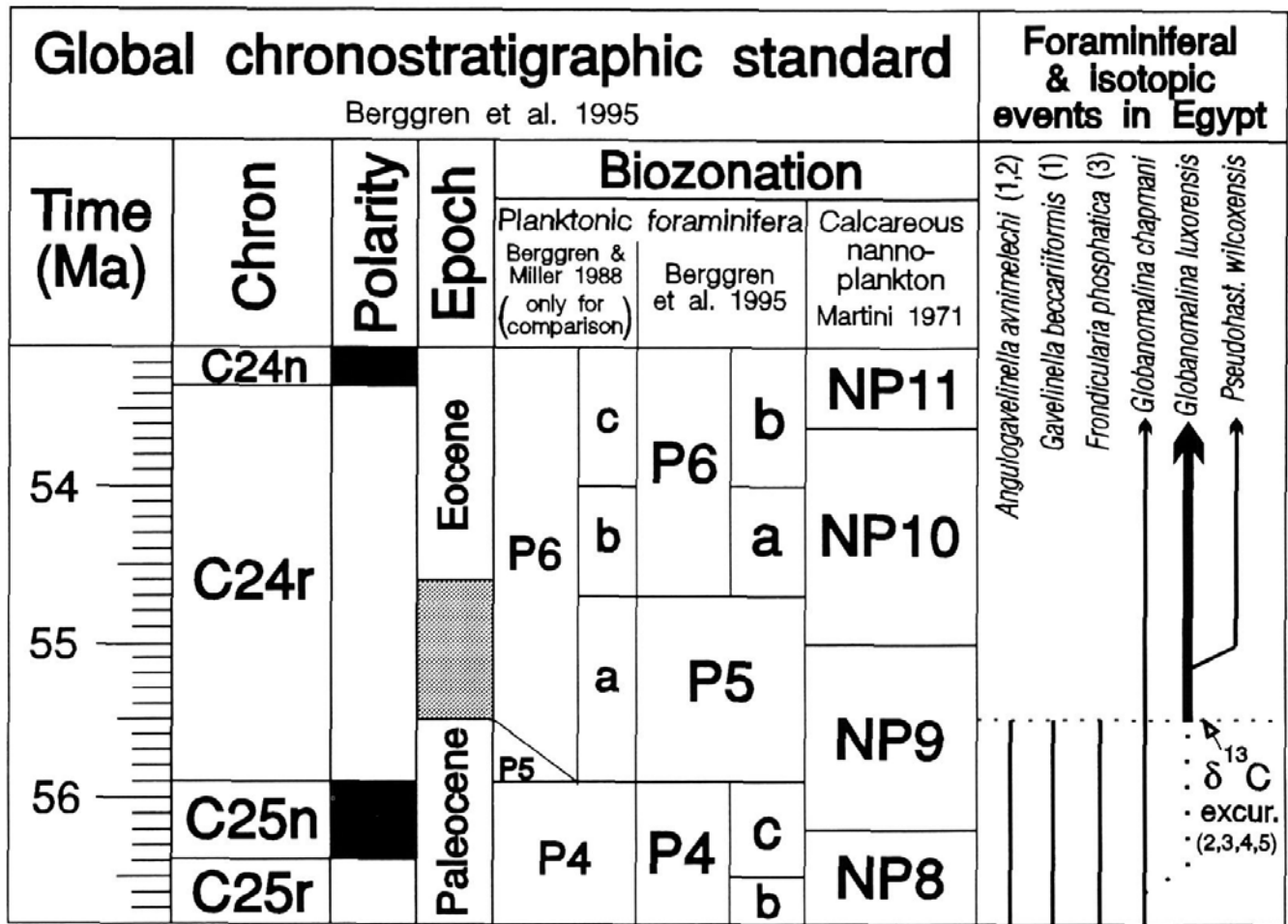
*Nonion wilcoxensis* CUSHMAN AND PONTON 1932, p. 64, pl. 8, fig. 11 (Alabama, USA)

