Cainozoic Research, 2(1-2) (2002), pp. 23-78, October 2003

Paleogene nummulitid foraminifera from the Indonesian Archipelago: a review

Willem Renema[1], Andrew Racey[2] & Peter Lunt[3]

[1]*Nationaal Natuurhistorisch Museum (Naturalis), Darwinweg 2, P.O. Box 9517, NL-2300 RA Leiden; e-mail: Renema@naturalis.nnm.nl*
[2]*BG Group, 100 Thames Valley Park Drive, Reading RG6 1PT, England*
[3]*Coparex Blora b.v., Jalan H.R. Rasuna Said, Kav. X-2, No. 1, Jakarta 12950, Indonesia*

Received 30 January 2002; revised version accepted 4 October 2002

Previous records of nummulitid foraminifera without chamberlets from Indonesia and contiguous areas are reviewed, with the emphasis on species previously assigned to the genera *Nummulites* Lamarck, 1801, *Assilina* d'Orbigny, 1826 and *Ranikothalia* Caudri, 1934. Of the 70+ species referred to these genera, sixteen are here considered valid. *Assilina orientalis* Douvillé, 1912b, *A. leymeriei* d'Archiac & Haime, 1853, *A. granulosa* d'Archiac, 1846, *A. spira* de Roissy, 1805, *A. exponens* Sowerby in Stykes, 1840, and *Nummulites (A.) umbilicata* Rutten *in* Waterschoot van der Gracht, 1915 are assigned to *Planocamerinoides* Cole, 1957, while *Camerina taballarensis* Caudri, 1934, *Nummulites pengaronensis* Verbeek, 1871, *N. beaumonti* d'Archiac & Haime, 1853, *C. crasseornata* Henrici, 1934, *C.* cf. *globula* Leymerie, 1846 [*sensu* Henrici, 1934], and *Lenticulites variolaria* Lamarck, 1804 are transferred to *Palaeonummulites* Schubert, 1908. Six species of *Nummulites (N. boninensis* Hanzawa, 1947, *N. djokdjokartae* (Martin, 1881), *N. fichteli* Michelotti, 1841, *N. javanus* Verbeek, 1891, *N. martini* n. sp. and *N. subbrongniarti* Verbeek, 1871), seven of *Palaeonummulites* (*P. beaumonti, P. crasseornatus, P. pengaronensis, P. songoensis* n. sp., *P. taballarensis, P. variolarius* and *P.* sp.), and three of *Planocamerinoides* (*Pl. orientalis, Pl. umbilicata* and *Pl.* sp.) from Eocene-Oligocene strata of the Indonesian Archipelago are described and illustrated. A revision of museum collections as well as a study of newly collected Paleogene larger nummulitids from Indonesia, coupled with new biostratigraphic data based mainly on calcareous nannoplankton, planktonic foraminifera and dinoflagellates, plus preliminary strontium isotope dates, have now resulted in a more refined picture of the stratigraphic/palaeobiogeographic distribution of Paleogene nummulitids in the region. Deposits of Early and early Middle Eocene age are rare in Indonesia; younger Paleogene sediments are commoner. Subsequent to the inundation of the Sunda Shelf at *c.* 45 Ma, shallow-marine carbonates became more widely distributed. In the best documented part of Indonesia, *i.e.* Java, strata of late Bartonian to early Rupelian age are missing. Upper Bartonian to lower Rupelian strata are represented in sections in Borneo and Sulawesi, although there Priabonian and lower Rupelian deposits often are poorly fossiliferous.

KEY WORDS: Foraminifera, Nummulitidae, systematics, new taxa, Paleogene, Indonesia.

Introduction

Larger foraminifera, especially those of the genera *Nummulites* and *Assilina*, have long been used for stratigraphic purposes, starting with De la Harpe (1877). More recently, Blondeau (1972) and Schaub (1981) have summarised the stratigraphic and geographic distribution of the numerous species in these genera. Blondeau's work covered the Tethys, Indo-West Pacific and North and South America, but it occasionally referred to Indonesia, Japan, and the West Pacific as well, whilst the much more elaborate review by Schaub (1981) dealt with species from around the Mediterranean and from Europe. Racey (1995) described nummulitids from Oman, an area situated at the boundary between two of the main Cainozoic larger foraminiferal faunal provinces, *i.e.* the Mediterranean and the Indo-Pacific, and integrated these with Schaub's zonal scheme. Schaub (1981) proposed a series of biozones for the Paleogene, based on species of *Nummulites* and *Assilina*, which were combined with biozones proposed by Hottinger (1960) for *Alveolina*, and calibrated against calcareous nannoplankton data. These zonations were subsequently integrated into the shallow-benthic zones (SBZ) covering the Paleocene-Eocene of the Mediterranean region by Serra-Kiel *et al.* (1998). All this work was based mainly on the western Tethys.

The most recent revisions of *Nummulites* and *Alveolina* from Indonesia were by Doornink (1932; the genus *Nummulites* in Java) and Bakx (1932; Alveolinidae in Indonesia). The principal objective of the present study is to improve the correlation of Eocene strata from Indonesia with Berggren *et al.*'s (1995) timescale. This could only be satisfactorily attempted when coupled with a revision of the taxonomic status of the various nummulitids previously recorded from the region. Many of these taxa, by modern taxonomic standards, have been inadequately described and in many cases poorly illustrated in the original papers. In part, our work aims to rectify these omissions.

In Indonesia, Martin (1881) originally followed the Lyellian method of European biostratigraphy, which was based on the ratio between extant and extinct molluscs, including selected foraminifera. Direct comparison between European and Indonesian outcrops led to different conclusions, based either on the occurrence of larger foraminiferal genera or on the extant/extinct ratio. The extant/extinct molluscan ratio resulted in an Oligocene age being assigned to the Nanggulan section, although the abundant occurrence of non-reticulate *Nummulites* suggested an Eocene age (*e.g.*, Martin, 1881). However, Martin's view was blurred by the fact that the samples he received from the Nanggulan section comprised a mixture of Eocene to Miocene material from the nearby Djonggranan Beds. When he collected samples himself in 1910, he immediately revised his earlier view and proposed an Eocene date.

Discrepancies in molluscan biostratigraphy led the Geological Survey in the then Netherlands East Indies to use larger benthic foraminifera for correlation, which resulted in the application of Van der Vlerk & Umbgrove's (1927) letter stages. Originally, there were six letter stages (Ta-Tf), which later increased to eight (Ta-Th). A total of sixteen subzones were also included, of which seven zones and thirteen subzones were based on ranges of larger foraminifera (Leupold & Van der Vlerk, 1931). The number of letter stages was then revised back to six (Ta-Tf) by Van der Vlerk (1955). The most recent revision of the letter stages for the entire Cainozoic was by Adams (1970), whilst the Oligocene-Miocene was revised by Boudagher-Fadel & Banner (1999). The Paleogene is covered by letter stages Ta to lower Te. When compared to the European sequence (Adams, 1970), the Ta and Tb stages cover the Paleocene and Eocene, while the Ta stage is subdivided into three parts, with Ta_{1-3} corresponding broadly to the Late Paleocene, Early Eocene and Middle Eocene, respectively. The Tb stage is equivalent to the Late Eocene. However, the subdivision of the Paleocene and Eocene in southeast Asia is based mainly on sections in India (Adams, 1970).

The use of planktonic biostratigraphy has improved the correlation between European and Indonesian stratigraphic units, leading *e.g.* to a more detailed stratigraphic scheme proposed by Boudagher-Fadel & Banner (1999) for the Neogene. To date, the application of planktonic biostratigraphy to Eocene and Lower Oligocene deposits in Indonesia and strontium isotope dates for the Oligocene has been restricted to in-house studies by some oil companies, published here for the first time.

The present paper addresses several taxonomic problems regarding nummulitids from Indonesia and discusses their revised stratigraphic ranges following new age assignments for the various sequences studied, and leading to an improved correlation with European strata.

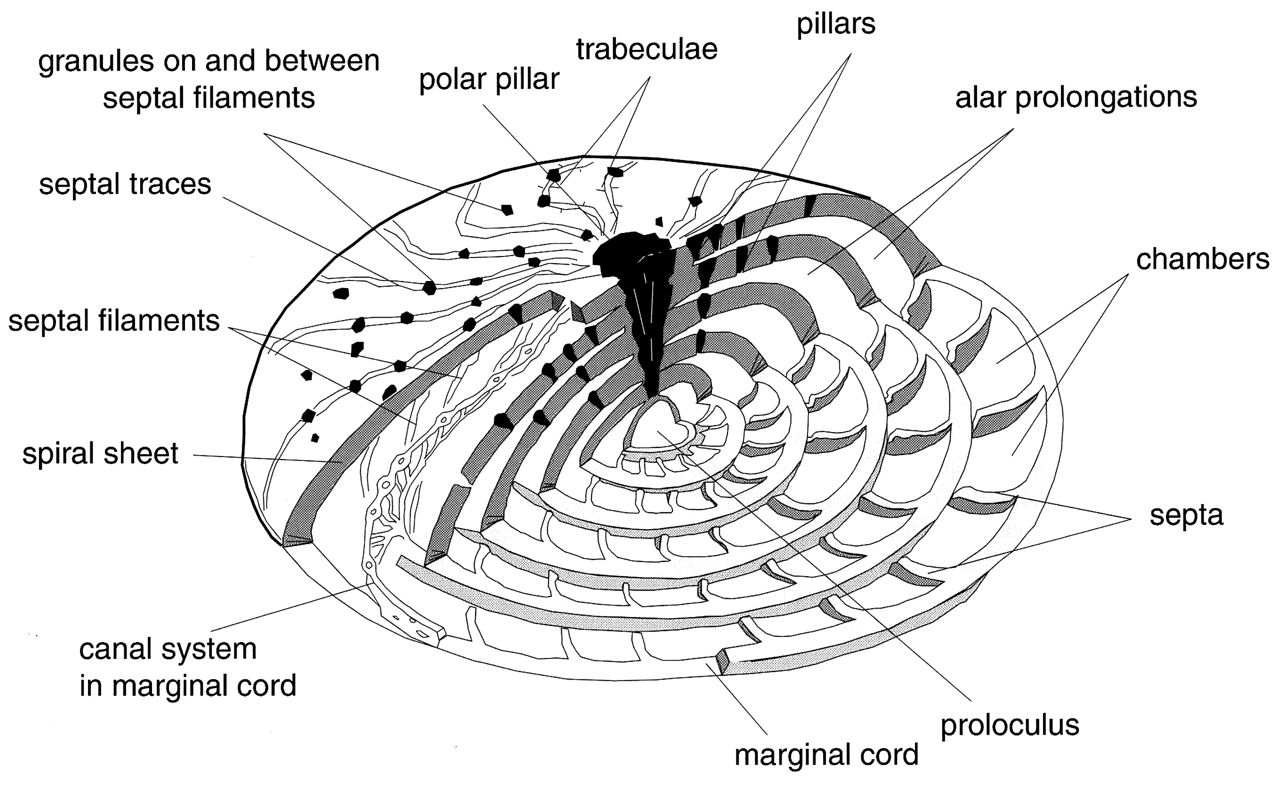


Figure 1. Structure and elements of *Nummulites* test, based on a macrospheric generation (modified after Racey, 1995).

