A revision of the Early Palaeogene nummulitids (Foraminifera) from northern Oman, with implications for their classification

J. R. HAYNES[1], A. RACEY[2] & J. E. WHITTAKER[3]*

[1]*Institute of Geography and Earth Sciences, Aberystwyth University, Ceredigion SY23 3DB, UK*

[2]*BG Group, 100 Thames Valley Park Drive, Reading, Berkshire RG6 1PT, UK*

[3]*Department of Palaeontology, The Natural History Museum, London SW7 5BD, UK*

**Corresponding author (e-mail: j.whittaker@nhm.ac.uk)*

Abstract: Fifteen nummulitid species are described from the Late Paleocene and Early Eocene of northern Oman. These comprise *Operculina* (five species), *Assilina* (one), *Planocamerinoides* (two), *Ranikothalia* (one), *Nummulitoides* (three), *Palaeonummulites* (one) and *Chordoperculinoides* (two). The taxa *Nummulitoides margaretae*, *Chordoperculinoides bermudezi*, *Palaeonummulites thalicus gwynae*, *Assilina ranikoti* and *Operculina libyca* are recorded from the Middle East for the first time. *Operculina canalifera* and *O. inaequilateralis* are reassigned to *Nummulitoides*; *Operculina jiwani* and *Assilina dandotica* are transferred to *Planocamerinoides*, and *Ranikothalia sahnii* is placed in *Chordoperculinoides.* Some revisions to the generic classification are proposed, with these simple forms being removed to the Palaeonumulitinae, new subfamily herein, genera with lateral chamberlets being confined to the Nummulitinae, and genera with subdivided equatorial chambers being assigned to the Heterosteginiae. Enrollment of the lamina and height of the coil (opening rate) is taken into account, as well as the presence or absence of vertical canals and the thickness of the marginal cord. On these grounds, a new genus, *Caudrina* (type species *C. soldadensis*), is formally described to include sub-evolute descendants of involute *Chordoperculinoides*. Trabeculae and trabecular canals are redefined and the problem of their misidentification in terms of presence/absence as a criterion in the systematics of the Nummulitidae is discussed.

The biostratigraphical and palaeobiogeographical implications of this early nummulitid fauna are significant. The presence of *Chordoperculinoides bermudezi* in Oman is considered to be of particular importance, since it has previously been considered to be restricted to the Caribbean faunal province. The occurrence also of *Ranikothalia nuttalli kohatica* extends the geographical distribution of this taxon, which hitherto was only known from NW Pakistan, while *Nummulitoides* was previously only recorded with certainty from West Africa, Libya, Pakistan, the Pyrenees and from off western Ireland. Other taxa such as *Assilina ranikoti* and *Palaeonummulites thalicus gwynae*, and *Operculina libyca*, were previously only known from Pakistan and Libya, respectively. The fauna therefore shows a marked mixing of taxa from the Indian Subcontinent, the Mediterranean/North Atlantic and West African regions, as well as including a taxon previously considered endemic to the Caribbean.

Forms with a massive marginal cord such as *Chordoperculinoides, Ranikothalia* and *Nummulitoides* indicate an age close to the Paleocene–Eocene boundary (nannoplankton zones NP8–NP10) with *Nummulitoides* possibly ranging as high as top NP11. *Assilina*, *Palaeonummulites* and *Planocamerinoides* have a first occurrence in the latest Paleocene (within NP9/P5a). Most of the genera studied first appear in the Late Thanetian (NP8/P4b–c) and were probably derived from a tightly coiled ancestor of *Palaeonummulites* earlier in the Paleocene. Possible lines of descent between these genera are also discussed.

Early Tertiary (especially Paleocene) nummulitids are poorly known from the Middle East. Moreover, the evolutionary relationships between genera and in some cases the generic definitions have yet to be clearly established. The objectives of this chapter are:

1. To describe an interesting and hitherto poorly known nummulitid fauna from the Late Paleocene–Early Eocene Jafnayn Formation of NE Oman (and from the broadly equivalent Umm er Rhaduma Formation, elsewhere in Oman).
2. To re-assign the 15 species recovered to seven genera of simple nummulitids (Palaeonummulitinae, herein) which are redefined with equal attention paid to enrollment of the spiral lamina (in the adult), height of the coil

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(opening rate), thickness of the marginal cord and presence or absence of vertical canals. Application of these criteria leads to the recognition of a new genus, *Caudrina*, based on a redescription of the type species, *C. soldadensis* (Vaughan & Cole 1941), from Trinidadian material. Although this genus has not yet been discovered in the Old World, it seems logical to include it here for completeness of coverage of the subfamily.

3. To discuss the biostratigraphic and palaeobiogeographic significance of the Oman fauna.

Following the orogenic upheaval related to the emplacement of the Oman ophiolite in the Campanian, the Oman Mountains became the site of widespread deposition of dominantly shallow marine Maastrichtian to Palaeogene sediments. Tertiary sediments (dominantly shallow marine carbonates) of Paleocene to Miocene age crop out widely in

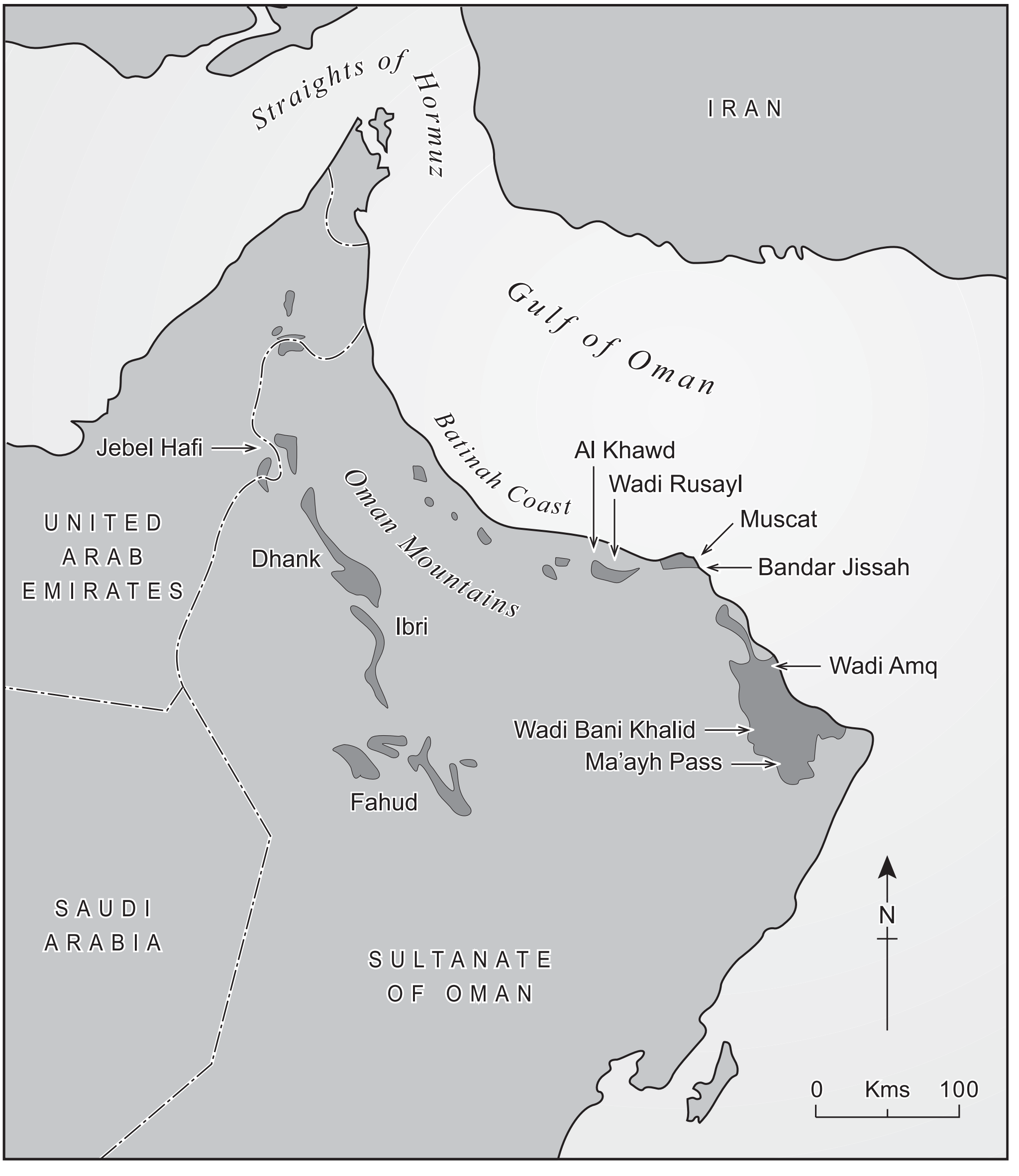

Fig. 1. Location map, northern Oman. Dark shading indicates extent of Tertiary sediments.

the foothills of northern Oman (Fig. 1) and contain a particularly rich larger foraminiferal fauna, including common nummulitids. Approximately 145 samples of assumed Late Paleocene age were collected, thin-sectioned and, where possible, broken down to extract the nummulitid foraminifera for individual examination. Forty-one of these samples yielded nummulitid foraminifera. All thin-sections and matrix-free specimens extracted have been deposited in the Department of Palaeontology, Natural History Museum, London, where they have been catalogued (numbers prefixed with the letter PF). Sections yielding nummulitids studied herein occur at Wadi Rusayl, Al Khawd, Wadi Bani Khalid, Wadi Amq and Bandar Jissah (otherwise known as Ras Ghissa) near Qantab, in NE Oman, and Fahud, inland, west of the Oman Mountains (Fig. 1). Several genera, especially *Assilina* and *Nummulites*, are particularly useful for zoning Tethyan shelf sequences, where they are often tied to nannoplankton and planktonic foraminiferal zonations, as shown by Schaub (1981) for the Mediterranean region, by Racey (1994, 1995) for Oman and by Blondeau (1972).

Previous works on the Tertiary of Oman are somewhat limited. Pilgrim (1908) and Lees (1928) looked briefly at the Tertiary and noted (without supporting evidence) that the sequences were broadly similar to coeval sections in Pakistan and India. Glennie *et al.* (1974) grouped the Tertiary sediments together for mapping purposes and briefly described them. None of these authors listed or illustrated any of the microfossils present. Montenat *et al.* (1977) were the first to describe and illustrate some of the larger Tertiary foraminifera, although they only illustrated 3 of the 23 species of nummulitids mentioned in their text. Interestingly, they recorded *Ranikothalia bermudezi*, a taxon whose affinities are discussed in this chapter and also in an earlier article by Haynes (1988). Racz (1979) described the biostratigraphy and sedimentology of some Paleocene carbonates from Ras al Hamra, near Muscat, and included records of massively chordate nummulitids, which he assigned to *Ranikothalia*. A sequence coeval to that studied by Racz was sampled by one of us (A. R.) some 15 km to the SE at Bandar Jissah and yielded *Nummulitoides canalifer*, *N. margaretae* and *N. inaequilateralis*. Nolan *et al.* (1986) formally described the lithostratigraphy for the Palaeogene of the Oman Mountains and Racey (1994, 1995) described the nummulitid biostratigraphy of the area. Other works of relevance include those by Jones & Racey (1994), who described the sequence stratigraphy of the Arabian Peninsula, and White (1994), who proposed a zonation for the Oman Mountains based on other larger foraminifera (excluding the nummulitids).

Biostratigraphy

The Jafnayn Formation, from which most of the fauna described herein was collected, mainly comprises an interbedded sequence of marls and limestones (mudstones–packstones) and was deposited in a shallow marine inner shelf–lagoonal environment. It is broadly equivalent to the Umm er Rhaduma Formation, known elsewhere throughout the Arabian Peninsula, to which the Fahud locality, west of the Oman Mountains, belongs (Fig. 1). The Jafnayn Formation unconformably overlies various formations and is conformably overlain by the Rusayl Shale Formation, which is broadly equivalent to the Rus Formation known elsewhere in the Arabian Peninsula. The Jafnayn is divided into two members, which are separated by a depositional hiatus representing the earliest Eocene, with the missing interval broadly correlating with parts of nannoplankton zones NP9–NP10. The lower member comprises low-energy, inner shelf lagoonal marls and wackestones, which pass upwards into wackestones and packstones deposited in a shallow inner shelf environment. The upper member consists of coral and red algal-rich *Alveolina*-dominated packstones and grainstones with occasional calcarenites deposited in a fairly high-energy open marine shoal environment with nearby patch reefs. The nummulitid fauna described herein came mainly from the lower member and is thus dominantly Thanetian (NP8–NP9) in age. The associated macrofauna and microfauna have been described by Racey (1994, 1995), White (1994) and Al-Sayigh (1992), with the microfauna comprising *Daviesina persica*, *D. iranica*, *D. intermedia*, *D. langhami*, *Lockhartia diversa*, *L. conditi*, *L. haimei*, *L. conica*, *Sakesaria nodulifera*, *S. somalica*, *S. migiurtina*, *S. dukhani*, *Glomalveolina (Alveolina) primaeva*, *Hottingerina lukasi*, *Kathina nammalensis*, *K. selveri*, *Miscellanea meandrina*, *M. miscella*, *M. primitiva*, *Miscellanoides* sp., *Discocyclina* cf. *ramaroi*, *D.* cf. *ranikoti*, *Rotorbinella* spp. and *Ornatanomalina* sp. Some taxa were also found in the upper member in association with *Alveolina oblonga*, *A. rotundata*, *Assilina plana*, *Planostegina ruida*, *Sakesaria cotteri*, *Nummulites globulus*, *Lockhartia hunti* and *Opertorbitolites*, and are thus of Early Eocene (NP12–13) age.

In the interior of Northern Oman (e.g. around Fahud) the Jafnayn Formation is replaced by lithologies more typical of the Umm er Rhaduma Formation (Fig. 1).

Various zonations for different genera of larger Tertiary foraminifera have been developed, and include those of Hottinger (1962) for *Alveolina* and Schaub (1981) for *Nummulites* and *Assilina* and more recently that of Serra Kiel *et al.* (1998). These zonations can be tied to the nannoplankton zonation of Martini (1971) and the planktonic foraminiferal zonation of Blow (1969, 1979) as illustrated in Jones & Racey (1994). Other planktonic zonations include that of Berggren *et al.* (1995) and Cavelier & Pomerol (1986). Some of these zonations are shown in Figure 2.

Of major importance to this chapter is the position of the Paleocene–Eocene boundary itself, since some of the genera described herein would be wholly restricted to the Upper Paleocene using one scheme, yet range into the Lower Eocene using another scheme. Cavelier & Pomerol (1986) had placed their boundary between zones P4 and P5, separating the lower Eocene *M. velascoensis* Zone from the uppermost Paleocene *Planorotalites pseudomenardii* Zone. Yet in the authoritative scheme of Berggren *et al.* (1995), because of the problems of dating the limits of Thanetian and Ypresian in their respective type areas, the Paleocene–Eocene boundary is defined on their figure 1 (p. 139) by a 'broad grey band spanning the interval between ~54.6 to 55.5 Ma', covering most of Zone P5. For the same reason, the larger foraminiferal zonation of Serra Kiel *et al.* (1998) shows the position of the Paleocene–Eocene boundary as being uncertain. De Graciansky *et al.* (1998), on seismic evidence, place it in the middle part of P5, which is equivalent to the SBZ5/6 boundary of Serra Kiel *et al.* (1998). Most recently (in 2000), the Paleocene–Eocene Boundary Subcommission (IGCP Project 308) has finally voted (H.-P. Luterbacher, pers. comm.) to place the boundary at the

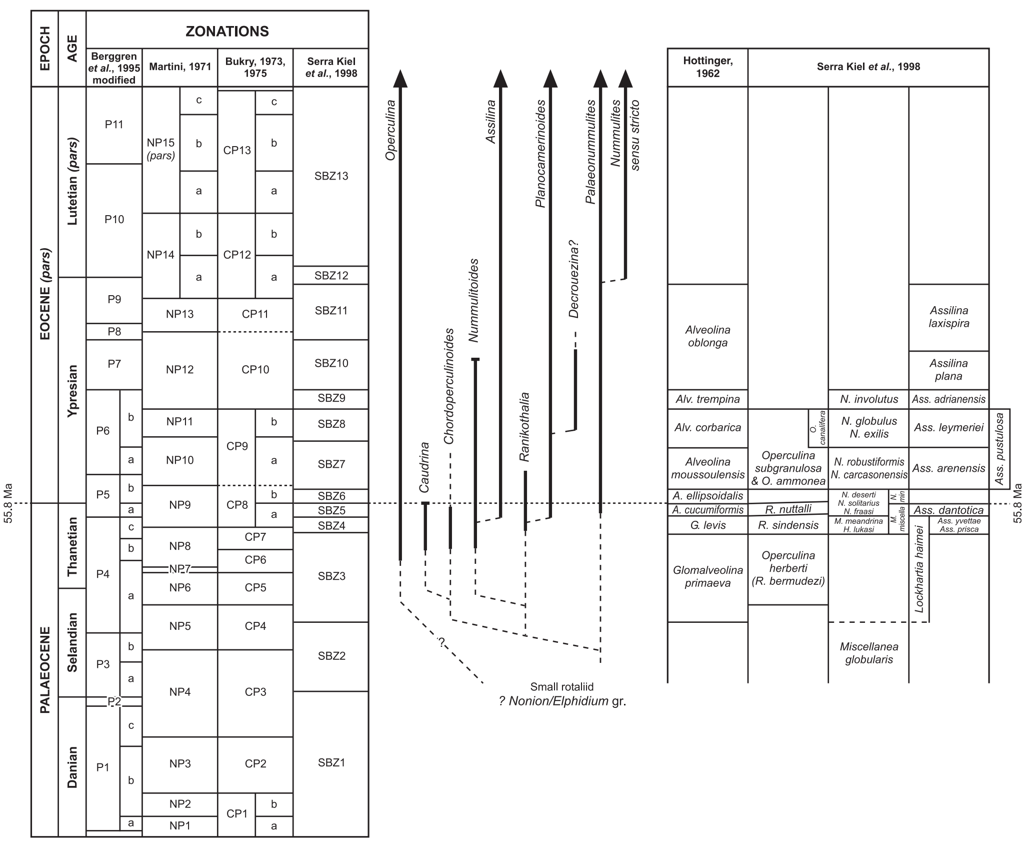

Fig. 2. Age ranges of the various members of the Palaeonummulitinae, with particular reference to Oman, with some suggested lines of evolution. Solid black lines indicate known ranges, dotted lines are conjectural. On the left, the planktonic foraminiferal (P) zonation used is that of Berggren *et al.* (1995), modified by Pardo *et al.* (1999), and the calcareous nannoplankton (NP) and (CP) zonations are those of Martini (1971) and Bukry (1973, 1975), respectively, which in turn are calibrated with the Tethyan larger foraminiferal (SBZ) zonation of Serra-Kiel *et al.* (1998). The Paleocene–Eocene boundary reflects the consensus following the recent vote of the Boundary Subcommission (see p. 33); this was calibrated by Norris & Röhl (2000) at 55 Ma, and subsequently recalibrated (Gradstein *et al.* 2004) to 55.8 Ma. Other, larger foraminiferal zonations (after Hottinger 1962; Serra-Kiel *et al.* 1998) are given on the right, for comparison. (*N. min* = *Nummulites minervensis*.)

level of the base of the carbon isotope excursion (calibrated at 55 Ma by Norris & Röhl (2000) and re-calibrated by Gradstein *et al.* (2004) at 55.8 Ma), marking a significant warming and benthic foraminiferal extinction, which is equivalent to the base of P5b of Pardo *et al.* (1999). This new concurrent range subzone is defined by the first appearance of *Acarinina sibaiyaensis* and/or *A. africana* at the base and the last appearance of *Morozovella velascoensis* at the top. It is equivalent to nannofossil Zone CP8a (of Bukry 1973, 1975) (within NP9 of Martini, 1971). This is the boundary shown on our Figure 2.

Features important in classification

The Palaeonummulitinae, new subfamily herein, includes genera characterized by a flat planispiral coil that is bilaterally symmetrical about the equatorial plane. They all possess a marginal cord with an internal canal system, and numerous simple chambers as in *Palaeonummulites*, *Planocamerinoides*, *Assilina*, *Ranikothalia*, *Operculina*, *Chordoperculinoides*, *Caudrina* and *Nummulitoides*.

The following features (summarized in Table 1 and illustrated graphically in Fig. 3) are considered important in the classification of the Palaeonummulitinae at generic and subgeneric level:

1. Relative amount of involution of the spiral lamina (spiral sheet): from fully involute (reaching the poles), to quasi-evolute (with the alar prolongations of the chambers pinched off), to subevolute (clasping the marginal cord of the previous whorl only), to fully evolute (not carried over from the previous whorl, at least in the adult, i.e. 'maturo-evolute').
2. Opening rate of the spire: from tight (with each whorl, the diameter d increases on average to $<1.75d$), to moderate (d increases to $1.75-2.25d$), to lax (d increases to $>2.25d$).
3. Number of whorls (B-form): from many (≥ 10), to moderate (5–9), to few (≤ 4).
4. Development of the marginal cord: from fine (slightly thicker than the spiral laminae), to moderate (noticeably thicker than the spiral laminae), to massive (may be wider than the chamber width in compressed forms).
5. Character of the septa: simple, primary septa only.
6. Character of the chamber wall: from finely perforated only, to moderate development of vertical canals ('cracks'), mainly over the umbilical area, to strong development of coarse trumpet-shaped vertical canals over the entire lamina.

It should be noted that these characters have to be taken in combination. It may be objected that they are all gradational and not definitive at generic level, but this logic leads directly to lumping all the nummulitids in *Nummulites*, as Cole did in the *Treatise on Invertebrate Paleontology* (Loeblich & Tappan 1964). Cole considered evoluteness/involuteness, number of whorls, height of whorls, character of spiral wall, chamber shape and marginal cord development to be only of specific value rather than generic value. This led him to place *Assilina*, *Operculina*, *Operculinella*, *Ranikothalia*, *Palaeonummulites* and *Sindulites* in synonomy with *Camerina* (= *Nummulites*).

Even supposed 'novelties' such as secondary chamberlets, which are supposed to provide a more secure basis, do not arise instantaneously but begin as small projections on the leading edge of the septa (as folds on the internal septal flap); for example, their polyphyletic appearance in the Heterostegininae in the Eocene and in the Miocene is clearly gradational. This vitiates the attempt by Romero *et al.* (1999) to confine *Operculina* to species with a 'more or less folded septal flap'. In any case, no folds are shown in their figure of *Operculina roselli* Hottinger, 1977 (Romero *et al.* 1999, fig. 9).

Table 1. *Diagnostic generic characters in the Palaeonummulitinae*

Enrolment of lamina (adult)	Height of coil (average opening rate)	Fine to moderately thick marginal cord	Massive marginal cord	
			Finely perforate	Coarse vertical canals
Evolute	Moderate to lax	*Operculina*	*Decruezina*	
Evolute	Tight to moderate		*Assilina*	
Sub-evolute	Moderate to lax		*Nummulitoides*	*Caudrina*
Quasi-evolute	Tight	*Planocamerinoides*		
Involute	Lax	*Palaeonummulites* (lax species)	*Sindulites*	
Involute	Tight to moderate	*Palaeonummulites*	*Ranikothalia*	*Chordoperculinoides*
Involute	Tight	*Nummulites*		

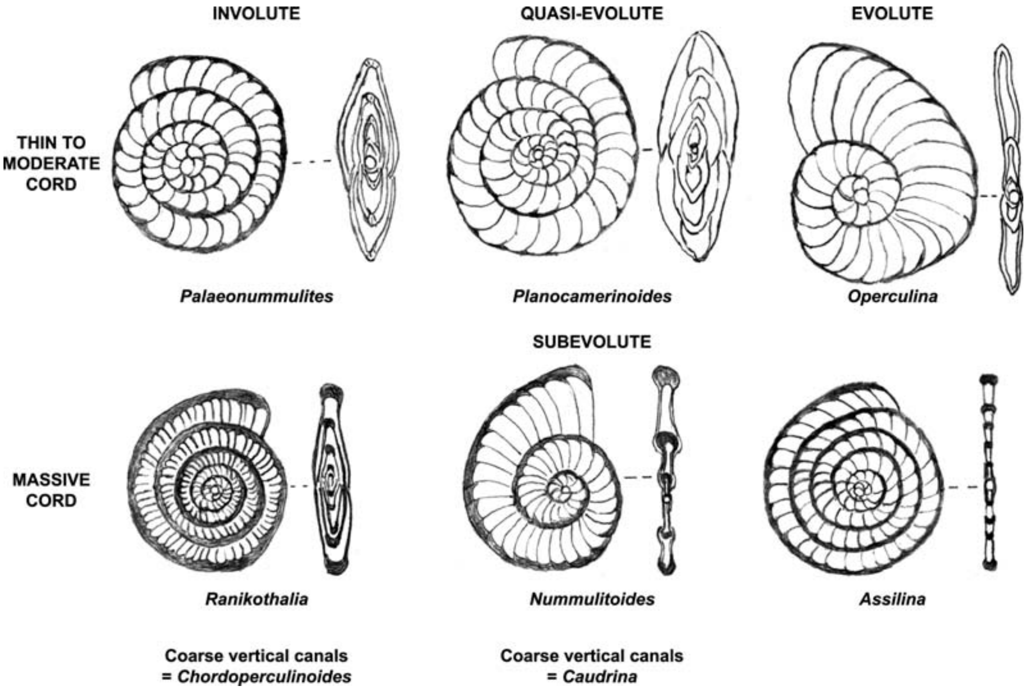

Fig. 3. Diagrammatic sections to illustrate the main genera of palaeonummulitids.

Similarly, Hottinger (1977) did not consider the degree of involution as being of importance in discriminating various nummulitid genera (nor did he consider the presence of secondary septa important in the classification of the closely related heterosteginids). Hottinger (1977) preferred to use the form of the intercameral stolons (only visible on exceptionally well-preserved specimens and therefore of limited use to micropalaeontologists dealing with fossil material) to discriminate various nummulitid genera, observing that these were irregular in *Operculina* (which he wrongly regarded as a synonym of *Assilina* and *Anastegina*, as is discussed later herein) and Y-shaped in *Heterostegina*.

However, the nature and terminology for these intercameral openings is currently in dispute, as pointed out by Banner & Hodgkinson (1991), with Spindler (1978) recording over 20 different names for these openings. Moreover, Spindler (1978), in a study of the extant nummulitid *Heterostegina depressa*, demonstrated that the shape and distribution of these intercameral openings is highly variable. Consequently, the use of such structures in discriminating genera as undertaken by Hottinger (1977) must be considered questionable, especially when one considers that his recommendations were based on the study of a very limited number of nummulitid species and that he did not study representatives of all the nummulitid genera (he looked at 12 species, of which 6 are extant, but did not include the type species of either *Operculina*, *Nummulites* or *Ranikothalia*).

Trabeculae

Much confusion has arisen in the literature as to the definition of trabeculae in the Nummulitidae. Strictly speaking, the term refers to the imperforate surface trace(s) of the underlying 'trabecular structure', that is, the septal canal or canals, leading to the septal pore. However, over time, the term has tended to become transferred to the underlying structure. Consequently, some authors (e.g. Haynes 1988) have chosen to avoid the use of the term.

The term 'trabecula', derived from the Latin for a minute beam (*trabs*) has been used in anatomy for connective tissue and in botany for rods or plates that may cross cavities. In classical nummulite studies, the term was applied to the short, imperforate bars seen on the surface of some species, running backward and forward from the septa and ending in small pores. As Smout (1954, p. 21) put it (somewhat ungrammatically), 'Trabeculae are caused by the branches of the intraseptal canal system running out over the chamber wall and the shell above them is imperforate and hyaline, although the perforations tend to spread over the canal and conceal it if the wall is thick.'

Trabeculae were defined by Haynes (1981) and by Loeblich & Tappan (1987, p. 686, in their diagnosis of *Nummulites*) as 'sutural canals ramified, directed obliquely backward and forward on both sides of the septa, the oblique paths of the sutural canals and the branches in the lateral walls visible on the lateral wall surface where the offset pores leave narrow unperforated bands as transverse trabeculae'.

However, it was perhaps inevitable that the term would also be applied to the internal structures. Boussac (1906) considered that trabeculae were rudimentary reticulate filaments, a view denied by Smout (1954) but supported by Glaessner (1945, p. 173): 'From the septa of some forms, fine, canaliculate branches extend into the spiral wall. These transverse trabecules correspond to the secondary septa of *Heterostegina* and are also the first stage in the development of the meandrine and reticulate septal filaments in some species of *Camerina* [i.e. *Nummulites*]'. (Incidentally, Glaessner also applied the term to the 'fiberous' structure of the keriotheca in fusulinids, on p. 66 of his book, where he refers to the 'calcite infillings of perforations or alveoli, their walls (trabecules) being represented by the dark zones'.) Nuttall (1926) and Davies & Pinfold (1937) applied the term to the secondary canal itself, suggesting that trabeculae are present in *Ranikothalia*, which has caused confusion in the literature, being denied by Hottinger (1977) because poreless, surface traces of the canals are absent, being found only in *Nummulites sensu stricto.* In *Ranikothalia*, as in *Caudrina* (a new genus defined herein), *Chordoperculoides* and *Nummulitoides*, the secondary canals emerge adjacent to the septum at a high angle. They are often well seen due to dark infilling and have attracted the term 'trabecular canals' (Spindler 1978; Banner & Hodgkinson 1991).