*Hastigerina eocenica* BERGGREN 1960, p. 85, pl. 5, figs. 1, 2; pl. 10, fig. 2; text-figs. 13-16

*Pseudohastigerina wilcoxensis* (Cushman and Ponton) in BERGGREN ET AL. 1967 (partim): p. 278, text-fig. 2, (?a-c, ?g-l), s-v; text-fig. 3, 2-5; text-fig. 4, 2-5; (?text-fig. 5, 1-9); text-fig. 6, 1-6. NOT: text-fig. 2, d-f, m-r. — STAINFORTH ET AL. 1975, p. 243, fig. 99, nos. 1-5. — BLOW 1979, p. 1193, pl. 159, figs. 8, 9; pl. 161, figs. 10, 11. — LUGER 1985, pl. 20, figs. 10-12. — TOUMARKINE AND LUTERBACHER 1985 (partim), p. 108, fig. 12, 9-11, (?12)

**Morphological characteristics:** The nearly planispiral test consists of about 13-15 strongly inflated chambers with 5-7 chambers to the last whorl. Lateral compression varies somewhat. The depressed sutures are radial and slightly curved on both sides. The earlier whorl can be (slightly) visible on both sides.





TEXT-FIGURE 3

Correlation of BEE-related foraminiferal and isotopic events in Egypt to the revised time scale (Berggren et al. 1995). BEE and associated isotopic excursions occurred at 55.5 Ma. The LCO of *Globanomalina luxorensis* and the carbon isotopic excursion provide independent ways of correlating the BEE level from bathyal to neritic deposits in Egypt. Note the modifications in the P-notation of the planktonic foraminifera biozones compared to Berggren and Miller (1988). Numbers between brackets refer to: 1 = Speijer 1995; 2 = Speijer et al. 1996a; 3 = Speijer et al. 1996b; 4 = Charisi and Schmitz 1995; 5 = Schmitz et al. 1996.

Pore distribution is less dense on the peripheral margin, but a true imperforate peripheral band is not present. The symmetric equatorial aperture is bordered by a distinct lip and opens in the trace of the spiral suture.

**Remarks:** This brief description of *P. wilcoxensis* largely follows the species concept of Blow (1979). It differs from the concept of Berggren et al. (1967) in the exclusion of clearly trochospiral specimens with an asymmetric equatorial aperture (= *G. luxorensis*). Early specimens of *P. wilcoxensis* are rather large and show an aperture that opens in the trace of the spiral suture (pl. 2, figs. 5a-c). Smaller specimens from the same populations show the apertural characteristics of *G. luxorensis*. Thus, the specific and generic difference between *G. luxorensis* and *P. wilcoxensis* is initially only well visible in the later stages of ontogenetic development of some specimens. At higher stratigraphic levels also smaller specimens show the typical *Pseudohastigerina* apertural features.

**Synonymy:** *Pseudohastigerina eocenica* (Berggren) is generally regarded as a junior synonym of *P. wilcoxensis* (Berggren et al. 1967; Stainforth et al. 1975; Blow 1979).

**Biostratigraphic distribution of *P. wilcoxensis* in Egypt:** Zones P5-P6 (extending probably higher).

**PROPOSED PHYLOGENY**

Our analysis of late Paleocene-early Eocene *Globanomalina* and *Pseudohastigerina* strongly suggests the following phylogenetic lineage: *G. chapmani* → *G. luxorensis* → *P. wilcoxensis* (text-figs. 1 and 3). Within Zone P4, populations of *G. chapmani* contain forms with more inflated chambers, generally 6 in the last whorl. All specimens show an aperture in umbilical-extraumbilical position. Extremely rare specimens of *G. luxorensis* show a more involute spiral side and a strongly asymmetric equatorial aperture. The apertural lip only slightly transgresses the imperforate peripheral band. These specimens