Morphology of *Nummulites*

Nummulitid morphology has been discussed previously by Blondeau (1972), Schaub (1981) and Racey (1995). Their terminology is applied herein and briefly summarised below. Additional data on morphological features and their relative value in classification may be found in Adams (1988), Haynes (1988), Racey (1992) and Haynes *et al.* (in press). Figure 1 illustrates the most important features of *Nummulites* and related genera. The terminology outlined below is also used for *Planocamerinoides* and *Palaeonummulites* in the present paper.

Septa and chambers

The septum forms a bilamellar, canaliculate, but primarily apertureless, curved plate (partition) between successive chambers. A basal foramen, formed by the secondary resorption of wall material at the base of the apertural face of the penultimate chamber, is almost invariably visible in accurately oriented equatorial sections. Other secondary pores may also be present near the peripheral margin (Adams, 1988). Septa may be regularly and closely spaced as in *N. boninensis* or widely and more irregularly as in some parts of *N. djokdjokartae*. Several chamber and septa shapes are illustrated in Figure 3.

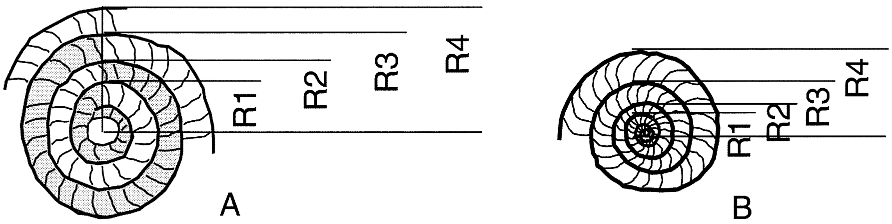


Figure 2. Equatorial section of *Nummulites* showing the method of measurement of the radius per whorl; A - macrospheric generation (A-form), B - microspheric generation (B-form).

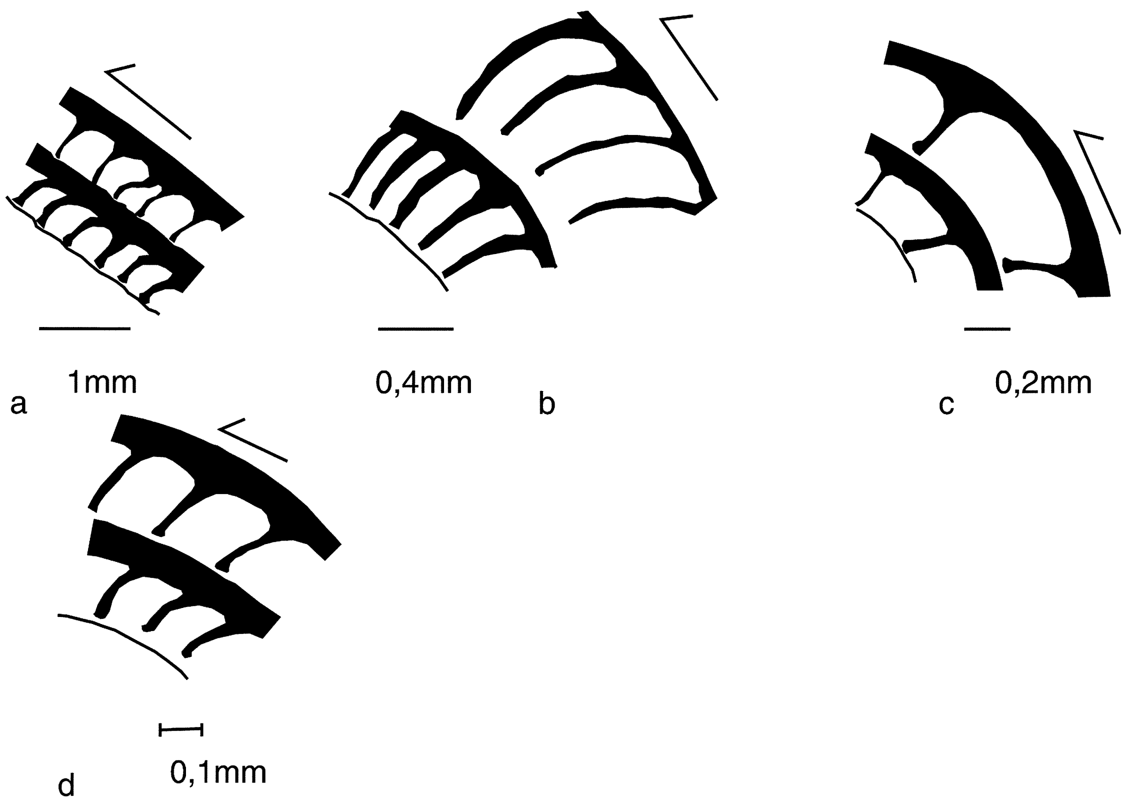


Figure 3. Chamber and septum shape of nummulitids; arrow indicates growth direction; A - chambers numerous, small, equidimensional (*N. gizehensis*); B - chambers higher than long, septa oblique, curved in the peripheral quarter (*P. crasseornatus*); C - chambers longer than high, septa perpendicular, almost straight (*N. fichteli*); D - chambers equidimensional, septa oblique, curved (*P. variolarius*).

Although septa and chamber shape are affected by food availability and temperature, they nevertheless constitute reliable characters for the discrimination of species since aberrations from the norm are easily recognised (Racey, 1992).

Septal filaments

Extension, sometimes thread-like, of a septum over the lateral surface of the test between the spiral laminae (Adams, 1988). The traces of the septa and septal filaments can often be observed on the test surface. Adams (1988) described the use and taxonomic significance of septal filaments and septal traces and distinguished the following forms:

* radial: straight or slightly curved, extending from the pole to the periphery. All septal filaments are necessarily slightly curved at the peripheral margin;
* sigmoidal: curved forwards at the periphery and backwards near the pole. If there is no polar twist, the shape is described as falciform;
* meandrine: appearing to wander haphazardly over the lateral surface of the spiral sheet;
* subreticulate: uniting to form a crude network within the spiral cavity, and showing as septal and filament traces on the outer surface of the spiral wall. Usually associated with pillars;
* reticulate: forming a complex network of filaments in which the individuality of the primary filaments is largely or completely lost.

In species with radial and sigmoidal septal filaments and septal traces, these become crowded towards the poles, where they terminate against a central pillar or boss (long septal filaments) or sometimes against a preceding septal filament (short septal filaments). Secondary septal filaments comprise the distal walls of the blister-like chamberlets which form over the lateral surfaces of the test (Adams, 1988). On the outer test surface, secondary filaments are recognised because they run from one (primary) septal filament to another.

Septal filaments change ontogenetically and may show some variation with environmental parameters (Racey, 1992). Quantitative use (number of septal traces, long/short septal traces, secondary septal traces etc., is highly variable and thus unreliable for species discrimination, but in adult specimens presence/absence criteria serve well to discriminate between species groups.

Spiral shape

The shape of the spire is important in distinguishing species of *Nummulites*. The spire may be regularly or irregularly coiled, open or tightly coiled and may show tripartition, doubling and/or reversals (Racey, 1995). In tight whorls, the same radius contains more whorls than in open ones. Following Schaub (1981) and Racey (1995), the radius of each whorl has been measured (Figure 2), and not the number of whorls in a certain radius (*e.g.*, Henrici, 1934) or the radius to a certain number of whorls (*e.g.*, Doornink, 1932) or the number of whorls contained in one-third of, two-thirds of or in the full spire (*e.g.*, Blondeau, 1972). The slope and shape of the coiling diagram provides additional information (Racey, 1995). Errors may occur in counting of whorls at the centre (especially in B-forms), since it is difficult to section large, undulating specimens through the proloculus, and/or because the first whorls are often poorly preserved and/or difficult to see clearly (Racey, 1995).

Regular whorls are even in height and chamber shape, whilst irregular ones show widely varying chamber heights. The opening rate is the ratio of the diameter of whorl x over whorl x-1 and is expressed as *e.g.*, 1.5d. In this example, the next whorl has a diameter that is 1.5 times larger. Therefore, higher values indicate more rapidly opening spires.

Tripartite spires show a threefold subdivision, each division being characterised by a marked change in tightness, which always follows the sequence tight-loose-tight. No Indonesian species shows this feature. *Nummulites javanus* comes nearest, but the first whorls gradually increase in height, instead of showing a more or less abrupt change as seen in *N. perforatus* de Montfort, 1808 or *N. deshayesi* d'Archiac & Haime, 1853 from the western Tethys.

Intercalatory whorls can form through the bifurcation of the spire by splitting of the marginal cord, so that two whorls are created simultaneously (Racey, 1995). This character usually involves thinning of the marginal cord. In Indonesian species this character is rather rare and is only seen in *N. djokdjokartae* and *N. martini* n. sp., in which the intercalatory whorls generally occur after the 7th to 9th whorl, and are usually incomplete. *Nummulites boninensis* from Indonesia and Japan occasionally shows one or two intercalatory whorls.

Temporary reversals in the coiling direction (often associated with doubling, *i.e.* growing two whorls simultaneously) were not observed in any of the Indonesian species. The spiral shape is summarised in a coiling diagram for both the A- and B-form. In the coiling diagram, the range of diameter of the studied specimens is shown for each whorl, as well as the average when more than one specimen was measured. The character of the spire (especially in the early and middle part of the specimen) is generally constant and is considered to be a feature of diagnostic importance in identifying to which group a species belongs. Abnormalities in the spire, however, are common and are usually caused by environmental features (*e.g.*, high hydrodynamic energy resulting in breakage) and are thus of no taxonomic value. Damaged animals usually quickly heal the broken part in order to get back to the normal growth character.

Marginal cord

The marginal cord forms a thickened, imperforate equatorial rim, containing a three-dimensional network of canals that communicate between the chambers. The thickness of the marginal cord (absolute or relative to the chamber height) can be used as a species character (Schaub, 1981). Tightening of the later whorls as seen in *e.g., N. djokdjokartae* is often caused by the thinning of the marginal cord or its replacement by the spiral sheet. Several of the lineages as defined by Schaub (1981) show similar trends in the thickness of the marginal cord.

Proloculus size in macrosphere

Proloculus size in the macrosphere is often regarded as an important character for species discrimination. However, proloculus size is shown to vary widely within populations (Khan & Drooger, 1970; Drooger *et al.*, 1971; Racey, 1992). Successive populations show an increase in proloculus size with time (Drooger *et al.*, 1971). Racey (1992) concluded that proloculus size was affected by temperature, water depth and food supply, and that variation was marked, resulting in poor reliability for species discrimination, especially when used on its own.

Pillars

The presence and size of pillars (seen as granules or pustules) on the exterior of the test is important, as are their size and arrangement with respect to the septal filaments, filamental traces and the spire as a whole (Racey, 1995). Two main types of pillars occur in *Nummulites*: textural and inflational (Racey, 1995; references therein). Textural pillars are produced by local changes in the texture of the laminae and are visible in axial thin sections, but usually do not reach the surface of the test. Inflational pillars are produced by local thickening of the laminae by lamellar superposition. Such pillars may reach the surface to form granules/pustules. Possible pillar arrangements are:

* arranged so that they form a spire on the outer surface;
* scattered 'randomly' all over the test surface, either on septal filaments (Figure 1), or on and between septal filaments (Figure 1);
* concentrated at the poles to form a large polar pillar (Figure 1).