Confusion as to what trabeculae actually are has led to their misidentification and misuse in generic classification and discrimination of nummulitid genera. For example, Boukhary (1994) grouped '*Ranikothalia*' species, including *R. nuttalli, R. sindensis*, *R. bermudezi*, *R. solimani*, *Nummulitoides tessieri* and *N. azilensis*, in the genus *Ranikothalia* on the basis that he believed that they all possessed trabeculae (transverse trabecules), thus, as demonstrated below, grouping several different genera under one genus.

Recommendation

To avoid confusion, the term 'trabecula(ae)' should either be abandoned or restricted to the poreless bars caused by the presence of underlying secondary (or tertiary) canals on the lateral wall in *Nummulites sensu stricto* and its allies. The use of 'trabecular canal' should be similarly restricted. (Note that the types of *Assilina*, *Nummulites*, *Operculina* and *Ranikothalia* all have branches to the subsutural canals, and the taxonomic level of variation in these 'trabecular structures' is still to be worked out.) Supposed presence or absence cannot be used as a key (e.g. Boukhary *et al.* 1998). Note also that Hottinger (1977) mistakenly made *Assilina ammonoides* the 'new' type of *Operculina* while the actual type, *O. complanata*, was removed to *Planoperculina*, thus contravening the rules of the International Commission of Zoological Nomenclature (as well as making *Planoperculina* an automatic junior synonym of *Operculina*).

Systematic palaeontology

Class **FORAMINIFERA** Lee, 1990
Order **ROTALIIDA** Lankester, 1885
Superfamily **NUMMULITACEAE** de Blainville, 1825
Family **NUMMULITIDAE** de Blainville, 1825

Subfamily **PALAEONUMMULITINAE** subfam. nov.

Diagnosis: Nummulitids with simple, primary septa only.

Range: Late Paleocene to Recent. Dominant in the Early Palaeogene (Late Paleocene to Early Eocene).

Remarks: The new subfamily includes *Assilina*, *Caudrina*, *Chordoperculinoides*, *Nummulitoides*, *Operculina*, *Palaeonummulites*, *Planocamerinoides* and *Ranikothalia.*

Adams (1988), in his study of septa and septal 'filaments' in *Nummulites*, showed that the Middle Eocene type species *N. laevigatus* and its allies such as *N. britannicus* develop secondary septa (filaments) leading to blister-like secondary chamberlets. Similarly, the Late Eocene and Oligocene *N. fabianii*/*N. fichteli* group possess both secondary and tertiary filaments that intersect to produce marked reticulations. It is convenient and logical to recognize these features as important at the subfamily level: the Nummulitinae, with lateral chamberlets, being restricted to the Middle and Late Palaeogene, and the Palaeonummulitinae being long-ranging but with a proliferation of genera near the Paleocene–Eocene boundary (Fig. 2).

Features considered important at generic level in the classification of the Palaeonummulitinae are listed in Table 1 and shown graphically, in diagrammatic sections, in Figure 3.

(Note that the Heterosteginae (Cycloclypeidae) are distinguished by subannular chambers with rectangular or hexagonal chamberlets, and the Cycloclypeinae by full development of subdivided annular chambers.)

Genus ***Assilina*** d'Orbigny, 1826

Type species: *Assilina depressa* d'Orbigny, 1826 [= *Nummulites spira* de Roissy, 1805]; subsequent designation by d'Archiac & Haime, 1853.

Generic diagnosis: Evolute, flat to flatly lenticular test, often with a central depression; radial septa; uniformly tightly to moderately coiled (approximately $2d$); chambers simple, uniform and rectangular (1.5–2.5 times higher than long); no alar prolongations (pinched-off); thick marginal cord ($\frac{1}{3}$–$\frac{1}{4}$ of chamber height). See Table 1 and Figure 3.

Range: Late Paleocene to Middle Eocene (Fig. 2). Tosquella & Serra-Kiel (1996) and Tosquella *et al.* (1996) included several species of *Operculina* under *Assilina*, following the scheme outlined by Hottinger (1977), although they did not include *Operculina sensu* Loeblich & Tappan (1987), which they considered to be *Planoperculina sensu* Hottinger (1977). This led them to unnecessarily reassign several well-known *Operculina* to the genus *Assilina*, for reasons discussed above. These generic reassignments were subsequently followed through in the proposed larger foraminiferal zonation of Serra-Kiel *et al.* (1998) for the Palaeogene, and include the species *azilensis*, *ornata*, *ammonea*, *subgranulosa*, *canalifera*, *karreri*, *schwageri*, *roselli*, *alpina* and *gomezi*, which are all mistakenly placed in *Assilina* instead of in *Operculina* (or *Nummulitoides*, as should be the case for *azilensis* and *canalifer*).

(Note that Tosquella & Serra-Kiel (1996) and Tosquella *et al.* (1996) also wrongly place *Operculina heberti* (a species present in Oman, see p. 49–50) in *Nummulites*, thus dramatically pushing back the first appearance of *Nummulites* into the mid Paleocene.)

Remarks: Hottinger (1977), in his study of canal and stolon structures in the Nummulitidae, placed *Assilina* in synonymy with *Operculina*, which he believed to have a similar structure. However, he did not figure or describe any species of *Assilina*, and therefore his recommendation cannot be supported. *Assilina* differs from *Operculina* in its tight spire and massive marginal cord.

Assilina ranikoti **Nuttall, 1926.** Plate 1, **1–5**, **8**, **11**

1926 *Assilina ranikoti* Nuttall: 117, pl. 10, figs 7–11.
1927 *Assilina ranikoti* Nuttall; Davies: 274, pl. 21, fig. 16.
1931 *Assilina ranikotensis* Nuttall; Nuttall: 307.
1981 *Assilina ranikoti* Nuttall; Schaub: 194, pl. 70, figs 14–27.

Material: Six specimens all A-forms comprising three loose, showing surface, one axial and two equatorial thin sections. All from Wadi Bani Khalid.

Description: *[A form]:* The test is small and lenticular, often with a marked polar depression. The centre of the test is often covered by large granules, while other smaller granules are sited over septal sutures. The last whorl is generally devoid of granules. The spire is uniform, slowly opening, with moderately thin to fairly thick septa, which are straight in the early whorls and more gently curved in the outer whorls. Chambers are rectangular to gently arcuate and twice as high as long. The proloculus is 0.08–0.18 mm in internal diameter.

Dimensions:

	Max.	Min.	Mean
Diameter d (mm)	3.40	1.82	2.75
Thickness t (mm)	0.75	0.54	0.65
t/d ratio	22%	29%	24%

Whorl	1	2	3	4
Radius (mm)	0.25	0.60	1.05	1.61
Chambers	9	16	21	30

Remarks: A distinctive small, lenticular, granular species. Previously only known from the Ranikot Formation, Sind, Pakistan (Nuttall 1926).

Nuttall (1931) in a footnote (p. 307) wrote '*Assilina ranikotensis* is here substituted as a correction for *A. ranikoti*'. This change is unnecessary and must be rejected. Article 32.2 of the International Code of Zoological Nomenclature (ICZN) (Ride *et al.* 1999) states that the original spelling is the 'correct original spelling' unless it is demonstrably incorrect as provided in Article 32.5. As *ranikoti* is the genitive case of a latinized word (Ranikot), it is perfectly correct.

Age and faunal associations: Found in Oman in the lower member of the Jafnayn Formation in association with the same fauna as *Planocamerinoides dandoticus* (see below) and assigned a similar latest Paleocene age. Considered by Serra Kiel *et al.* (1998) to be a zonal species for their SBZ5 Zone, which is equivalent to the *Alveolina cucumiformis* Zone of Hottinger (1962) (or P5a/lower NP9) (see Fig. 2).

Genus ***Caudrina*** gen. nov.

Type species: *Miscellanea soldadensis* Vaughan & Cole, 1941; designated herein.

Derivation of name: Named after M. B. Caudri in recognition of her work on nummulitids from the Carribbean region.

Generic diagnosis: Test large, reaching more than 1 cm in diameter in the B-form, compressed, discoidal with massive marginal cord; quasi-evolute to sub-evolute, that is, 'maturo'-subevolute with spiral lamina clasping massive (thick) marginal cord only; moderately tightly coiled, with opening rate reduced to 1.5–2*d* in adult whorls; wall thick, finely perforate and with coarse vertical canals. See Table 1 and Figure 3.

Range: Late Paleocene (Fig. 2).

Remarks: The new genus *Caudrina* is necessary to encompass palaeonummulitids that have coarse vertical canals like those of *Chordoperculinoides* but are quasi-evolute to sub-evolute. *Caudrina*, moreover, would appear to occupy the same evolutionary endpoint in the Western Hemisphere as the finely perforate *Nummulitoides* does in the Eastern Hemisphere (see Fig. 2).

Caudrina soldadensis **(Vaughan & Cole, 1941).** Plate 1, **10**

1941 *Miscellanea soldadensis* Vaughan & Cole: 36, pl. 4, figs 8–9.

1944 *Ranikothalia soldadensis* (Vaughan & Cole); Caudri: 23, pl. 4, fig. 19; pl. 5, figs 24, 26.

1953 *Operculinoides georgianus* Cole & Herrick: 6, pl. 1, figs 1–21 (?11–14, 19); pl. 2, figs 1–3 [*nom. nov.*].

1960 *Ranikothalia soldadensis* (Vaughan & Cole); Drooger: 312, pl. 5, figs 1–4.

1975 *Ranikothalia soldadensis* (Vaughan & Cole); Caudri: 539, pl. 6, figs 1–3; pl. 7, figs 1–5; pl. 8, figs 1–3.

1996 *Ranikothalia soldadensis* (Vaughan & Cole); Caudri: 1185, pl. 5, fig. 4; pl. 9, fig. 1.

Description: The following description is based on the original material, with details from Caudri (1944) and Cole & Herrick (1953).

B-form: Test flattened, discoidal, up to 13 mm in diameter and 1.25 mm thick, with massive expanded marginal cord producing a submarginal gutter, periphery bluntly rounded or truncate; quasi-evolute to sub-evolute with spire clasping the marginal cord only; up to six or seven whorls; increasing at more than 2*d* for the first two or three and at less than 2*d* thereafter; number of chambers reaches about 30 by the fifth whorl, with height three to four times length; septa in equatorial view relatively straight before curving over at the top into the marginal cord; marked septal canals with diverging branches (well seen in Caudri 1975, pl. 6, fig. 3); wall thick (375 μm), finely perforate and with coarse, trumpet-shaped vertical canals 30–75 μm in diameter that also penetrate the marginal cord and link with the ramifying marginal canals; very slight surface boss, from which radiate the slightly raised septa.

A-form: Test up to 3 mm in diameter and 0.5 mm thick, compressed with raised umbonal areas and thickened subrounded or truncate periphery; quasi-evolute to sub-evolute, with up to three whorls, increasing moderately in diameter (about 2*d*) in the second whorl, less in the third; chamber number increases from 7 to 13 and reaches about 24 by the third whorl, with height/length ratio 2:1–3:1. In what may be the A1 generation, proloculus diameter is 125–175 μm. In what may be the A2 generation, proloculus diameter is 300 μm, while chamber number increases from 8 to 19 in the second whorl, with the third whorl incomplete.

Dimensions:

Equatorial B-form (Caudri 1975, pl. 6, fig. 3):

Whorl	1	2	3	4	5	6	7
Radius (mm)	0.1	0.3	0.75	1.70	3.60	6.00	7.00 (incomplete)
Chambers	?7	?12	?17	22	28	39	>17 (incomplete last whorl)

Axial B-form (Caudri 1975: pl. 1, fig. 9; pl. 7, fig. 1):

Whorl	1	2	3	4	5	6	7
Diameter *d* (mm)	–	–	0.8	2.0	4.0	8.0	12.0
Thickness *t* (mm)	–	–	0.3	0.5	1.0	1.0	1.0
t/*d* ratio	–	–	37%	25%	25%	12.5%	8.3%

A-form (Cole & Herrick 1953, pl. 1, figs 3, 4, 6, 16, 17):

?A1 generation equatorial sections (figs 3, 4) and axial section (fig. 17):

fig. 3:

Whorl	1	2	3
Radius (mm)	0.5	1.2	1.9 (incomplete)
Chambers	7	13	>12 (incomplete last whorl)

Proloculus maximum diameter 125 μm

fig. 4:

Whorl	1	2	3
Radius (mm)	0.5	1.4	2.0
Chambers	7	13	23

Proloculus maximum diameter 125 μm

fig. 17:

Whorl	1	2
Diameter *d* (mm)	0.85	1.6
Thickness *t* (mm)	0.3	0.45
t/d ratio	35%	28%

Proloculus maximum diameter 175 μm

?A2 generation equatorial section (fig. 6) and axial section (fig. 16):
fig. 6:

Whorl	1	2	3
Radius (mm)	1.0	2.5	incomplete
Chambers	8	19	>5 (incomplete)

Proloculus maximum diameter 300 μm

fig. 16:

Whorl	1	2
Diameter *d* (mm)	1.0	2.3
Thickness *t* (mm)	0.4	0.5
t/d ratio	40%	21%

As noted in the synonymy, some of the specimens shown in axial section by Cole & Herrick (1953, pl. 1, figs 11–14, 19) appear to be different, in having umbilical pillars and in being more involute. This also puts a question against the specimens shown in equatorial section, especially since there are two groups of proloculus size.

Radius-per-whorl diagrams for the A- and B-forms of *C. soldadensis* are shown in Figures 4 and 5, respectively, and a chambers-per-whorl diagram for the B-form is shown in Figure 6.

Remarks: As pointed out by Cole & Herrick (1953), although both *Caudrina soldadensis* and *Chordoperculinoides bermudezi* possess vertical canals, *C. soldadensis* has a 'more compressed test and less robust walls'. *Caudrina* is very similar to *Nummulitoides*, but differs in its coarsely canaliculate spiral sheet – which originally led Vaughan & Cole to include *soldadensis* in *Miscellanea.*

When Cole & Herrick (1953) transferred *Miscellanea soldadensis* to *Operculinoides*, they coined the new name, *georgianus*, for it to avoid homonymy with *Operculinoides soldadensis* described in the same paper by Vaughan & Cole (1941). Caudri (1944) had already transferred the former to *Ranikothalia* (see the synonymy above) and it could be argued that the name change was totally unnecessary; however, according to previous ICZN Rules, a junior secondary homonym replaced before 1961 is permanently invalid. Luckily, Article 59.3 of the ICZN of Ride

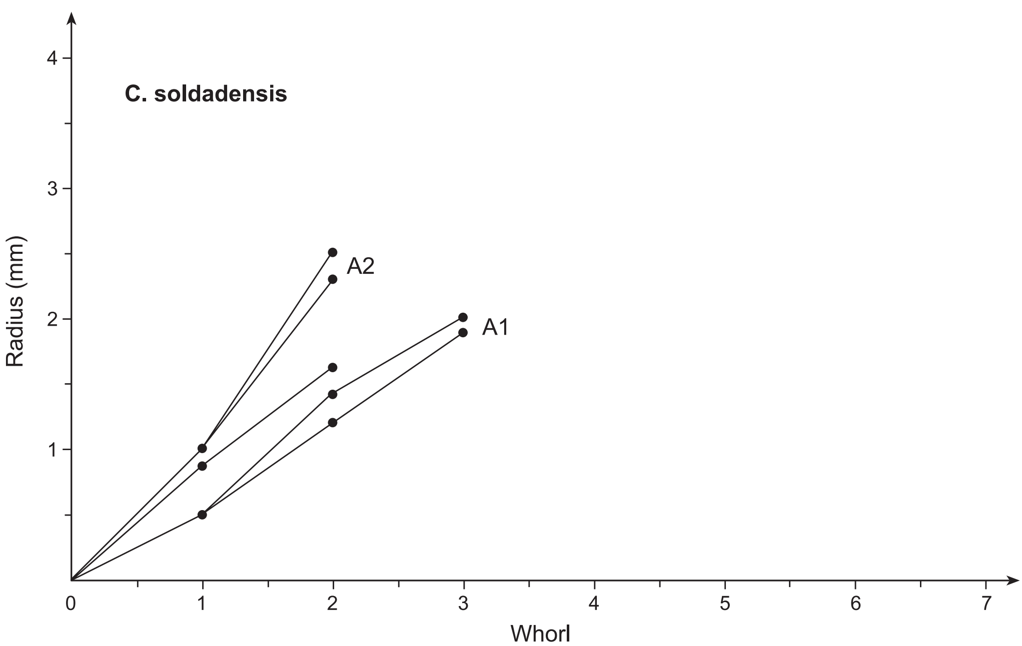

Fig. 4. Radius-per-whorl diagram for A-forms of *Caudrina soldadensis* (Vaughan & Cole).

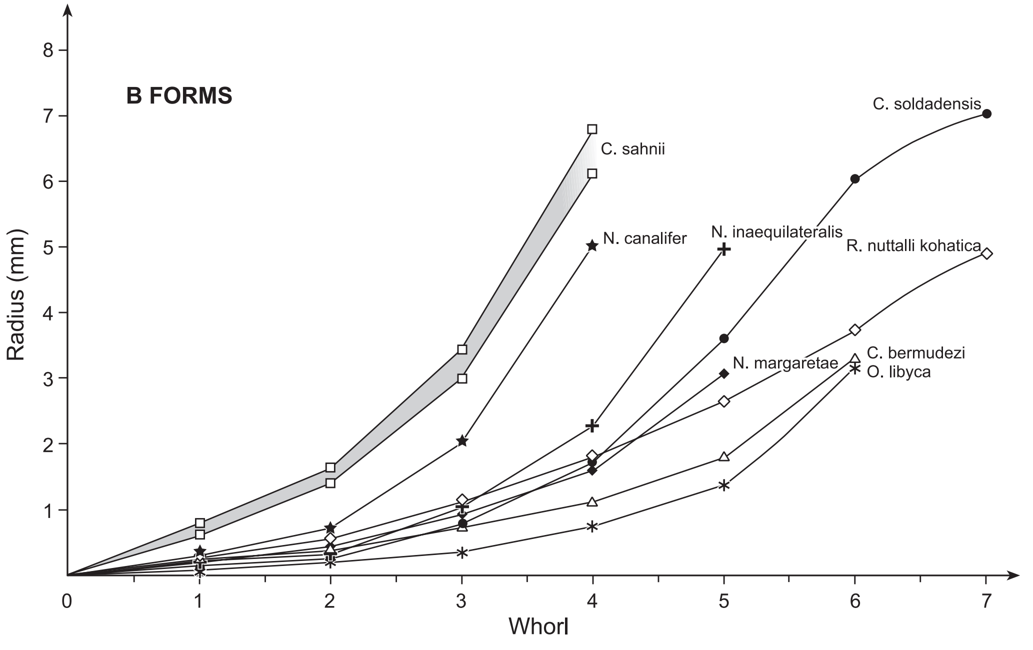

Fig. 5. Radius-per-whorl diagram for B-forms of *Caudrina soldadensis* (Vaughan & Cole), *Chordoperculinoides bermudezi* (Palmer), *C. sahnii* (Davies), *Nummulitoides canalifer* (d'Archiac & Haime), *N. inaequilateralis* (Carter), *N. margaretae* Haynes & Nwabufo-Ene, *Operculina libyca* Schwager and *Ranikothalia nuttalli kohatica* (Davies).

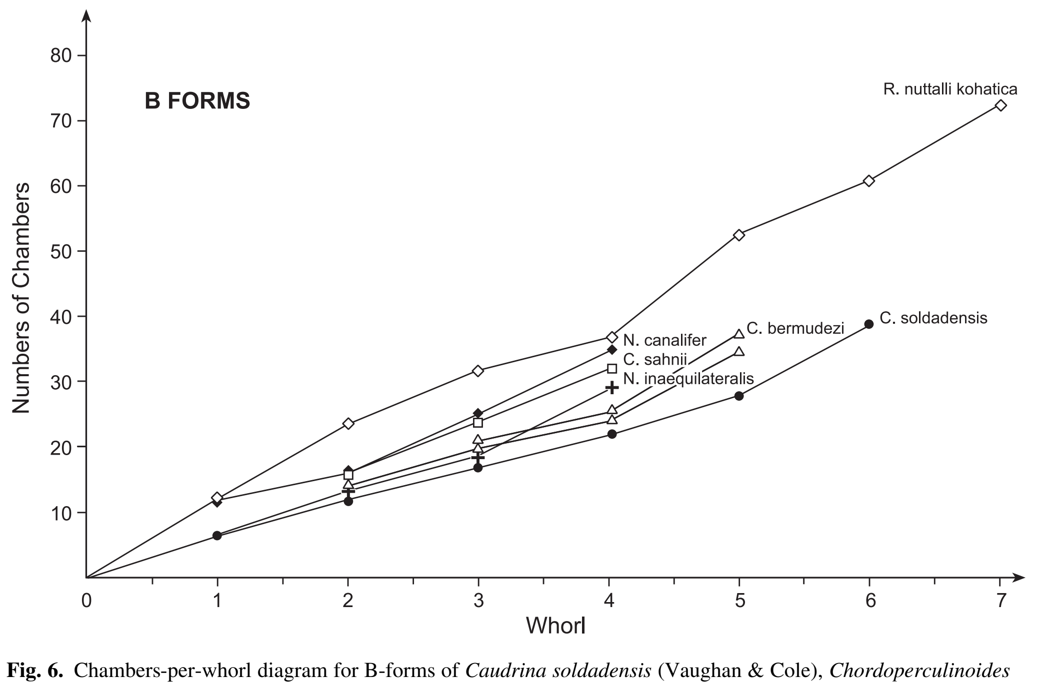

Fig. 6. Chambers-per-whorl diagram for B-forms of *Caudrina soldadensis* (Vaughan & Cole), *Chordoperculinoides bermudezi* (Palmer), *C. sahnii* (Davies), *Nummulitoides canalifer* (d'Archiac & Haime), *N. inaequilateralis* (Carter) and *Ranikothalia nuttalli kohatica* (Davies).

et al. (1999) now allows us to keep the name *soldadensis*, since the substitute name (*georgianus*) is not in use and the relevant taxa are no longer considered congeneric.

Drooger's (1960) material is included here, although it apparently consists largely of small juveniles in the quasi-evolute stage, because it otherwise demonstrates all the characters of *soldadensis* including extreme test thinness.

The only record for this species in the Eastern Hemisphere is that of Rahaghi (1978) from upper Paleocene limestones in Iran. It is illustrated by three axial sections assigned by him to *Ranikothalia*, which appear to show a species of *Chordoperculinoides*, rather than *Caudrina*. More material and further study are needed to settle the question.

A similar form is also illustrated by Kuss & Leppig (1989, fig. 8g) as *Ranikothalia* n.sp., from the western Gulf of Suez. They also illustrate some other, disparate specimens (their figs 8d, f) under this heading, including an involute, strongly tuberculate, cordate form (their fig. 8a) assigned to '*Operculina azilensis*'. Again, these records require further study.

Age and faunal associations: The type locality is Soldado Rock, Trinidad, in slumped masses of '*Ranikothalia* Limestone' of Late Paleocene age (reworked into Bed 3 of the Upper Eocene, San Fernando Formation). Associated species include *Actinosiphon barbadensis*, *Athecocyclina soldadensis*, *Hexagonocyclina inflata*, *H. meandrica*, *Neodiscocyclina barkeri*, *N. grimsdalei*, *N. fonslacertensis*, *N. mestieri* and two species referred to *Ranikothalia antillea* and *R. tobleri* that require further study.

The material of Cole & Herrick (1953) is from the Upper Paleocene, Porters Creek Formation of Georgia, USA, which also contains *Pseudophragmina stephensoni* (Vaughan). Drooger's material is from the Upper Paleocene, Basses Plaines Formation, French Guyana. This genus has not, so far, been recorded in the Eastern Hemisphere.

Genus ***Chordoperculinoides*** Arni, 1965

Type species: *Operculina bermudezi* Palmer, 1934; by original designation.

Generic diagnosis: Test large, exceeding 1 cm diameter in B-form, semi-compressed with massive marginal cord; involute; moderately tightly coiled with an opening rate of approximately 2*d*; chamber height becoming greater than two times length; wall finely perforate and with thick, coarse vertical canals; massive (thick) marginal cord with ramifying marginal canals also; strong septal canals link with the marginal canals and also with the surface via diverging branches in two alternating rows either side of the suture line. See Table 1 and Figure 3.

Range: Late Paleocene (Fig. 2).

Remarks: The generic diagnosis given above is emended from that given by Haynes (1988, p. 219), in which '*Ranikothalia*' *soldadensis* was treated as a member of the '*Ranikothalia* gr. *bermudezi*', leading to the description of the coiling as quasi-evolute to evolute. However, '*R. soldadensis*' is analogous to *Nummulitoides tessieri* Abrard in becoming subevolute (rather than to *sindensis* in the *R. nuttalli* series, which remains involute) and clearly requires a new generic name. Study of the Cuban material shows that *C. bermudezi* is involute throughout (Haynes 1988, pl. 1, fig. 1), and the generic diagnosis is therefore emended in this respect.

Chordoperculinoides bermudezi **(Palmer, 1934).** Plate 2, **1–6**

1934 *Operculina bermudezi* Palmer: 238, pl. 12, figs 3, 6–9.
1947 *Miscellanea bermudezi* (Palmer); Cole: 235–236, pl. 3, fig. 12.
1953 *Operculinoides bermudezi* (Palmer); Cole: 35–37, pl. 1, figs 5–7; pl. 3, figs 2–12.
1957 *Operculinoides bermudezi* (Palmer); Sachs: (*pars*), pl. 14, figs 21–23.
1948 *Nummulites (Operculinoides) bermudezi* (Palmer); de Cizancourt: 27, pl. 1, figs 1–6.
1988 *Chordoperculinoides bermudezi* (Palmer); Haynes: pl. 1, figs 1–5.
non 1966 *Chordoperculinoides bermudezi sensu* Arni: 340, figs 1, 2 (= *Nummulitoides margaretae* Haynes & Nwabufo-Ene, 1988).

Material: Eighteen specimens from Fahud, comprising eight thin sections; four A-forms (two equatorial and two axial) and four B-forms (three equatorial and one axial). Plus two unsectioned B-forms and four unsectioned A-forms.

Description:

B-form: Test large, up to 7 mm in diameter, semi-compressed, involute with raised umbonal areas and expanded marginal cord producing a pronounced peripheral gutter, test margin rounded or truncate; up to six whorls, which increase only moderately in diameter (2*d*), with chambers increasing slowly in height (up to about three times length), with about 30 chambers in the fourth whorl; septa gently curved with marked septal canals from which regular branches arise, diverging towards the surface on either side; chamber wall thick, finely perforate and with coarse vertical canals; marginal cord with ramifying marginal canals and vertical canals; test surface smooth apart from umbilical papillae and surface expression of septa and whorl suture.

A-form: Juveniles quite globular, with thickness/diameter ratios around 50%; adults show lower values. Similar to B-form in overall internal and external features, but smaller, developing only two or three whorls, reaching up to 3 mm in diameter and 1 mm thickness, with about 24 chambers at the periphery.

Dimensions:

B-forms: Three damaged specimens in equatorial sections, which do not show the initial whorls clearly, plus one axial section; also two matrix-free B-forms with thickness/diameter ratio of 1.2 mm/5.5 mm (22%) and 1.5 mm/3.6 mm (41%).

Equatorial sections:

Whorl	1	2	3	4	5
Radius (mm)	–	0.4	1.1	1.25	3.1
Chambers	–	14	20	24	35

Whorl	1	2	3	4	5
Radius (mm)	–	–	–	1.25	3.2
Chambers	–	–	–	28	38

Whorl	1	2	3	4	5
Radius (mm)	–	–	1.0	2.0	3.5
Chambers	–	–	21	25	38

Axial section (Pl. 2, **5**):

Whorl	1	2	3	4	5
Radius $\frac{1}{2}d$ (mm)	0.2	0.45	0.9	1.75	2.65
Thickness t (mm)	0.15	0.5	0.9	1.3	1.6
t/d ratio	36%	55%	50%	36%	33%

A-forms: Eight loose specimens, 2 equatorial and 2 axial sections.

Loose specimens:

Diameter d (mm)	Thickness t (mm)	t/d ratio
2.3	0.9	39%
2.5	1.0	40%
2.0	1.6	80%
2.6	0.9	34%
2.0	1.0	50%
1.5	0.8	52%
1.6	0.9	55%
2.4	1.3	55% (half specimen)

Figured specimen (Pl. 2, **4**), equatorial section:

Whorl	1	2
Radius (mm)	0.6	1.05
Chambers	8	17

Proloculus diameter 38 μm

Unfigured specimen, equatorial section:

Whorl	1	2
Radius (mm)	0.5	0.9
Chambers	8	18

Proloculus diameter 30 μm

Figured specimen (Pl. 2, **3**), axial section:

Whorl	1	2
Radius (mm)	0.55	1.1
Proloculus diameter (μm)	37	
Test diameter (mm)	1.10	2.2
Test thickness (mm)	0.7	1.1
t/d ratio	63%	50%

Radius-per-whorl diagrams for the B- and A-forms of *Chordoperculinoides bermudezi* are shown in Figures 5 and 7, respectively, and a chambers-per-whorl diagram for the B-form is shown in Figure 6.

