On the origin of *Nummulites: Urnummulites schaubi* n. gen. n.sp., from the Late Paleocene of Egypt

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ABSTRACT: *Urnummulites schaubi* n. gen. n. sp., is a rotaliid foraminifera. It is found for the first time in the Late Paleocene toe of slope sediments of a carbonate platform Stratigraphic section D6, Bir Dakhl, Southern Galala, Eastern Desert, Egypt. The form is believed to be the ancestor of *Nummulites.* It is distinguished from *Kathina* by having asymmetrical polar pustules on both sides. The pustule is only well pronounced ventrally, where it possesses perforations (punctuation) and is lacking the umbilical pillar found in *Kathina*. In the involute ventral side the test possesses "alar" prolongations. s. str., while these prolongations are lacking dorsally. The form also recalls *Laffitteina* (a Maastrichtian genus) but it lacks the double septa and the ramifying interseptal canals. *Urnummulites* differs from all the representatives of Rotaliidae by the presence of the septal filaments. The form is believed to be the ancestor of *Nummulites.*

INTRODUCTION

Nummulites are good markers for Early Tertiary (Eocene, Oligocene) sedimentary sequences in the Tethyan realm. The species of this genus had evolved very rapidly and are classified into evolutionary groups (Blondeau 1972 and Schaub 1981) which have common characteristic morphologic features that undergo changes during evolution.

In each species, the morphologic features that distinguish the group to which it belongs can be easily observed in the megalospheric form and could be also observed in the inner whorls of individuals of the microspheric generation, as the various growth stages observed in the first whorls of microspheric tests of a species recapitulate the spiral development of the ancestral forms of the group to which the species belongs. The geographical distribution and "islands" of isolation should be investigated for the entire range of stratigraphical distribution of a group of species in order to evaluate the terminal evolutionary stages that lead to its extinction. Many authors (Boussac 1911, Douville 1919, Schaub 1964, 1981, Nemkov 1967 and Blondeau 1972) presented evolutionary schemes for the groups of *Nummulites*. The present study depends on several successive populations found in a well developed stratigraphic sequence which allows the evaluation of their phylogenetic relationships.

Because the species of *Nummulites* are bottom dwellers, phylogenetic relationships can be only deduced by studying either single or neighboring stratigraphical sections. Sometimes different basins can be included in these relationships, due to the possibility of migration.

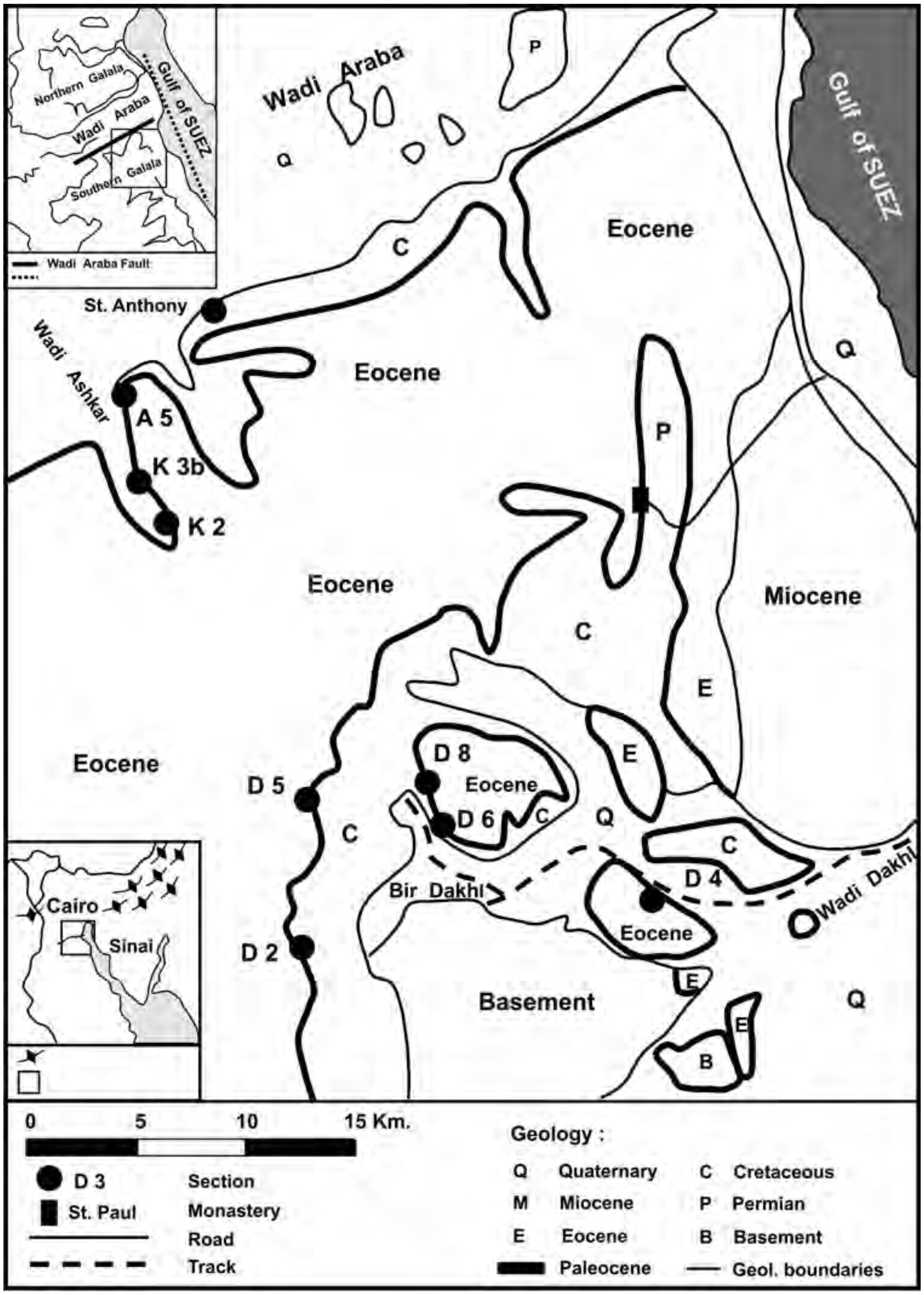
The well established criteria to evaluate the phylogeny of species of *Nummulites* involve: morphologic similarity, the internal whorls of ontogenetic stages, the stratigraphical position of each stage of evolution, and the geographical distribution of each.