are regarded as the first true *G. luxorensis*. This species is very rare up to the level of the BEE (mid Zones P5 and NP9). Just above this level, *G. luxorensis* becomes the dominant species in the lineage in faunas from the studied sections. The first specimens of *P. wilcoxensis* appear in small numbers somewhat higher above the BEE (upper Zones P5 and NP9). These early specimens are always large compared to the numerous specimens of *G. luxorensis*. At that level, juvenile specimens with a *P. wilcoxensis* morphology are not encountered, suggesting that initially only under specific circumstances the *P. wilcoxensis* morphology developed during a late stage of ontogenetic development of *G. luxorensis*. Later in the early Eocene, heterochronic pre-displacement (McNamara 1990) in *P. wilcoxensis* is observed, as also smaller specimens show the typical apertural features of *Pseudohastigerina*. This feature clearly shows the arbitrary division of these two species/genera in this time-slice and is probably the root to much taxonomic confusion.

In essence, the phylogeny proposed here does not differ much from earlier proposed phylogenies (Berggren et al. 1967; Blow 1979). The main difference is the nomination of a separate species for specimens transitional between *G. chapmani* and *P. wilcoxensis*, as also suggested by Banner (1989). The sudden increase in frequency of *G. luxorensis* relative to *G. chapmani* during the BEE indicates an acceleration in the gradual evolution from *G. chapmani* to *P. wilcoxensis*. The exact cause for this remains elusive, but it must be related to the global paleoceanographic changes that occurred at the end of the Paleocene.

Our studies do not support the proposal by Canudo (1994) to distinguish the new genus *Luterbacheria* from *Globanomalina* on the basis of the presence of an imperforate peripheral band or keel and by less globose chambers in *Luterbacheria*. Not only varies the amount of globosity of the chambers in *G. luxorensis* considerably, but also, the imperforate peripheral band may, or may not be present (usually it is poorly developed) in *G. luxorensis*. Yet, Canudo (1994) included *G. luxorensis* within *Luterbacheria*, and is not considered to be the precursor of *P. wilcoxensis*. In our view, *G. luxorensis* is conspecific with *G.*

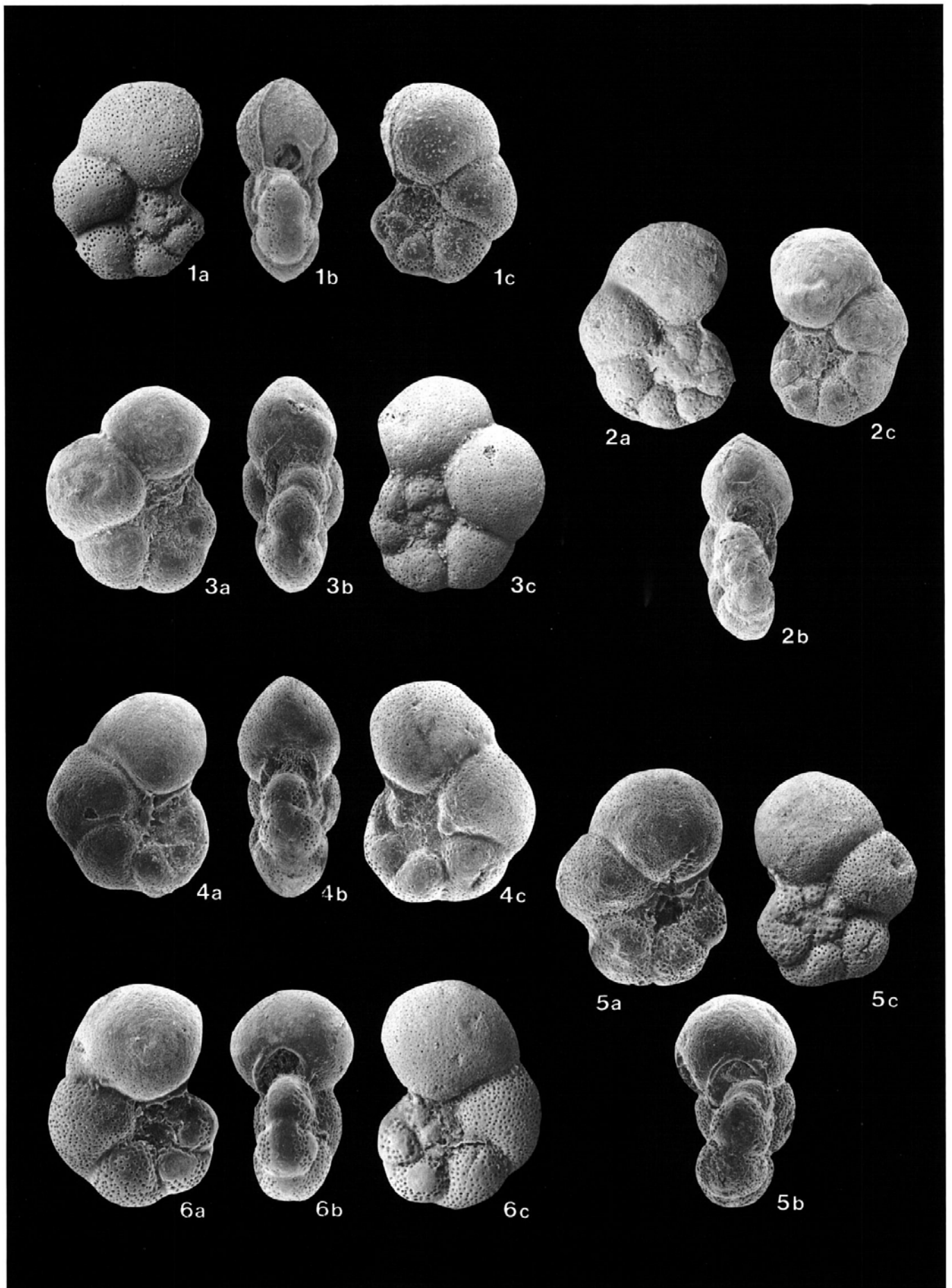
*ovalis*, the type species of *Globanomalina*, and ancestral to *Pseudohastigerina*.