Remarks: Sachs (1957), after a restudy of topotype material from Cuba, synonymized a large number of species with *Chordoperculinoides bermudezi*: including *Pellatispirella antillea* Hanzawa, *Miscellanea tobleri* Vaughan & Cole, *M. soldadensis* Vaughan & Cole, *Operculinoides georgianus* Cole & Herrick (new name for *M. soldadensis*), *O. catenula* Cushman & Jarvis and 12 species ascribed to *Nummulites* by de Cizancourt (1948). This was done on the supposed intergradation revealed by scatter diagrams plotting:

- total chambers and chambers in the 'last whorl' against whorl number;
- number of whorls and, chambers in the 'last whorl' against test diameter;
- test diameter against thickness.

However, as shown by Haynes (1988), unless the generic lines are distinguished in the first place, this approach is oversimplified and misleading. Because overlap of the spiral sheet, dimorphism, ornament and chamber height were ignored, disparate forms were brought together. Even on its own terms, the specimens of '*Operculinoides georgianus* (= *soldadensis*) stand apart', as originally claimed by Cole & Herrick (1953, pl. 1, figs 11, 12, 19 and 23) and noted by Drooger (1960). Only plate 1, figures ?21, 22 and 24 of Cole & Herrick appear to be *Chordoperculinoides bermudezi.*

Although Caudri (1975) said she considered Cole (1958, 1959) right in putting '*Miscellanea*' *antillea* and *M. tobleri* in synonymy with

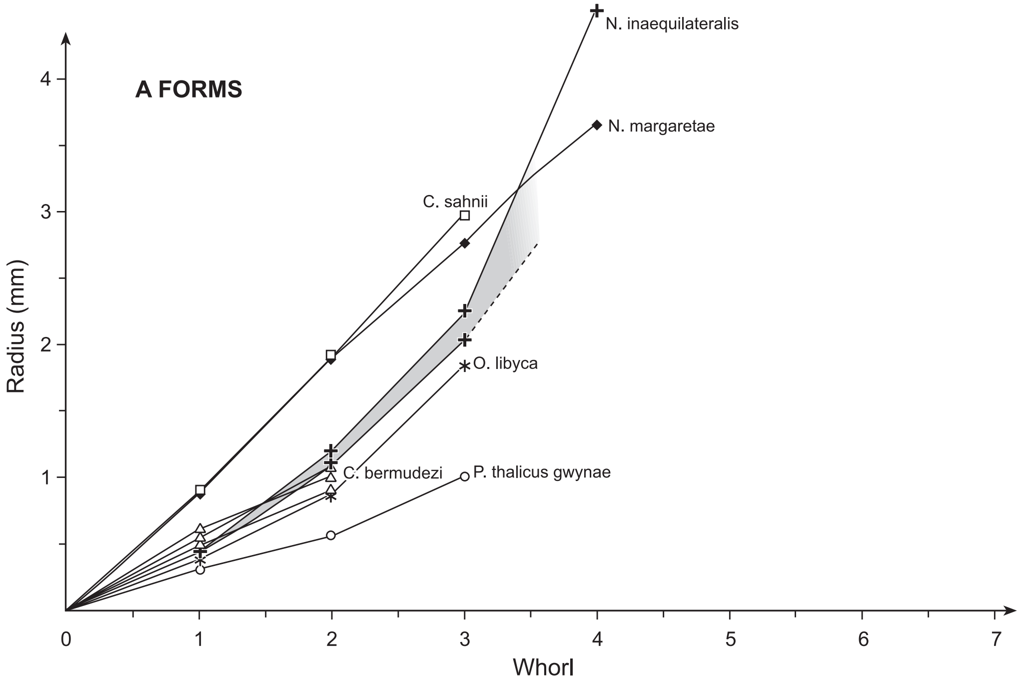

Fig. 7. Radius-per-whorl diagram for A-forms of *Chordoperculinoides bermudezi* (Palmer), *C. sahnii* (Davies), *Nummulitoides inaequilateralis* (Carter), *N. margaretae* Haynes & Nwabufo-Ene, *Operculina libyca* Schwager and *Palaeonummulites thalicus gwynae* (Davies).

'*Operculina bermudezi*' and that 'strictly speaking, all our material . . . should probably go under the name *Ranikothalia catenula* (Cushman & Jarvis)', she went on to point out that in Soldado material, 'the forms *antillea*, *tobleri* and *soldadensis* . . . are more or less easy to separate from one another; there are few transitional specimens. Therefore in order not to efface a difference which one day might turn out to be significant after all, we have continued to list them under their separate names in the present study'.

It should be noted that despite these remarks, Robinson & Wright (1993) have revived *catenula* for this wide spectrum of forms, but it can be objected to on the grounds that it rests on a single, uncut specimen and should not be allowed to displace the well-established *bermudezi*.

References to '*bermudezi*' based on random sections from West Africa and elsewhere need further study. Some may belong to *Chordoperculinoides sahnii* (see below). The material referred to *C. bermudezi* by Arni (1966) from Libya properly belongs to *Nummulitoides margaretae* Haynes & Nwabufo-Ene (1988).

Age and associated fauna: Palmer (1934) originally considered the type level, under the railway bridge on the Central San Antonio, 2 km west of Madruga, Cuba, to be Late Cretaceous. This view was later revised to Paleocene with derived Cretaceous elements, in the letters of Davies (1949) and Cole (1953). The associated discocyclinid fauna was described by Sachs (1957) and comprises: *Discocyclina barkeri*, *D. cristensis*, *D. mestieri* and *Pseudophragmina stephensoni*, indicating a Late Paleocene age.

Ranikothalia catenula was recorded from the Late Paleocene (NP6-7) Chepstow Formation of Jamaica by Robinson & Jiang (1990), which is equivalent to within Zone P4a of Berggren *et al.* (1995) and SBZ3 (in part) of Serra-Kiel *et al.* (1998).

In Oman, *C. bermudezi* is found in the lower member of the Jafnayn Formation in association with *Lockhartia diversa*, *Sakesaria dukhani*, *Alveolina (Glomalveolina)* sp., *Miscellanea* sp., *Kathina selveri*, *Daviesina langhami* and *D. persica* and below the first occurrence of *Palaeonummulites*, *Nummulites*, *Planocamerinoides* and *Assilina*, indicating a Late Paleocene age, most likely SBZ3/4 of Serra-Kiel *et al.* (1998) and Zone P4 of Berggren *et al.* (1995).

R. bermudezi is considered by Serra-Kiel *et al.* (1998) to represent their SBZ3 Zone, which is within Zones P4a–P4c/NP5–NP8 (Fig. 2). However, the illustrations used by them to show this species are from Hottinger (1977) and lack axial sections. It is therefore not possible to assign their specimens to *Ranikothalia*, *Nummulitoides* or *Chordoperculinoides* with confidence.

***Chordoperculinoides sahnii* (Davies, 1952).** Plate 3, **1–7**; Plate 14, **3**

1952 *Ranikothalia sahnii* Davies: 155, pl. 1, figs 1, 2, 4, 5, 7, 8 [B-form].
1952 *Ranikothalia savitriae* Davies: 155, pl. 1, figs 3, 6, 9, 10 [A-form].
1969 *Ranikothalia savitriae* Davies; Butterlin & Monod: 601, pl. 3, figs. 1, 5 (not 8).
1988 *Ranikothalia savitriae* Davies: Haynes & Nwabufo-Ene: 233, pl. 1, figs 1–4, 6–8.
1995 *Ranikothalia sahnii* Davies; Racey: 78, figs 13, 14, 19, 20, 22.

Material: Eight specimens (two equatorial sections and one axial section of the B-form; three equatorial and two axial sections of the A-form) plus numerous loose specimens. All are from Fahud.

Description:

B-form: Test large (up to 11 mm in diameter) flattened lenticular with massive marginal cord and pronounced gutter, umbones raised; whorls irregular, increasing in diameter at about 2*d*; chambers becoming up to five times as high as long and about 30 in number by the fourth whorl; septa initially straight but markedly curved into the roof and oblique to the perpendicular; spiral sheet finely perforate and pierced by moderate development of vertical canals; ramified canals of the marginal cord, subsutural canals and simple branches often visible; surface marked by raised septal sutures and granulations on prominent umbones.

A-form: Test diameter up to about 5 mm, compressed lenticular with tendency to prominent umbones; three to four whorls, with chambers becoming about four times as high as long in the second whorl, about 30 in the third whorl; other features as in B-form.

Dimensions (mm):

B-form: Average t/d ratio of five loose specimens:

	Max.	Min.	Mean
Diameter d (mm)	11.10	8.56	9.83
Thickness t (mm)	2.43	1.85	2.14
t/d ratio	22%	22%	22%

Davies' average t/d ratio was 24%.

Equatorial section (based on two specimens of Racey 1995):

Whorl	1	2	3	4
Radius (mm)	0.6–0.7	1.41–1.62	3.03–3.42	6.12–6.63
Chambers	12	16	24	32

A-form: Average t/d ratio based on five loose specimens:

	Max.	Min.	Mean
Diameter d (mm)	5.45	2.89	4.17
Thickness t (mm)	1.47	0.98	1.23
t/d ratio	27%	34%	29%

Equatorial section (mean values of three specimens based on Racey 1995):

Whorl	1	2	3
Radius (mm)	0.87	1.88	2.95
Chambers	8	18	31

Radius-per-whorl diagrams for the B- and A-forms of *Chordoperculinoides sahnii* are shown in Figures 5 and 7, respectively, and a chambers-per-whorl diagram for the B-form is shown in Figure 6.

Remarks: *Ranikothalia sahnii* and *savitriae* were described by Davies in 1952 as a dimorphic pair, and, at the request of Professor Sahni, the name *savitriae* (in honour of his wife) was retained for this species by Haynes & Nwabufo-Ene (1988). Unfortunately, however, *R. sahnii* must be used instead. Haynes & Nwabufo-Ene were not the first reviewers, as a footnote in the *Ellis & Messina Catalogue of Foraminifera*, supplement for 1954, makes clear 'the name *R. savitriae* is therefore to be suppressed as a synonym (*fide* Davies, personal communication, September 1953)'.

The species is here transferred to *Chordoperculinoides* because the spiral sheet shows clear development of the vertical canals, 'radial fissures' of Davies, which are such a marked feature of that genus. It differs from *C. bermudezi* in its more open coil (faster opening rate) and higher chambers in both generations. The vertical canals are also much less strongly developed and the cord, though massive, is thinner.

Age and associated fauna: The species was described from the presumed, uppermost Paleocene (Sparnacian = Thanetian *sensu lato*) of Togoland, West Africa. Some of the specimens ascribed to *bermudezi* from other parts of Africa may belong here: for example part of the material of Amard & Blondeau (1979) from Algeria, which also includes *Nummulitoides*. The *Nummulitoides* '*bermudezi*' of Blondeau (1982) from Senegal shows a similar initial part with limited development of vertical canals but a final subevolute whorl and appears to be different, as does *Ranikothalia sindensis sensu* Barut *et al.* (1967) from the Pyrenees. The specimens referred to the A-form (*savitriae*) from the Late Paleocene of Turkey by Butterlin & Monod (1969) may belong here, but no equatorial sections were given. Their B-form (*sahnii*) (fig. 8) is much more operculine than the types, and is probably different. Further work is required before these records can be properly evaluated.

C. sahnii is found in the lower member of the Jafnayn Formation of Oman in association with *Daviesina* sp., *Sakesaria* spp., *Alveolina (Glomalveolina)* sp. and *Miscellanoides* sp., taxa that together indicate a Late Paleocene age. It occurs below the first occurrence of *Palaeonummulites*, *Planocamerinoides* and *Assilina*. The associated microfauna suggest a SBZ3/4 age according to the scheme of Serra-Kiel *et al.* (1998), most likely P4 or NP5-8.

Genus ***Nummulitoides*** Abrard, 1956

Type species: *Operculina (Nummulitoides) tessieri* Abrard, 1956; by original designation.

Generic diagnosis: Test large, reaching up to 1 cm in diameter in the B-form, compressed, discoidal with massive marginal cord; quasi-evolute to subevolute, that is, 'maturo'-subevolute with spiral laminae clasping marginal cord only; spire moderate to lax; wall thick and finely perforate, marginal cord thick, massive with ramifying marginal canals. See Table 1 and Figure 3.

Range: Late Paleocene to Early Eocene (Fig. 2).

Remarks: *Ranikothalia* differs in being fully involute (Table 1 and Fig. 3). *Decrouezina* Boukhary (1994) from the lower Eocene of Egypt appears to differ in becoming fully evolute, that is, not clasping the cord of the previous whorl (assiline), directly following a quasi-evolute juvenile phase.

Note that Butt (1991) mistakenly identified a species of *Nummulitoides* as *Ranikothalia sindensis* and therefore described *Ranikothalia* as evolute. On the basis of his figures, it is not possible to know what species he was actually dealing with. It should be pointed out that Haynes (1988) had already been able to show that Davies was correct in his original assertion that *R. sindensis* was involute throughout. Although a search through the collections in Calcutta proved that the holotype was lost (presumed destroyed), being represented by an empty slide, three paratypes were found in the Davies collection in the Natural History Museum, London. One of these is an axial section figured by Davies (1927, pl. 19, fig. 13) and the other two (uncut) are the specimens figured in his plate 19, figures 10 and 12. In his diagnosis, Davies also made use of the material of Nuttall, now housed in the Sedgwick Museum, Oxford. As these specimens are also technically paratypes, Haynes (1988) made use of them in his redescription of the species, making several more axial sections. These showed beyond doubt that Davies was correct in thinking that the species was involute throughout (although his specimen was broken); see Haynes (1988, pl. 3, figs 1–6). To make matters clear, we have refigured on our Plate 1, **9** and Plate 4, **9**, respectively, Davies' axial section (his pl. 19, fig. 13) and also the external surface of the uncut specimen (his pl. 19, fig.12), which was chosen by Haynes (1988) as the neotype. This species is the type of *Sindulites* Eames (1968), treated as a subgenus of *Ranikothalia* by Haynes & Nwabufo-Ene (1988), being distinguished by the opening rate of the spire alone. It should be noted that the neotype is somewhat eroded and therefore appears 'evolute', causing difficulties for authors, despite Davies' careful description of the species as involute. Further work is required to test the validity of the recognition of lax species as subgenera of *Nummulitoides* and *Palaeonummulites* as well as in *Ranikothalia.*

Nummulitoides canalifer **(d'Archiac & Haime, 1853).** Plate 4, **1–8**

1853 *Operculina canalifera* d'Archiac & Haime: 182, 346, pl. 12, fig. 1a-c; pl. 35, figs 5, 5a; pl. 36, figs 15, 15a (not 16, 16a).
1927 *Operculina* cf. *canalifera* d'Archiac & Haime; Davies: 276, pl. 20, figs 11–13.
1937 *Operculina* cf. *canalifera* d'Archiac & Haime; Davies & Pinfold: 35, pl. 5, fig. 5.
1995 *Operculina canalifera* d'Archiac & Haime; Racey: 64, pl. 10, figs 7–10.

Material: Eight specimens, three B-forms from Fahud (two equatorial sections plus one showing the surface) and five from Qantab (one axial and one equatorial section of A-forms, one equatorial section of a juvenile B-form (eroded) and two specimens showing the surface, one ?B-form and one ?A-form).

Description:

B-form: Test large (up to 10 mm diameter), compressed, with raised umbilical area and prominent, thickened marginal cord; quasi-involute to subevolute; four or five whorls increasing at more than 2.25*d*, that is, 'operculine'; chambers five to six times as high as long by the fourth whorl and with number per turn reaching 35; septa initially straight then curved back into the roof; ornament of granules developed on septa, strongest at periphery (and on spiral suture) and decreasing downwards, also present at umbones.

?A-form: Test large, up to 5 mm diameter, with surface details as in the B-form and showing the same pronounced cord and gutter: up to three whorls increasing in diameter at just over 2*d*. (Note that further details require better equatorial sections. Plate 4, **7** shows a specimen with the centre parasitized and wider chambers than in Plate 4, **5**, and probably not typical.)

Dimensions:

Equatorial B-form (Pl. 4, **3**):

Whorl	1	2	3	4	5
Radius (mm)	0.25	0.7	2.0	5.0	incomplete
Chambers	?	?16	25	35	?

The measurements for another B-form figured (Pl. 4, **2**) are closely similar.
?A-form, axial section (Pl. 4, **8**):

Whorl	1	2
Radius $\frac{1}{2}d$ (mm)	0.75	1.6
Thickness t (mm)	0.6	0.66
t/d ratio	40%	20%

Radius-per-whorl and chambers-per-whorl diagrams of the B-form of *Nummulitoides canalifer* are shown in Figures 5 and 6, respectively.

Remarks: This species is characterized by its 'operculine' coiling, which has led to its inclusion in *Operculina*, despite its marked cord and pinched gutter. Together with its ornament, this distinguishes it from other species of the *Nummulitoides* group. Davies (1927) regarded the coiling as truly evolute, regardless of the fact that the septa clearly continue over the marginal cord of the previous whorl, as shown in his figures (pl. 20, figs 11, 12). Associated with this species at Qantab, we have found A-forms with similar ornament that probably belong here, but our material is insufficient to prove the point.

Because Davies included part of d'Archiac & Haimes's material of '*Operculina*' *canalifera* (their figs 16 and 16a) in *O. sindensis*, later workers have confused the two; for instance, Haynes (1962) considered that the material represented a general 'operculine trend', which led him to describe a Libyan species of *Nummulitoides* as '*Operculina canalifera sindensis*'. However, as pointed out above, *Ranikothalia* (*nuttalli*) and subgenus *Sindulites* (*Sindulites*) are involute throughout, whereas *Nummulitoides* is subevolute (with spiral lamina clasping the marginal cord of the previous whorl only).

This raises the important point that both axial and equatorial sections are required in order to distinguish these genera (as well as surface details in the case of species). For example, the supposed A-forms of *R. sindensis* illustrated by Hottinger (1977) from the Salt Range in the Punjab are shown in equatorial section only. On the other hand, the supposed specimens of *R. sindensis* figured by Butt (1991) from the Kala Chitta Range are represented only by axial sections and are clearly *Nummulitoides* (see further below under *Ranikothalia*).

In their original description, d'Archiac & Haime (1853) equated material from southern France with *O. canalifera.* This has led to difficulties, because, with the types unavailable, workers have inevitably made comparison with the French material instead. An attempt by Hottinger (1977) to alleviate 'le confusion autour de cenom d'espèce' has, unfortunately, confused matters further, because in setting up a 'neotype' from the Upper Paleocene of Tournissan, Corbières, Aude, he has not only offended against the Rules of Nomenclature by not using material from the type level and area (Ranikot of Sind) but also chose a specimen different from the Ranikot material of Davies (1927). The suggested 'neotype' (Hottinger 1977, pl. 32, fig. 1) is relatively unornamented and described as entirely evolute with the cord not (?well) developed and not visible on A-forms until the last whorl. No axial sections were given. Clearly, further progress in this matter will only be achieved by study of material from the Ranikot with good axial sections. This species was wrongly placed in *Assilina* by Serra Kiel *et al.* (1998).

Age and associated fauna: The type locality is the lower Tertiary of the Hala Chain, Sind, and it was subsequently recorded by Davies from the upper Ranikot (Thanetian) of Sind and Thal in the NW Frontier Province (now in Pakistan). Davies (1927) recorded this species (as *O.* cf. *canalifera*) from the uppermost Ranikot Beds in association with *Ranikothalia nuttalli kohatica*, *Palaeonummulites thalicus*, *P. thalicus gwynae*, *Ranikothalia sindensis*, *Nummulites globulus* var. *indicus*, *Miscellanea miscella*, *M. stampi*, *Alveolina oblonga*, *Lockhartia conditi*, *L. newboldi*, *L.haimei*, *Discocyclina ranikotensis* and *Assilina ranikoti*. This fauna (much of which is also present in Oman) would indicate a Late Paleocene to earliest Eocene age. Davies & Pinfold (1937) also recorded it from the upper Ranikot of the Kairabad Limestone of the Salt Range in the Punjab in association with the species recorded above plus *Alveolina globosa*, *A. vredenburgi*, *Planocamerinoides dandoticus*, *P. jiwani*, *Assilina subspinosa*, *Operculina patalensis*, *O. subsalsa* and *Orbitosiphon punjabensis*, which together suggest a latest Paleocene age, that is, Zone P5a, or SBZ5 in the Serra-Kiel *et al.* (1998) scheme (Fig. 2), or slightly older.

According to Serra-Kiel *et al.* (1998), however, *Operculina canalifera* is a zonal species for their Zone SBZ8, equivalent to part of P6b, Early Eocene (Fig. 2). In Oman, it is found in association with *Operculina subgranulosa*, *O.* cf. *ammonea*, *Assilina pustulosa* and *Nummulites globulus. A. pustulosa* and *O. subgranulosa* are considered by them to range throughout zones SBZ7 and 8, while *N. globulus* is taken to represent Zone SBZ8 (see Fig. 2), Early Eocene. Yet in Oman, *N. canalifer* appears to be restricted to the Early Eocene (probably no younger than Zone P6b). However, the records from Pakistan (above) clearly indicate that it ranges down into the Late Paleocene (P5a).

Nummulitoides inaequilateralis **(Carter, 1853).** Plate 5, **1–11**; Plate 6, **1–3**; Plate 7, **1–7**

1853 *Operculina inaequilateralis* Carter: 167, pl. 7, figs 1, 2.

Material: The Natural History Museum, London holds a rock (BMNH no. P 29812) and a slide (P 30020) from Carter's own collection labelled *Operculina inaequilateralis.* This had come to the Museum when the Geological Society of London's Overseas Collection, in which it had been housed, was transferred there in 1911. They are labelled 'Rhas Ghissa, south of Muskat, Arabia' and, according to Adams *et al.* 1980, 'may be syntypes, certainly topotypes'. The glass slide has glued to it a small piece of rock containing a partially broken microspheric specimen, which might just be that figured by Carter (1853, pl. 7, fig. 1). In our opinion, it is most certainly a syntype, and is herein designated lectotype; it is refigured in Plate 7, **5**. From the original rock several specimens were extracted and one is illustrated here (Pl. 7, **6**, **7**).

In addition, material collected by one of us (A. R.) produced 21 specimens from Bandar Jissah (Ras Ghissah), near Qantab, and from Wadi Rusayl, which must be considered (near-)topotypes: of the 14 specimens from Bandar Jissah, 12 are A-forms (7 equatorial sections and 4 axial sections, plus 1 (?A-form) specimen showing surface details) and two are ?B-forms (both equatorial sections); of the seven specimens from Wadi Rusayl, there are six A-forms (4 equatorial sections and 2 axial sections) plus one axial section of a B-form.

Description:

B-form: Test up to 5 mm in diameter, compressed, inequilateral, with markedly raised umbones and truncate periphery formed by the enlarged marginal cord; at least five whorls, increasing at more than $2d$, irregular, quasi-evolute to sub-evolute and clasping the cord of the previous whorl; chambers reaching height four times length by the fourth whorl and 30 in number; septa straight then curved into the roof, tending to be almost perpendicular; wall thick, finely perforate; cord with ramified canals.

A-form: Test as in B-form, with up to three whorls, the second more than $2d$, the third less, quasi-evolute to sub-evolute by the end of the second whorl; 7–8 chambers in the first whorl, to 15–16 in the second to about 25 in the third, becoming three times as high as long by the third whorl; septa gently curved, tending to be swept back in the roof and somewhat irregular; subsutural canals with simple diverging secondary canals; spiral walls thick with marked but fine perforations; surface is generally coated with sand grains at the type locality but, as shown in Plate 5, **5**, is characterized by raised umbones and raised, papillate septa.

Dimensions

B-form:

Axial section (Pl. 5, **4**):

Whorl	1	2	3	4
Radius $\frac{1}{2}d$ (mm)	?	0.2	0.6	1.2
Thickness t (mm)	?	0.11	0.32	0.32
t/d ratio	?	28%	24%	19%

Equatorial section (Pl. 7, **3**):

Whorl	1	2	3	4	5
Radius (mm)	0.1	0.3	1.0	2.25	(max. diam. >5, incomplete)
Chambers	?7	13	19	29	–

A-form, equatorial sections (Pl. 6, **1**, Qantab):

Whorl	1	2	3
Radius (mm)	0.45	1.0	(max. diam. >2.7, incomplete)
Chambers	8	16	approx. 26

Proloculus 250 μm

(Pl. 6, **3**, Bandar Jissah):

Whorl	1	2	3
Radius (mm)	0.45	1.2	(max. diam. >3.5, incomplete)
Chambers	8	16	approx. 25

Proloculus 300 μm

(Pl. 7, **2**, Bandar Jissah):

Whorl	1	2	3	4
Radius (mm)	0.5	1.2	2.2	(max. diam. 4.5, incomplete)
Chambers	8	16	23	>6

Proloculus ?200 μm

Axial sections (Pl. 6, **2**, Qantab):

Whorl	1	2	3
Radius $\frac{1}{2}d$ (mm)	0.4	0.9	1.9 (last whorl broken)
Thickness t (mm)	0.4	0.6	0.6
t/d ratio	50%	33%	15%

Proloculus 240 μm

(Pl. 5, **1**):

Whorl	1	2	3
Radius $\frac{1}{2}d$ (mm)	0.5	1.1	2.2
Thickness t (mm)	0.4	0.8	0.8
t/d ratio	40%	35%	19%

Proloculus not clear

(Pl. 5, **2**):

Whorl	1	2	3
Radius $\frac{1}{2}d$ (mm)	0.5	1.0	2.0
Thickness t (mm)	0.5	1.0	1.0
t/d ratio	50%	45%	25%

Proloculus 200 μm

These figures show that the B-form reaches 5 mm in diameter in five whorls while the A-forms reach up to about 4.0 mm in three whorls. Proloculus diameters range from 200 to 300 μm (however, note the oval shape and excentric placing shown by the thin sections).

Radius-per-whorl diagrams for the B- and A-forms of *Nummulitoides inaequilateralis* are shown in Figures 5 and 7, respectively, and a chambers-per-whorl diagram for the B-form is shown in Figure 6.

Remarks: This species was first described from Oman by Carter in the middle of the 19th century and has gone unrecorded for almost 150 years. Carter was struck by the odd, inequilateral shape and thus gave this species the name *inaequilateralis*. This may be related to the oval proloculus and the tendency of the proloculus and the first chamber to be eccentrically placed (Pl. 5, **7**). These features distinguish it from other species of *Nummulitoides*, as do the strongly raised umbones. *Nummulitoides canalifer* (d'Archiac & Haime, 1853) is much more strongly ornamented and compressed in the outer whorls (see Pl. 8, **8**).

Nummulitoides margaretae Haynes & Nwabufo-Ene (1988) is much flatter, with the spiral, marginal cord more strongly developed, being raised as high as the umbones. In equatorial view, the chambers of the A-form are higher and narrower. However, in the B-forms of *N. inaequilateralis*, shown in equatorial section (Pl. 7, **3**, **4**) the chambers are higher and the coiling actually more lax than in *margaretae* (faster opening rate).

Age and faunal associations: The type locality is Ras (or Rhas) Ghissa (or Ghissah), 'the first little cape south of Muskat' in Oman, as Carter (1853, p. 167) described it. The original specimens were obtained from a thick, pink, calcareous sandstone belonging to the 'nummulitic series', that is, Palaeogene. Our topotypes from Bandar Jissah (Ghissa), near Qantab, occur in a similar lithology in association with *Miscellanea miscella*, *Lockhartia diversa*, *Sakesaria dukhani*, *S.ornata*, *Kathina* sp. and *Discocyclina* sp. Specimens from Wadi Rusayl came from the lower member of the Jafnayn Formation, while the unit in which the material was collected at Bandar Jissah is yet to be assigned to a formation; it is assumed, however, to be coeval. The associated assemblage indicates a Late Paleocene age. At Wadi Rusayl, it occurs in association with *Lockhartia haimei*, *Sakesaria dukhani* and *Kathina* sp., indicating a Late Paleocene age. *Miscellanea miscella* is a taxon considered by Serra-Kiel *et al.* (1998) to represent their Zones SBZ4 and 5 (equivalent to upper P4c–top of P5a in the modified Berggren *et al.* (1995) scheme) (Fig. 2). Racz (1979) described a similar assemblage from nearby Bandar Jissah with a taxon (unillustrated) ascribed to '*Ranikothalia*', which may represent this species. This is the first time that the range of *N. inaequilateralis* has been accurately dated.