The stratigraphical interval of the Paleocene-Eocene boundary has been intensively studied worldwide during the last few years. This is perhaps due to the fact that during the early Paleogene (from 59 to 52 Ma) the most pronounced warming episode of the Cenozoic was detected (Zachos et al., 2001). This also included a brief period of extreme warming at the Paleocene-Eocene boundary, called the Paleocene-Eocene thermal maximum (PETM). Another reason for the interest in the Paleocene-Eocene boundary interval is the search for a stratotype (global stratotype and section or GSSP) and the establishment of criteria for the definition of this boundary. The Dababiya section in southern Egypt was recently chosen for this purpose (Ouda and Aubry 2003) and the negative carbon isotopic excursion (CIE), as introduced as boundary criterion.

In this study a conceptual model is proposed to explain the appearance and evolution of the larger foraminifera (*Nummulites*) during the latest Paleocene. The study is based on samples from a section (D.6) collected from a carbonate platform in the Galala Mountains (Egypt), which are located approximately 300km north of the GSSP section in Dababyia. This investigation led to the erection of one new taxon: *Urnummulites schaubi* n. gen. n. sp., which is believed to be the ancestor of *Nummulites*.

GEOLOGICAL SETTING

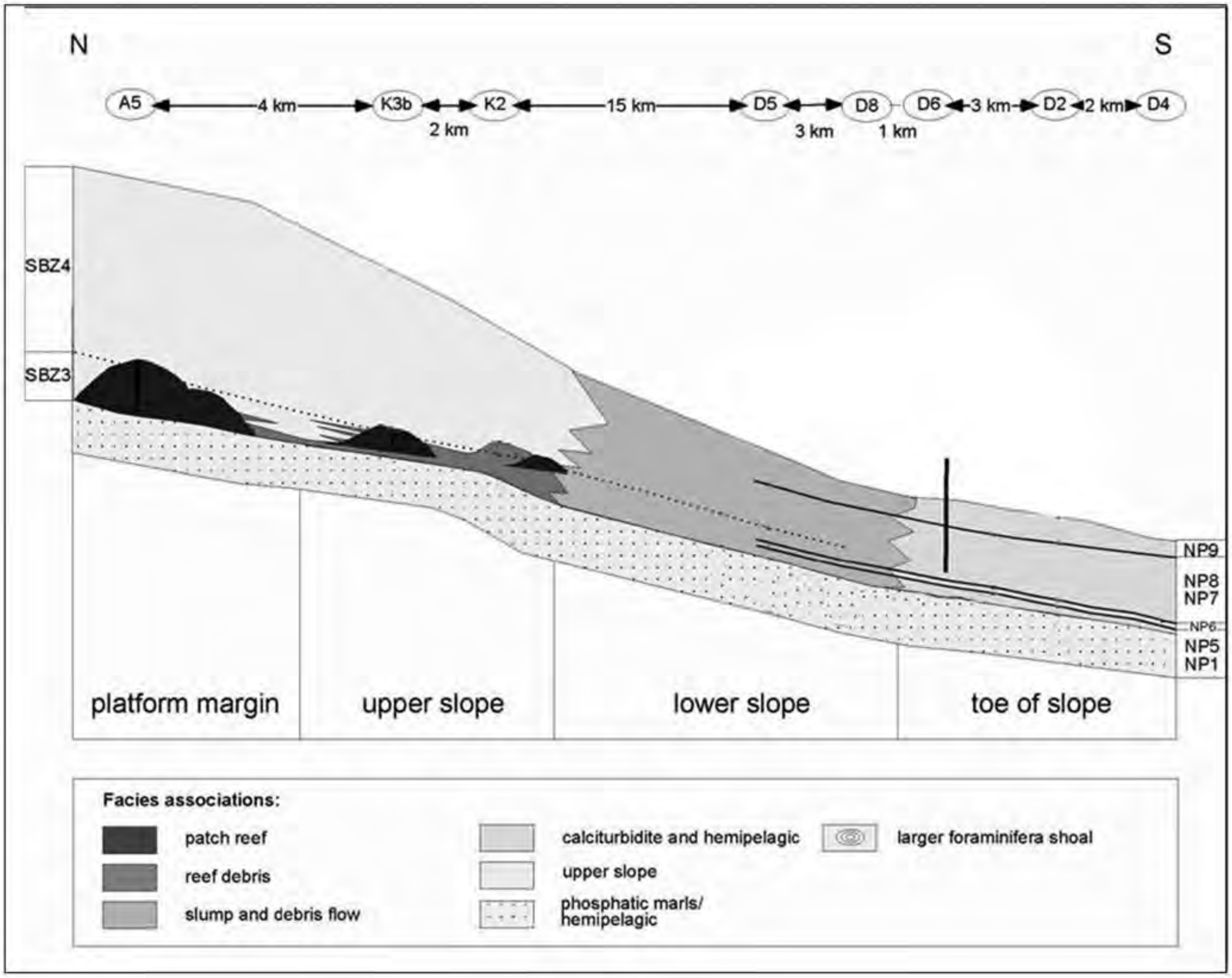
The Galala Mountains in the Eastern Desert, west of the Gulf of Suez, represent a southern branch of the Syrian Arc fold belt, called the Northern Galala/Wadi Araba High (NGWA; Kuss et al. 2000; text-fig. 1, lower inlay). On the NGWA High a mixed carbonate platform developed during the Late Campanian to the Eocene. The investigated sections follow a paleogeographical transect through five different facies belts running perpendicular to the former strike and ranging from the platform in the north to the basin in the south: platform margin, upper slope, lower slope, toe of slope, and basin (text-fig. 2).