#### TEMPORAL AND SPATIAL DISTRIBUTION OF *GLOBANOMALINA LUXORENSIS*

In Egypt, *G. luxorensis* has previously been recorded in many localities under its proper name (Nakkady 1950, 1959; LeRoy 1953; Ansary and Fahmy 1969), but also as (or included within) *P. wilcoxensis* (Luger 1985; Speijer 1995), or *G. troelseni* (El-Naggar 1966). It is usually found in the Esna Formation (Zones P5-P6), but it has also been recorded in the Tarawan Formation (Zone P4) (Nakkady 1959). Both observations are confirmed in the present study. In Zone P4 and in the lower part of Zone P5 (Tarawan Formation and the basal part of the Esna Formation), this taxon is extremely rare: scanning through thousands of Paleocene planktonic foraminifera and through *Globanomalina* in particular, resulted in finding merely two specimens of *G. luxorensis* below the BEE level. Consequently, this species comprises less than 0.1% of Paleocene pre-BEE planktonic assemblages. By contrast, *G. luxorensis* is very common in post-BEE assemblages in Egypt (text-fig. 3). It strongly increases in abundance at or just above the BEE level (from mid Zones P5 and NP9 upwards): relative abundances reach up to about 10% of the planktonic assemblages, in particular in neritic localities such as Gebel Aweina and Gebel Duwi (Speijer et al. 1996a,b). Studies on material from Israel, Tunisia, and Spain (text-fig. 1) essentially confirm this pattern. Detailed quantitative studies on the Caravaca section, Spain (Canudo et al. 1995) essentially confirm our findings; a sharp relative abundance increase up to 11% of *G. ovalis* was found just above the BEE bed. Below this bed, between 1% and 3% *G. ovalis* was encountered. However, only found *G. chapmani* in pre-BEE assemblages at Caravaca, suggesting that the species concept of *G. ovalis* by Canudo et al. (1995) may not fully correspond to our concept of *G. luxorensis*. Nevertheless, in the Mediterranean region the lowest common occurrence (LCO) of *G. luxorensis* appears to be a very useful marker, for correlation of a specific event level between bathyal and neritic settings.