***Nummulitoides margaretae* Haynes & Nwabufo-Ene, 1988.** Plate 8, **1–9**

1988 *Nummulitoides margaretae* Haynes & Nwabufo-Ene: 236, pl. 4, fig. 5; pl. 5, figs 1–6; text-figs 2–5. [*cum syn.*]

1998 *Nummulitoides margaretae* Haynes & Nwabufo-Ene; Haynes & Nwabufo-Ene: 68, pl. 9, figs 3–5; pl. 10, figs 1–7; pl. 11, figs 1–5.

Material: Four specimens from Wadi Rusayl (one axial section of an A-form and three uncut ?A-forms to show surface features) plus three specimens from Bandar Jissah (Ras Ghissah), Qantab (one axial section of an A-form, one axial section of a B-form and one equatorial section of an A-form).

Description:

B-form: Test large (up to 6 mm diameter), planispiral, compressed, flat with smoothly pinched gutter on either side of the marginal cord, quasi-evolute to sub-evolute (clasping marginal cord); up to five whorls of chambers. Equatorial section not available; therefore form of septa and chambers uncertain.

A-form: Test large (up to 4.0 mm in diameter), flat with smoothly pinched-in gutter; up to three and a half whorls, second just above $2d$, third below $2d$; number of chambers reaches 25 in the third whorl and they are narrow, four to five times higher than long; septa straight to curved in the roof; surface marked by raised septal sutures and occasional umbonal granules.

Dimensions:

B-form:

Axial section (Pl. 8, **4**):

Whorl	1	2	3	4	5
Radius* r (mm)	?0.1	0.45	0.9	1.6	3.0
Thickness t (mm)	?	?	0.35	0.55	0.55
t/d ratio (i.e. $t/2r$)	?	?	20%	17%	9%

(*Note that the radius was measured directly, i.e. not the half-diameter, because only half the section is preserved.)

A-form:

Equatorial section (Pl. 8, **9**):

Whorl	1	2	3	4
Radius	0.5	1.0	1.75	(max. diam. 3.6, incomplete)
Chambers	7	16	25	>2

Axial section (Pl. 8, **8**):

Whorl	1	2
Radius $\frac{1}{2}d$ (mm)	0.6	1.5
Thickness t (mm)	0.4	0.4
t/d ratio	33%	14%

Proloculus 220 μm

Axial section (Pl. 8, **5**)

Whorl	1	2	3
Radius $\frac{1}{2}d$ (mm)	0.4	1.3	1.9
Thickness t (mm)	0.25	0.5	0.5
t/d ratio	31%	20%	13%

Proloculus diameter approximately 180 μm (not exactly centred)

Radius-per-whorl diagrams for the B- and A-forms of *Nummulitoides margaretae* are shown in Figures 5 and 7, respectively.

Remarks: This species was first described from Libya (Silvestri 1934) and Nigeria (Morley Davies 1934) as *Operculina* and later referred to *O. canalifera sindensis* by Haynes (1962) as well as to *Chordoperculinoides bermudezi* by Arni (1966). It was finally described as a new species of *Nummulitoides* by Haynes & Nwabufo-Ene (1988). *N. tessieri* Abrard, the type of *Nummulitoides* from West Africa, differs in its faster opening rate, higher chambers and fewer chambers per whorl, as does *N. azilensis* Tambareau (1966) from the Pyrenees (see figures in Haynes & Nwabufo-Ene 1988).

This is the first time that the genus has been described from the Arabian Peninsula (although it was recorded without description by Al-Sayigh 1992). *Nummulitoides* has been recorded from Pakistan but as '*Ranikothalia sindensis*' by Butt (1991), although he only figured axial sections and it is not possible to make a specific determination on these alone (Butt 1991, pl. 1, figs a–h; Akhtar & Butt 1999, 134, pl. 3, fig. 4). Butt (1991) has suggested that '*Ranikothalia sindensis*' can be used as a distinctive Upper Paleocene zone representing NP6–NP8 (= P3b–P4) of Cavelier & Pomerol (1986), with its last appearance datum at the top of the *Glomalveolina levis* Zone of Hottinger (1962) and its first appearance at the base of NP6/P3b. However, this would refer to the range of *Nummulitoides* sp.

Age and associated fauna: In Libya, it occurs in shales, chalky limestones and dolomites with *Lockhartia diversa*, *Rotalia darbyensis*, *Woodella pontica*, *Rotorbinella hensoni*, *Cibicides libycus*, etc. indicative of a Late Paleocene (Thanetian) age.

In the Kalambaina Limestone of Sokoto, Nigeria (Haynes & Nwabufo-Ene 1998), it occurs with *Ornatanomalina hafeezi*, *Woodella pontica*, *Elphidium hiltermanni*, *Rotorbinella hensoni*, *Rotalia darbabyensis* and *Planorotalites* cf. *chapmani*, an assemblage considered to be Late Paleocene in age.

In Wadi Rusayl and at Qantab, Oman it occurs with *Ornatanomalina* sp. (see Haynes & Nwabufo-Ene (1998), often misidentified as *Thalmannita*) and above the last occurrence of *Daviesina danieli*, *D. intermedia*, *D. langhami*, *Lockhartia haimei*, *L. prehaimei*, *L. conica* and *L. conditi.* In Oman, *N. margaretae* is found in the lower member (upper part) of the Jafnayn Formation, which is broadly equivalent to the Umm er Rhaduma Formation known elsewhere throughout the Arabian Peninsula. The lower member of the Jafnayn Formation has been dated as Late Paleocene (Thanetian), on the basis of the occurrence of the Paleocene taxa *Lockhartia diversa*, *Daviesina persica* and *Kathina* sp., an assemblage that occurs within the *Glomalveolina primaeva* Zone of Hottinger (1962), which is broadly equivalent to nannoplankton zones (mid) NP5–NP8 of Martini (1971) or P4a-within P4c of Berggren *et al.* (1995) (Fig. 2). Racey (1995) and White (1994) have demonstrated that a hiatus corresponding to the interval NP9–NP10 occurs at the boundary between the upper and lower members of the Jafnayn Formation. Consequently, the most likely Late Paleocene age for *N. margaretae* at this locality is NP8 (upper P4), that is, mid SBZ3 to basal SBZ4 of Serra-Kiel *et al.* (1998).

Genus ***Operculina*** d'Orbigny, 1826

Type species: *Lenticulites complanatus* Defrance, 1822; subsequent designation by Cushman 1914.

Generic diagnosis: Involute to evolute; lenticular to compressed test; spire moderate to lax, few whorls and high chambers. See Table 1 and Figure 3. (Note that the type species has buttresses (incipient secondary septa) on the leading edge of the primary septa.)

Range: Paleocene to Recent (Fig. 2).

Remarks: As already pointed out (p. 35), Hottinger (1977) changed the type species of *Operculina* to *O. ammonoides* and placed the original type species, *O. complanata*, in his new genus *Planoperculina. O. ammonoides* was not among the species originally included by d'Orbigny in *Operculina* and is therefore not available for designation. The ICZN Rules state that once the type species has been designated, it cannot be changed. Banner & Hodgkinson's (1991) attempt to retain *Planoperculina* was also doomed to failure, because, by placing *O. complanata* in *Planoperculina*, Hottinger had already, and automatically, made the latter a junior synonym of *Operculina*. As Hottinger's decision also has implications for the status of *Assilina* (see above), Loeblich & Tappan (1987) were at pains to point out (on both pp. 682 and 686) the error of his ways. Unfortunately, some authors (e.g. Hottinger and Serra-Kiel *et al.*) continue this usage, regardless.

More recently, as noted below, Boukhary *et al.* (1998) have set up *Bassiouina*, with *Operculina libyca* Schwager (1883) as type species, again on the basis of the presence of trabeculae. To repeat what was said in the Introduction, it would be wise to wait until the taxonomic level of variation in these 'trabecular structures' is worked out before placing generic weight on them.

During this study, four species of *Operculina* were found that had been described earlier by Racey (1995) and are therefore, for the most part, only illustrated here with some key remarks. A somewhat fuller treatment, however, is afforded for *O. subgranulosa*. The remaining species, *O. libyca*, is described in detail, since it is new to the Middle East.

Operculina ammonea **Leymerie, 1846.** Plate 9, **1–3**

1846 *Operculina ammonea* Leymerie: 359, pl. 13, fig. 11a, b.
1995 *Operculina* cf. *ammonea* Leymerie; Racey: 62, pl. 10, figs 1–3, text-fig. 60. [*cum syn.*]

Remarks: This is distinguished from other operculines by its tighter spire (four whorls in 2.68 mm in the B-form and three whorls in 1.9 mm in the A-form) and characteristic ornament comprising numerous small granules between the septa and over the marginal cord. The Oman specimens differ from the type in having a slightly larger test diameter and looser spire. The species is previously known from southern Europe and Pakistan and is considered to range from P4 to the basal part of P7 (Hottinger, 1977). In Oman, it is found in association with *Assilina pustulosa*, *Nummulites globulus*, *Nummulitoides canalifer* and *Operculina subgranulosa*, indicating an Early Ypresian (earliest Eocene) age – equivalent to latest NP9–NP11 of Martini (1971), within late P5b–P6b of Berggren *et al.* (1995) (Fig. 2). Serra-Kiel *et al.* (1998) consider *O. ammonea* and *O. pustulosa* (as *Assilina pustulosa*) to be zonal taxa representing SBZ7/8, while the further occurrence of *N. globulus* and *N. canalifer* (*Operculina canalifera* of Serra-Kiel *et al.* 1998), suggest SBZ8. This species was wrongly assigned to *Assilina* by Serra-Kiel *et al.* (1998).

Operculina hardiei **d'Archiac & Haime, 1853.** Plate 9, **4–7**

1853 *Operculina hardiei* d'Archiac & Haime: 346, pl. 35, figs 6, 6a–c.
1995 *Operculina hardei* d'Archiac & Haime (*sic*); Racey: 64, pl. 10, figs 7–10, text-fig. 62. [*cum syn.*]

Remarks: A distinctive small species with numerous, thin, equally spaced curved and inclined septa, high chambers and a rapidly opening spire. Previously known from India and Oman (Racey 1995). Found in Oman in association with *Planocamerinoides dandoticus*, *Ranikothalia nuttalli kohatica*, *Palaeonummulites thalicus gwynae*, *Planocamerinoides jiwani*, *Miscellanea* spp. and *Glomalveolina* sp. According to Serra-Kiel *et al.* (1998), the presence of the genera *Glomaveolina* and *Miscellanea* would indicate Zones SBZ3–5, but this can be refined by the co-occurrence of *P. dandoticus* (= *Assilina dandotica* of Serra-Kiel *et al.* 1998), which is a zonal taxon for their Zone SBZ5 (approximately equivalent to early NP9 of Martini (1971), or within P5a of the modified Berggren *et al.* (1995) scheme), latest Paleocene (Fig. 2).

Operculina heberti **Munier-Chalmas, 1882.** Plate 9, **8**, **9**; Plate 10, **2**

1882 *Operculina heberti* Munier-Chalmas: 619, text-fig. 30 (1, 2).
1995 *Operculina heberti* Munier-Chalmas; Racey: 65, pl. 10, figs 11, 12, text-fig. 63. [*cum syn.*].

Remarks: This is similar to *O. ammonea* but lacks granules, has less-curved septa and has the spire visible in relief over the central portion of the test. It was previously known from the Pyrenees (Hottinger 1977) and Oman (Racey 1988, 1995). It was considered by Hottinger (1977) to represent the *Glomalveolina primaeva* Zone (SBZ3 of Serra-Kiel *et al.* (1998), equivalent to within Zone P4 of Berggren *et al.* (1995)). It was found in Oman in association with *Miscellanoides* sp., *Daviesina* spp. and *Sakesaria* spp., indicating a Paleocene age older than the first occurrence of the Late Paleocene taxon, *Chordoperculinoides sahnii*, that is, Zone P4b (mid NP8) or slightly older. This species was wrongly assigned to *Nummulites* by Serra-Kiel *et al.* (1998).

***Operculina libyca* Schwager, 1883.** Plate 10, **1**, **3–5**; Plate 11, **1**, **2**

1883 *Operculina libyca* Schwager: 142, pl. 29, fig. 2a–g.

Material: Six B-forms and 11 A-forms from Fahud, southern Oman Mountains. Comprising two equatorial B-forms, one equatorial and one axial A-form, plus one B-form and one A-form to show the surface.

Description:

B-form: Test large, flat, evolute with a rounded periphery. Granules on test surface are aligned along septal sutures with denser granules over the centre of the test. Spire regular and rapidly opening; chambers arcuate with septa markedly curved in their basal one-third to one-half, in some cases becoming almost asymptotic at their base. In slightly oblique sections (Pl. 10, **5**), short branches of the subsutural canals are visible along the septal sutures. Marginal cord is relatively thin (approximately one-tenth chamber height) and uniform, and does not stand out in relief on the test surface except in the outermost whorl.

A-form: Test of moderate size, flat with a rounded periphery, comprising three whorls. Spire, septa and chambers like those of B-form in appearance.

Dimensions (mm):

B-form:

	Max.	Min.	Mean
Diameter d (mm)	7.10	4.80	6.25
Thickness t (mm)	1.10	0.85	1.05
t/d ratio	15%	18%	17%

Whorl	1	2	3	4	5	6
Radius (mm)	–	0.18	0.36	0.73	1.36	3.18
Chambers	10	11	16	18	24	32

A-form:

	Max.	Min.	Mean.
Diameter d (mm)	5.10	3.42	4.15
Thickness t (mm)	0.65	0.45	0.55
t/d ratio	13%	13%	13%

Whorl	1	2	3
Radius (mm)	0.40	0.88	1.84
Chambers	9	16	23

Radius per whorl diagrams for the B- and A-forms of *Operculina libyca* are shown in Figures 5 and 7, respectively.

Remarks: This is a distinctive *Operculina* with a very uniform spire, septa and chambers. It is similar to *O. subgranulosa* but with a slightly more rapidly opening spire, smaller proloculus and less-pronounced surface ornament (granules). The Oman specimens are similar to those described by Hottinger (1977), although slightly smaller. The presence of branches to the subsutural canals could be used to place this species in a new genus, *Bassiounina* (Boukhary *et al.* 1998), but such 'trabecular structures' occur in all nummulitids and the precise weighting to be given them is yet unknown (see p. 35).

Age and faunal associations: This is found in Oman in association with *Nummulitoides canalifer*, *Nummulites globulus*, *Assilina pustulosa* and *Operculina subgranulosa.* According to Serra-Kiel *et al.* (1998), these species would equate to Zone SBZ8 (within P6b of Berggren *et al.* 1995), Early Eocene. Previously, it was only known from Libya (Schwager 1883), where it is recorded from the lower part of the Libyan stage (which is inferred to be upper Paleocene).

***Operculina subgranulosa* d'Orbigny, 1850.** Plate 11, **3–7**

1846 *Operculina granulosa* Leymerie: 359, pl. 13, fig. 12a–c (*non* Michelotti, 1844).

1850 *Operculina subgranulosa* d'Orbigny: 336. (figs after Leymerie, 1846) (*nom. nov.*).

1850 *Operculina thouini* d'Orbigny: 336.

1926 *Operculina subgranulosa* d'Orbigny; Doncieux: 58, pl. 6, figs 12–18 [B-form].

1926 *Operculina cuizaensis* Doncieux: 59, pl. 6, figs 19–21 [A-form].

1937 *Operculina alpina* Douvillé var. *multiseptata* Silvestri: 204, pl. 9, figs 1–4.

1973 *Operculina subgranulosa* d'Orbigny; Massieux: 97–98, pl. 16, figs 5–14.
1977 *Operculina subgranulosa* d'Orbigny; Hottinger: 57–59, pl. 20.23, figs 11–15, text-figs 18A–C, 21.
1995 *Operculina subgranulosa* d'Orbigny; Racey: 66, pl. 10, figs 16–18. [*cum syn.*]

Material: Two equatorial sections and one axial section, plus two matrix-free specimens showing surface ornament. From Fahud, Oman.

Description: Test large (up to 5 mm diameter in B-form and 4 mm in A-form), compressed; up to four whorls in A-form, five to six in B-form, opening rate moderate, initially more than 2*d* but falling below 2*d* in the fourth and fifth whorls; chamber height reaching two to three times length by the fourth whorl; septa straight to slightly curved and turned back towards chamber roof; septa raised and granulate on the surface, with oval to elongate pustules increasing from two to three on inner whorls to chains of six to eight on outer whorls; umbilical cluster of granules tending to be larger; wall thick, finely perforate.

Dimensions:

A-form:

Whorl	1	2	3	4
Radius (mm)	0.25	0.6	1.2	2.1 (estimated)
Chambers	7	16	23	27

Proloculus 0.15 mm

A-form:

Whorl	1	2	3	4
Radius (mm)	0.4	0.9	1.75	broken
Chambers	7	16	22	

Proloculus 0.25 mm

These two A-forms show different proloculus sizes and growth rates and may represent A1 and A2 generations of the sexual gamonts. This phenomenon does not appear to have been noted in *Operculina*, although it has been demonstrated in *Heterostegina* by Röttger *et al.* (1990).

Remarks: The description given above is based on the original material and redescriptions of the types by Massieux (1973) and Hottinger (1977), as well as our own specimens. *Operculina thouini* d'Orbigny and *O. alpina* var. *multiseptata* Silvestri are synonyms of this species, both erroneously applied to *Nummulitoides margaretae* in the past (see Haynes & Nwabufo-Ene, 1988). This species was wrongly assigned to *Assilina* by Serra-Kiel *et al.* (1998).

Age and faunal associations: The types are from the Early Eocene (Ypresian Zones of *Alveolina moussoulensis* and *A. corbarica*, according to Hottinger 1977) (Zones SBZ7 and 8 of Serra-Kiel *et al.* 1998; see Fig. 2) of the Montagne Noire, Couiza, Corbières, Departement de l'Aude, France. Our specimens are from the Jafnayn Formation. They are similar to, though slightly smaller than, the specimens figured by Hottinger (1977, p. 57). They are found in Oman in association with *Operculina ammonea*, *O. libyca*, *Nummulitoides canalifer*, *Nummulites globulus* and *Assilina pustulosa*, indicating an Early Eocene age approximately equivalent to latest NP10 or NP11 of Martini (1971), within P6 of Berggren *et al.* (1995). They have also been recorded from Spain, Egypt, Pakistan and Afghanistan (see Racey 1995).

Genus ***Palaeonummulites*** Schubert, 1908

Type species: *Nummulina pristina* Brady 1874; by original designation.

Generic diagnosis: Planispiral, involute, semi-compressed to globular; spire tight to moderately tightly coiled; whorls relatively few, generally no more than four or five in the A-form; chambers up to twice as high as long in equatorial section; primary septa and extensions ('filaments') only; septal sutures radial to sigmoid; marginal cord finely to moderately developed. See Table 1 and Figure 3.

Range: Late Paleocene to Early Oligocene (Fig. 2).

Remarks: *Nummulites willcoxi* Heilprin (1883), the type of *Operculinoides* Hanzawa 1935, was considered a simple nummulite by Nagappa (1959). It has a tight coil with the chambers reaching little more than one and a half times as long as high, that is, rather square. Eames *et al.* (1962) made it a synonym of *Palaeonummulites*, and this was followed by Haynes (1988). Eames *et al.* (1962) also regarded *Operculinella* Yabe, 1918 (type species *Amphistegina cumingii* Carpenter, 1860) to be a synonym of *Palaeonummulites.* Hottinger (1977, p. 11) mistakenly assigned *Operculinella cumingii* to *Nummulites* on the basis that the former possessed trabeculae (a feature that he considered wholly restricted to the genus *Nummulites*). However, 'trabecular structures' are often misidentified for reasons outlined previously and do occur in other nummulitid genera. Moreover, the trabeculae illustrated by Hottinger for *O. cumingii* are really no more than a series of pores ('sutural canals') on the septal sutures, as observed by us on many specimens of this species in the collections of the Natural History Museum, London, and thus are not true 'trabeculae'. Moreover, and perhaps more importantly, in order to demonstrate that *Nummulites* possesses trabeculae, Hottinger should have studied the type species, *N. laevigatus*. In all other respects, '*cumingii*' is an *Operculinella* as originally defined by Yabe (1918). More recently, Hohenegger *et al.* (2000), in a review of living West Pacific nummulitids, have retained *Operculinella*, noting that trabeculae are not visible on its surface and 'not proven'.

As shown by the excellent, very detailed description by Carpenter (1860), *Operculinella* differs from *Palaeonummulites* in developing highly reflexed later chambers (resembling *Amphistegina*) with the alar prolongations pinched off but with the spiral lamina extending towards the poles (i.e. 'maturo' quasi-evolute). These 'operculine' chambers appear as a marked peripheral flange. The genus *Operculinella* has not been recorded from the Paleocene (Range: mid-Eocene to Recent).

The dimensions of the A-form of *Nummulites willcoxi* re-illustrated by Nagappa (1959, pl. 21, fig. 6 showing the equatorial section) are as follows:

Whorl	1	2	3	4	5	6
Radius (mm)	0.28	0.50	0.84	1.28	1.88	>3.68 (max. diam. incomplete)
Chambers	9	14	?23	25	27	>3

Measurements of *P. thalicus gwynae* (given below) are similar, with much the same opening rate (about 1.5d) and chamber number in each whorl but with higher, narrower chambers.

Nagappa dispatched species of *Operculinoides* with lax coiling such as the *O. ocalanus* group into *Operculina*, on the grounds that involution is a gradational character, but he did concede that species with operculine coiling could be subgenerically distinguished if it was thought necessary.

***Palaeonummulites thalicus gwynae* (Davies, 1927).** Plate 12, **1–8**

1927 *Nummulites thalicus* var. *gwynae* Davies: 271, pl. 20, fig. 5.

?1980 *Ranikothalia nuttalli* (Davies); Samanta: 126, pl. 2, figs 1–4; pl. 3, figs 1–5; pl. 4, figs 1–4.

1995 *Ranikothalia nuttalli* (Davies); Racey: 77, pl. 7, figs 6, 8.

Material: Three equatorial sections, two axial sections, two uncut specimens to show surface characters, plus numerous loose specimens, all A-forms from Al Khawd and Fahud.

Description:

[A-form]: Test compressed with moderate marginal cord; up to three and a half whorls, increasing in diameter at just below 2d; about 20 chambers by the third whorl, becoming about twice as high as long; septa straight, directed back at an angle and curved into the roof; expression of septa on the surface very clear, straight to falciform, traces of branches of subsutural canal visible (Pl. 12, **1**); alar prolongation of the fourth whorl withdrawn from pustulate umbones, so the 'last whorl' is only partially involute.

Dimensions:

Equatorial section (Pl. 12, **3**):

Whorl	1	2	3	4
Radius (mm)	0.33	0.57	1.0	max. diameter 2.4
Chambers	7	15	21	>22

Proloculus oval with maximum diameter of 150 μm but sectioned slightly off-centre

Axial section (Pl. 12, **8**):

Whorl	1	2	3
Radius $\frac{1}{2}d$ (mm)	0.55	1.0	1.5
Thickness t (mm)	0.6	1.0	1.0
t/d ratio	55%	50%	33%

Proloculus maximum diameter 230 μm

A radius-per-whorl diagram of the A-form of *Palaeonummulites thalicus gwynae* is shown in Figure 7.

Remarks: This subspecies is distinguished by its compression and a test thickness one-third or less of the diameter (i.e. more compressed) compared with the more globular *P. thalicus thalicus*, as well as by its higher chambers, height up to more than twice length (see Pl. 12, **6**) and the peculiar character of the final (fourth) whorl, which tends to withdraw from the tuberculate umbonal area.

Palaeonummulites thalicus thalicus and *P. thalicus gwynae* were first described by Davies (1927) and assigned to *Nummulites*. He initially considered that *P. thalicus* might be the A-form of *Nummulites nuttalli* (a taxon later (Caudri, 1944) reassigned to *Ranikothalia*). Measurements of *thalicus thalicus* and *thalicus gwynae* demonstrate that their spires are significantly tighter than the supposed possible B-form partner, *R. nuttalli*, while their marginal cord is markedly thinner and their chamber height markedly less. Consequently, on strict morphological criteria, they belong with *Palaeonummulites*, although undoubtedly they are closely related. It is intriguing that *R. nuttalli kohaticus* and *P. thalicus gwynae* occur together both in Thal, Pakistan and in Oman.

The material described by Samanta (1980) (assigned by him to *R. nuttalli*) from the Discocyclinid Limestone of the Pondicherry Formation of southern India may belong here, but consists of random thin sections only. The associated planktonic foraminifera allow this record to be dated as ranging from the lower part of the *Globorotalia aequa* Zone to the upper part of the *G. pseudomenardii* Zone, which he considers to be equivalent to the base of the *Alveolina cucumiformis* Zone to within the overlying *Alveolina ellipsoidallis* Zone of Hottinger (1962) (see Fig. 2). This represents Zones SBZ5 and 6 of Serra-Kiel *et al.* (1998) (within P5a to within P5b), effectively straddling the Paleocene–Eocene boundary.

Age and associated fauna: It occurs in the lower member of the Jafnayn Formation with *R. nuttalli kohatica* at Al Khawd and Fahud, Oman. Serra-Kiel *et al.* (1998) consider *R. nuttalli* to range through their Zone SBZ5 into the lower part of SBZ6, which, combined with the data compiled for *P. thalicus gwynae* by Samanta (1980), re-enforces a latest Paleocene–earliest Eocene age. Further comments on its age are given under Remarks, above.

Genus ***Planocamerinoides*** Cole, 1958.

Type species: *Nummularia exponens* Sowerby (*in* Sykes, 1840); by original designation.

Generic diagnosis: Planispiral, compressed, often with an inflated polar region and marked central depression; spire tightly and uniformly coiled, opening rate less than 1.5*d*; whorls numerous in both A- and B-forms and quasi-evolute (i.e. the spiral sheet extends towards the poles, although the alar prolongations are pinched off); chambers regular, more than 1.5 times as high as long; marginal cord finely developed and generally less than one-quarter chamber height. See Table 1 and Figure 3.

Range: Late Paleocene to Middle Eocene (Fig. 2).

Planocamerinoides dandoticus **(Davies, 1937).** Plate 1, **6**, **7**

1937 *Assilina dandotica* Davies (*in* Davies & Pinfold): 28, pl. 4, figs 1–3, 6–8.
1995 *Assilina dandotica* Davies; Racey: 70, pl. 9, figs 1–5, text-fig. 70 [*cum syn.*]

Remarks: This is a small distinctive lenticular *Planocamerinoides* with a tight spire and compact, regular, rectangular chambers about twice as high as long, with curved septa in early whorls. It is similar to *Asssilina ranikoti*, but *P. dandoticus* has a thicker test, tighter spire and fewer surface granules. Previously recorded from Pakistan, Afghanistan, Italy and Oman (Racey 1995). Found in association with *Ranikothalia nuttalli kohatica*, *Palaeonummulites thalicus gwynae*, *Miscellanea* spp., *Discocyclina ramaroi*, *Assilina ranikoti* and *Planocamerinoides jiwani*, a typical Late Paleocene microfauna. This species is assigned by Schaub (1981) to the Lower 'Ilerdian', by Hottinger (1962) to the *Alveolina cucumiformis* Zone, and by Serra-Kiel *et al.* (1998) to Zone SBZ5, equivalent to P5a/lower NP9, latest Paleocene (see Fig. 2).

Planocamerinoides jiwani **(Davies, 1937).** Plate 9, **10–12**

1937 *Operculina jiwani* Davies (*in* Davies & Pinfold): 39, pl. 5, figs 11–14, 16.
1995 *Operculina jiwani* Davies; Racey: 65, pl. 10, figs 13–15, text-fig. 64 [*cum syn.*].

Remarks: This was originally described as an *Operculina* by Davies (1937), but the compact spire and quasi-evolute lamina indicate *Planocamerinoides*. It is a very small (1.3–2.4 mm diameter), tightly coiled (four whorls in 1–1.1 mm) species with relatively low chambers. The compact nature of the spire, especially in the outer whorls, suggests close affinities to *Assilina*. Similarities and differences with other species are discussed by Racey (1995). It was previously known from Pakistan, the Pyrenees and Oman (Racey 1995). It is found in the Pyrenees within the *Alveolina cucumiformis–Alveolina ellipsoidallis* Zone of Hottinger (1977) or Zones SBZ 5 and 6 of Serra-Kiel *et al.* (1998), latest Paleocene–earliest Eocene. It is found in Oman in association with *Ranikothalia nuttalli kohatica*, *Palaeonummulites thalicus gwynae* and *Daviesina* spp. Since *Daviesina* is not really known from post-Paleocene deposits, and *R. nuttalli kohatica* and *P. thalicus gwynae* are themselves only known from the latest Paleocene, a P5a (latest Paleocene) age is inferred for this taxon.

Genus ***Ranikothalia*** Caudri, 1944

Type species: *Nummulites nuttalli* Davies, 1927; by original designation.

Generic diagnosis: Test large, involute (B-form up to 1 cm in diameter), flat to flattened lenticular, semi-compressed; spire moderately tightly coiled; opening rate less than 2*d* in adult whorls (laxer in earlier whorls); whorls few (up to four in B-form), involute with alar prolongations extending towards poles; chambers narrow and high (height becoming more than three times length) and numerous; spiral laminae finely perforate; marginal cord massive, thick and coarsely reticulate; septa thick; branches of sutural canals simple, non-bifurcating and vertical. See Table 1 and Figure 3.