TEXT-FIGURE 1
Satellite image of the Late Paleocene-Early Eocene sections in the Southern Galala Mountains, Eastern Desert, Egypt. Lower inlay: Syrian arc structures in Egypt, Sinai and Israel. Upper inlay: The Galala Mountains on the western side of the Gulf of Suez. The Northern Galala and the Southern Galala are separated by the Wadi Araba. Rectangle marks the area of the satellite image. The strike directions of the Wadi Araba Fault (related to Mesozoic to Paleogene tectonics) and the Gulf of Suez Faults (related to the Miocene opening of the Gulf) lie perpendicular to each other. Satellite image courtesy http://zulu.ssc.nasa.gov/mrsid/

The development of the Paleocene carbonate platform margin and the variation of the biotic content along the Southern Galala Mountains (Egypt) are closely related to tectonic activity (various amounts of uplift and subsidence) instead of eustatic sea-level changes (Scheibner et al. 2003). The following four tectono-sedimentary stages characterize the evolution of this Paleocene carbonate platform:

1) Through the Maastrichtian to Selandian seabed bottom topography controlled the initial lateral facies distribution across the platform-basin transect.



TEXT-FIGURE 2
Facies distribution along the paleogene platform-margin to toe-of slope-transect based on eight stratigraphic sections (A5 to D4 of text-fig. 1). The rectangle marks figure 3. On the left the Standard shallow benthos zonations and on the right the calcareous nannofossil zonations are listed.

2) The combination of a significant drop in sea level and tectonic uplift of the Northern Galala/Wadi Araba High initiated the late Paleocene platform progradation in the Selandian (59 Ma).