#### PLATE 1 all magnifications $\times 170$

- |      |   |      |  |
|------|---|------|--|
| 1-3  | <i>Globanomalina chapmani</i> Parr, 1938  | 46   | <i>Globanomalina luxorensis</i> Nakkady, 1950  |
| 1a-c | " <i>troelseni</i> "-morphology with weakly developed keel on the earlier chambers (sample 21283/1; Zone P4, pre-BEE, Darb Gaga)    | 4a-c | laterally compressed specimen with a nearly equatorially symmetric aperture (sample base Esna Fm +26.5 m; Zones P5 and NP10, post-BEE, Gebel Aweina)   |
| 2a-c | specimen with seven chambers in the last whorl (sample S 1371; Zones P5 and NP9, pre-BEE, Wadi Nukhl)                               | 5a-c | inflated specimen with a slightly less dense pore distribution on the periphery (sample S 1031; Zones P5 and NP9/NP10, post-BEE, Gebel Duwi)   |
| 3a-c | specimen with a poorly developed imperforate peripheral band (sample base Esna Fm +15.5 m, Zones P5 and NP9, pre-BEE, Gebel Aweina) | 6a-c | inflated specimen with a distinct imperforate peripheral band, almost as pronounced as in the <i>G. chapmani</i> " <i>troelseni</i> " morphology; the aperture only slightly transgresses the periphery (sample base Esna Fm +26.5 m, Zones P5 and NP10, post-BEE, Gebel Aweina) |



In Pakistan, the LO of *G. luxorensis* ("*G. ovalis*") is within Zone P5 (Haque 1956; Gibson 1996), and in terms of calcareous nannofossil biozonation, within (the upper part of) Zone NP9 (Haq 1972; Gibson 1996). Therefore, the LO of *G. luxorensis* is in the same stratigraphic interval as the BEE and the carbon isotopic excursion elsewhere, i.e. within Zones P5 and NP9. In lack of detailed studies on the distribution of *G. luxorensis* in Pakistan, we can not assess whether this LO concerns actually a LCO as in the Mediterranean region. In New Zealand, the LO of *G. pseudoiota* is within the Waipaiian Stage (Hornibrook 1958a); this level correlates with the upper part of Zone NP9, (just?) above the BEE (extinction of e.g. *G. beccariiiformis*, *Neoflabellina*) (Hornibrook 1958a; Hornibrook and Edwards 1971; Kaiho et al. 1993). Therefore, irrespective of the exact taxonomic status of *G. pseudoiota*, it is striking that its LO is found in close connection with the BEE. Detailed taxonomic and distributional studies are required to solve questions related to the affinity of *G. pseudoiota* to *G. luxorensis* and to the exact position of its LCO relative to the BEE level.

#### TOWARDS REDEFINITION OF THE PALEOCENE/Eocene BOUNDARY

Members of International Geological Correlation Program (IGCP) Project 308 "Paleocene/Eocene Boundary Events in Time and Space" are currently investigating upper Paleocene to lower Eocene stratigraphy in order to propose a Global Stratotype Section and Point (GSSP) for the Paleocene/Eocene (P/E) boundary. Perhaps the most suitable level to define an unequivocal GSSP for the P/E boundary is within the narrow timeslice that comprises the latest Paleocene global events (BEE and isotopic excursions) that mark the middle of Zones NP9 and P5 in the lower part of Chron C24r at  $\approx 55.5$  Ma (text-fig. 3; Berggren et al. 1995; Berggren and Aubry 1996). This level has been determined by the extinction of *G. beccariiiformis* and associated taxa in Tethyan bathyal successions in Egypt (Speijer and Van der Zwaan 1994; Speijer 1995), Israel (Benjamini 1992; Speijer 1995) and Spain (Coccioni et al. 1994; Ortiz 1995). Also in neritic successions in Egypt, this level can easily be traced by a turnover in benthic foraminifera. The extinction of *Angulogavelinella avnimelechi* and associated taxa marks