Range: Late Paleocene–Early Eocene (Fig. 2).

Remarks: The tortuous history of the supposed relationships of the '*Ranikothalia bermudezi* group' was reviewed by Haynes (1988), with the conclusion that the distinction drawn by Eames (1968) between *bermudezi* and *nuttalli* (which he returned to *Nummulites*) on the presence or absence of vertical canals was valid. Both genera possess two rows of secondary septal canals per septum, branching from the subsutural septal canal. However, they do not show imperforate surface traces on the lateral walls of the chambers (trabeculae in the classic sense). This is because the secondary canals open immediately adjacent to the septum and do not turn over and open well away from it, producing a poreless bar, as in *Nummulites sensu stricto*, where the secondary canals are also further branched.

Ranikothalia differs from *Chordoperculinoides* in its finely porous spiral sheet and from *Nummulitoides* in remaining involute throughout (Table 1 and Figure 3). Note that Butt (1991) attempted to synonomize these genera on the grounds that they lacked septal filaments, that is, they were operculine. As noted above, this view arose because of confusion between *'Operculina' sindensis*, which is involute, and *'Operculina' canalifera*, which is subevolute and belongs to *Nummulitoides. Sindulites* (*sindensis*) was separated generically from *Ranikothalia* by Eames (1968), but differs only in being much more lax in coiling – a difference considered subgeneric by Haynes (1988).

***Ranikothalia nuttalli kohatica* (Davies, 1927).** Plate 13, **1–8**; Plate 14, **1**, **2**

1927 *Nummulites nuttalli* var. *kohaticus* Davies: 269, pl. 19, figs 1–6.
1976 *Nummulites nuttalli sensu* Sirel: 100, pl. 10, figs 10–13.
1988 *Ranikothalia nuttalli sensu* Haynes: pl. 1, figs 6–10.
1995 *Ranikothalia nuttalli sensu* Racey: 77–78, pl. 7, figs 7, 10, 11, 15–18, 21, text-fig. 79.

Material: Fifteen B-form specimens (5 uncut, 3 axial and 7 equatorial sections) from Al Khawd: three from Fahud (1 uncut and 2 equatorial sections). Also numerous random thin sections.

Description:

[B-form]: Test large (up to 11 mm in diameter and 1.9 mm thick at the poles in the types), semi-compressed with massive canaliculate marginal cord and pronounced gutter marking final whorl; periphery bluntly rounded or truncate; spire irregular with up to seven whorls, first two or three whorls 2*d*, later whorls less; chambers become between two and three times higher than long by the third whorl and number 32 at the periphery, reaching about 72 by the seventh whorl; septa straight or curved; prominent subsutural canal with double row of simple secondary branches to septal pits on either side of the septum; externally, the septa are gently curved to falciform with a polar twist; small prominent pillars over the polar areas.

Dimensions:

[B-form]: External dimensions (three illustrated specimens), thickness/diameter ratio:

1. 1.6 mm /8.8 mm = 18%.
2. 1.6 mm/9.0 mm = 18%.
3. 1.8 mm/9.0 mm = 20%.

Average = 19%

Equatorial section (mean values based on seven thin sections):

Whorl	1	2	3	4	5	6	7
Radius (mm)	0.26	0.57	1.10	1.82	2.60	3.68	4.85
Chambers	12	24	32	37	53	61	72

Radius-per-whorl and chambers-per-whorl diagrams of the B-form of *Ranikothalia nuittalli kohatica* are shown in Figures 5 and 6, respectively.

Remarks: The A-form was not found. Davies (1927) considered that *Nummulites thalicus* 'may be' the megalospheric associate of *nuttalli*, and this view was formalized by later workers such as Rama Rao *et al.* (1940), Nagappa (1959), Eames (1968) and Samanta (1980). Racey (1995), on the other hand, noted that the taxonomic status of the A-form of *R. nuttalli* was problematic. He observed that the coiling diagram for the A-form did not match the initial part of the coiling diagram of the B-form while the height of the chambers and the thickness of the marginal cord were distinctly different for the two 'generations'. However, it is noteworthy that Davies thought it necessary on general morphological grounds to leave the species in *Nummulites*. Based on the same reasoning, we assign *thalicus thalicus* and *thalicus gwynae* to *Palaeonummulites*, which may well be the ancestor of *Ranikothalia*.

The Oman material corresponds to the smaller, flatter variety (*nuttalli kohatica*) from Thal that Davies distinguished from the robust form of *nuttalli* (*nuttalli nuttalli*) from Sind. Oman specimens also show the more compressed final whorl and more granulated poles that Davies considered characteristic of the former. His figures for the thickness of 10 specimens were a range of 16–22% and an average of 18% of the diameter (compared with a range of 19–35% and an average of 25% for the Sind material). Our two axial sections (Pl. 13, **7**, **8**) have average 19% and range 18–20%, and are clearly closer to the subspecies *kohatica*. The fact that the Oman specimens show the same thickness/diameter ratio and ornament as Davies' material from Thal strengthens his case for recognizing this geographical subspecies as valid. Its noteworthy that specimens recorded from the eastern side of the Indian Subcontinent clearly belong to the robust form (Shillong Plateau: Jauhri, 1996). Material described from Turkey by Sirel (1976) as '*Nummulites planulatus*' and *Ranikothalia nuttalli* shows even lower thickness percentages (11–13%) and may be intermediate with *R. (S.) sindensis* but lacks the more open whorls (more than 2*d*) of that subgenus (*Sindulites*). The specimen at the Natural History Museum, London, figured by Haynes (1988, pl. 1) in discussing the differences between *R. nuttalli s.l* and *C. bermudezi* was that of Smout from Thal and therefore actually of the subspecies *kohatica*.

The B-forms of *Ranikothalia solimani* Butterlin (*in* Butterlin & Monod, 1969) from the Upper Paleocene of Turkey have test dimensions varying from 0.9 mm thickness/8.4 mm diameter to 1.6 mm thickness/11.1 mm diameter, that is, 10.7–14.4%, and have 3–4.5 whorls, with 9, 14, 19 and 24 chambers respectively in whorls 1–4.

It should be noted that Hottinger (1977) figured a specimen from Sind in the Nuttall Collection as *Ranikothalia nuttalli* (his pl. 17, fig. 10). However, its lax coiling and marked cord and gutter suggest *R. sindensis* and therefore that it is the same as Nuttall's '*Operculina canalifera*' included by Davies in his diagnosis of that species. The other figures on the same plate (pl. 17, figs 2–9), taken to represent both megalospheric and microspheric generations of *R. sindensis* from the French Pyrenees and Libya, appear to be different, but no axial sections are given to help in the elucidation of the relationships.

Hottinger's specimens referred to *R. nuttalli* from the Ranikot of Sind (in the Marks Collection), shown in his plate 18, figures 1–6, are compressed, loosely coiled, flaring forms, with raised, tuberculate umbilical areas, which again, cannot be equated with either *R. nuttalli nuttalli* or *R. nuttalli kohatica*. They appear to represent an undescribed species. The other material figured on that plate (pl. 18, figs 7, 9–17), from the Ranikot, Khairabad Formation in the Salt Range, also shows lax coiling and may be the same, but in the absence of axial sections and surface views this must remain in doubt.

Age and faunal associations: The types are from the Late Paleocene Ranikot Formation (uppermost Ranikot Beds) of Thal, Pakistan, where they are found in association with *Ranikothalia* (*Sindulites*) *sindensis*, *Palaeonummulites thalicus thalicus*, *P. thalicus gwynae*, *Nummulites globulus* var. *indicus*, *Miscellanea miscella*, *Miscellanea stampi*, *Assilina ranikoti*, *Discocyclina ranikotensis*, *Lockhartia conditi*, *L. haimei*, *L. newboldi* and *Alveolina oblonga*.

They are found at Al Khawd, Wadi Amq and Wadi Bani Khalid in Oman in association with *Planocamerinoides jiwani*, *Discocyclina ramaroi*, *Sakesaria dukhani*, *S. nodulifera*, *Kathina* sp., *Hottingerina lukasi*, *Lockhartia diversa*, *Miscellanea meandrina* and *Planocamerinoides dandoticus*. The presence of *P. dandoticus*, according to Serra-Kiel *et al.* (1998) and Schaub (1981), indicates a latest Paleocene (SBZ5/P5a) age, while the former authors consider *H. lukasi* and *M. meandrina* to signify Zone SBZ4 (equivalent to within P4c–P5a or NP8/9) (see Fig. 2). This assignation is further supported by the co-occurrence of typical Late Paleocene taxa such as *Discocyclina ramaroi*, *Miscellanea*, *Kathina*, *Sakesaria dukhani* and *S. nodulifera.* Carbone *et al.* (1993) note the occurrence of *nuttalli* in the Upper Paleocene (P5) of Somalia, but without illustration.

Discussion

Biostratigraphy

Although the larger foraminifera described herein are difficult to identify to species level without matrix-free material and oriented thin sections, it is possible to use the simple classification scheme outlined in Table 1 and Figure 3 to identify genera from random thin sections (especially hard limestones).

The age ranges for the various Oman nummulitids described herein are summarized in Figure 2. It is clear from our work that the presence of *Nummulitoides*, *Chordoperculinoides* or *Ranikothalia* indicates an age close to the Paleocene–Eocene boundary. Consequently, the presence of any of these taxa, all of which have a distinctive massive marginal cord and are therefore as a group easily identifiable in random thin sections, may provide a useful biostratigraphic marker. The first occurrence of *Assilina* (effectively the *Assilina* '*spira*' group of Schaub, 1981) and *Planocamerinoides* (effectively the '*Assilina exponens*' group of Schaub, 1981) in the latest Paleocene (within NP9, base of P5a) may also prove to be useful, as may the first occurrence of *Palaeonummulites* and *Ranikothalia*, at the base of Zone NP9 of Martini (1971). Furthermore, the separation of *Nummulites sensu lato* into

Palaeonummulites and *Nummulites sensu stricto* provides a useful marker, since the latter only occurs in strata of Middle Eocene (Lutetian/P10) or younger age.

Evolution in the Palaeonummulitinae

A tentative scheme to show the possible lines of evolution in the Palaeonummulitinae is shown in Figure 2.

Most of the genera appear in a burst in the Thanetian (late in Zone P4), possibly from a tightly coiled ancestor of *Palaeonummulites* in the early Thanetian. This suggests a trend from tight to lax coiling, with particular success of moderately coiled, compressed forms in the Late Paleocene. In the Eocene, tight coiling becomes dominant, especially after the advent of *Nummulites sensu stricto* in the Lutetian.

The following lines of descent are suggested:

- *Palaeonummulites* to *Ranikothalia* near the P3/P4 boundary;
- *Ranikothalia* to *Chordoperculinoides* (Western Hemisphere group) and *Nummulitoides* (Eastern Hemisphere group) in P4a;
- *Nummulitoides* to *Assilina*, and *Ranikothalia* to *Planocamerinoides* near the P4/P5 boundary;
- *Planocamerinoides* to *Decrouezina* in the Early Eocene;
- *Palaeonummulites* to *Nummulites* near the Ypresian–Lutetian boundary.

Difficulties with this scheme include uncertainties in the ranges because the necessary taxonomic revision has still to be carried out in many areas. It also must not be forgotten that Danian, shallow marine, epicontinental deposits are quite restricted compared with those of the preceding Late Cretaceous transgressions (the greatest since the Cambrian) and the subsequent Thanetian deposits that widely overstep them. This helps to explain the obscurity of the origin of *Palaeonummulites*, which presumably arose from among the small rotaliids, possibly via a radial hyaline member of the *Nonion*/*Elphidium* group. *Operculina*, which, according to Hottinger (1977), differs from the *Ranikothalia* group in the complication of the branches of its septal canals, may have arisen separately from this ancestral group. As noted above, further work needs to be done on the internal structures before this kind of evidence can be related to the traditional taxonomic breakdown based on coiling rate and enrollment of the spiral lamina.

From the evidence produced here, it would seem that the claim that *Urnummilites* (based on *U. schaubi*) Boukhary & Scheibner (2009) from the Late Paleocene of Egypt is the ancestor of *Nummulites* is both in error and the wrong age as well.

Palaeobiogeography

With respect to the massively chordate nummulites that were generally previously assigned to '*Ranikothalia*', the following conclusions on geographical distribution (Fig. 8) can be made on the basis of the revisions suggested herein:

1. *Caudrina*: at present represented by one species (*C. soldadensis*), which is only known from the Caribbean (Soldado Rock, Trinidad and Georgia) (Fig. 8). Rahaghi's (1978) record from Iran needs further study.
2. *Chordoperculinoides*: at present represented by two species, *C. bermudezi* and *C.sahnii*. This genus is known from the Caribbean, West Africa and Oman. It may also be present in Senegal (Blondeau 1982) and Algeria (see Amard & Blondeau 1979) as '*bermudezi*' and, in Turkey (see Butterlin & Monod 1969) as '*savitriae*' (Fig. 8). These records merit further investigation.
3. *Nummulitoides*: at present represented by three species in Oman: *N. canalifer* (also known from Pakistan), *N. margaretae* (also known from Nigeria and Libya) and *N. inaequilateralis*. Other valid species comprise *N. tessieri* and *N. azilensis* from West Africa and the Pyrenees, respectively, while specimens from Pakistan assigned to *R. sindensis* (e.g. by Butt 1991) clearly belong in the genus *Nummulitoides. Nummulites rockallensis*, from the Rockall area (van Hinte & Wong 1975) and from the Porcupine Seabight (Hennah 1995) west of Ireland, is also a *Nummulitoides*. Amard & Blondeau (1979) have also illustrated some specimens assigned to '*bermudezi*' from Algeria that may also be placed in *Nummulitoides*, but this requires further investigation. The genus therefore has a broad distribution covering Europe from the Pyrenees to the North Atlantic, West and North Africa, Oman and Pakistan (Fig. 8).
4. *Ranikothalia*: represented by one species (*R. nuttalli kohatica*) in Oman. In our opinion, the genus comprises only three, possibly four, species/subspecies at present: *R. nuttalli nuttalli*, *R. nuttali kohatica* and *R. solimani* (plus an unamed form referred to *R. nuttalli* by Hottinger from the Salt Range), and is restricted (Fig. 8) to the eastern Tethys (Turkey, Oman and Pakistan). Records of *Ranikothalia* from Indonesia are wholly restricted to A-forms (e.g. van der Vlerk 1929; Caudri 1934), and should be assigned to

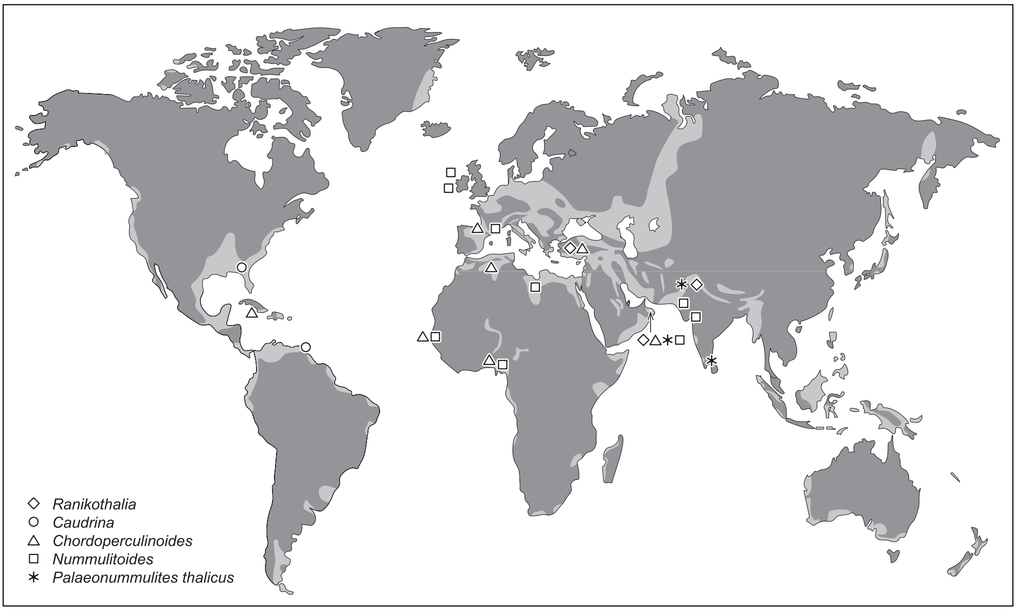

Fig. 8. Map showing geographical distribution of some described taxa.

Palaeonummulites. It is hoped to redescribe these forms elsewhere, at a later date.

With respect to the *Operculina* species present in Oman, many of these also occur in the Indian Subcontinent (Pakistan and India) and southern France, but in the case of *O. libyca* the species was only previously known from Libya.

Palaeonummulites thalicus gwynae (Fig. 8) appears to be restricted to the eastern Tethys (Pakistan and Oman), while *Planocamerinoides dandoticus* is known from Italy, Afghanistan, Pakistan and Oman. Species attributed to *Palaeonummulites* in the Caribbean (de Cizancourt, 1948) need further study.

Oman occupies a unique position between two major Tertiary larger foraminiferal faunal provinces (Adams 1967, 1983). It is therefore not too surprising to find *Ranikothalia nuttalli kohatica*, a taxon generally considered restricted to the Indian Subcontinent and *C. sahnii*, previously known from West Africa, and *Nummulitoides* previously known from Nigeria, Libya and the French and Spanish Pyrenees, as well as *Chordoperculinoides bermudezi*, originally described from the Caribbean. Note that Adams & Racey (1992) also found the supposed endemic Caribbean foraminifer *Yaberinella* in Oman. A mixing of Tethyan and American faunas in North Africa is further supported by the reports by Brun *et al.* (1982) of *Helicostegina* in the Eocene of the Gulf of Guinea and by Neumann *et al.* (1986) of various American species of *Discocyclina, Lepidocyclina* and *Helicolepidina* from Senegal.

A worldwide Late Paleocene *R. bermudezi* fauna, as suggested by Fleury *et al.* (1985), was mainly based on the grouping of these different, massively cordate nummulitids into this single taxon. However, Haynes (1988) was wrong in supposing that *bermudezi sensu stricto* was restricted to the Caribbean region, when contesting this idea.

Eames (1975), who based his views partly on earlier works by authors such as Davies & Pinfold (1937), lists the typical upper Ranikot (Paleocene) assemblage of Pakistan as comprising *Assilina dandotica**, *Dictyoconoides flemingi*, *Alveolina vrendenburgi*, *Lockhartia haimei**, *Miscellanea meandrina**, *Ranikothalia nuttalli**, *Operculina canalifera**, *O. jiwani**, *O. patalensis*, *O. salsa* and *Sindulites sindensis* (asterisked taxa are those present in Oman). Samanta (1968) recorded a broadly similar assemblage from the Pondicherry Formation of southern India, with the addition of *Discocyclina furoni* and *D. ramaroi* to the above list.

The Oman 'Paleocene' foraminiferal assemblage can therefore be seen to have marked similarities with those of India/Pakistan, especially with respect to its nummulitid assemblage, but with north and West African as well as Caribbean connections shown by the presence of *C. savitriae*, *N. margaretae* and *C. bermudezi*.

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Appendix: Glossary of terms

Septal filament: Extension of the septum over the lateral surface of the test, that is, polar extension of the front wall of each successive chamber 'instar' (*sensu* Smout 1954).

Septal trace: Surface expression of the septum on the outer surface of the test.

Septum(a): Partition(s) separating the chambers in each whorl.

Trabecula(e): a problematic term (see the main text); generally, unperforated strip(s) on the lateral wall of the chamber that represent the surface expression of the sutural canals that extend forwards and backwards from the septum.

Alar prolongation: Lateral extension of the chamber cavity over the surface of the test.

Marginal cord: Complex three-dimensional meshwork of canals encased in shell material, but open to the outside, which forms the keel of the test and assumes the function of the aperture seen in other genera of foraminifera.

Evolute: Chamber cavities do not extend into alar prolongations and adult whorls simply abut the marginal cord of preceding whorls.

Involute: Spiral laminae extend over the test to the poles, forming alar prolongations and covering previous whorls.

Quasi-evolute: Alar prolongations are absent, although spiral lamina covers previous whorls.

Maturo-evolute: Evolute in adult whorls.

Subevolute: Spiral lamina clasp and overlap the marginal cord only.

Spiral laminae: The spiral sheets built-up by each successive chamber 'instar'.

References

ABRARD, D. 1956. Une Operculine cordelée de l'Éocène inférieur de la Côte-d'Ivoire. *Operculina (Nummulitoides) tessieri*, n. subgen., n. sp. *Bulletin de la Société géologique de France* (série 6), **5**, 489–493.

ADAMS, C. G. 1967. Tertiary foraminifera in the Tethyan, American and Indo-Pacific provinces. *In*: ADAMS, C. G. & AGER, D. V. (eds) *Aspects of Tethyan Biogeography*, Systematics Association, London (Publication **7**), 195–217.

ADAMS, C. G. 1983. Speciation, phylogenesis, tectonism, climate and eustasy: factors in the evolution of Cenozoic larger foraminiferal bioprovinces. *In*: SIMS, R. W., PRICE, J. H. & WHALLEY, P. E. S. (eds) *Evolution, Time and Space: The Emergence of the Biosphere*. Academic Press, London, 255–289.

ADAMS, C. G. 1988. Septa, septal traces and septal filaments in the foraminiferal genus *Nummulites* Lamarck. *Journal of Micropalaeontology*, **7**, 89–102.

ADAMS, C. G. & RACEY, A. 1992. The occurrence and palaeobiogeographical significance of the foraminiferid *Yaberinella* from the Eocene of Oman. *Palaeontology*, **35**, 237–245.

ADAMS, C. G., HARRISON, C. A. & HODGKINSON, R. L. 1980. Some primary type specimens of foraminifera in the British Museum (Natural History). *Micropaleontology*, **26**, 1–16.

AKHTAR, M. & BUTT, A. A. 1999. Lower Tertiary biostratigraphy of the Kala Chitta Range, northern Pakistan. *Revue de Paléobiologie*, **18**, 123–146.

AL-SAYIGH, A. R. S. 1992. *Foraminifera of the Palaeocene/Eocene boundary in Oman*. MPhil dissertation, University of Wales, Aberystwyth.

AMARD, B. & BLONDEAU, A. 1979. Le Paléocène supérieur à *Ranikothalia bermudezi* et l'Éocène inférieur (Ilerdien basal) à *Nummulites fraasi* et *N. deserti* du Tademait-E. et Tinhert-W. *Geobios*, **12**, 635–651.

ARNI, P. 1965. Contribution à la systematique des *Nummulites s.l. Mémoires du Bureau de recherches géologiques et minières*, **32**, 21–28.

ARNI, P. 1966. Contribution to the history of the growth of *Chordoperculinoides* shell. *Eclogae Geologicae Helvetiae*, **59**, 339–346.

BANNER, F. T. & HODGKINSON, R. L. 1991. A revision of the foraminiferal subfamily Heterosteginae. *Revista española de micropaleontología*, **23**, 101–140.

BARUT, C., BOUROULLEC, J. & VILLATE, J. 1967. Sur la présence de *Nummulitoides sindensis* (Davies, 1927) dans le Thanétian de l'Ariège (Pyrénées centrales, France). *Bulletin du Centre de recherches de Pau – Société nationale des pétroles d'Aquitaine*, **1**, 383–403.

BERGGREN, W. A. 1974. Paleocene benthonic foraminiferal biostratigraphy, biogeography and paleoecology of Libya and Mali. *Micropaleontology*, **20**, 449–485.

BERGGREN, W. A., KENT, D. V., SWISHER, C. C. III & AUBRY, M.-P. 1995. A revised Cenozoic geochronology and chronostratigraphy. *In*: BERGGREN, W. A., KENT, D. V., AUBRY, M.-P. & HARDENBOL, J. (eds) *Geochronology, Timescales and Global Stratigraphic Correlation. SEPM (Society for Sedimentary Geology) Special Publication*, **54**, 129–212.

BLONDEAU, A. 1972. *Les Nummulites.* Vuibert, Paris.

BLONDEAU, A. 1982. Les nummulites de l'Afrique. *Mémoire, Quatrième colloque africain de micropaléontologie*, 56–57.

BLOW, W. H. 1969. Late middle Eocene to Recent planktonic foraminiferal biostratigraphy. *In*: BRÖNNIMANN,

P. & RENZ, H. H. (eds) *Proceedings of the First International Conference on Planktonic Microfossils*. Volume 1. E. J. Brill, Leiden, 199–422.

BLOW, W. H. 1979. *The Cainozoic Globigerinina. A Study of the Morphology, Taxonomy, Evolutionary Relationships and the Stratigraphical Distribution of some Globigerinida (mainly Globigerinacea)*. E. J. Brill, Leiden.

BOUKHARY, M. 1994. *Decrouezina* n.gen: descendant of *Ranikothalia* in Nummuliticea. *Micropaleontology*, **40**, 95–99.

BOUKHARY, M. & SCHEIBNER, C. 2009. On the origin of *Nummulites*: *Urnummulites schaubi* n.gen. n. sp., from the late Paleocene of Egypt. *Micropaleontology*, **55**, 413–420.

BOUKHARY, M., KULBROOK, F. & KAUS, J. 1998. New nummulitids from lower Eocene limestones of Egypt. *Micropaleontology*, **44**, 99–108.

BOUSSAC, J. 1906. Sur la formation du réseau des Nummulites réticulées. *Bulletin de la Société géologique de France* (série 4), **6**, 98–100.

BRADY, H. B. 1874. On a true Carboniferous nummulite. *Annals and Magazine of Natural History*, series 4, **13**, 222–231.

BRUN, L., BUTTERLIN, J. & MONTEIL, L. 1982. Découverte de lépidocyclines (Foraminifères) d'âge Éocène dans le Golfe de Guinée. Implications paléobiogéographiques. *Cahiers de Micropaléontologie*, **2**, 91–109.

BUKRY, D. 1973. Low-latitude cocolith biostratigraphic zonation. *Initial Reports of the Deep Sea Drilling Project*, **15**, 127–149.

BUKRY, D. 1975. Coccolith and silicoflagellate stratigraphy, northwestern Pacific Ocean, Deep Sea Drilling Project Leg 32. *Initial Reports of the Deep Sea Drilling Project*, **32**, 677–701.

BUTT, A. F. 1991. *Ranikothalia sindensis* Zone in late Paleocene biostratigraphy. *Micropaleontology*, **37**, 77–85.

BUTTERLIN, J. & MONOD, O. 1969. Biostratigraphie (Paléocène d'Éocène moyen) d'une coupe dans le Tamus de Beysehir (Turquie). Étude des 'Nummulites cordelées' et revision de ce groupe. *Eclogae Geologicae Helvetiae*, **62**, 583–604.

CARBONE, F., MATTEUCI, R., PIGNATTI, J. S. & RUSSO, A. 1993. Facies analysis and biostratigraphy of the Auruda Limestone Formation in the Barbera-Sheikh area, NW Somalia. *Geologica Romana*, **29**, 213–235.

CARPENTER, W. B. 1860. Researches in the Foraminifera. Part 3. On the genera *Peneroplis, Operculina* and *Amphistegina*. *Philosophical Transactions of the Royal Society of London*, **149** (for 1859), 1–41.

CARTER, H. J. 1853. Descriptions of some of the larger forms of fossilised foraminifera in Scinde: with observations on their internal structure. *Annals and Magazine of Natural History* (Series 2), **11**, 161–177.

CAUDRI, C. M. B. 1934. *Tertiary Deposits of Soemba*. H.J. Paris, Amsterdam.

CAUDRI, C. M. B. 1944. The larger foraminifera from San Juan de los Morros, State of Guarico, Venezuela. *Bulletins of American Paleontology*, **28**, 5–43.

CAUDRI, C. M. B. 1975. Geology and paleontology of Soldado Rock, Trinidad (West Indies). Part 2: The larger foraminifera. *Eclogae Geologicae Helvetiae*, **68**, 533–589.

CAUDRI, C. M. B. 1996. The larger foraminifera of Trinidad (West Indies). *Eclogae Geologicae Helvetiae*, **89**, 1137–1309.

CAVELIER, C. & POMEROL, C. 1986. Stratigraphy of the Paleogene. *Bulletin de la Société géologique de France* (série 8), **2**, 255–265.

COLE, W. S. 1947. Internal structure of some Floridian foraminifera. *Bulletins of American Paleontology*, **13**, 227–254.

COLE, W. S. 1953. Criteria for the recognition of certain assumed camerinid genera. *Bulletins of American Paleontology*, **35**, 27–46.

COLE, W. S. 1958. Names of and variation in certain American larger foraminifera, particularly in the camerinids – no. 2. *Bulletins of American Paleontology*, **38**, 261–284.

COLE, W. S. 1959. Faunal associations and the stratigraphic position of certain American Paleocene and Eocene larger foraminifera. *Bulletins of American Paleontology*, **39**, 377–393.