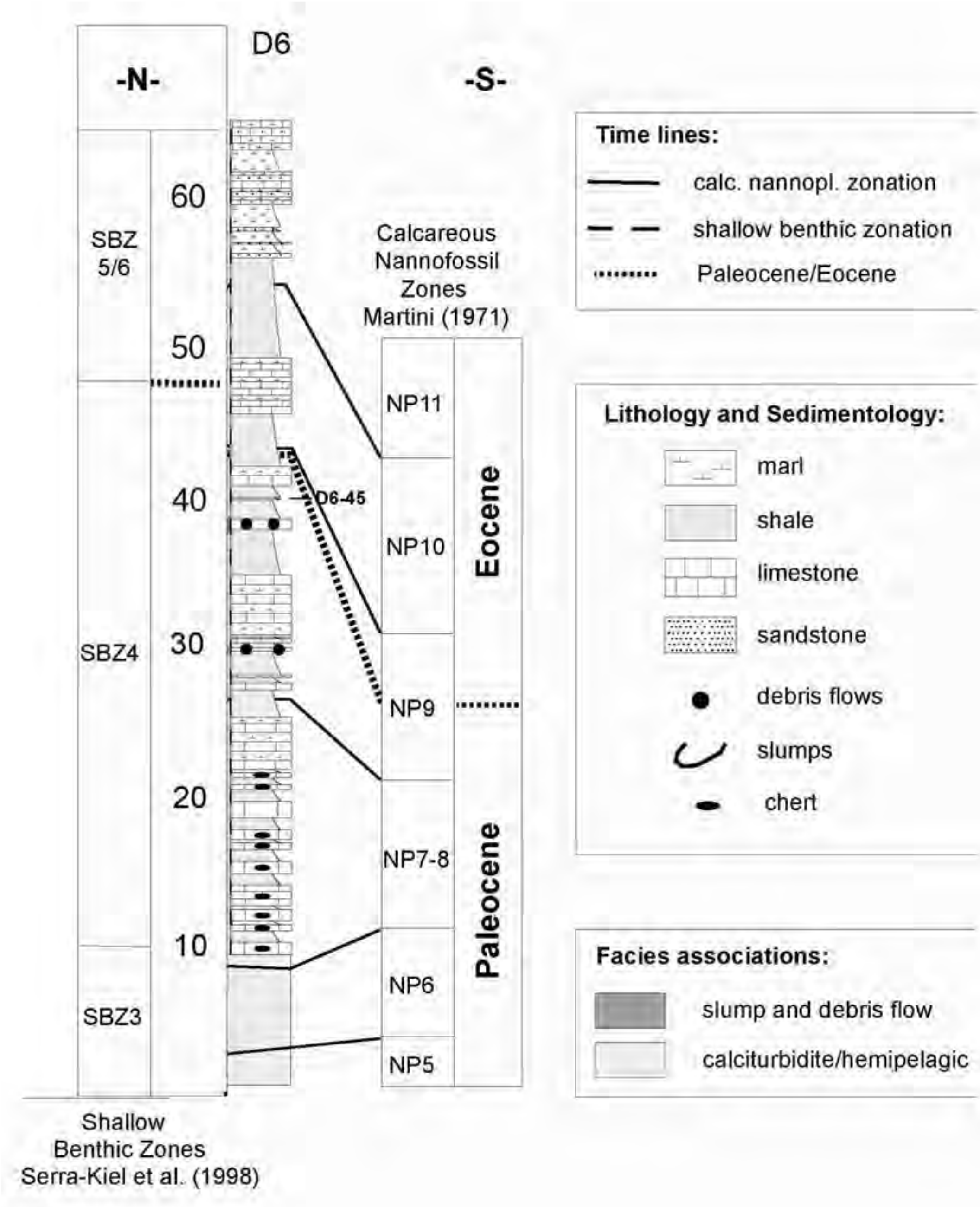
3) During the progradation phases of the carbonate platform (59-56.2 Ma; NP5 - NP8) the following facies belts developed: coral patch reefs, and reef debris were deposited at the platform margin, well bedded carbonates on the upper slope, slumps and debris flows on the lower slope, calciturbidites at the toe of slope and hemipelagic sediments in the basin.

4) During the retrogradational phase (56.2 Ma-55.5 Ma; NP9) the combination of a sea-level rise and differential subsidence of various parts of the platform due to rotational block movements not only resulted in a change of organisms at the platform margin from coral patch reefs to larger foraminiferal shoals, but also in a decrease in slump and debris-flow activity on the lower slope, and a decrease in calciturbidite activity at the toe of slope.