The intensity of pillar development is strongly affected by environmental parameters in extant populations of *Operculina ammonoides* (Gronovius, 1781) and correlates with depth and substrate type (Pecheux, 1995; W.R., pers. obs.). Pillar location and shape characters (*e.g.*, extending to test surface or not) varies less within populations and may thus constitute valid characters for species discrimination.

Test shape

The test shape was defined as a diameter/thickness (D/T) ratio, as follows:

diameter/thickness	shape
1.5- 2.5	inflated lenticular
2.5- 4.5	lenticular
4.5- 7	flattened lenticular
>7	flat

Some species show a highly undulose periphery, whilst others have inflated polar regions and/or variations in the shape of the test margin. Test shape is influenced by environmental parameters and is, as such, of limited taxonomic use (Racey, 1992).

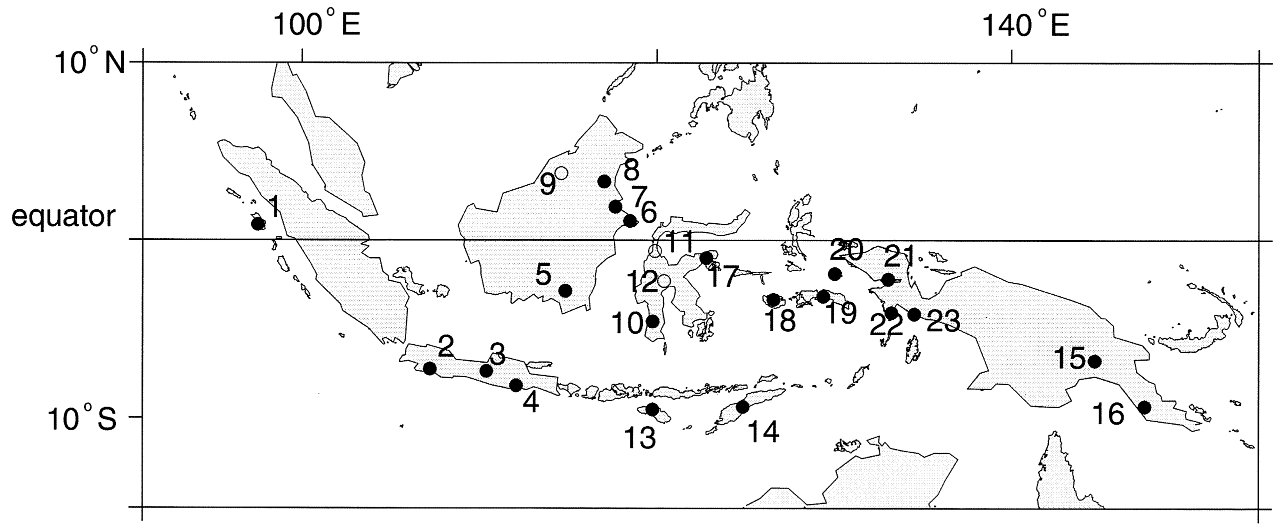


Figure 4. Map showing the localities of samples studied (filled symbols) and known from the literature only (open symbols); 1 - Nias; 2 - Banten/Bantam; 3 - Wirosari area; 4 - Nanggulan and Jiwo area; 5 - SE Borneo; 6 - Mangkalihat; 7 - 'Tidoengsche landen'; 8 - Boeloengan; 9 - Melinau Gorge; 10 - Tonasa Limestone; 11 - Donggala; 12 - Palossi; 13 - Sumba; 14 - Timor; 15 - Chimbu Limestone; 16 - New Britain; 17 - Poh; 18 - Buru; 19 - Seram; 20 - Misool; 21 - Sabang, West Irian; 22 - Lorentz River, West Irian; 23 - Putri Adri, West Irian.

Review of previous work

1 – Indonesia

Sumatra

Very few fossiliferous Eocene and Oligocene deposits are known from Sumatra. There are scattered reports of *Nummulites*-bearing deposits in northern Sumatra (*e.g.*, Verbeek *et al.*, 1881; Tobler, 1923). The only specimens studied herein were collected by Schröder from Nias (Figure 4, no. 1) and described by Douvillé (1912b; Table 1 here) and are deposited in the collections of the Nationaal Natuurhistorisch Museum (Naturalis) at Leiden (NNM). Most samples comprise very coarse packstones assigned to Ta (Ta_3 of Adams, 1970), equivalent to the Lutetian or lowermost Bartonian (Figure 5).

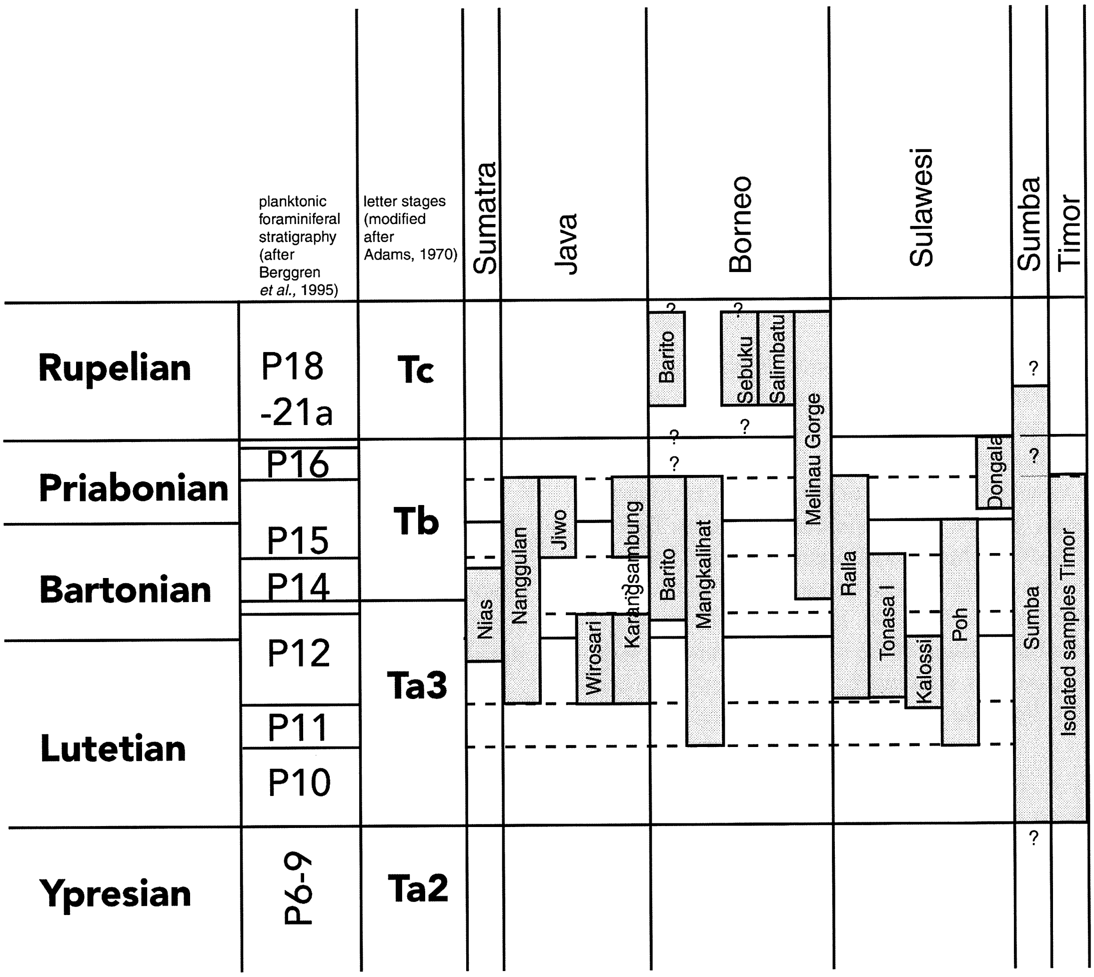


Figure 5. Ages of the deposits studied. Localities with deposits of Oligocene age on Java and Sulawesi are not shown.

Nias	Douvillé, 1912b	Reinterpretation
N. bagelensis	x	Oblique section of a striate species
N. lamarcki	x	A-form of *Nummulites djokdjokartae*
N. laevigatus	x	B-form of *Nummulites djokdjokartae*
N. pengaronensis	x	*Palaeonummulites pengaronensis*
N. kelatensis	x	*Palaeonummulites beaumonti*
A. orientalis	x	*Planocamerinoides orientalis*
A. granulosa	x	*Planocamerinoides* sp.

Table 1. Previously published records of *Nummulites* and *Assilina* from Nias.

Java

The Paleogene deposits of Java are the best studied in Indonesia (Figure 4, nos 2-4; Figure 5) and are consequently covered in more detail. Early workers, such as Van Dijk (1872), who surveyed for coal at Nanggulan, recognised the importance of *Nummulites* found. Verbeek (1891) and Verbeek & Fennema (1896) located nearly all the *Nummulites*-bearing outcrops in Java knowon to date, of which Nanggulan is the most famous on account of its exceptional preservation.

Nanggulan	Douville, 1912b	Verbeek, 1881	Martin, 1881	Verbeek, 1891, Verbeek and Fennema, 1896	Doornink, 1932	Reinterpretation
N. cf. *lamarcki*		x				A-form of *N. djokdjokartae*
N. djokdjokartae	x		x		x	
N. djokdjokartae				x		pars *N. djokdjokartae*, pars *N. martini* (A-form)
N. laevigatus		x		x		pars *N. djokdjokartae*, pars *N. martini* (B-form)
N. sp. indet.			x			B-form of *N. djokdjokartae*
N. vredenburgi	x					*N. djokdjokartae*
N. nanggoelani				x		B-form of *P. pengaronensis*
N. pengaronensis	x				x	*P. pengaronensis*
N. pustulosa					x	*P. songoensis*
N. variolarius					x	*P. taballarensis*
N. orbignyi					x	*P. crasseornatus*
N. irregularis					x	*P. crasseornatus*
N. cf. *lucasana*					x	no material available, not sufficiently figured by Doornink
N. semiglobula					x	*P. variolarius*

Table 2. Previously published records of *Nummulites* and *Assilina* from Nanggulan. Records published originally as *Camerina* are here shown as *Nummulites.*

western Java	Verbeek, 1891, Verbeek and Fennema, 1896	Doornink, 1932	reinterpretation
N. javanus	x		pars *N. javanus*, pars *N. boninensis*
N. bagelensis	x	x	pars *N. javanus* A-form, pars *P. variolarius*
N. perforatus		x	*N. javanus*
N. gizehensis		x	*N. boninensis*
N. mamilla		x	*P. variolarius*
N. hoogenraadi		x	A-form of *P. beaumonti*
N. djokdjokartae		x	*N. djokdjokartae*
N. intermedia		x	*N. fichteli*
N. divina		x	A-form of *N. subbrongniarti*
N. absurda		x	see remarks at *N. fichteli*