COLE, W. S. & HERRICK, S. M. 1953. Two species of larger foraminifera from Paleocene beds of Georgia. *Bulletins of American Paleontology*, **35**, 6–9.

CUSHMAN, J. A. 1914. A monograph of the foraminifera of the North Pacific Ocean. Part 4, Chilostomellidae, Globigerinidae, Nummulitidae. *Bulletin of the United States National Museum*, **71**, 1–46.

D'ARCHIAC, A. & HAIME, J. 1853. *Description des animaux fossiles du groupe nummulitique de l'Inde, précédé d'une résumé géologique et d'une monographe des Nummulites*. Gide & J. Baudry, Paris.

DAVIES, L. M. 1927. The Ranikot Beds at Thal (North-West Frontier Provinces of India). *Quarterly Journal of the Geological Society of London*, **83**, 260–289.

DAVIES, L. M. 1949. *Ranikothalia* in East and West Indies. *Geological Magazine*, **86**, 113–116.

DAVIES, L. M. 1952. *Ranikothalia sahnii* n. sp. and *R. savitriae* n. sp.: a possible link between the Palaeocene faunas of the East and West Indies. *Palaeobotanist*, **1**, 155–158.

DAVIES, L. M. & PINFOLD, E. S. 1937. The Eocene Beds of the Punjab Salt Range. *Memoirs of the Geological Survey of India, Palaeontologia Indica* (New Series), **24**, 14–79.

DE CIZANCOURT, M. 1948. Nummulites de l'ile da la Barbade (Petites Antilles). *Mémoire de la Société géologique de France*, **27/58**, 1–40.

DEFRANCE, J. L. M. 1822. *Dictionnaire des sciences naturelles*. Volume 25, laa–leo. F.G. Levrault, Paris.

DE GRACIANSKY, P.-C., HARDENBOL, J., JACQUIN, T. & VAIL, P. R. (eds) 1998. Mesozoic and Cenozoic sequence stratigraphy of European basins. *SEPM (Society of Sedimentary Geology) Special Publication*, **60**, 1–786.

DE ROISSY, F. 1805. *Histoire naturelle, générale et particulière de Mollusques (Buffon et Sonnini)*. Volume 5. Dufart, Paris.

DONCIEUX, L. 1926. Catalogue descriptif des fossiles nummulitiques de L'Aude et de l'Hérault: deuxieme partie (Fascicule III) – Corbières septentrionales, *Annales de l'Université de Lyon* (nouvelle série 1, Sciences, Medicine), **45**, 1–99.

D'ORBIGNY, A. 1826. Tableau méthodique de la classe des Céphalopodes. *Annales des sciences naturelles*, **7**, 245–314.

D'ORBIGNY, A. 1850. *Prodrome de paléontologie stratigraphique universelle des animaux mollusques et rayonnés*. Volume 2. V. Masson, Paris.

DROOGER, C. W. 1960. Some early rotaliid foraminifera. *Proceedings, Koninklijke Nederlandse Akademie van Wetenschappen* (Section B), **63**, 287–334.

EAMES, F. E. 1968. *Sindulites*, a new genus of the Nummulitidae (Foraminiferida). *Palaeontology*, **2**, 453–437.

EAMES, F. E. (revisor, with a contribution by Savage, R. J. G.) 1975. *Tertiary Faunas*. Volume 2. George Allen & Unwin [Revision of Morley Davies, 1934].

EAMES, F. E., BANNER, F. T., BLOW, W. H. & CLARKE, W. J. 1962. *Fundamentals of mid-Tertiary Stratigraphical Correlation*. Cambridge University Press, Cambridge.

ELLIS, B. F. & MESSINA, A. R. 1940. *et seq Catalogue Foraminifera*. The American Museum of Natural History, New York.

FLEURY, J.-J., BIGNOT, G., BLONDEAU, A. & POIGNANT, A. 1985. Biogéographie de Foraminifères benthiques téthysiens du Sénonien à l'Éocène supérieur. *Bulletin de la Société géologique de France*, (série 8), **5**, 757–770.

GLAESSNER, M. F. 1945. *Principles of Micropalaeontology*. Melbourne University Press, Melbourne.

GLENNIE, K. W., BOUEF, M. G. A., HUGHES CLARKE, M. K., MOODY-STUART, M., PILAAR, W. F. H. & REINHARDT, B. M. 1974. The geology of the Oman Mountains. *Verhandelingen van het Koninklijk Nederlandsch Geologisch Mijnbouwkundig Genootschap*, **31**, 1–433.

GRADSTEIN, F. M., OGG, J. G. & SMITH, A. G. (eds) 2004. *A Geologic Time Scale*. Cambridge University Press, Cambridge.

HANZAWA, S. 1935. Some fossil *Operculina* and *Miogypsina* from Japan and their stratigraphical significance. *Science Reports of the Tohoku Imperial University, Sendai* (Series 2, Geology), **18**, 1–29.

HAYNES, J. R. 1962. *Operculina* and associated foraminifera from the Paleocene of the N.E. Fezzan, Libya. *Contributions from the Cushman Foundation for Foraminiferal Research*, **13**, 90–97.

HAYNES, J. R. 1981. *Foraminifera*. Macmillan, London.

HAYNES, J. R. 1988. Massively cordate nummulitids (Foraminifera) at the Paleocene/Eocene boundary in Tethys. *Indian Journal of Geology*, **60**, 215–230.

HAYNES, J. R. & NWABUFO-ENE, K. 1988. Palaeocene nummulitids from Libya and West Africa. *Indian Journal of Geology*, **60**, 230–247.

HAYNES, J. R. & NWABUFO-ENE, K. 1998. Foraminifera from the Paleocene Phosphate Beds, Sokoto, Nigeria. *Revista española de micropaleontología*, **30**, 51–76.

HEILPRIN, A. 1883. On the occurrence of nummulitic deposits in Florida, and the association of *Nummulites* with a freshwater fauna. *Proceedings of the Academy of Natural Sciences of Philadelphia*, **1882** (pt. 2), 189–193.

HENNAH, T. J. 1995. *Studies in Palaeogene Nummulitids: Taxonomy and Biostratigraphy of Nummulitidae from Offshore Britain and Ireland*. Doctoral dissertation, University of Wales.

HOHENEGGER, J., YORDANOVA, E. & HATTA, A. 2000. Remarks on West Pacific Nummulitidae (Foraminifera). *Journal of Foraminiferal Research*, **30**, 3–28.

HOTTINGER, L. 1962. Recherches sur les Alvéolines du Paléocène et de l'Eocène. *Schweizerische Paläontologische Abhandlung*, **75/76** (for 1960), 1–242.

HOTTINGER, L. 1977. Foraminifères operculiniformes. *Mémoires du muséum national d' histoire naturelle*, **40**, 1–159.

JAUHRI, A. K. 1996. *Ranikothalia nuttalli* (Davies), a distinctive early Ilerdian marker in the Shillong Plateau. *In*: PANDEY, J. ET AL. (eds) *Contributions to the XV Indian Colloquium on Micropalaeontology and Stratigraphy, Dehra Dun*, 209–218.

JONES, R. W. & RACEY, A. 1994. Cenozoic stratigraphy of the Arabian Peninsula and Gulf. *In*: SIMMONS, M. D. (ed.) *Micropalaeontology and Hydrocarbon Exploration in the Middle East*. Chapman & Hall, London, 273–307.

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.

LEES, G. M. 1928. The geology and tectonics of Oman and of parts of south-eastern Arabia. *Quarterly Journal of the Geological Society of London*, **84**, 583–670.

LEYMERIE, A. 1846. Mémoire sur le terrain à *Nummulites* (épicrétacé) des Corbières et de la Montagne Noire. *Mémoires de la Société géologique de France* (série 2), **1**, 337–373.

LOEBLICH, A. R. JR & TAPPAN, H. 1964. Sarcodina chiefly 'Thecamoebians' and Foraminiferida. *In*: MOORE, R. C. (ed.) *Treatise on Invertebrate Paleontology, Part C, Protista 2*. Geological Society of America and University of Kansas Press, Lawrence.

LOEBLICH, A. R. JR & TAPPAN, H. 1987. *Foraminiferal Genera and their Classification*. Van Nostrand, Reinhold, New York.

MARTINI, E. 1971. Standard Tertiary and Quaternary Calcareous Nannoplankton Zonation. *In*: FARINACCI, A. (ed.) *Proceedings of the Second International Conference on Planktonic Microfossils, Rome, 1969*. Edizioni Tecnoscienza, Roma, 739–785.

MASSIEUX, M. 1973. *Micropaléontologie stratigraphique de l'Éocène des Corbières septentrionales (Aude)*. Cahiers de paléontologie. Éditions du Centre national de la recherche scientifique, Paris.

MONTENAT, C., BLONDEAU, A., BIZON, G., PERREAU, M., RAJU, D. S. N. & ROMAN, J. 1977. Premier aperçu du Tertiaire d'Oman (Péninsule arabique orientale). *Bulletin de la Société géologique de France*, **19**, 1285–1295.

MORLEY DAVIES, A. 1934. *Tertiary Faunas*. Volume 2. Thomas Murby, London.

MUNIER-CHALMAS, E. 1882. Observations sur le dimorphisme des Nummulites. *Bulletin de la Société géologique de France* (série 3), **10**, 424–427.

NAGAPPA, Y. 1959. Note on *Operculinoides* Hanzawa 1935. *Palaeontology*, **2**, 156–160.

NEUMANN, M., LY, A. & BUTTERLIN, J. 1986. Présence d'*Helicolepidina* et de lépidocyclines primitives dans l'Éocène du Sénégal (Casamance). *Revue de micropaléontologie*, **29**, 120–136.

NOLAN, S. C., SKELTON, P. W., CLISSOLD, B. P. & SMEWING, J. D. 1986. Late Campanian to Tertiary palaeogeography of the central and northern Oman Mountains. *In*: *Symposium on the Hydrocarbon Potential of Intense Thrust Zones, Abu Dhabi, December 1986*, 176–195.

NORRIS, D. R. & RÖHL, U. 2000. Astronomically-tuned chronostratigraphy for the Palaeocene-Eocene transition. *In*: SCHMITZ, B., SUNDQUIST, B. & ANDREASSON, F. P. (eds) *Early Paleogene Warm Climates and Biosphere Dynamics*. *GFF*, **122**, 117–118.

NUTTALL, W. L. F. 1926. The larger foraminifera of the upper Ranikot Series of Sind. *Geological Magazine*, **63**, 112–121.

NUTTALL, W. L. F. 1931. The stratigraphy of the upper Ranikot Series of Sind. *Records of the Geological Survey of India*, **65**, 306–313.

PALMER, D. K. 1934. Some large fossil foraminifera from Cuba. *Memorias de la Sociedad cubana de historia natural 'Felipe Poey'*, **8**, 235–264.

PARDO, A., KELLER, G. & OBERHÄNSLI, H. 1999. Paleoecological and paleoceanographic evolution of the Tethyan realm during the Paleocene-Eocene transition. *Journal of Foraminiferal Research*, **29**, 37–57.

PILGRIM, G. E. 1908. The geology of the Persian Gulf and the adjoining portions of Persia and Arabia. *Memoirs of the Geological Survey of India*, **34**, 1–177.

RACEY, A. 1988. *Nummulitid Biostratigraphy and Palaeogene Environments, Sultanate of Oman*. PhD dissertation, University of London.

RACEY, A. 1994. Biostratigraphy and palaeobiogeographical significance of Tertiary nummulitids (foraminifera) from northern Oman. *In*: SIMMONS, M. D. (ed.) *Micropalaeontology and Hydrocarbon Exploration in the Middle East.* Chapman & Hall, London, 343–370.

RACEY, A. 1995. Lithostratigraphy and larger foraminiferal (nummulitid) biostratigraphy of the Tertiary of Northern Oman. *Micropaleontology*, **41**, 1–123.

RACZ, L. 1979. Paleocene carbonate development of Ras al Hamra, Oman. *Bulletin des Centres de recherches exploration–production, Elf-Aquitaine*, **312**, 767–779.

RAHAGHI, A. 1978. Paleogene biostratigraphy of some parts of Iran. *Publications of the National Iranian Oil Company Geological Laboratories*, **7**, 1–161.

RAMA RAO, L., RAO, S. R. N. & NAGAPPA, Y. 1940. On *Nummulites* cf. *thalicus* Davies from the Eocene beds in the Pondicherry Cretaceous area, s. India. *Current Science*, **8**, 166–167.

RIDE, W. D. L., COGGER, H. G. *ET AL.* (eds) 1999. *International Code of Zoological Nomenclature*. 4th edition. International Trust for Zoological Nomenclature, London. xxix + 306 pp.

ROBINSON, E. & JIANG, M. M.-J. 1990. Palaeogene calcareous nannofossils from western Portland, and the ages and significance of the Richmond and Mooretown Formations of Jamaica. *Journal of the Geological Society of Jamaica*, **27**, 17–26.

ROBINSON, E. & WRIGHT, R. W. 1993. Jamaican Paleogene larger foraminifera. *Memoir of the Geological Society of America*, **182**, 283–345.

ROMERO, J., HOTTINGER, L. & CAUS, E. 1999. Early appearance of larger foraminifera supposedly characteristic of the late Eocene in the Igualada Basin, NE Spain. *Revista española de paleontología*, **14**: 79–92.

RÖTTGER, R., KRUGER, R. & DE RIJKS, S. 1990. Trimorphism in foraminifera (Protozoa) – verification of an old hypothesis. *European Journal of Protistology*, **25**, 226–228.

SACHS, K. N. 1957. Restudy of some Cuban larger foraminifera. *Contributions from the Cushman Foundation for Foraminiferal Research*, **8**, 106–120.

SAMANTA, B. K. 1968. *Discocyclina* from Pondicherry, South India. *Contributions from the Cushman Foundation for Foraminiferal Research*, **19**, 70–74.

SAMANTA, B. K. 1980. Foraminiferal genus *Ranikothalia* Caudri from the Pondicherry Formation, South India. *Quarterly Journal of the Geological, Mineralogical & Metallurgical Society of India*, **52**, 121–133.

SCHAUB, H. 1981. Nummulites et Assilines de la Téthys Paléogène. Taxinomie, phylogenèse et biostratigraphie. *Schweizerische Paläontologische Abhandlungen*, **104–106**, 1–236 (+ Atlas).

SCHUBERT, R. J. 1908. Beiträge zu einer natürlichen Systematik der Foraminiferen. *Neues Jahrbuch für Mineralogie,Geologie und Paläontologie, Beilage-Band*, **25**, 232–260.

SCHWAGER, C. 1883. Die Foraminiferen aus den Eocaenablagerungen der libyschen Wüste und Aegyptens. *In*: ZITTEL, K. A. (ed.) Geologie und Paläontologie der angrenzenden Gebiete von Aegypten. *Palaeontographica*, **30**, 79–153.

SERRA-KIEL, J., HOTTINGER, L. *ET AL.* 1998. Larger foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene. *Bulletin de la Société géologique de France*, **169**, 281–299.

SILVESTRI, A. 1934. Su di alcuni Foraminiferi Tertzianzi della Sirtica. *Missione della Reale Accademia d'Italia a Cufra*, **3**, 5–30.

SILVESTRI, A. 1937. Fossile eocenico singolare della Tripolitania. *Bolletino della Società Geologica Italiana*, **56**, 203–208.

SIREL, E. 1976. Systematic study of some species of the genera *Alveolina, Nummulites*, *Ranikothalia* and *Assilina* in the south Polath (S.W. Ankara), *Türkiye Jeoloji Kurumu Bülteni*, **19**, 89–102.

SMOUT, A. H. 1954. *Lower Tertiary Foraminifera of the Qatar Peninsula*. British Museum (Natural History), London.

SOWERBY, J. DE C. 1840. *In*: SYKES, W. H. (ed.) A notice respecting some fossils collected in Cutch, by Captain Walter Smee, of the Bombay Army. *Transactions of the Geological Society of London* (Series 2), **5**, 715–719.

SPINDLER, M. 1978. Anatomy of the test of *Heterostegina depressa* (Foraminiferida). *Journal of Foraminiferal Research*, **8**, 319–331.

Tambareau, Y. 1966. Sur une nouvelle espèce d'Operculine cordelée, *Operculina (Nummulitoides) azilensis* nov. sp. *Bulletin de la Société d'histoire naturelle de Toulouse*, **102**, 302–307.

Tosquella, J. & Serra-Kiel, J. 1996. Los nummulítidos (*Nummulites* y *Assilina*) del Paleoceno Superior–Eoceno Inferior de la Cuenca Pirenaica: Sistematica. *Acta Geologica Hispanica*, **31**, 37–159.

Tosquella, J., Serra-Kiel, J., Fernàndez-Cañadell, C. & Samsó, J. P. 1996. Las biozonas de nummulítidos del Paleoceno Superior–Eoceno Inferior de la Cuenca Pirenaica. *Acta Geologica Hispanica*, **31**, 23–36.

van der Vlerk, I. M. 1929. Groote foraminiferen van N. O. Borneo. *Wettenschappelijke Mededeelingen van de Dienst van de Mijnbouw in Nederlandsch-Oost-Indië*, **9**, 1–45.

van Hinte, J. E. & Wong, T. E. 1975. *Nummulites rockallensis* n. sp. from the upper Paleocene of Rockall Plateau (North Atlantic). *Journal of Foraminiferal Research*, **5**, 90–101.

Vaughan, T. W. & Cole, W. S. 1941. Preliminary report on the Cretaceous and Tertiary larger foraminifera of Trinidad, British West Indies. *Special Papers of the Geological Society of America*, **30**, 1–137.

White, M. R. 1994. Foraminiferal biozonation of northern Oman Tertiary carbonate succession. *In*: Simmons, M. D. (ed.) *Micropalaeontology and Hydrocarbon Exploration in the Middle East*. Chapman & Hall, London, 309–331.

Yabe, H. 1918. Notes on *Operculina*-rocks from, Japan, with remarks on *'Nummulites' cumingi* Carpenter. *Science Reports of the Tôhoku University, Sendai* (Series 2, Geology), **4**, 104–126.

Explanation of plates

Plate 1

1–5, 8, 11. *Assilina ranikoti* Nuttall, 1926

1, **2**. External view (both sides) of B-form (×8.8, diameter 2.8 mm). BMNH no. PF 67024.
3–**5**. External view (both sides) (×14.4) and (subsequent) axial section (×24), respectively, of A-form (diameter 1.85 mm). BMNH no. PF 67025.
8, **11**. Equatorial section of A-form (×14.4, diameter 3.38 mm), and close-up of central part of same equatorial section (×68). BMNH no. PF 67026.
All are from the lower member of the Jafnayn Formation, Wadi Bani Khalid, Oman. Latest Paleocene (Zone P5a).

6, 7. *Planocamerinoides dandoticus* (Davies, 1937)

6. Axial section of B-form (×16, diameter 2.0 mm). BMNH no. P52470.
7. Equatorial section of A-form (×16, diameter 2.3 mm). BMNH no. P 52468.
Both are from the lower member of the Jafnayn Formation, Wadi Amq, Oman. Latest Paleocene (Zone P5a).

9. '*Operculina*' *sindensis* Davies, 1927

Axial section of paratype, B-form (×8, diameter 8.5 mm). Previously figured by Davies (pl. 19, fig. 13). From the Ranikot beds of Thal, NW Pakistan. BMNH no. P 39411. Late Paleocene.

10. *Caudrina soldadensis* (Vaughan & Cole, 1941)

Axial section of B-form (×8, diameter 12.4 mm), after Caudri (1975, pl. 7, fig. 1). From sample Rz.248, an erratic limestone block originating from the Paleocene, Soldado Rock, Trinidad, West Indies. Naturhistorisch Museum, Basel, no. C 31227.

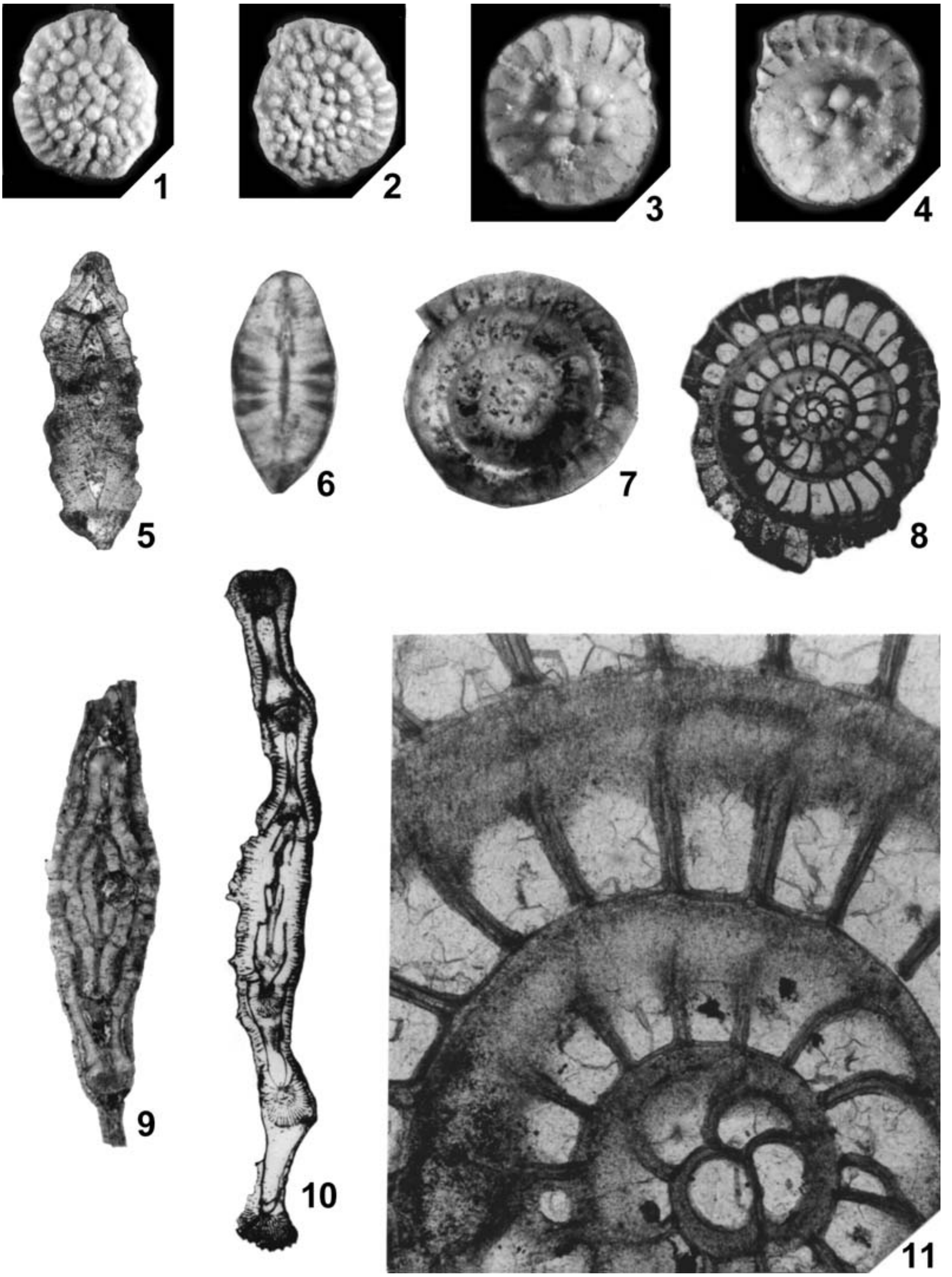

Plate 1

Plate 2

1–6. *Chordoperculinoides bermudezi* (Palmer, 1934)

1. External view of juvenile A-form in oil immersion (×32, diameter 1.5 mm) showing involute whorls and straight septa turned back towards the periphery. BMNH no. PF 67027.
2. Detail of **1** (scale bar: 0.1 mm) with openings of simple branches to septal canal either side of septa.
3. Axial section of A-form (×32, diameter 2.2 mm) showing thick walls and coarse, vertical canals. BMNH no.PF 67028.
4. Equatorial section of A-form (×28, diameter 2.5 mm). BMNH no. PF 67029.
5. Axial section of B-form in oil immersion (×36, diameter 5 mm). BMNH no. PF 67030.
6. Equatorial section of B-form in oil immersion (×38) showing simple branches of septal canals. BMNH no. PF 67031.
All are from the Umm er Rhaduma Formation (broadly equivalent to the Jafnayn Formation, lower member), Fahud, Oman. Late Paleocene.

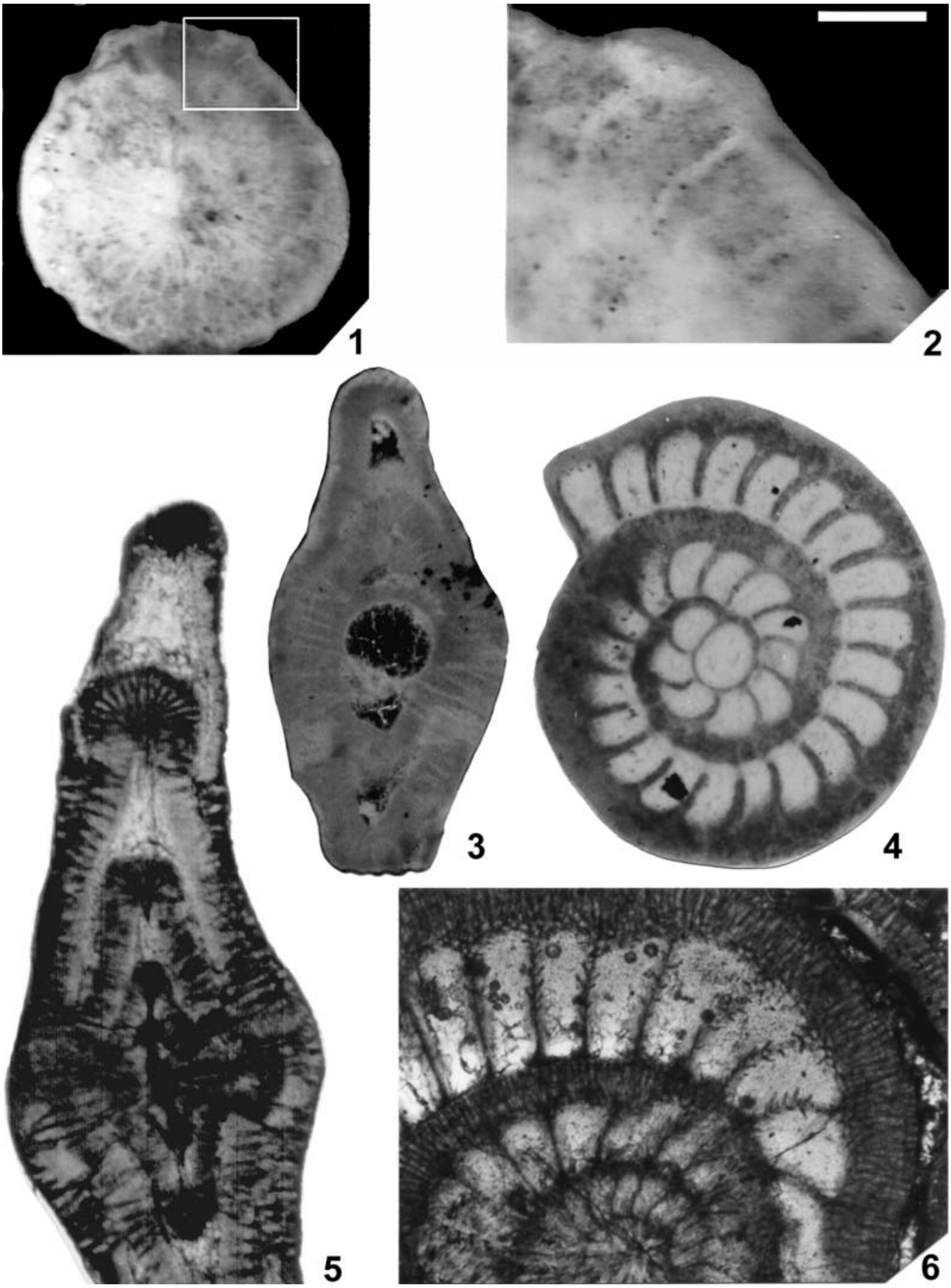

Plate 2

Plate 3

1–7. *Chordoperculinoides sahnii* (Davies, 1952)

1. Axial section of A-form (×16, diameter 5.0 mm). BMNH no. P 52447.
2, **4**, **7**. Equatorial section of B-form (diameter 6.5 mm): **4**. General view (×4). **2**, **7**. Enlargements (×80 and ×40, respectively) showing simple branches of septal canals. BMNH no. P 42448.
3. Equatorial section of B-form (×4, diameter 6.5 mm). BMNH no. P 52446.
5. Axial section of A-form (×16, diameter 4.5 mm). BMNH no. P52449.
6. Equatorial section of A-form (×8, diameter 5.0 mm). BMNH no. P 52456.
All are from the Umm er Rhaduma Formation (broadly equivalent to the Jafnayn Formation, lower member), Fahud, Oman. Late Paleocene.