In this work we concentrated on the strata deposited during the progradation and retrogradation phases of the carbonate platform (stages 3-4: 59-55.5 Ma). The lithostratigraphic units of the studied successions encompass two lithostratigraphic units that can be subdivided into the shallow-water Southern Galala Formation and the deep-water Dakhla Formation:

1) Dakhla Formation: In the lower slope to toe of slope sections D2-D4 (text-fig. 2), it consists of shaley grey-green marls in the Paleocene and compares well with the foraminiferal content in the stratotype at the north of Mut, Dakhla, Oasis, Egypt.

2) Southern Galala Formation: In the lower slope section D5, it is composed of limestones that were gravity deposited such as glides, slumps and debris flows, similar to descriptions of Scheibner et al. (2000; 2001). In the toe of slope sections D6



TEXT-FIGURE 3
Stratigraphic section measured at Bir Dakhl (D6).

and D8, the Southern Galala Formation is represented mainly by alternating up to (<1m thick) limestones (calciturbidites) with abundant chert layers or nodules and shaley marls (up to 0.70m thick). The toe of slope section D8 consists also of few debris flows and therefore is transitional between sections D5 and D6.

BIOSTRATIGRAPHY

The biostratigraphic scheme of Serra-Kiel et al. (1998) has been applied to the larger foraminifera (SBZ), that of Martini (1971) to the nannoplankton (NP-Zones), and that of Berggren et al. (1995, 2000) to the planktic foraminifera (P-Zones). The CP nannofossil biostratigraphic scheme of Bukry (1973) and Okada and Bukry (1980) provides additional resolution, especially within NP7/8 (CP6/7) and NP9 (CP8). The CP nannofossil biozonation was originally based on low-latitude areas and deep-sea sections, whereas the NP scheme of Martini (1971) has a broader latitudinal range and was erected using mainly near-shore, hemipelagic environments. Thus, we primarily utilized the NP Zones.

The Paleocene-Eocene boundary has been recently globally delineated by the Carbon Isotope Excursion (CIE) (Aubry and Ouda 2003) which coincides with the boundary of NP9a and NP9b and the Benthic Extinction Event (BEE) and in our sections with the boundary between SBZ4 and SBZ5.

TABLE 1
Comparison between *Urnummulites* n. gen. n. sp. with allied genera such as *Lockhartia*, *Rotalia* and *Nummulites*

Genera / Characters	*Kathina* Smout	*Lockhartia* Davies	*Rotalia* Lamarck	*Nummulites* Lamarck	*Urnummulites* n. gen.
Overall shape of the Test	Lenticular or unequally biconical	Biconical to lenticular in which the dorsal side is more convex than the ventral side	Biconvex, asymmetric	Biconvex, lenticular or flat	Unequally biconvex in which ventral side is more convex than the dorsal one
Wall	Calcareous very finely perforate lamellar and radially fibrous	Calcareous, coarsely perforate and punctuate on the spiral side evolute	Calcareous perforate	Calcareous, hyaline	Calcareous, radially fibrous and finely perforate
Type of coiling	Low trochospiral	Trochospiral	Trochospiral	Planispiral and symmetrical	Trochospiral
Dorsal side	Less convex than ventral or flat or even concave	Convex, spiral side evolute	Evolute	Symmetrical	evolute
Ventral side (with umbilical structure)	With pillars and central plug and vertical canals opening as pores or slits on this side	Involute with numerous umbilical pustules	Involute	Symmetrical	Involute
Spire, septa and chambers	Spire simple and trocoid, chambers without supplementary chambers, septa double and having basal inter-cameral foramen	Simple spire, numerous chambers visible	Chambers visible on dorsal side while the test formed chambers are visible ventrally	Lax to tight chamber, variable and septa curved back at the periphery	Lax spire, chambers variable and septa thick similar to those in *Nummulites*
Pillars or polar pustules	Pillars and plug exist ventrally and in some species the plug is surrounded by grooves	Broad umbilicus filled with numerous pillars, that end at the surface as pustules	Umbilical plug exists and a spiral canal encircles the central umbilical mass of pillars	Some species with central boss, others lacking with or without granules externally pillars ,on or between septal filaments and appear at the surface as pustules	Broad umbilicus (boss), with circular pores, with polar pustules on both sides, lacking granules or pustules and without externally umbilical plug and pillars interspersed on the septal filaments or in between and seen ventrally
Alar prolongation	No present	Not present	Not present	Exists between successive whorls	Exists only ventrally
Aperture	Interiomarginal slit	Interiomarginal slit	Interiomarginal and intercameral foraminifers extending from umbilical periphery	Intercameral	Intercameral
Dimorphism	In some species a small nucleocone exists and a real dimorphism is not pronounced	Not pronounced	Not pronounced	Pronounced	Pronounced
Age	Paleocene	Paleocene-Middle Eocene	Upper Cretaceous to Eocene	Eocene-Oligocene and Paleocene (?)	Late Paleocene
Environment	Marine sheltered, restricted	Marine sheltered, restricted	Marine	Shallow opened marine	Deep open marine