this level in outer neritic deposits of Gebel Aweina (Speijer et al. 1996a), while in the middle neritic succession of Gebel Duwi it can be traced by the local disappearance of *Fronidularia phosphatica* (Speijer et al. 1996b). Stable isotopic studies provide independent support for delineation of this level in neritic deposits in Egypt (Charisi and Schmitz 1995; Schmitz et al. 1996; Speijer et al. 1996a,b) (text-fig. 3). Our studies add another independent marker to recognize this level in various Tethyan continental margin settings. At least in the Mediterranean region and perhaps also in Pakistan, the LCO of *G. luxorensis* provides a valuable marker for recognition of the level of the BEE; this applies in particular to neritic environments where the BEE is less pronounced (Speijer et al. 1996a,b). Carbon isotope stratigraphic studies on paleosol carbonate and tooth enamel suggest that this level can even be correlated to non-marine successions in France (Sinha and Stott 1994) and in the US (Koch et al. 1995). The possibility to correlate a specific stratigraphic level between various marine and perhaps even non-marine settings makes this event level very suitable to serve as a baseline for the establishment of a GSSP for the P/E boundary.

#### CONCLUSIONS

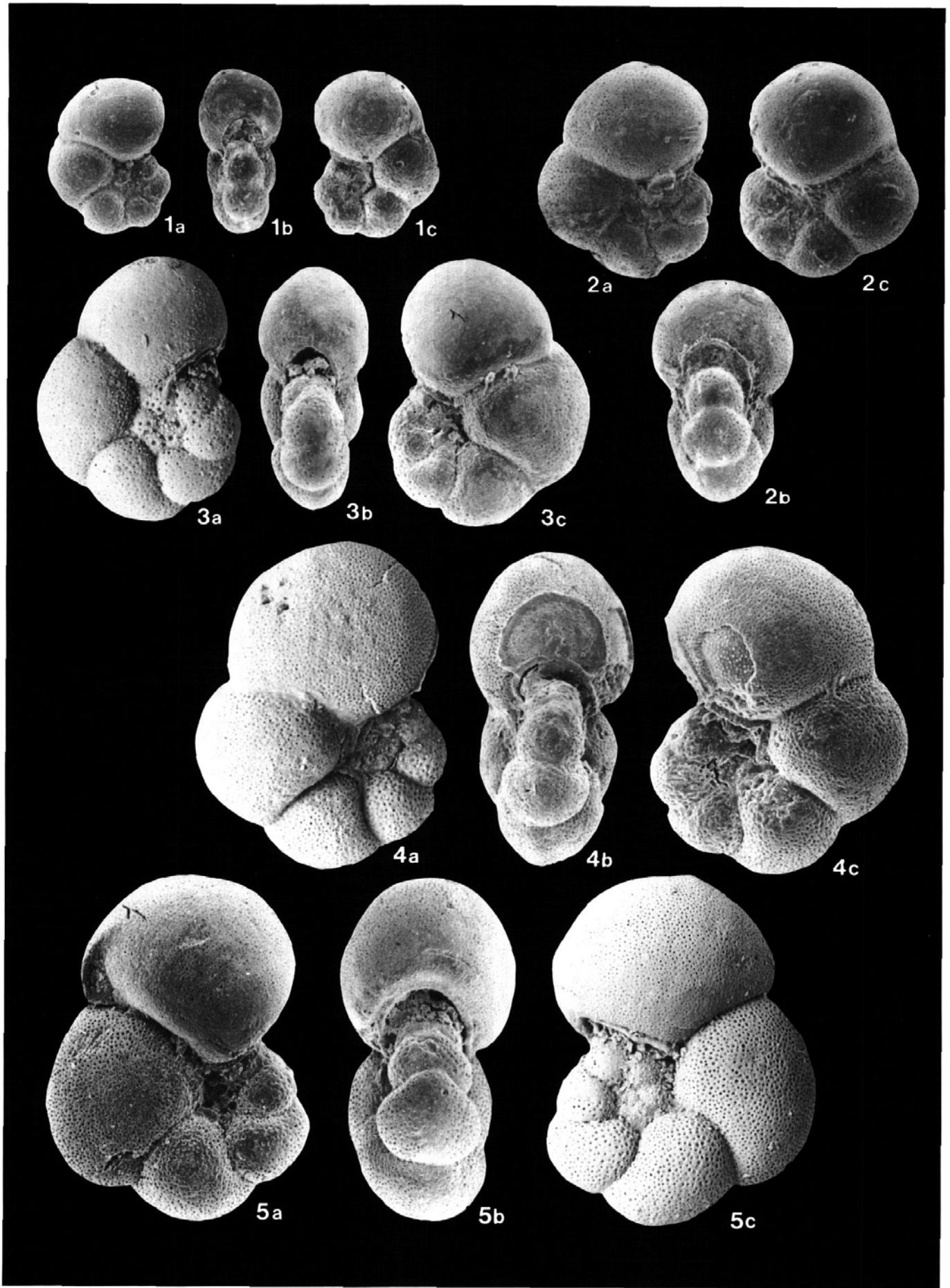
Transitional forms between *Globanomalina chapmani* (Parr) and *Pseudohastigerina wilcoxensis* (Cushman and Ponton) from the Tethyan region are regarded as *G. luxorensis* (Nakkady), which we consider to be a senior synonym of *G. ovalis* Haque. These taxa are primarily distinguished by their apertural characteristics. Within Zones P4-P6, *G. luxorensis* intergrades with *G. chapmani*. From the upper part of Zone P5 onwards, *G. luxorensis* also intergrades with *P. wilcoxensis*. Initially, the *P. wilcoxensis* morphology is only attained in some large adult specimens; later on, also juvenile specimens show the characteristic features of *P. wilcoxensis* (heterochronic replacement).