Table 3. Previously published records of *Nummulites* from western Java. Records published originally as *Camerina* are here shown as *Nummulites.*

Nanggulan, just west of Yogyakarta and type locality of *N. djokdjokartae* (Table 2), was at first dated as Oligocene (Martin, 1881). Martin collected new samples himself in 1910 (Martin, 1915) and came to the conclusion that it must be of Late Eocene age. Even this age was not easily acquired, and Martin followed with many papers suggesting that the Cainozoic faunas of the Indo-Pacific had developed separately from those of Europe, and therefore the European stratigraphic scheme could not be used in the Far East. This was the fundamental reason for developing the Indonesian letter stages that were first published in 1927 (Van der Vlerk & Umbgrove, 1927). Most recent studies have shown the Nanggulan section, and certainly all localities which have yielded larger foraminifera, to be of Middle Eocene age, well within zones P12-P14, with the planktonic foraminiferal genera *Morozovella*, *Acarinina* and *Truncorotaloides* present throughout. More detailed work, including a revision of the nannofossil data of Okada (1981), has shown that the *Nummulites*-bearing sections are assignable to the upper part of NP16 (early part of Okada's

CP14), with *Helicosphaera salebrosa* and *Cribrocentrum reticulatum* occurring to the centre of the anticline (Lunt, 2000a). This narrow age range straddles the Lutetian- Bartonian stage boundary (Berggren *et al.*, 1995). A selection of clasts from the Ta *Nummulites* fauna described above have been analysed for $^{87}Sr/^{86}Sr$ ratios. These appear to give consistent results, but it must be stressed that seawater calibration curves in Middle Eocene times have such a low gradient that the error in calibrating a $^{87}Sr/^{86}Sr$ ratio to GPTS age is very high. An exceptionally well-preserved, on apparently pristine, glassy tests of *N. djokjokartae* from a mudstone sample also containing nacreous aragonitic molluscan fragments, from a depth of 12 m in a core at the centre of the Nanggulan anticline yielded a $^{87}Sr/^{86}Sr$ ratio = 0.707722; 2 sem (%) 0.000017, age 38.8 (37.6-41.5) Ma.

central Java (excluding Nanggulan)	Verbeek, 1891, Verbeek and Fennema, 1896	Doornink, 1932	reinterpretation
N. javanus	x		pars *N. javanus*, pars *N. boninensis*
N. bagelensis	x	x	pars *N. javanus* A-form, pars *P. variolarius*
N. perforatus		x	*N. javanus*
N. gizehensis		x	*N. boninensis*
N. laevigatus		x	B-form of *N. martini*
N. pengaronensis		x	*P. pengaronensis*
N. intermedia		x	B-form of *N. fichteli*
N. pustulosa		x	*P. songoensis*
N. densa		x	*P. beaumonti*
N. cf. *lucasana*		x	no material available, not sufficiently figured by Doornink
N. semiglobula		x	*P. variolarius*
A. spira	x	x	*Pl.* sp.
A. leymeriei	x	x	*Pl.* sp.

Table 4. Previously published records of *Nummulites* and *Assilina* from central Java, excluding Nanggulan. Records published originally as *Camerina* are here shown as *Nummulites.*

All Sr isotope ratios used in this paper were obtained by the same laboratory using the following parameters:

$^{87}Sr/^{86}Sr$ ratios normalised to $^{86}Sr/^{88}Sr = 0.1194$
$^{87}Sr/^{86}Sr$ ratios normalised to NBS987 $^{87}Sr/^{86}Sr = 0.710235$

Measured NBS987 $^{87}Sr/^{86}Sr = 0.710251 \pm 0.0020\%$ ($\pm$ 0.000014) (95% confidence limits). The seawater calibration curve of Howarth & McArthur (1997 (SIS look-up table version 3, October 1999) is used for age calibration to the GPTS of Berggren *et al.* (1995). The given error range is larger than the range resulting from the look-up table since errors in the measurement and the nearest linkage method for calibration of the ages has been taken into account.

Other *Nummulites*-bearing localities in Java include sections with a history as old as Nanggulan, such as the various outcrops around Karangsambung and Lukulo, and areas to the north in the district of Bagelen, type locality of *N. bagelensis* Verbeek, 1891, and the Jiwo Hills west of Yogyakarta, a primary site for *N. javanus*. In the Bagelen area, apart from Karangsambung, a very soft scaly clay dominates, but rarely crops out because of its softness. New samples from Verbeek's Kali Gua are from here and have yielded *N. boninensis*, examined for the present paper. These specimens were from very large boulders, although coin-like loose specimens are common in the soil there. While the slightly argillaceous limestone was found to be of NP16 age, as based on associated calcareous nannofossils, with a consistent Sr date from a *Nummulites*-clast (see below), the host scaly mudstone is correlated with similar lithologies nearby as well as a few kilometres away at Worowari, Kali Bongbong and Sigugur, where planktonic foraminifera, calcareous nannofossils and Sr dates all point to an Early Oligocene age for the scaly clay olistotrome.

For the main Karangsambung section, Paltrinieri *et al.*'s short note (1976) did not extend down to the nummulitic limestone upon which the LIPI geological field camp is built. Underlying this limestone are conglomerates and silts, but a short way above are open marine mudstones containing a diverse planktonic foraminifera fauna including *Chiloguembelina cubensis* (P12 to mid P21), *Morozovella lehneri* (no younger than P14), *Truncorotaloides* and *Acarinina* (no younger than P14), and species of the *Turborotalia cerroazulensis* lineage in the range of the *pomeroli-cerroazulensis* subspecies which characterise P12-13. Nannofossils suggest the older part of this range (P12, overlapping with upper NP15) as based on *Helicosphaera seminulum*, *Cruciplacolithus dela*, *Blackites gladius*, and other species (nannofossils identified by A. Baky, by permission of Coparex Banyumas b.v.). There is no sign of scaly clay in the Eocene at Karangsambung. The Jatibungkus Limestone at the top of the Karangsambung section is at least a laterally discontinuous olistolith several hundred metres wide and 50-70 m thick, set within later Middle Eocene turbidites. Work has not been concluded on this anomalous bed, the age of which is still unclear.

Verbeek & Fennema's survey (1896) detailed several localities in the Banten (Bantam) area (western Java) with both Eocene rocks and younger strata characterised by reticulate *Nummulites*. The geologist W.C.B. Koolhoven collected specimens which were made available to Doornink for inclusion in his 1932 paper on Javanese nummulitids. Doornink (1932) described seven new species, and argued that *N. javanus* was closely related to both *N. perforatus* and, in part, *N. gizehensis* (Forskål, 1775). Among his new species was *Camerina divina*, the A-form of *N. subbrongniarti*. He also discussed the taxonomic status of *N. subbrongniarti* and argued that that species was synonymous with *N. intermedius* d'Archiac, 1846, now the B-form generation of *N. fichteli*.

From the *Nummulites*-bearing strata at Watu Perahu (Jiwo Hills), distinct *Morozovella* planktonic forams can be recognised in the limestones and subsequent processing of weathered limestone in soil has yielded loose specimens of this genus, as well as ?*Acarinina*. The brown mudstones overlying the Watu Perahu *javanus* limestone have yielded sparse nannofossils, including *Helicosphaera compacta* and *H. seminulum*, indicating a late NP15 to NP16 age, but no planktonic forams. About 600 m south of Watu Perahu is a short dry valley (Pendul section) known for its abundant loose *N. javanus* as well as metre-size boulders of dark grey *javanus* limestone, often containing large *Planocamerinoides*. Another 400 m south is the village of Gamping, famous for loose *Discocyclina* tests, up to several centimetres in size, released by the thousands into the brown soil, as well as rarer *P. pengaronensis*. This facies is mapped as the Gamping Formation, and is traditionally considered Late Eocene in age, but on no specific evidence. The Pendul section contains clasts centimetre- to metre-size suspended in the grey mudstone, and nummulitids are a major part of those clasts, along with fragments of basement. The *Nummulites*-bearing sediment here is a pebbly mudstone or olistotrome. Low-grade metamorphism from the nearby volcanic intrusion hampers age determination but a concerted recent effort appears to have confirmed a general Eocene age (P. Lunt and A. Baky, pers. obs.) and therefore contrasts with the olistostrome from the Bagelan area in which '*N. javanus*' limestone and other boulders are in a mud matrix of Early Oligocene age. The Gamping Beds at Jiwo, a few hundred metres south of Watu Perahu, and traditionally considered to be Late Eocene, have been redated as Middle Eocene (NP15-16, based on the presence of *Acarinina* sp. and the nannofossils *Discoaster* cf. *saipanesis*, *Helicosphaera dineseenii*, *Pemma* sp. in a poor assemblage).

Outcrops of other Eocene strata are geographically and stratigraphically less extensive and less complete. Several isolated occurrences have also been dated using nannofossils and dinoflagellates. The new Kali Gua samples, containing *N. boninensis*, examined for the present paper, was found to be of NP16 age based on associated nannofossils. Note, however, that these northerly Lukolo sites (Kali Gua, Worowari, Kali Bongbong and Sigugur) are characterised by boulders of limestone embedded in a mudstone which is currently under investigation as a possible scaly clay melange of Early Oligocene age, which contains olistoliths of basement and Eocene lithologies.

Samples collected by W.C.B. Koolhoven were made available to Doornink for inclusion in his 1932 paper. Of the Eocene samples some of the best came from a small section in the Cicarucup Beds (locality Tji Karang in Doornink). Samples from this locality contained common *Pellatispira* as well as Doornink's *Camerina gerthi*, here considered to be synonymous with *P. pengaronensis*. The type, and only other, locality for *C. gerthi* is the Gamping Barat or Gunung Gamping locality east of Yogya, not to be confused with the village of Gamping and beds at Jiwo. The Gamping Barat locality was lost (quarried away), but has been relocated for the present paper. Here, *P. pengaronensis* is seen to co-occur with abundant *Pellatispira* suggesting a younger Eocene age than the other Javanese faunas described above. In the xenoliths brought to surface by the mud volcano at the core of the Sangiran Dome are some, head-sized boulders of very similar *Pellatispira*-rich limestone with *C. gerthi/P. pengaronensis* as well as frequent planktonic foraminifera, including *Porticulosphaera semiinvoluta* (P15 restricted).