Late Paleocene Larger Foraminifera

Several index species were identified in thin sections from the Late Paleocene of Bir Dakhl (Southern Galala): *Hottingerina lukasi, Glomalveolina* spp, *Ranikothalia* spp., *Miscellanea* spp. and *Urnummulites schaubi* n. gen. n.sp. These species were found in different locations as follows:

1) *Hottingerina lukasi:* According to Drobne (1975), *H. lukasi* ranges within her *Glomalveolina primaeva* Biozone in Slovenia. However, White (1994) showed that this species ranges from the *Glomalveolina primaeva* to *G. ellipsoidalis* Biozones in Oman. Gietl (1998) and Kuss and Leppig (1989) described *Hottingerina lukasi* in the Galala Mountains from the *G. levis* Biozone (SBZ4). In this last mentioned study *H. lukasi* is considered to be an index fossil for SBZ4.

2) *Glomalveolina* spp.: Up to the Paleocene/Eocene boundary we found *G. telemetensis, G. pilula?, G. levis* and *G. dachelensis* which all belong to the biozones SBZ3 or SBZ4.

3) *Ranikothalia* spp.: different species *(R. nuttali, R.* sp.) were recorded within the Middle and Late Paleocene by Loeblich and Tappan (1988).

4) *Miscellanea* spp.: *Miscellanea rhomboidea* and other species are recorded within the Late Paleocene.

SYSTEMATIC PALEONTOLOGY

Family ROTALIIDAE Ehrenberg 1839
Subfamily ROTALIINAE Reiss 1963

Genus ***Urnummulites*** Boukhary and Scheibner, **n. gen.**
Type species: *Urnummulites schaubi* n. gen., n. sp.

Etymology: The prefix of the name (Ur-) is derived from ancient (in German) and the suffix after the genus *Nummulites* to which the new taxon is related.

Diagnosis of the genus: The test is small and trochoid. The dorsal side is flat or slightly convex and evolute, while the ventral side is strongly convex and rounded or slightly pointed periphery and involute. Specimens cut near the dorsal side are composed of a number of whorls like those of *Nummulites.* In the ventral side, a large central boss with fine punctuation is developed together with a number of septal filaments. The areas in between the sutures are beaded ventrally. An umbilical boss penetrated by canals is also developed ventrally.

The chambers are arranged in a trochospiral pattern. The dorsal side of the test is slightly convex and evolute, while the ventral side of the test is strongly convex and involute. The umbilical cavity is filled by a large central plug/boss. The external surfaces of the microspheric generation are badly preserved, so that the ornamentation can not be safely described (pl.1, figs. 1-2). However, the external surface of the megalospheric forms are covered by the septal filaments similar to that of *Nummulites* (pl. 1, figs. 7-9, 11-14).

Differential diagnosis

The here described new genus resembles the representatives of Rotaliidae by the chambers arrangement on the dorsal and ventral sides and well developed umbilical plug (pl. 1, figs. 5, 6, 18) on one hand and it seems resemble the species of *Nummulites* Lamarck in having septal filaments on the both external surface on the other hand (pl. 1, figs. 7-9, 11, 14). This new genus placed in the family of Rotaliidae Ehrenberg in its internal features, namely chambers arrangement and strongly developed umbilical plug.

The genus *Laffitteina* Marie differs from *Urnummulites* n.gen. in possessing the ramifying interseptal canals that open as two alternating rows of opening along the septal sutures on the dorsal side (Loeblich and Tappan 1988, p. 661).

It is distinguished from *Kathina* Smout in its septal filament on the external surface. In addition, some figures of *Kathina* show the umbilical flap in the equatorial and sub-equatorial sections (Smout,1954, pl. 4, fig. 7; pl. 7, figs. 11-12). The new genus has its septal filaments and central knob on the external surfaces in common with *Nummulites,* but the former has an umbilical plug or pillars with vertical canals (pl.1, figs. 5, 18). *Urnummulites* differs from all the representatives of Rotaliidae by the presence of the septal filaments.