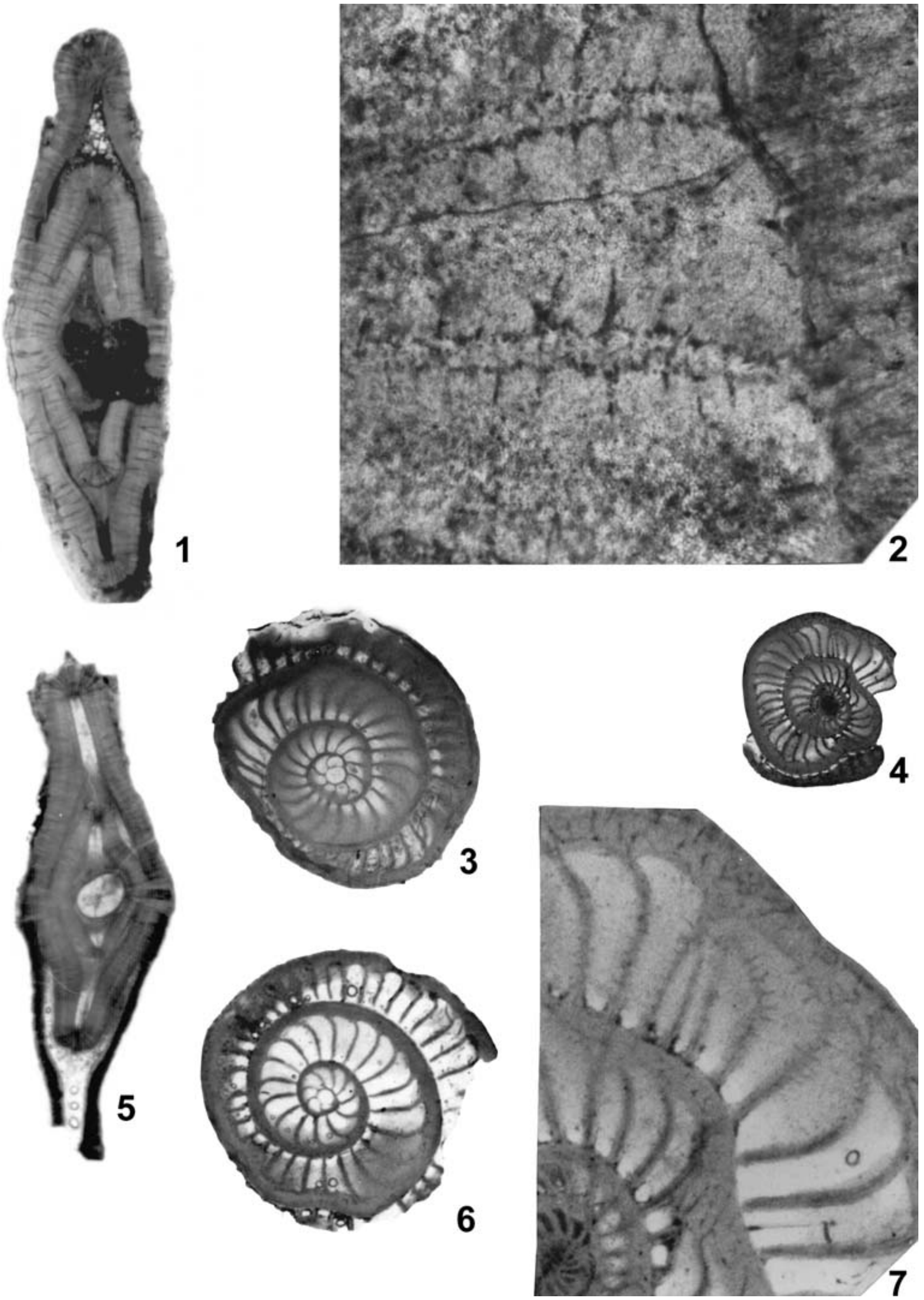

Plate 3

Plate 4

1–8. *Nummulitoides canalifer* (d'Archiac & Haime, 1853)

1, **2**. External and equatorial half-section of B-form (×4, diameter 9.8 mm). BMNH no. P 52493.
3. Equatorial half-section of B-form (×4, diameter 8.0 mm). BMNH no. P 52494.
4, **7**. External view (×5.6) and (subsequent) equatorial section (×8.8) of A-form (diameter 4.6 mm), the initial megalospheric whorl affected by possible parasitism. BMNH no. PF 67034.
5, **6**. External view (×8) and (subsequent) equatorial section (×9.6) of B-form (diameter 4.2 mm), microspheric initial whorls affected by possible parasitism. BMNH no. PF 67033.
8. Axial section of A-form (×26.4, diameter 3.1 mm) showing tuberculate umbilical shoulders. BMNH no. PF 67035.
4–8 are '*Operculina*' *sindensis auctt.* (see text).
1–3 are from the Umm er Rhaduma Formation (broadly equivalent to the Jafnayn Formation, lower member), Fahud, Oman. Early Eocene (Zone P6b). **4–8** are from the Jafnayn Formation, Qantab, Oman.

9. **'*Operculina*' *sindensis* Davies, 1927**

External view of Neotype (chosen by Haynes, 1988), B-form previously figured by Davies (pl. 19, fig, 12) (×3, diameter 12.5 mm). From the Ranikot beds of Thal, NW Pakistan. BMNH no. P 39410. Late Paleocene.

10. *?Ranikothalia* sp.

Equatorial section (×80) showing simple branches of septal canal. BMNH no. PF 67036. From the Umm er Rhaduma Formation, Fahud, Oman.

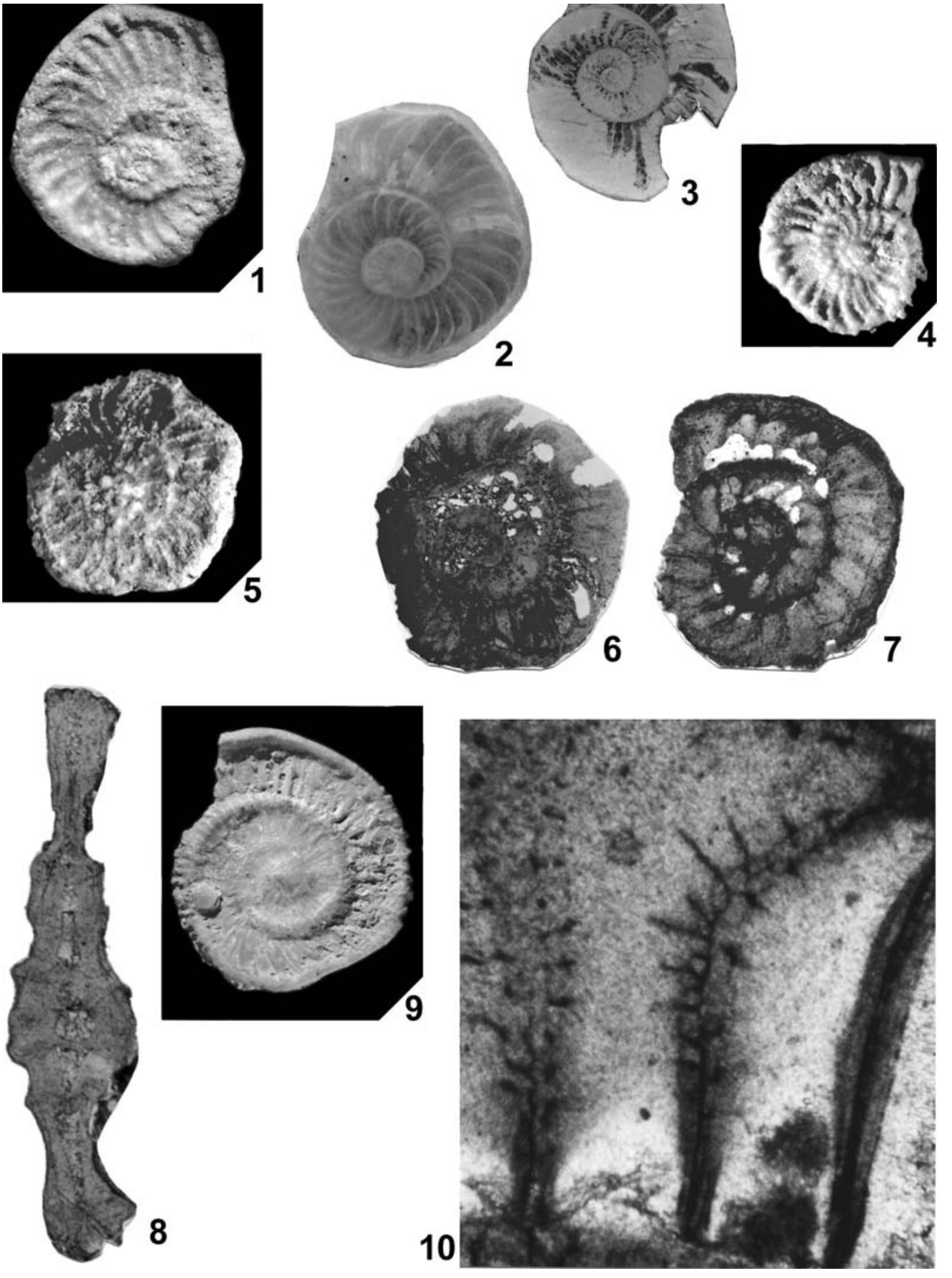

Plate 4

Plate 5

1–11. *Nummulitoides inaequilateralis* (Carter, 1853)

1. Axial section of A-form (×16, diameter 4.2 mm). BMNH no. PF 67037.
2. Axial section (×16, diameter 4.0 mm). BMNH no. PF 67038.
3. Axial section of A-form (×72, diameter 1.6 mm). BMNH no. PF 67039.
4. Axial section of B-form (×29.6, diameter 2.6 mm). BMNH no. PF 67040.
5. External view of ?A-form (×16, diameter 2.0 mm). BMNH no. PF 67041.
6. Axial section of A-form (×16, diameter 2.5 mm). BMNH no. PF 67042.
7. Axial section of A-form (×32, diameter 1.1 mm). BMNH no. PF 67043.
8. Equatorial section of A-form (×24, diameter 1.7 mm). BMNH no. PF 67044.
9. Polished half-section of A-form (×16, diameter 2.5 mm, incomplete). BMNH no. PF 67045.
10. Equatorial section of A-form (×24, diameter 1.5 mm). BMNH no. PF 67046.
11. Equatorial section of A-form (×14.4, diameter 2.6 mm). BMNH no. PF 67047.
1, **2**, **5**, **6**, **9** are from the lower member of the Jafnayn Formation, Qantab, Oman. **3**, **4**, **7**, **8**, **10**, **11** are from the same formation, Wadi Rusayl, Oman. Both Late Paleocene (late P4c or P5a).

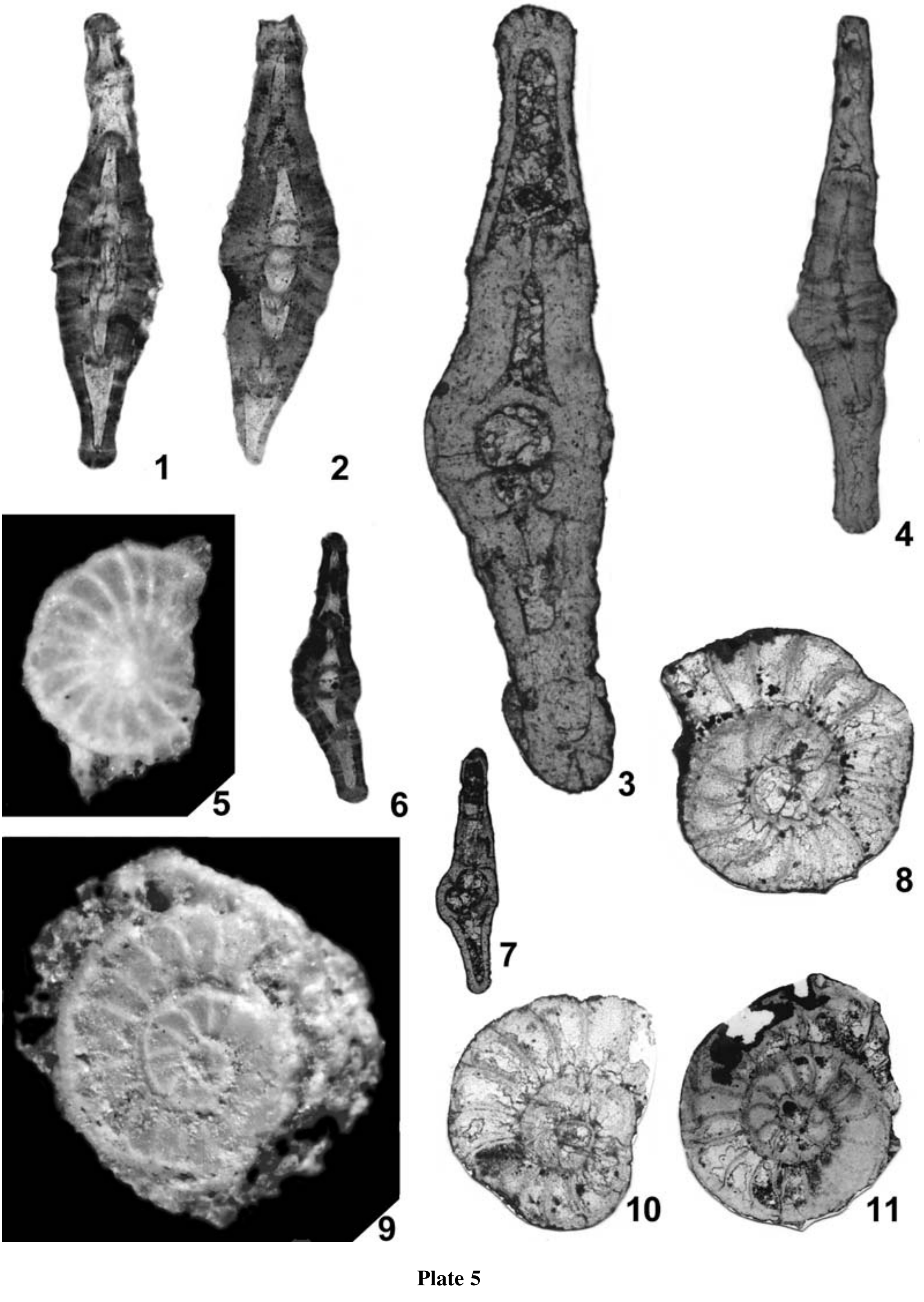

Plate 5

Plate 6

1–3. ***Nummulitoides inaequilateralis*** **(Carter, 1853)**

1. Equatorial section of A-form (×28, diameter 3.2 mm). BMNH no. PF 67048.
2. Axial section of A-form (×28, diameter 3.8 mm, thickness 0.6 mm). BMNH no. PF 67049.
3. Equatorial section of A-form (×28, part only, incomplete). BMNH no. PF 67050.
1, **2** are from Qantab. **3** is a (near)-topotype from Bandar Jissah (Rhas Ghissa), Oman. Both Late Paleocene (lower member of the Jafnayn Formation).

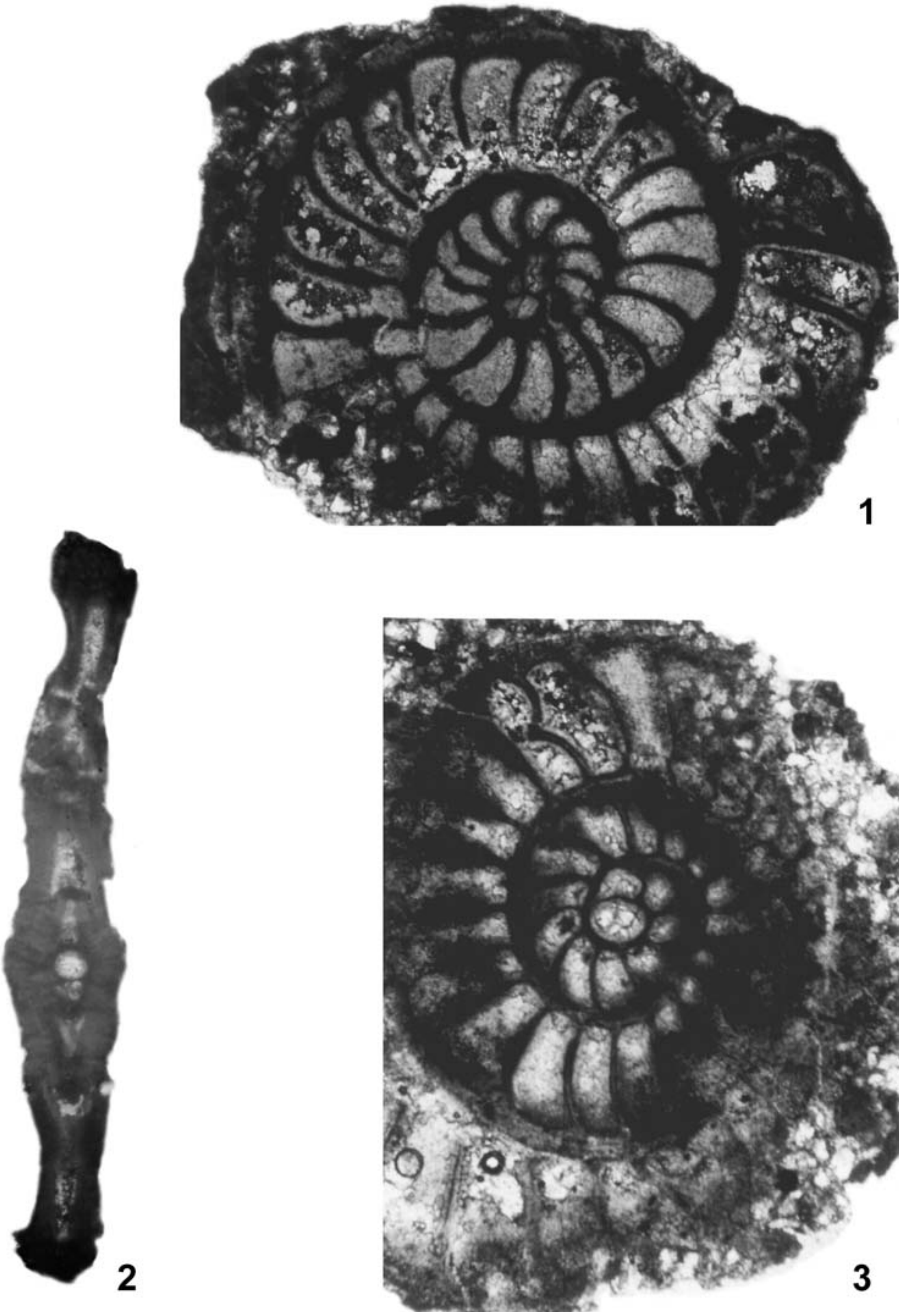

Plate 6

Plate 7

1–7. *Nummulitoides inaequilateralis* (Carter, 1853)

1. Equatorial section of A-form ($\times 32$) to show oval proloculus (first whorl and a half shown). BMNH no. PF 67051.
2. Equatorial section of A-form ($\times 20$) showing simple branches to septal canal. BMNH no. PF 67052.
3. Equatorial section of B-form ($\times 8$, diameter 4.5 mm, incomplete). BMNH no. PF 67053.
4. Equatorial section of B-form ($\times 8$, diameter 6.00 mm, incomplete). BMNH no. PF 67054.
5. External view of the lectotype, a probable B-form, partially broken ($\times 6.8$, diameter 5.75 mm). BMNH no. P 30020.
6, **7**. Opposite external views of specimen removed from original rock in Carter's Collection (BMNH no. P 29812), showing the distinctive inequilateral test ($\times 9$, diameter 5.1 mm).
1–4 are (near-) topotypes from Bandar Jissah (Rhas Ghissa). **5** (lectotype) and **6**, **7** (syntype/metatype) are from Rhas Ghissa, south of 'Muskat', Oman. Late Paleocene (lower member of the Jafnayn Formation).

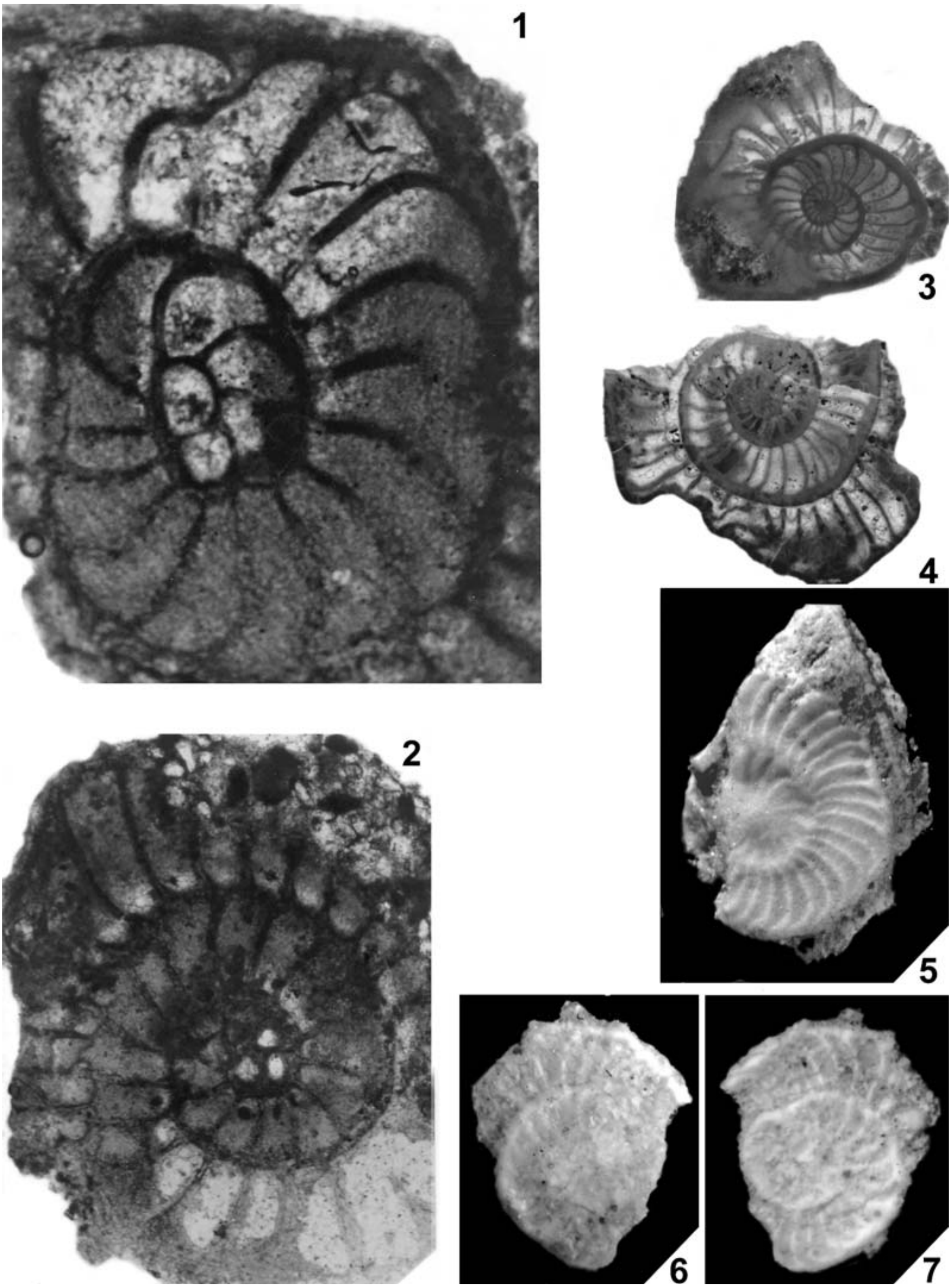

Plate 7

Plate 8

1–9. ***Nummulitoides margaretae*** **Haynes & Nwabufo-Ene, 1988**

1–3. External views (both sides) (×16) and (subsequent) equatorial section (×12), respectively, of possible A-form (diameter 3.3 mm). BMNH no. PF 67055.

4. Axial section of B-form (×16, diameter 3.6 mm, incomplete). BMNH no. PF 67056.

5. Axial section of A-form (×16, diameter 3.75 mm). BMNH no. PF 67057.

6, **8**. External view (×18.4) and (subsequent) axial section (×28) of A-form (diameter 2.8 mm). BMNH no. PF 67059.

7. Equatorial half-section of A-form (×16, diameter 3.1 mm, incomplete). BMNH no. PF 67058.

9. Equatorial section of A-form (×16, diameter 3.6 mm). BMNH no. PF 67060.

1–3, **6–8** are from Wadi Rusayl. **4**, **5**, **9** are from Qantab, Oman. Both localities are in the Jafnayn Formation (lower member). Late Paleocene.

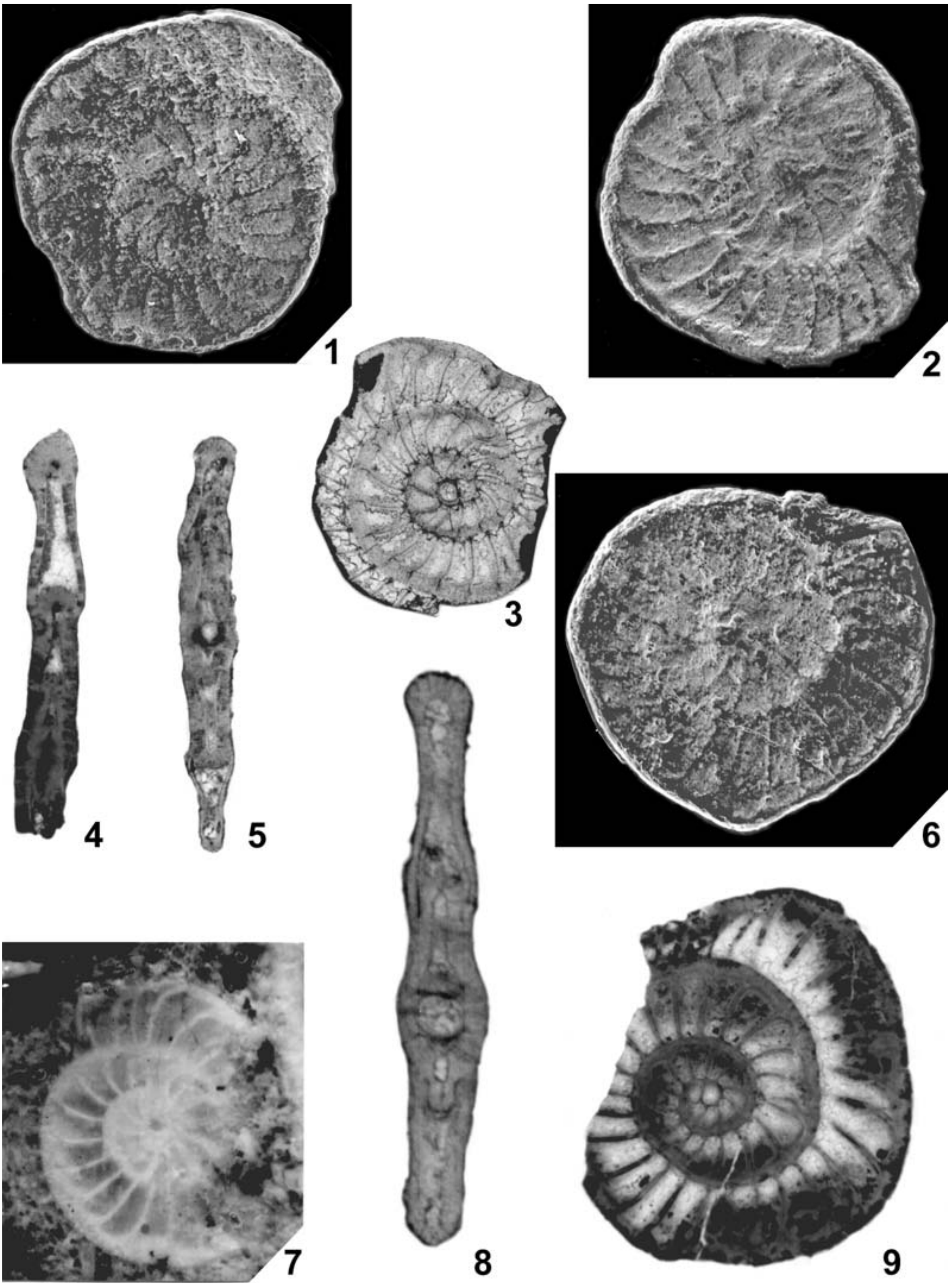

Plate 8

Plate 9

1–3. *Operculina ammonea* Leymerie, 1846

1. External view of probable B-form (×8, diameter 5.5 mm). (ex slide P 52491) BMNH no. PF 67061.
2. Equatorial section of B-form (×8, diameter 5.0 mm). BMNH no. P 52490.
3. Equatorial section of A-form (×16, diameter 2.1 mm). BMNH no. 52492.
All are from the Umm er Rhaduma Formation, Fahud, Oman. Early Eocene (Zone P6b).