Also in Banten (western Java) are some of the better-preserved 'Tertiary C' localities, made famous by Tan Sin Hok in his 1932 monograph on *Cycloclypeus*, and containing an appendix on the heterostegines of this area. This, plus nearby sections at Cikalong (Cimandiri) and Gunung Walat, contain locally abundant *N. fichteli* and *N. subbrongniarti*. These classic Lower Oligocene sites have almost no plankton, just sparse nannofossils, and have also been dated through Sr isotopic analysis. Overlying mid-Oligocene (Td) samples from this area have been treated similarly, as have other Td sites from eastern Java, records of which have not been published previously (localities Pelang and Kujung). These Sr analyses are on picked *Nummulites* tests from mudstone or whole rock, and while slight diagenesis is likely, especially in whole rock samples, the data seem highly consistent between samples. All three Tc samples have $^{87}Sr/^{86}Sr$ ratios that fall in a range from 0.707787 34.1 (33.9-34.4) Ma, Cihara, 0.707792 33.9 (33.7-34.2) Ma, Cikalong, to 0.707832 33.2 (32.7-33.7) Ma, Cimanggu. The Td sample from Ciapus is from just above the first appearance of *Eulepidina*, which defines the Tc-Td boundary, and has the lowest $^{87}Sr/^{86}Sr$ ratio for this letter stage, 0.707892, corresponding to 32.0 (31.8-32.2) Ma. In eastern Java, there are five Td data points, four from the same Kujung area, known from a nearby oil well (Kujung-1) shown to be well above the base of Td, and possibly near its upper limit. These, plus the small Pelang outcrop 150 km west, all share $^{87}Sr/^{86}Sr$ ratios between 0.707955 to 0.708084, corresponding to 30.4-27.1 Ma. Of these samples the near-basal Td sample from Ciapus has been dated as the lower part of NP24, based on the co-occurrence of *Helicosphaera recta, H. bramlettei, H. compacta*, and *Sphenolithus pseudoradians*. The samples from within (possibly later) Td, in the Kujung area are of a very similar age, zone P21 (lower part), based on the presence of *Globigerina angulisuturalis* and *Chiloguembelina cubensis*. Work is still in progress on the Tc-Te transitions, and a detailed discussion is beyond the scope of the present paper.

The *Nummulites* material studied herein includes samples collected by Van Dijk, Doornink, Martin and Verbeek, all deposited in the NNM collections. Samples containing isolated specimens of *N. javanus* from western Java (Bantam; Figure 4, no. 2) were also studied together with new samples collected from the Eocene at Nanggulan, Jiwo Hills and Karangsambung and in the Kali Gua area (Figure 4, nos 3, 4). There are a total of 25 samples from various *Nummulites*-bearing Oligocene sites including Cijengkol and Cinagnang in southern Bantam, and the nearby Cikalong (also called Cimandiri) sites in the old Prianger district.

Borneo	Pengaron district (Verbeek, 1871, 1874)	Tidoengsche Landen (van der Vlerk, 1929)	Boeloengan (van der Vlerk, 1929)	Mangkalihat (van der Vlerk, 1929)	Marah (Yabe, 1921)	Melinau Gorge (Adams, 1965)	Reinterpretation
N. javanus						x	*N. javanus*
N. bagelensis		x					*P. variolarius*
N. sp. (striate)						x	?
N. striatus	x						A-form of *P. beaumonti*
N. biarritzensis	x						B-form of *P. beaumonti*
N. pengaronensis			x		x		*P. pengaronensis*
N. kelatensis				x			*P. beaumonti*
N. nuttalli				x			*P. taballarensis*
N. thalicus				x			*P. taballarensis*
N. mamilla		x					*P. variolarius*
N. variolarius				x			*P. variolarius*
N. cf. *divina*							A-form of *N. subbrongniarti*
N. subbrongniarti					x		
N. fichteli		x	x				pars A-form of *N. fichteli*, pars A-form of *N. subbrongniarti*
N. fichteli						x	
N. intermedius			x				B-form of *N. fichteli*
A. orientalis					x		*Pl. orientalis*
A. granulosa					x		*Pl.* sp.

Table 5. Previously published records of *Nummulites* and *Assilina* from Borneo. Records published originally as *Camerina* are here shown as *Nummulites*, records originally published as *Nummulites (Assilina)* are here recorded as *Assilina*.

Borneo

Borneo has numerous deposits of Eocene to Oligocene age. Verbeek (1871, 1874) was the first to describe *Nummulites* from the area around Banjarmasin, describing several new species of Middle Eocene to Early Oligocene age, including *P. pengaronensis* and *N. subbrongniarti* (Figure 4, no. 5; Table 5). Subsequent studies on Eocene deposits by Van der Vlerk are summarised in his 1929 paper in which he described samples from the area between Sangkuliran and Tarakan (NE Borneo), which contained abundant *Nummulites* comprising nine species (Figure 4, nos 6-8). However, he named the A- and B-forms of each species separately and two of his species (*N. thalicus* and *N. nuttalli* Davies, 1927) are now synonymised with *P. taballarensis*. The strata studied range in age from early Lutetian to Oligocene. These samples, together with additional material from field surveys, are housed in the NNM collections.

Adams (1965) described the Ta through Te (basal Bartonian to Chattian) succession in the Melinau Gorge (Sarawak), one of the few places with a continuous Middle Eocene to Oligocene section, although around the Eocene-Oligocene boundary the sediments are poorly fossiliferous (Figure 4, no. 9; Table 5).

Sulawesi

Previously, little attention has been paid to the *Nummulites* faunas of Sulawesi. Dollfus (1917) briefly examined the fossil content of carbonates found on Sulawesi. Crotty & Engelhardt (1993) studied the larger foraminifera and palynomorphs from the Tonasa II quarry, whilst Wilson (1995) studied the sedimentology of the Tonasa Formation in southwest Sulawesi. Several of Wilson's localities were visited and sampled in 1997, and some of these samples have been dated using dinoflagellates by H. Brinkhuis

(Universiteit Utrecht, pers. comm.) as approximately late Lutetian to Priabonian. In the Ralla area, *Nummulites*-bearing deposits range from at least late Lutetian to Priabonian in age, with abundant isolated specimens in the P15-P17 interval (stratigraphic data in Wilson, 1995; Figure 4, no. 10 here).

Sulawesi	Tonasa (van der Vlerk & Dozy, 1934; Crotty & Engelhardt, 1993; Wilson, 1995)	Donggala (Osimo, 1908)	Central Sulawesi (Rutten *in* Waterschoot van der Gracht, 1915)	Central Sulawesi (Dollfus, 1917)	Reinterpretation
N. javanus	x	x	x	x	pars *N. javanus*, pars *N. boninensis*
N. elegans		x			*P. variolarius*
N. heeri		x			*P. variolarius*
N. guettardi		x			*P. variolarius*
A. umbilicata			x		*Pl. umbilicata*
N. djokdjokartae				x	
N. laevigata				x	*N. martini*
N. bagelensis				x	pars *N. javanus*, pars *N. boninensis*
N. kelatensis				x	*P. beaumonti*
N. cf. *globula*	x				*P.* sp.

Table 6. Previously published records of *Nummulites* and *Assilina* from Sulawesi. Records published originally as *Camerina* are here recorded as *Nummulites.*

Osimo (1908) described a Priabonian fauna from Donggala (northern Sulawesi; see Figure 4, no. 11 here), although these specimens have not been restudied. Other specimens studied herein comprise Eocene larger foraminifera from several localities in central and eastern Sulawesi (Kalossi and Poh) that have not been published, but are deposited in the NNM collections. Based on the nummulitids found, these strata range from middle Lutetian to Bartonian in age (Figure 4, no. 12). The previously published records of *Nummulites* and *Assilina* from Sulawesi are summarised in Table 6.

At the Institut für Paläontologie (Universität Bonn), samples collected and published by Wanner (1912) from the eastern branch of Sulawesi were available for study. These contain numerous thin sections and rock samples. From locality 257, Bach Pang, five thin sections of a small miliolid-algal bioclastic packstone were available for study.

Sumba	Caudri, 1934	reinterpretation
A. aff. *granulosa-exponens*	x	*Pl.* sp. and/or *Pl. umbilicata*
A. orientalis	x	*Pl. orientalis*
N. bagelensis	x	not described, nor figured
N. borneensis	x	*P. taballarensis*
N. discoidea	x	*Pl.* sp.
N. djokdjokartae	x	
N. fichteli	x	pars A-from of *N. fichteli*, pars A-form of N. subbrongniarti
N. aff. *irregularis*	x	*P. crasseornatus*
N. javanus var. á	x	B-form of *N. boninensis*
N. javanus var. ß	x	B-form of *N. javanus*
N. kemmerlingi	x	see remarks *P. crasseornatus*
N. kelatensis	x	*P. beaumonti*
N. pengaronensis	x	*P. pengaronensis*
N. aff. *taballarensis*	x	*P. taballarensis*
N. cf. *variolaria*	x	*P. variolarius*

Table 7. Previously published records of *Nummulites* and *Assilina* from Sumba. Records published originally as *Camerina* are here recorded as *Nummulites.*

These contain numerous *Alveolina timorensis* Verbeek in Verbeek & Fennema, 1896, and additionally a large and a small species of *Alveolina.* Also present are *P. variolarius*, *P.* cf. *pengaronensis*, *N. javanus* (A-form), and a discocyclinid resembling *Discocyclina molengraaffi* Henrici, 1934. Samples labelled '250 Liangbolo' and '251 Liangbolo nach Tuhan' contain *P. variolarius, P. pengaronensis, Borelis*, large *Discocyclina* and *Spiroclypeus*, a typical Priabonian assemblage. Wanner (1907) presented a different species list.

Sumba

Caudri (1934) studied the larger foraminifera from Sumba and described faunas of 'Tertiary A, Tb, Tc, Td' and younger age, with definitions consistent with modern usage (Ta being undivided except into fossiliferous and unfossiliferous parts, equivalent to Ta_3 of Adams, 1970). Because *Camerina taballarensis* and *C. borneensis* Caudri, 1934 were later reassigned to *Ranikothalia*, a genus restricted to the Upper Paleocene and lowermost Lower Eocene, Ta of Caudri (1934) is sometimes interpreted as Lower Eocene, but there is no evidence for assigning this age to these rocks.

There is probably a hiatus at the end of the Eocene with much of the Priabonian missing, which would match new biostratigraphic work in Java, at Nanggulan and Karangsambung. *Nummulites* were found in Middle Eocene to Oligocene deposits (Table 7). Some of these samples were deposited in the NNM collections, and these have been restudied (Figure 4, no. 13).

Moluccas

The Eocene of the Moluccas is poorly known. Wanner (1907, 1910, 1922) published on the general geology of the islands of Buru, Misool and Seram. On Buru and Seram, Eocene deposits are rare. In Wanner's collections at the Institut für Paläontologie (Universität Bonn) thin sections comprise a small-miliolid packstone with some alveolinids, together with *P.* cf. *variolarius* (thin sections labelled 118, 119). No isolated specimens were available for study to verify this identification. Thin sections (labelled 170, Kamaka Wallar) from another locality contain numerous *P. variolarius*, large *Discocyclina, Borelis, Operculina* and *Pellatispira*, a typical Late Eocene assemblage.

All Eocene samples from Misol and Seram available for study comprise small-miliolid packstones, with alveolinids, rare *N. javanus* A-forms and *N. boninensis* A-forms (sample labelled Wai Sasifu).

Timor	Henrici, 1934	reinterpretation
N. perforata	x	*N. javanus*
N. bonleonensis	x	A-form of *N. javanus*
N. bagelensis	x	*P. variolarius*
N. guettardi	x	A-form of *P.* sp.
N. variolaria	x	*P. variolarius*
N. cf. *globula*	x	*P.* sp.
N. pengaronensis	x	*P. pengaronensis*
N. kelatensis	x	*P. beaumonti*
N. crasseornata	x	*P. crasseornatus*

Table 8. Previously published records of *Nummulites* and *Assilina* from Timor. Records published originally as *Camerina* are here recorded as *Nummulites*.