Discussion: This genus is a typical rotaliid taxon. It is distinguished from *Kathina* by having asymmetrical polar pustules on both sides. The pustule is only well pronounced ventrally, where it possesses perforations (punctuation) and is lacking the umbilical pillar found in *Kathina.* In the involute ventral side the test possesses "alar" prolongations similar to those of *Nummulites* s. str., while these prolongations are lacking dorsally. The form also recalls *Laffitteina* (a Maastrichtian genus) but it lacks the double septa and the ramifying interseptal canals. It is also noticeable that in *Laffitteina* the test is more flattened and the umbilical plug is wider than that of the nominate genus. *Smoutina* (another Maastrichtian taxon) has a broader punctuate ventral plug and a much more convex (almost conical) dorsal whorl, in addition to a much more complex canal system.

Urnummulites schaubi Boukhary and Scheibner **n. sp.**
Plate 1, figures 1-18

Etymology: The species is named in honor of the late Prof. Hans Schaub, for his outstanding contributions on *Nummulites.*

Holotype: megalospheric form, (pl. 1, fig. 13), sample no. D6-45.

Paratypes: 4 microspheric and 70 megalospheric specimens.

Occurrence: Bir Dakhl, stratigraphic section D6 (text-fig. 1). Bed No. D6-45 (text-fig. 3).

Age: Late Paleocene.

Diagnosis
Microspheric form: The test is discoid to trochoid and asymmetrical in shape. The dorsal with a central swelling. Ventrally, there is a broad central punctuated boss. The diameter ranges from 1.8 to 2.3mm, thickness ranges from 1.25 to 1.4mm. The steps of coiling are regular. Septa are inclined from the base. Number of whorls per radius: 2 whorls in a radius of 0.25mm, 3 whorls in a radius of 0.5mm, and 4 whorls in a radius of 1.0mm.

Megalospheric form: The test is trochoid, ranging in shape from nearly planoconvex to asymmetrically biconvex. The diameter ranges from 1.1 to 2.1mm, while the thickness ranges from 0.7 to 1.5mm. The steps of coiling are tight to lax, the septa thick and slightly inclined at the base and becoming straight. Number of whorls per radius are: 2 whorls in a radius of 0.35 to 0.5mm, 3 whorls in a radius of 0.50 to 0.75mm. Protoconch size ranges from 0.075 to 0.125mm. In axial sections, an alar prolongation is pronounced ventrally rather than dorsally. In addition, polar pustules are developed asymmetrically.

Phylogeny and Systematic meaning

Urnummulites n. gen. is a typical member of the family Rotaliidae. It differs from *Lockhartia* because the convexity of the dorsal side of the test is less than that of the ventral side, where in *Lockhartia* the dorsal side is the more convex. In *Lockhartia,* the polar pustules are asymmetrically developed and often lacking at the dorsal side. Blondeau (1972) believes that *Ranikothalia* could be the ancestral form of the genus *Nummulites.* This has even been named as *Nummulites* by some earlier authors (Davies 1927), who named the type species of *Ranikothalia.* Although both genera have transverse trabecules, the relation of *Ranikothalia* with *Urnummulites* is not possible since the former genus is larger than the latter, has a plexus marginalis and a very thick cord, that are lacking in the genus *Nummulites.* This does not conform with Cope's Rule, and consequently the genus *Ranikothalia* is certainly not the ancestor of *Nummulites.* In addition, *Nummulites* lacks the broad areas of fine canals in the marginal cord, which are pronounced at the tips of the V-shaped Laminae in *Ranikothalia. Nummulites (?) paleocaenicus* described by Hillebrandt (1962) differs from *Urnummulites schaubi* n.gen. n.sp. in possessing only an earlier trochospiral part, while the test is completely trochospiral in *Urnummulites.* Furthermore, *Nummulites (?) paleocaenicus* has an evolute last spire as *N. exilis* Douville 1919, *N. couisensis* d'Archiac 1866, *N. robustus* Schaub 1951 and *N. bearnensis* Schaub and Schweighauser 1951 as mentioned by Hillebrandt (1962). This is not the case of *U. schaubi.* We agree with Hillebrandt (1962) in accepting forms in which the earlier chambers and the last chambers have trochospiral arrangements to be possible ancestors of the genus *Nummulites. Nummulites rockallensis* Van Hinte and Wong 1975 differs from *Urnummulites schaubi* in the flat nature of the test, in the type of coiling, by displaying whorls increasing rapidly as added like in *Operculina* and by lacking the alar prolongation characteristic for *Nummulites.*

PLATE 1

Urnummulites schaubi Boukhary and Scheibner, n. gen. n. sp. Depository no. D6 (451-4518). Scale bar = 1mm.