4–7. *Operculina hardiei* d'Archiac & Haime, 1853

4. Equatorial section of B-form (×8, diameter 3.5 mm). BMNH no. P 52496.
5. External view of probable A-form (×16, diameter 2.3 mm). (ex slide P 52495) BMNH no. PF 67061.
6. Equatorial section of A-form (×16, diameter 2.8 mm). BMNH no. P 52497.
7. External view of B-form (×8, diameter 5.0 mm). (ex slide P 52498) BMNH no.PF 67062.
All are from the lower member of the Jafnayn Formation, Wadi Bani Khalid, Oman. Latest Paleocene (Zone 5a).

8, 9. *Operculina heberti* Munier-Chalmas, 1882

8. Equatorial section of A-form (×16, diameter 2.8 mm). BMNH no. P 52500.
9. Equatorial section of A-form (×16, diameter 2.3 mm). BMNH no. P 52499.
Both are from the lower part of the Umm er Rhaduma Formation (broadly equivalent to the lowermost Jafnayn Formation or slightly older), Fahud, Oman. Late Paleocene (Zone P4).

10–12. *Planocamerinoides jiwani* (Davies, 1937)

10. Axial section of A-form (×32, diameter 1.6 mm). BMNH no. P 52501.
11. Equatorial section of probable B-form (×32, diameter 1.0 mm). BMNH no. P 52502.
12. Equatorial section of A-form (×32, diameter 1.5 mm). BMNH no. P 52503.
All are from the lower member of the Jafnayn Formation, Al Khawd, Oman. Latest Paleocene (Zone P5a).

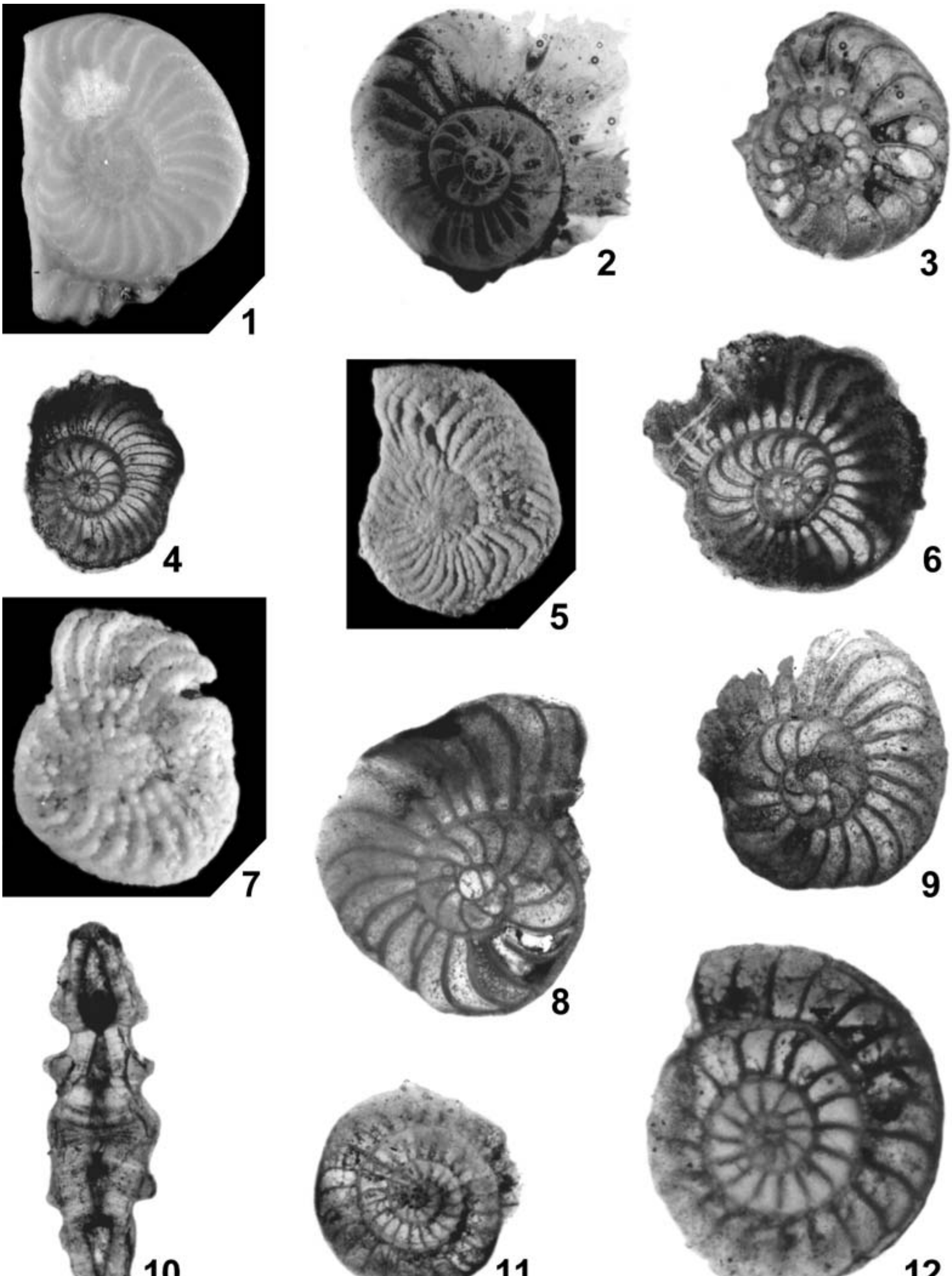

Plate 9

Plate 10

1, 3–5. *Operculina libyca* Schwager, 1883

1. External view of possible B-form in oil immersion (×16, diameter 4.4 mm) BMNH no. PF 67063.
3. Axial section of A-form (×13.6, diameter 4.5 mm). BMNH no. PF 67065.
4. External view of A-form in oil immersion (×19.2, diameter 2.5 mm).
5. Detail of part of equatorial section of B-form (×25.6).
All are from the upper part of the Umm er Rhaduma Formation, Fahud, Oman. Early Eocene (Zone P6b).

2. *Operculina heberti* Munier-Chalmas, 1882

External view of possible B-form in oil immersion (×14.4, diameter 4.6 mm). BMNH no. PF 67064. From the lower part of the Umm er Rhaduma Formation (broadly equivalent to the lowermost Jafnayn Formation or slightly older), Fahud, Oman. Paleocene (Zone P4).

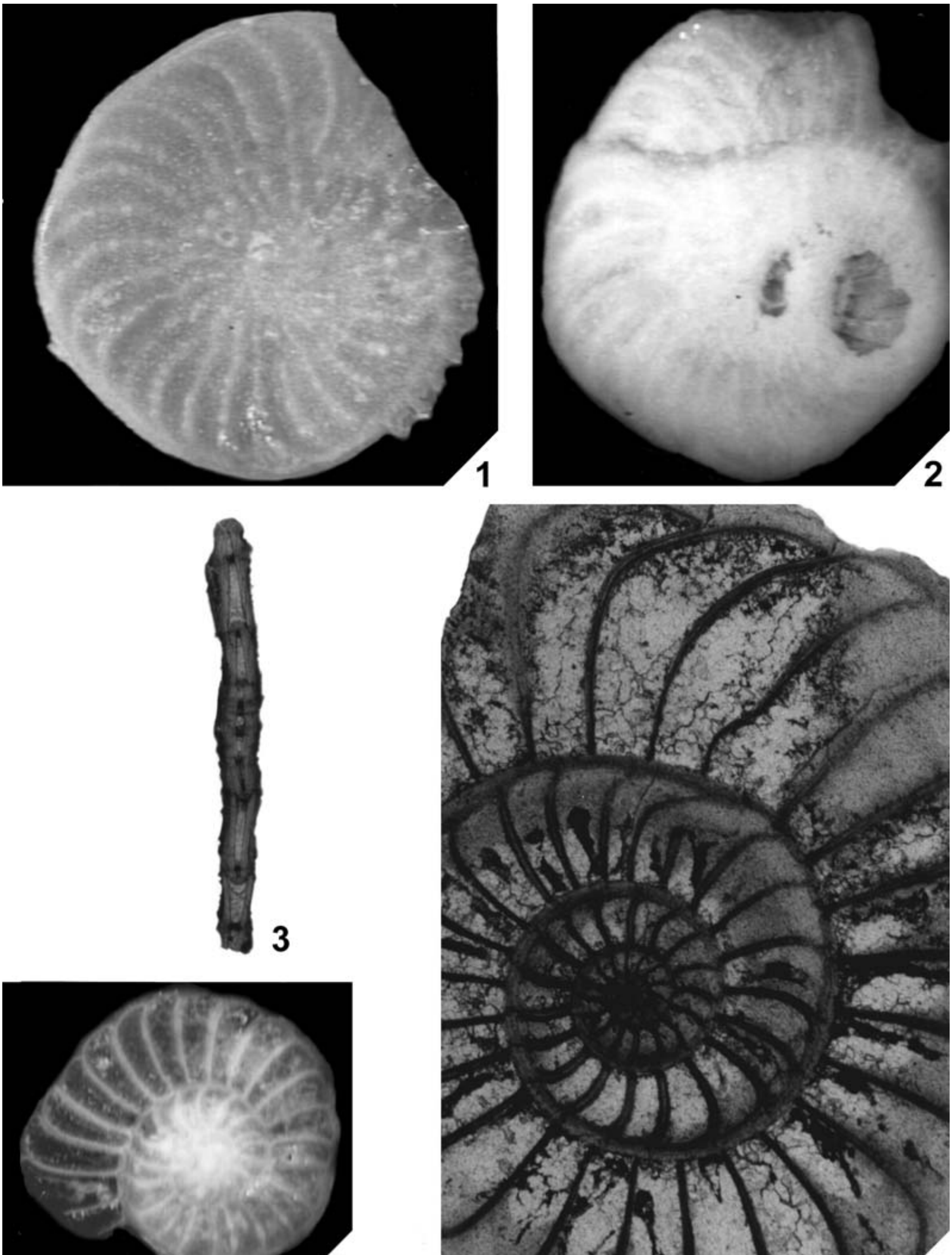

Plate 10

Plate 11

1, 2. *Operculina libyca* Schwager, 1883

1. Equatorial section of B-form (×8.8, diameter 5.2 mm).
2. Equatorial section of A-form (×10, diameter 4.1 mm).
Both from the Umm er Rhaduma Formation, Fahud, Oman. Early Eocene (Zone P6).

3–7. *Operculina subgranulosa* d'Orbigny, 1850

3. Axial section of A-form (×16, diameter 2.5 mm).
4, **5**. External view (×18) and (subsequent) equatorial section of A-form (×16, diameter 3.5 mm). BMNH no. P 52505.
6, **7**. External view (×16) and (subsequent) equatorial section of A-form (×18.4, diameter 3.75 mm). BMNH no. P 52504.
All are from the Umm er Rhaduma Formation, Fahud, Oman. Early Eocene (Zone P6).

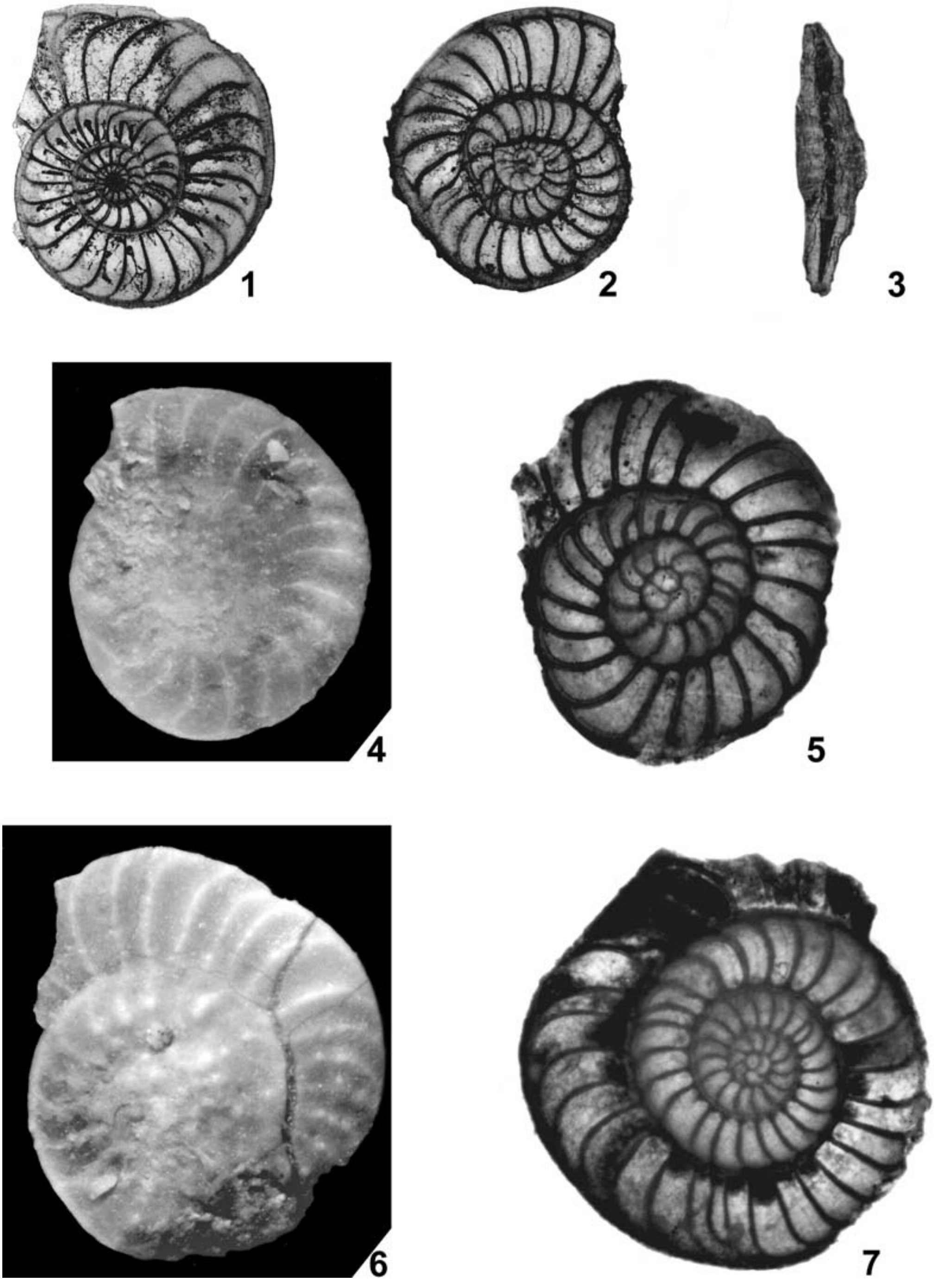

Plate 11

Plate 12

1–8. *Palaeonummulites thalicus gwynae* (Davies, 1927)

1. External view of probable A-form in oil immersion ($\times 20$, diameter 3.2 mm). BMNH no. P 52438.
2. Detail ($\times 80$) of same specimen to show marginal cord and branches of the septal canals.
3. Equatorial section of A-form ($\times 16$, diameter 2.4 mm). BMNH no. PF 67066.
4. Axial section of A-form ($\times 16$, diameter 3.15 mm, thickness 1.25 mm). BMNH no. P 52437.
5. External view (other side) of A-form shown in **1** ($\times 8$, diameter 3.2 mm). BMNH no. P 52438.
6. Equatorial section of A-form ($\times 20$, diameter 2.8 mm). BMNH no. P 52440.
7. Equatorial section of A-form ($\times 16$, diameter 2.1 mm). BMNH no. PF 67067.
8. Axial section of A-form ($\times 27.2$, diameter 3.25 mm, thickness 1.0 mm). BMNH no. PF 67068.
1, **2**, **4–7** are from the lower member of the Jafnayn Formation, Al Khawd. **3**, **8** are from the Umm er Rhaduma Fortmation, Fahud, Oman. Both samples are latest Paleocene–earliest Eocene in age (mid P5a–mid P6a).

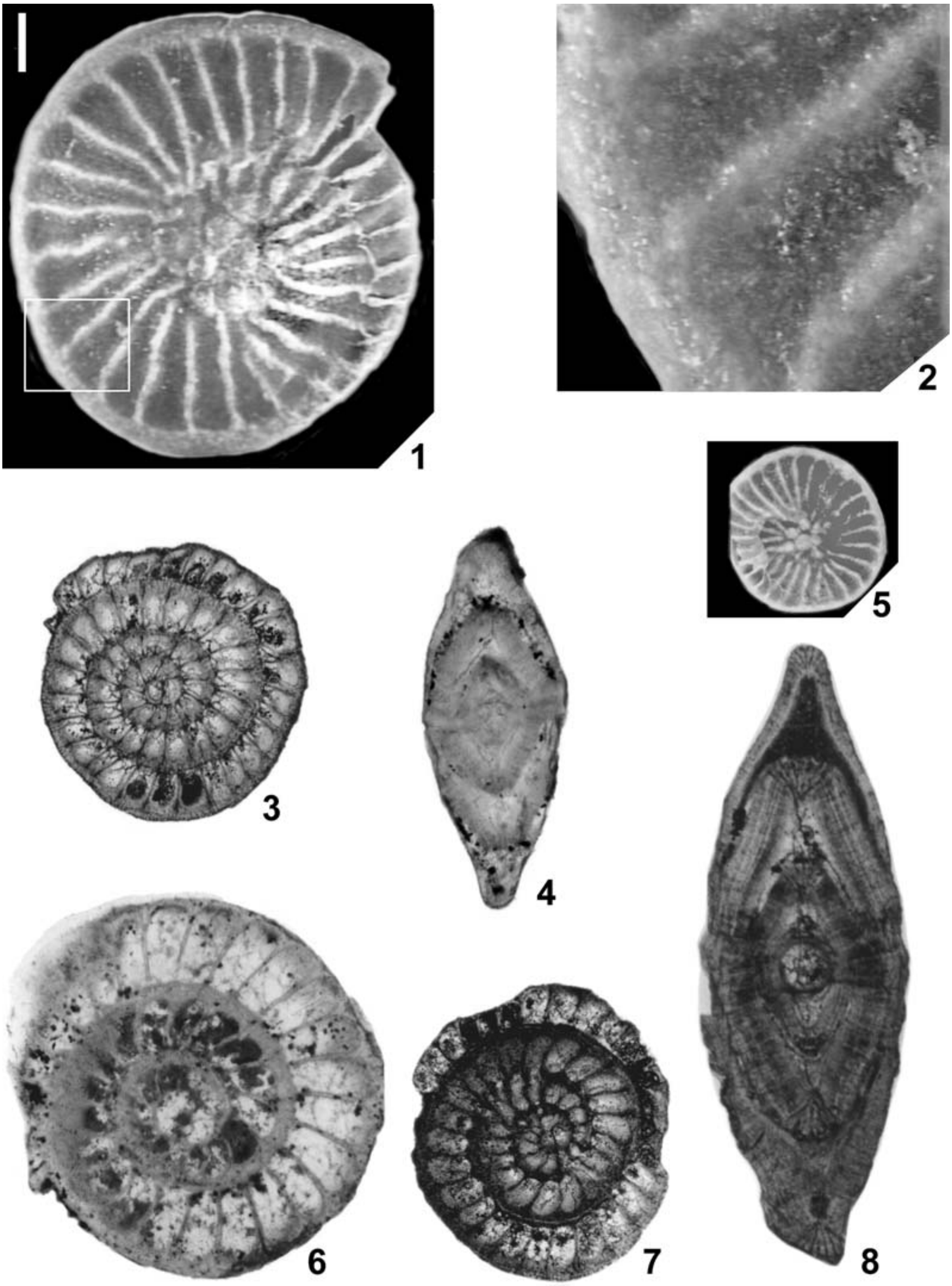

Plate 12

Plate 13

1–8. *Ranikothalia nuttalli kohatica* (Davies, 1927)

1, **4**, **6**. External view of B-form (×4.8), (subsequent) equatorial section (×4, diameter 9.1 mm), and detail of surface (×8) showing septa, respectively. BMNH no. P 52441.
2, **5**. External view of B-form (×4.8) and (subsequent) equatorial section (×4, diameter 9.8 mm). BMNH no. P 52442.
3. Equatorial section of B-form (×4, diameter 9.0 mm). BMNH NO. PF 67069.
7. Axial section of B-form (×8, diameter 8.5 mm, thickness 1.7 mm). BMNH no. P 52444.
8. Axial section of B-form (×8, diameter 8.6 mm, thickness 1.6 mm). BMNH no. P 52445.
All are from the lower member of the Jafnayn Formation, Al Khawd, Oman. Latest Paleocene–earliest Eocene (mid P5a–mid P5b).

9. *Ranikothalia nuttalli nuttalli* (Davies, 1927)

Detail of surface (×16) of paratype, showing septa and simple branches of septal canals. BMNH no. P 39408. From the Ranikot beds, Jhirak, Sind, N Pakistan. Late Paleocene.

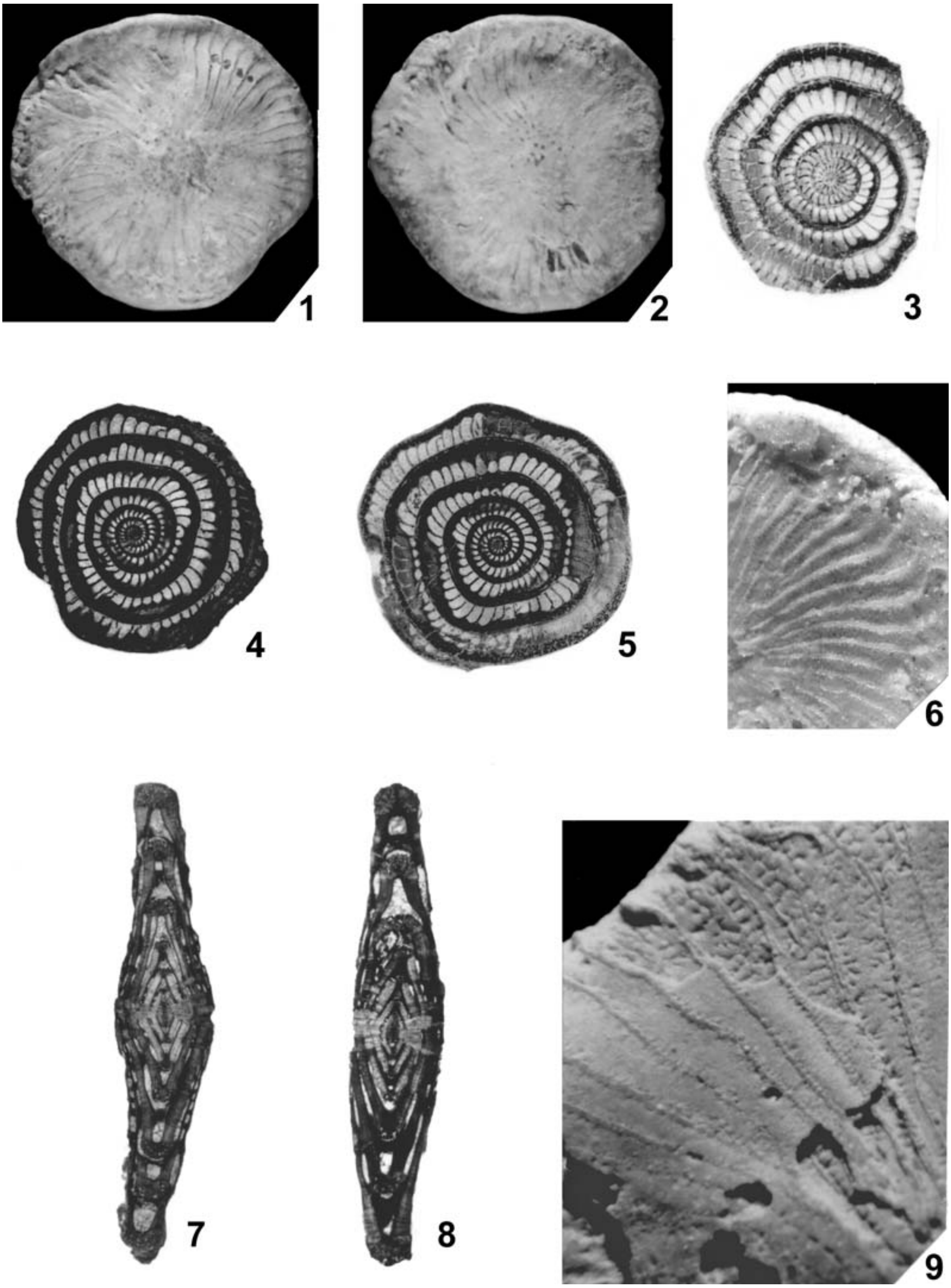

Plate 13

Plate 14

1, 2. *Ranikothalia nuttalli kohatica* (Davies, 1927)

1a. External view of half-section of B-form in oil immersion (×110.4, diameter 7.4 mm), areas of detailed photographs are indicated: **1b**. Close-up showing the massive, reticulate marginal cord (×64). **1c**. Close-up showing the simple branches of septal canals (×64).
2. Equatorial view of same half-section in oil immersion (×11.2). BMNH no. PF 67070.
From the Umm er Rhaduma Formation, Fahud, Oman. Late Paleocene.

3. *Chordoperculinoides* sp. cf. *sahnii* (Davies, 1952)

Part of equatorial section of B-form showing septal canals joining ramifying canals of marginal cord and simple branches (top left). This specimen has the high chambers typical of *C. sahnii* but is difficult to name on equatorial section alone. BMNH no. PF 67071. From the lower member of the Jafnayn Formation, Bandar Jissah, Oman. Late Paleocene.

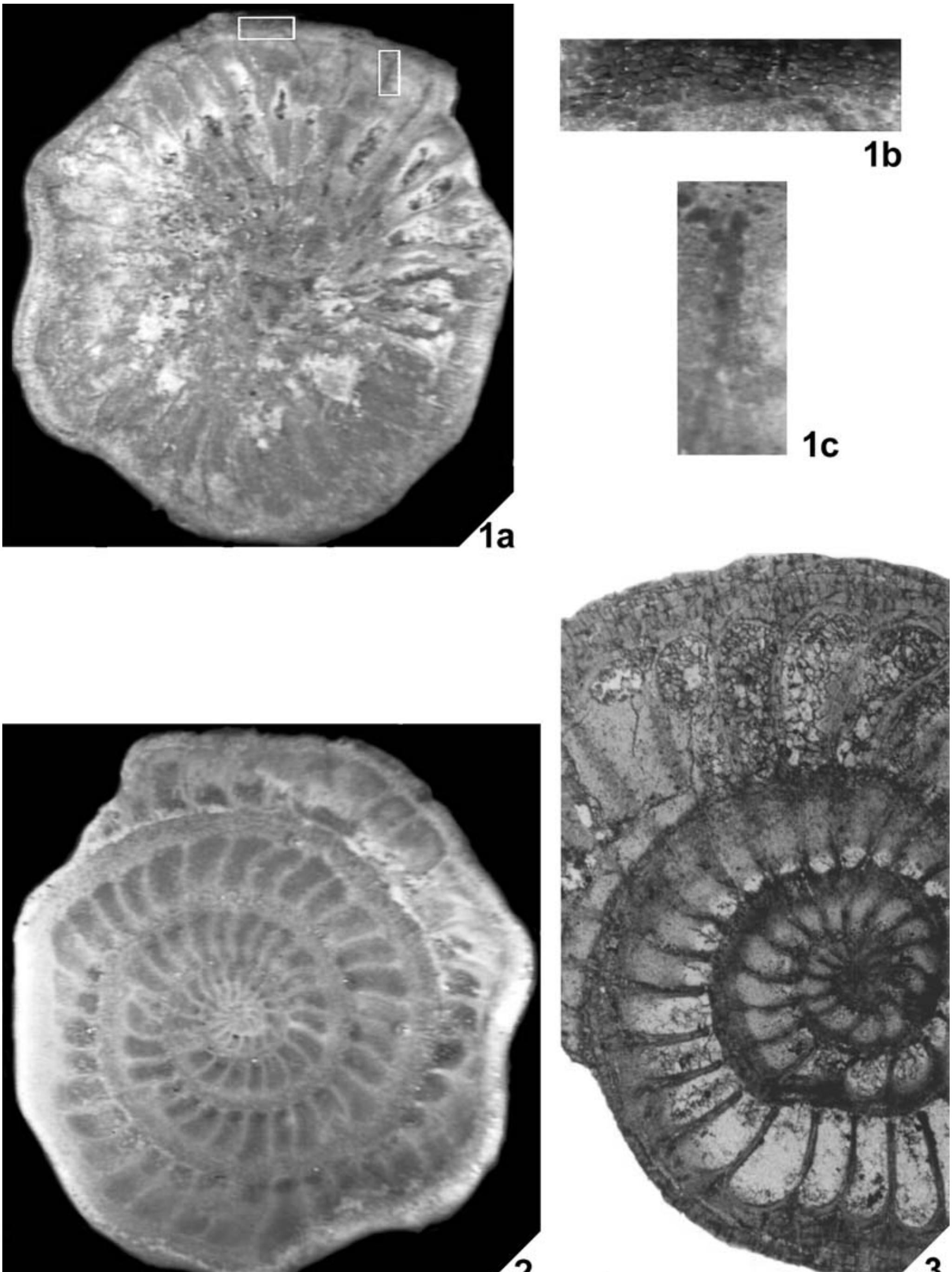

Plate 14