Timor

The only work concerning Eocene larger foraminifera of Timor is Henrici's paper (1934), in which there are nine (after revision five) species of *Nummulites* (Table 8). These range in age from earliest Lutetian to Priabonian. His original samples are deposited in the Geologisch Museum (Technische Universiteit Delft) and at the Institut für Paläontologie (Universität Bonn), and these have been restudied (Figure 4, no. 14). This has led to the recognition of some species previously unrecorded from Timor, among which are *N. boninensis* (several localities represented in the Molengraaff Collection), and *N. martini* n. sp. (only from Uwaki, collected by Wanner).

Samples labelled Bonleo, Miomaffo and Harmeno contain the planktonic foraminifer *Cribrohantkenina* cf. *inflata*, and are of probable P16 age. All three samples have a very similar larger benthic foraminiferal fauna with *P. variolarius, Discocyclina* and *Borelis*. Other species present are *P. pengaronensis* in samples from Miomaffo and Harmeno, and *Orthocyclina soeroeanensis* van der Vlerk, 1923 and *Pellatispira* only from Miomaffo, a typical Tb (Priabonian) assemblage. A sample labelled Uwaki contains the planktonic foraminifera *Morozovella lehneri* and *Acarinina* sp., of P12-P14 age, together with *N. javanus* and *Alveolina timorensis*.

West Papua

Several samples from the Birds Head, Lorentz River and Bibis River collected by Wanner are present in the collections at the Institut für Paläontologie (Universität Bonn). Most of these samples are of Middle Eocene age. A sample labelled 142 from 'Arguni Bai, Abfall Gusi Gebirges' (Figure 4, no. 21) contains Lacazinella and *P. variolarius*, another sample (labelled 24) from the same area yields *N. javanus* (A-form) and *N. boninensis* (A-form, identified as *N. bagelensis* by Wanner).

In samples from Pulau Adi (Figure 4, no. 22), *P. pengaronensis* together with *N. javanus* were observed, whilst samples from Etna Bai (Figure 4, no. 23) contain several specimens of *N. djokdjokartae* (A- and B-forms, identified as *N.* cf. *laevigatus* by Wanner). The single recognisable species from another sample is *P. variolarius*.

Beyond Indonesia

Philippines

Very little is known about the occurrence and distribution of larger foraminifera, especially *Nummulites*, in the Philippines. Douvillé (1911) reported on larger foraminifera, but did not describe any Paleogene deposits. Between 1978 and 1985, several papers by a group of Japanese scientists (Hashimoto & Matsumaru, 1978, 1981b, c, 1984; Hashimoto *et al.*, 1978a-c, 1979), describing the larger foraminifera from the Philippines came out, which in part dealt with Eocene and Oligocene deposits. Their specimens were not available for restudy. Moreover, their figured specimens often comprise oblique sections or fragments of specimens, which do not allow positive identification. Cosico *et al.* (1989) described larger foraminifera from the Visayas Islands, central Philippines, and summarised the history of larger foraminiferal research in the Philippines. The oldest unit they described was the Late Eocene *Pellatispira* Zone, which did not contain any *Nummulites*. The only species of *Nummulites* they recorded is *N. fichteli* from the overlying Early Oligocene biozone.

Papua New Guinea

Papers by Binnekamp (1973) and Bain & Binnekamp (1973) are the main studies dealing with the Cainozoic (mainly Paleogene) larger foraminifera from Papua New Guinea. Several other studies have been undertaken mainly dealing with Upper Oligocene to Miocene deposits. Binnekamp (1973) found *P. pengaronensis* co-occurring with *Pellatispira*, indicating a probable Priabonian or late Bartonian age. In Bain & Binnekamp's (1973) study a larger stratigraphical interval was covered, and they found *N. javanus* and *N. fichteli* together with the only published record of *N. vascus* Joly & Leymerie, 1848 known from the Indo-West Pacific. Their *N. vascus* specimens resemble *P. pengaronensis*, but lack an axial plug. However, the presence of an axial plug is highly variable in *P. pengaronensis*, which led Doornink (1932) to separate *N. semiglobulus* Doornink, 1932 from *P. pengaronensis* based on the presence of an axial plug in the latter. Doornink's specimens of *N. semiglobulus* show the beginning of the development of an axial plug as do the specimens of *N. vascus* figured by Bain & Binnekamp (1973). Their specimens were not available for study.

Western Pacific

Numerous studies have been undertaken on atolls in the western Pacific, but Paleocene-Eocene sedimentary rocks generally are lacking. Cole & Bridges (1953) and Cole (1954, 1956, 1957, 1963) described the larger foraminifera from various boreholes in Saipan, Eniwetok and Bikini. Cole described *N. saipanensis* in Cole & Bridges (1953), and recorded *N. djokdjokartae* from Saipan (Cole, 1954). On Bikini, Cole (1954) recorded *P. pengaronensis*, and in his synonymy of this species he included *N. saipanensis*. Hanzawa (1957) described the foraminifera from Micronesia, including Saipan, recording *P. pengaronensis*, *N. bagelensis* (= *N. javanus*) and *P. striatus* (Bruguière, 1792). In his opinion, the latter is a senior synonym of *N. saipanensis*. Deprat (1905) described the larger foraminifera from New Caledonia, comprising *N. djokdjokartae, N. nangoulani* Deprat, 1905 (= *P. pengaronensis*), *N. bagelensis* (= *N. javanus*) and *N. variolarius* (= *Palaeonummulites variolarius*).

Japan

Studies on Japanese *Nummulites* are mainly from the Bonin Islands. Hanzawa (1947) described *N. boninensis*, whilst Matsumaru (1984, 1994, 1996) restudied these specimens as well as additional material. Matsumaru (1996) subdivided *N. boninensis* into five species. Matsumaru (1996) described the complete Eocene larger foraminifera fauna from the Bonin Islands dividing the fauna into three assemblages, two of which contain *Nummulites*. The *Nummulites*-bearing part of the Eocene on the Bonin Islands may be assigned a P12-P14 age, based on the occurrence of planktonic foraminifera (*Morozovella* sp., *Acarinina* sp. and *Turborotalia cerroazulensis*, and hantkeniids; see Matsumaru, 1996), and is thus contemporaneous with the Nanggulan section in Java.

The oldest assemblage comprises *N. boninensis, N. javanus* and *P. pengaronensis*, and is assigned a late Ta_3 (late Lutetian) age. The middle assemblage comprises mainly *P. pengaronensis* and *N. javanus*, and is assigned a Bartonian age. The uppermost assemblage contained no *in situ Nummulites* and was assumed to be late Bartonian or earliest Priabonian in age on the basis of the presence of planktonic foraminifera.

Systematic palaeontology

Order Foraminiferida Eichwald, 1830
Suborder Rotaliina Delage & Hérouard, 1896
Superfamily Nummulitacea de Blainville, 1827
Family Nummulitidae de Blainville, 1827
Subfamily Nummulitinae de Blainville, 1827

Diagnosis — 'Test planispiral, involute or evolute with numerous median chambers which may be simple or divided into chamberlets, with or without lateral chamberlets; complex canal system of septal, marginal and axial canals; aperture an arched slit over the apertural face' (Loeblich & Tappan, 1987).

Discussion — The family Nummulitidae ranges from the Paleocene to the present (Loeblich & Tappan, 1987) in predominantly tropical marine environments. The family contains sixteen genera, eleven of which have been found in the Indo-Pacific. Of these, only those with simple undivided chambers are relevant to the present study. The generic descriptions in the following sections are based on Haynes (1988) and Haynes *et al.* (in press).

Genus *Nummulites* Lamarck, 1801

Type species — *Camerina laevigata* Bruguière, 1792, by subsequent designation.

Diagnosis — Test discoidal to globular, commonly large, up to 12 cm in diameter in B-form; dimorphism pronounced in larger species; planispirally, rather tightly coiled, involute; primary septa straight, curved or undulate, secondary septa present; chambers undivided with a distinct, fine to moderately thick marginal cord. Pillars often present and may appear as pustules on the outer test surface.

Stratigraphic range — Paleocene-Middle Oligocene, Tethys.

Discussion - Most records of *Nummulites* from the Caribbean, North and South America should be reassigned to *Palaeonummulites* (see Blondeau, 1972; Haynes, 1988). Large species showing marked dimorphism are especially common in the Middle Eocene. The group comprises numerous lineages in the Eocene, with only a few species extending into the Oligocene.

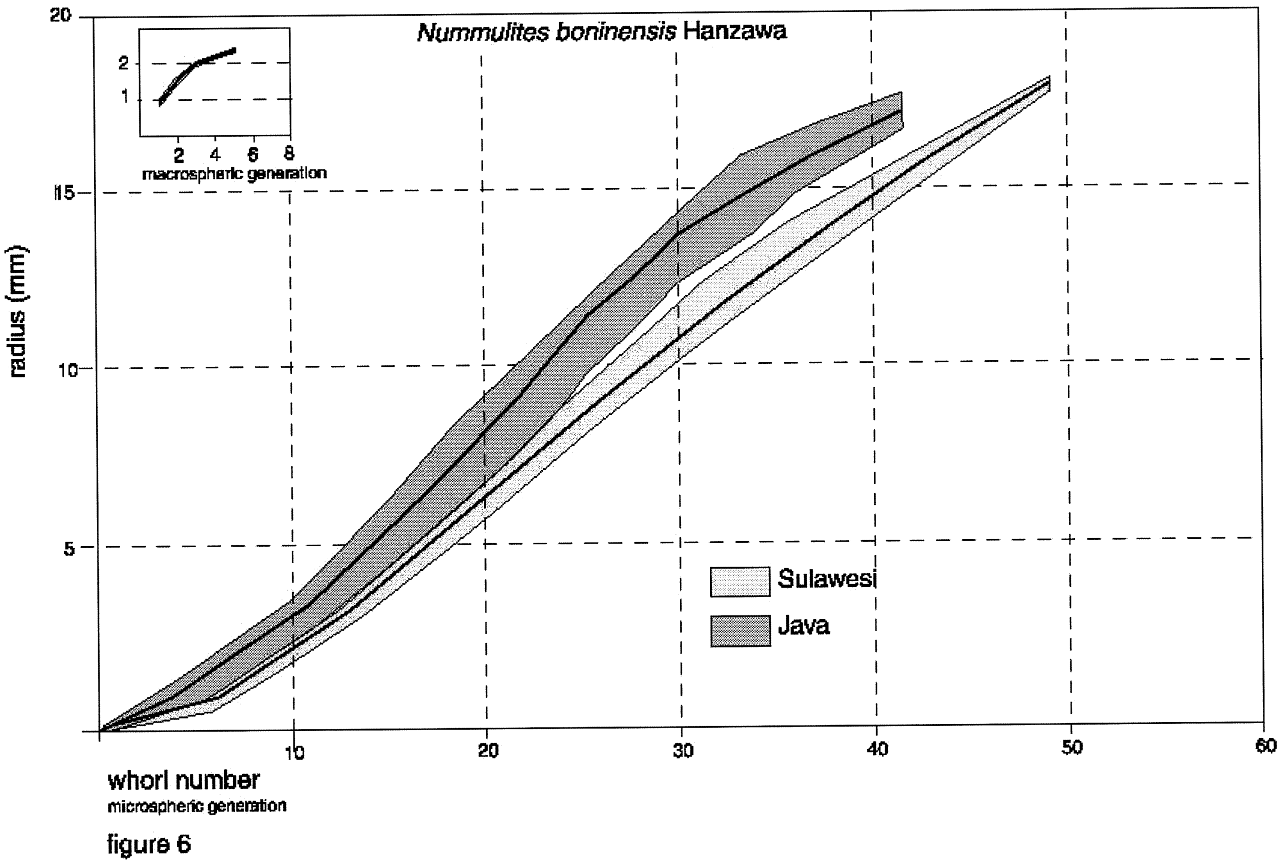


Figure 6. Coiling diagram of *Nummulites boninensis* Hanzawa, 1947.