1,2 external view, microspheric

3,4 equatorial section, microspheric

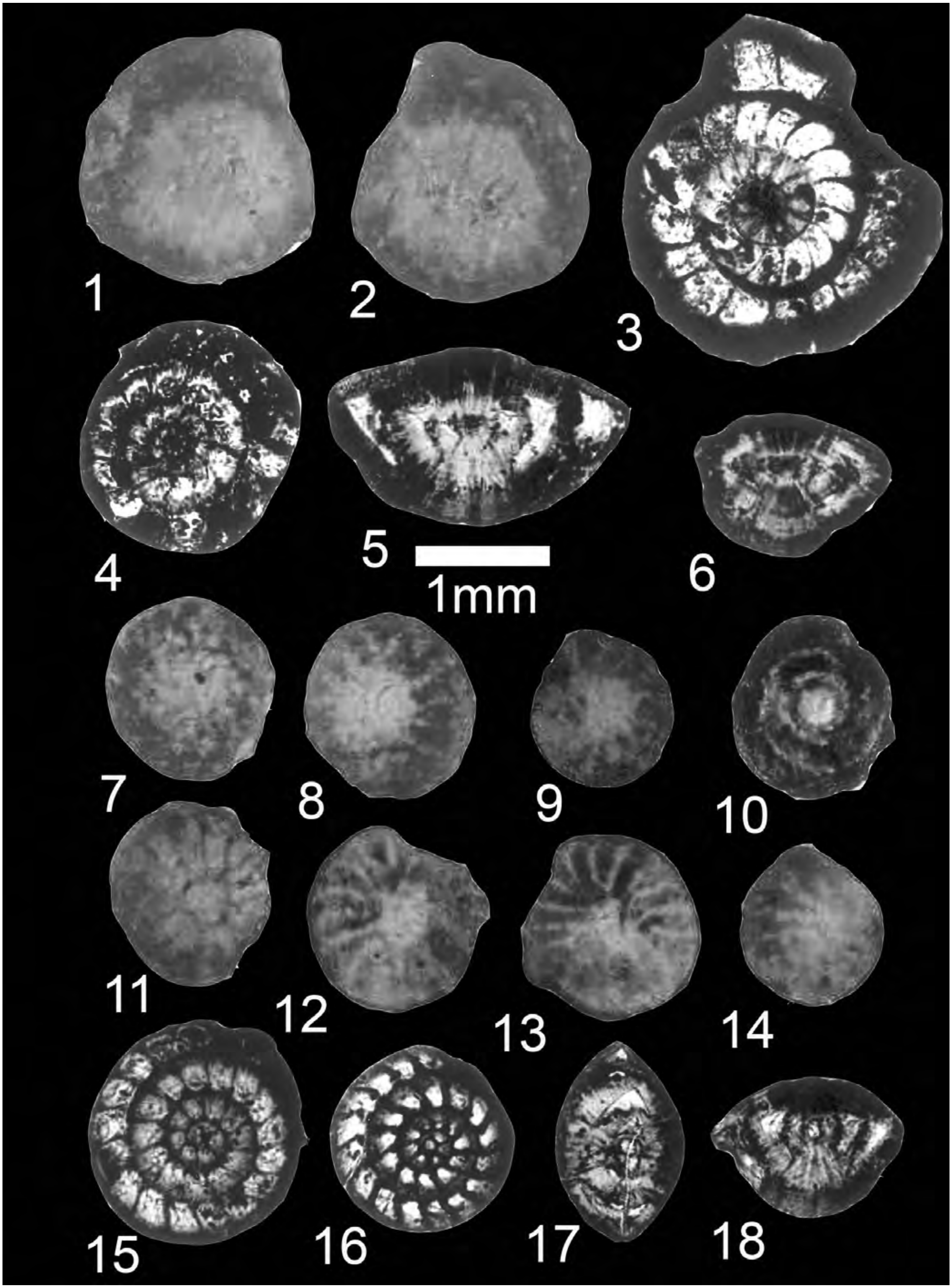
5,6 axial section, microspheric

7-14 external view, megalospheric

13 Holotype, megalospheric form

15,16 equatorial section, megalospheric

17,18 axial section, megalospheric.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The comparison between *Urnummulites* n. gen. n sp. and allied genera such as: *Kathina, Lockhartia, Rotalia* and *Nummulites* is shown in Table 1.

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