In the Mediterranean region the LCO of *G. luxorensis* coincides with the extinction of *Gavelinella beccariiiformis* and associated taxa and with the negative excursion in the  $\delta^{13}\text{C}$  record. From that stratigraphic level onwards, *G. luxorensis* is an important constituent of planktonic assemblages (composing up to 10%)

#### PLATE 2 all magnifications $\times 170$

- |      |  |   |
|------|--|---|
| 1-4  | <i>Globanomalina luxorensis</i> Nakkady, 1950  |   |
| 1a-c | juvenile specimen with highly arched and asymmetric aperture (sample 3382/27; Zone P5, post-BEE, Pyramidal Hill)   | 4a-c  |
| 2a-c | tightly coiled specimen with only five chambers to the last whorl and less dense pore distribution on the periphery (sample 20283/5; Zone P5, post-BEE, Darb Gaga) | large inflated specimen with equatorially asymmetric aperture and a less dense pore distribution on the periphery (sample base Esna Fm + 39.5 m, Zones P5 and NP10, Gebel Aweina) |
| 3a-c | laterally compressed specimen with distinct pore-pits on spiral side of earlier chambers (sample base Esna Fm +26.5 m, Zones P5 and NP10, post-BEE, Gebel Aweina)  | 5   |
|      |  | <i>Pseudohastigerina wilcoxensis</i> Cushman and Ponton, 1932   |
|      |  | 5a-c  |
|      |  | early large specimen with diagnostic apertural features, but distinct trochospiral coiling mode (sample base Esna Fm +26.5 m, Zones P5 and NP10, Gebel Aweina)                    |





and the most common species in the *Globanomalina* lineage. Below the BEE level, *G. luxorensis* is very rare (<0.1%) and *G. chapmani* is the most common species in this lineage. In Egypt, the LCO of *G. luxorensis* provides an excellent independent marker for delineating the level of the BEE, and is particularly useful in neritic successions, where the benthic turnover is less pronounced. In combination, the BEE, the LCO of *G. luxorensis* and the carbon isotope excursion, are powerful tools to recognize a distinct horizon in various marine environments. Therefore, we strongly support the proposal to define a GSSP for the P/E boundary in connection to this unique horizon.

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