Nummulites boninensis Hanzawa, 1947
Figures 6, 27A-C; Tables 9, 10

1891 *Nummulites javanus* var. Verbeek, p. 105.
1896 *Nummulites javanus* var. Verbeek, 1891 – Verbeek & Fennema, p. 1096.
1915 *Camerina gizehensis* (Forskål, 1775) – Rutten *in* Waterschoot van der Gracht, p. 54.
1926a *Camerina gizehensis* (Forskål, 1775) – Nuttall, p. 139.
1931 *Camerina gizehensis* (Forskål, 1775) – Umbgrove, p. 50.
1932 *Camerina gizehensis* (Forskål, 1775) – Doornink, p. 272.
*1947 *Nummulites boninensis* Hanzawa, p. 254, pls 39, 40.
1970 *Nummulites gizehensis* (Forskål, 1775) – Adams, p. 122.
1995 *Nummulites boninensis* Hanzawa - Racey, p. 36.

Material — > 25 specimens from Kali Gua (central Java), including five axial sections and five equatorial sections of A-forms and two axial and five equatorial sections of B-forms (RGM 202020); > 25 specimens from Sungai Ular (southwest Sulawesi), including five equatorial and one axial sections of B-forms, and four equatorial sections of A-forms (RGM 202016, RGM 202017), plus five specimens from Timor, including one axial section of an A-form, and four equatorial sections of B-forms (Technische Universiteit Delft).

Whorl number	1	2	3	4	5
Radius (mm)	0.8	1.4	1.9	2.2	2.5
Chambers	7	12	21	23	-

Table 9. Whorl number, radius and number of chambers per whorl in the A-form of *Nummulites boninensis* Hanzawa.

Description — A-form: test lenticular with a sharp margin, diameter up to 7 mm, thickness up to 2.5 mm; D/T = 3. Septal filaments radiating, and strongly curved with granules over entire test surface on and between septal filaments, becoming denser and larger towards the poles. Spire comprises five whorls, the first two rather high, the latter more tightly coiled (Figure 6). Chambers initially 1.5-2x higher than broad, becoming isometric in later whorls. Marginal cord ¼ of chamber height. In axial section, pillars are concentrated in the polar region occasionally reaching the test surface. Proloculus large, 0.55-1.0 mm in diameter.

B-form: test discoidal with an undulose, sharp periphery, diameter 26 to 45 mm, thickness up to 6 mm; D/T = 6.5 (5.8-9.1). Numerous granules occur on and between the meandriform septal filaments over the entire test surface, but are commoner in the polar region. In equatorial section, the spire opens regularly, tightening in the last few whorls (Figure 6) and consisting of up to 40 whorls. Chambers higher than broad in the initial whorls, 1.5-2x broader than high in the final whorls. Septa oblique, straight. Marginal cord thick, half the chamber height in the outer whorls. In axial section, there are numerous pillars, some of which reach the surface of the test. In axial section with many, very fine pillars, especially in the polar region, most of which do not reach the outer surface. Spiral laminae thick in the peripheral region, but very thin in the polar region.

Whorl number	1	2	3	4	5	6	7	8	9	10	11	12	13
Radius (mm)-Java	0.16	0.36	0.58	0.80	1.1	1.4	1.8	2.29	2.62	3.1	3.5	4.0	4.5
Radius (mm)-Sulawesi	0.17	0.31	0.48	0.63	0.92	1.28	1.55	1.86	2.23	2.69	3.05	3.44	3.94
Whorl number	14	15	16	17	18	19	20	21	22	23	24	25	26
Radius (mm)-Java	5.0	5.7	6.4	7.0	7.6	8.0	8.6	9.2	9.9	10.5	11.0	11.7	12.2
Radius (mm)-Sulawesi	4.48	4.75	5.16	5.58	6.12	6.46	6.88	7.48	8.00	8.53	8.98	9.37	10.0
Whorl number	27	28	29	30	31	32	33	34	35	36	37	38	39
Radius (mm)-Java	12.9	13.5	14.0	14.4	14.9	15.5	16.1	16.6	16.9	17.2	17.5	-	-
Radius (mm)-Sulawesi	10.5	11.0	11.4	11.7	12.2	12.7	13.0	13.5	13.9	14.3	15	15.6	5.9
Whorl number	40	41	42	43	44	45							
Radius (mm)-Java	-	-	-	-	-	-							
Radius (mm)-Sulawesi	16.0	16.1	16.2	16.3	16.4	16.4							

Table 10. Whorl number and radius in the B-form of *Nummulites boninensis* Hanzawa, showing the difference between two populations, from Java and Sulawesi. The number of chambers per whorl could not be counted due to flexure of the test.

Remarks — Some of the specimens used in the original description of *Nummulites javanus* are actually referable to *N. boninensis*. For example, although *N. javanus* var. and of Verbeek (1891) are slightly smaller than the specimens found at Kali Gua and in Sulawesi, they have the same internal structure and surface ornament and should be included in *N. boninensis*. *Nummulites bagelensis* Verbeek, 1891 was also described as comprising several variations and *N. bagelensis* I Verbeek is very similar to the A-form of *N. boninensis*.

The original description of *N. boninensis* refers to a species in which the B-form differs from *N. gizehensis* by its sharper periphery, more regular coiling without intercalatory whorls, thicker marginal cord (equalling chamber height vs half of chamber height in *N. gizehensis*). In axial section, the pillars are more pronounced than in *N. gizehensis*. The specimens from Sulawesi exactly match this description although the maximum size of the specimens is less (diameter up to 40 mm vs 60 mm in Ogasawara Island).

Matsumaru (1984) restudied *N. boninensis* and concluded that specimens described under this name from Ogasawara Island would be better attributed to three different taxa, *N. aturicus* Joly & Leymerie 1848, *N. aturicus/perforatus*, and *N. perforatus* (Denys de Montfort, 1808). In 1996, Matsumaru recognised four larger *Nummulites* species, viz. *N. aturicus, N. gizehensis, N. millecaput* (Boubée, 1832) and *N. perforatus*. The species mentioned by Matsumaru as '*N. gizehensis*' does not fit the description given by Schaub (1981, 1995) and Racey (1995), in that it lacks intercalatory whorls [1-11 in the specimens of Schaub (1981, 1995) and Racey (1995)], and in having a thicker marginal cord and test. These characteristics are sufficient to distinguish *N. boninensis* from *N. gizehensis*.

Geographic distribution — Indonesia: Ralla (SW Sulawesi), Kali Gua (central Java) and several localities in Timor. Elsewhere: Hillsborough Island (Japan) and Oman (Racey, 1995).

Stratigraphic range — Bartonian in Sulawesi (nannoplankton [NP17] and dinoflagellate age assignments [H. Brinkhuis, pers. comm.]); Bartonian (P13-P14) in Hillsborough Island (Hanzawa, 1947; Matsumaru, 1996), and co-occurring with *N. perforatus* and *N. lyelli* d'Archiac & Haime, 1853 in Oman, suggesting an early Bartonian age (SBZ 17; Serra-Kiel *et al.*, 1998). The stratigraphic range in Indonesia is interpreted to be Middle Eocene (Ta_3, or Bartonian).

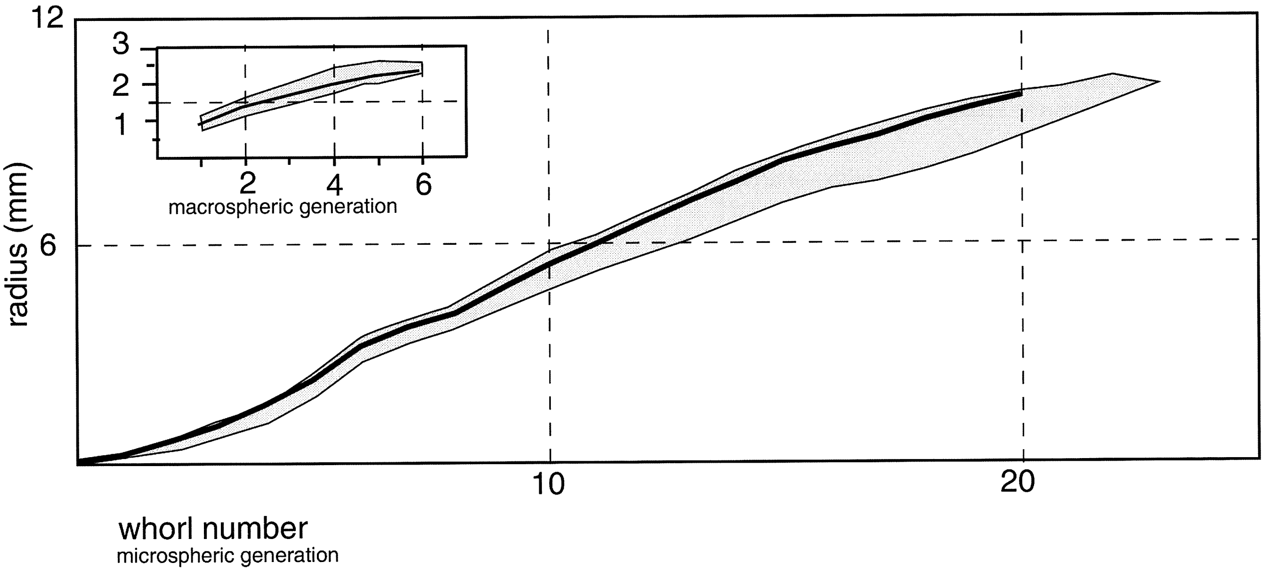


Figure 7. Coiling diagram of *Nummulites djokdjokartae* (Martin, 1881).

Nummulites djokdjokartae (Martin, 1881)

Figures 7, 24A, B, G-J, 25D, E; Tables 11, 12

*1881 *Nummulina djokdjokartae* Martin, p. 109.
1891 *Nummulites jogjakartae* [*sic*] Martin, 1881 – Verbeek, p. 116.
1896 *Nummulites jogjakartae* [*sic*] Martin, 1881 – Verbeek & Fennema, p. 1106.
1896 *Nummulites javanus* var. ß Verbeek & Fennema, p. 1098.
1899 *Nummulites djokjokartae* [*sic*] Martin, 1881 – Newton & Holland, p. 255.
1905 *Nummulites jogjakartae* [*sic*] Martin 1881 – Deprat, p. 495.
*1906 *Nummulites douvillei* Vredenburg, p. 79.
*1908 *Nummulites vredenburgi* Prever in Vredenburg, p. 239.
1908 *Nummulites djokjokartae* [*sic*] Martin, 1881 – Osimo, p. 33.
1912a *Nummulites vredenburgi* Prever, 1908 – Douvillé, p. 280.
1912a *Nummulites djokdjokartae* Martin, 1881 – Douvillé, p. 283.
1915 *Nummulites djokdjokartae* Martin, 1881 – Martin, p. 194.
1917 *Nummulites laevigatus* Lamarck var. *vredenburgi* Prever – Dollfus, p. 972.
1917 *Nummulites djokjakarta* [*sic*] Martin, 1881 – Dollfus, p. 973.
1926a *Nummulites acutus* (Sowerby, 1840) – Nuttall, p. 133.
1929 *Nummulites vredenburgi* Prever, 1908 – Gerth, p. 598.
1932 *Camerina djokdjokartae* Martin, 1881 – Doornink, p. 281.
1957 *Camerina djokdjokartae* (Martin, 1881) – Cole, p. 329.
1959 *Nummulites acutus* (Sowerby, 1840) – Nagappa, p. 145.

Material — Numerous individuals, comprising eighteen equatorial sections of A-forms, and fifteen of B-forms, plus five axial sections of A-forms and five axial sections of B-forms from Nanggulan (Java) (RGM 3320, RGM 3334, RGM 47196). Two equatorial sections of B-forms from Poh (Sulawesi; Universität Bonn) and five equatorial sections of A-forms, plus five of B-forms from Banten (Java; RGM 202021).

Description — A-form: lenticular with rounded periphery; diameter up to 5 mm, thickness up to 2.2 mm; D/T= 1.6-2.4. Trace of septal filaments radiating, S-shaped, occasionally branching with coarse granules on and between the septal filaments, granules concentrated on, but not limited to, the central part of the test. In equatorial section spire regular, consisting of 4.5 to 6 whorls (Figure 7) with the first whorl wider than subsequent ones. Marginal cord thick, 1/4-1/3 of chamber height. Chambers rectangular, initially almost isometric, becoming 1.5x broader than high. Septa perpendicular to marginal cord, curving backwards. In axial section, pillars occur over entire test surface from centre to periphery, and often reach the test surface to form granules. Proloculus 0.6-0.9 mm in diameter.

Whorl number	1	2	3	4	5	6
Radius (mm)	0.97	1.36	1.70	2.06	2.19	3.32
Chambers	8	17	23	26	22	-

Table 11. Whorl number, radius and number of chambers per whorl in the A-form of *Nummulites djokdjokartae* (Martin).

B-form: test flat lenticular, with sharp to rounded periphery. Test diameter up to 25 mm, thickness up to 6 mm with D/T = 3.5-4.5. Septal filaments meandriform, with large granules on and between them. In equatorial section, spire regularly increasing in width, up to the 6th-8th whorl (Figure 7), after which the spire becomes irregular, with partial intercalatory whorls developed. Marginal cord thick in the first 6-8 whorls (about 1/4 of chamber height), equally thick (0.15-0.2 mm) and thinner (or absent) in remaining whorls. Chambers 2-6x higher than long in first four whorls (on average 3, s.d = 1.4), 1.5 to 3x higher than long in whorls 5-6 (8), about 1.5-2x longer than high in the later whorls. Septa straight, sharply curved backwards at the peripheral margin, perpendicular to marginal cord in first whorls and curved in later (>8) whorls, irregularly spaced. In axial section, chamber height increases in height towards margin. Spiral laminae thickest near marginal cord, then much thinner, lateral splitting of the spiral laminae is common, sometimes into three thin laminae, but usually only into two. Splitting occurs near the marginal cord. Alar prolongations very narrow. Pillars of varying size and shape, distributed from pole to periphery. Most pillars do not protrude up to the surface, *i.e.* they are buried.

Whorl number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Radius (mm)	0.16	0.54	0.91	1.5	2.18	3.08	3.60	3.96	4.65	5.30	5.82	41	98	7.49
Chambers	8	14	24	30	32	36	40	44						
Whorl number	15	16	17	18	19	20	21	22						
Radius (mm)	8.04	8.41	8.73	9.16	9.49	10.0	10.4	11.1						

Table 12. Whorl number, radius and number of chambers per whorl in the B-form of *Nummulites djokdjokartae* (Martin). From the 9th whorl onwards, the chamber number could not be counted due to irregularities in the spiral.

Remarks — This species has been the subject of a lot of confusion in the literature. The A-form was described as *N. djokdjokartae* by Martin (1881), and ten years later Verbeek reported *N.* cf. *laevigatus* (B-form) and *N.* cf. *lamarcki* (A-form) from the same area (Verbeek, 1891). In 1896, Verbeek & Fennema recorded only *N. laevigatus* (B-form) and *N. djokdjokartae* (A-form).

In 1840, *N. acutus* was described by Sowerby from Lakhpat (Cutch, India). In the same area, Vredenburg (1906) found another species which he described as *N. douvillei*. Prever pointed out to him that this name was preoccupied and proposed the substitution name '*N. vredenburgi* Vredenburg' (Vredenburg, 1908; Samanta, 1982). Since Prever published this taxon, the formal name ought to be *N. vredenburgi* Prever. Many subsequent authors have synonymised *N. acutus*, *N. vredenburgi* and *N. djokdjokartae*. Although *N. acutus* is the oldest available name, the (youngest) name *N. vredenburgi* has been used for this taxon as well.

The initial whorls of *N. vredenburgi* are quite tight, but the 4th to 7th whorl are wider and the chambers are 2-3x higher than wide, and the marginal cord thins after the 10th-12th whorl (said in description, but not visible in specimens illustrated). In axial section, the spiral laminae split frequently into two-three thin laminae, a character also seen in the Indonesian specimens (Samanta, 1982). The measurements provided by Samanta (1982) for *N. vredenburgi* all fall within the range of the Indonesian specimens, although his A-forms are generally slightly flatter.

We agree with Samanta (1982) that the type specimen of *N. acutus* is morphologically distinct from *N. vredenburgi* and *N. djokdjokartae*. Samanta did not discuss the similarities and differences between *N. vredenburgi* and *N. djokdjokartae*, although, as discussed above, they are very similar in nearly all characters and we consider them to be synonymous, with the name *N. djokdjokartae* having priority.

The B-forms figured by Nagappa (1959) as *N. acutus* have all the characters in common with *N. djokdjokartae*, and therefore should be reassigned to *N. djokdjokartae*. Some small specimens of *N. djokdjokartae* (B-forms, diameter 9-11 mm) in the NNM collections (RGM 3334), identified by Douvillé (1912a) as *N. vredenburgi*, turned out to have exactly the same coiling pattern as *N. djokdjokartae* for the first six whorls, but do not have intercalatory whorls or the very thin marginal cord in the later whorls. These specimens are otherwise similar to *N. djokdjokartae* and probably are juveniles of that species.

Geographic distribution — Indonesia: central and western Java, Sulawesi, Sumba, Nias and West Papua. Elsewhere: western India (Vredenburg, 1906, 1908; Nagappa, 1959), New Caledonia (Deprat, 1905) and Saipan (Cole, 1956).

Stratigraphic range — Known from upper Middle Eocene sediments (later P12/NP16, uppermost Lutetian/lowermost Bartonian) in Nanggulan. The Harudi Formation from which *N. vredenburgi* was described is assigned a P12 age (Samanta, 1982). The stratigraphic range in Indonesia is interpreted as upper Lutetian to lower Bartonian (P12).

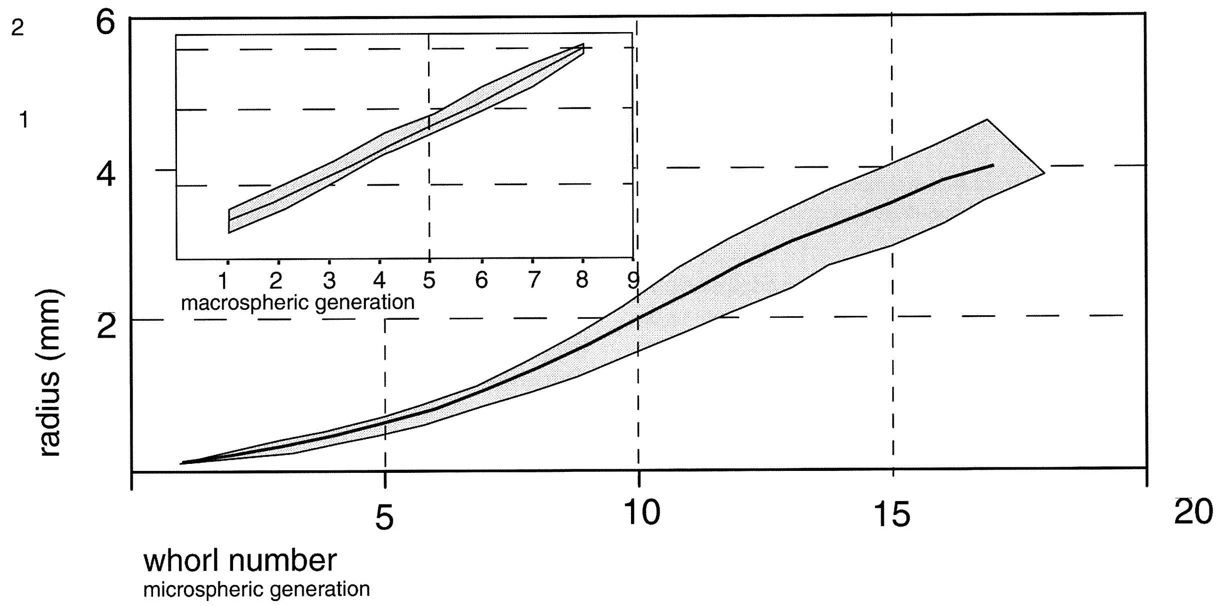


Figure 8. Coiling diagram of *Nummulites fichteli* Michelotti, 1841.

Nummulites fichteli Michelotti, 1841
Figures 8, 30D, E; Tables 13, 14

*1841 *Nummulites fichteli* Michelotti, p. 44.
1905 *Nummulites subbrongniarti* Verbeek, 1871 – Douvillé, p. 439.
1909 *Nummulites fichteli* Michelotti, 1841 – Provale, p. 92.
1909 *Nummulites intermedia* d'Archiac, 1846 – Provale, p. 93.
1929 *Nummulites intermedius* d'Archiac, 1846 – Van der Vlerk, p. 18.
1929 *Nummulites fichteli* Michelotti, 1841 – Gerth, p. 598.
1929 *Nummulites intermedius* d'Archiac – Gerth, p. 598.
1931 *Camerina fichteli* (Michelotti, 1841) – Umbgrove, p. 49.
1931 *Camerina intermedius* d'Archiac, 1846 – Umbgrove, p. 50.
1932 *Camerina intermedia* (d'Archiac) – Doornink, p. 285.
1934 *Camerina fichteli* (Michelotti, 1841) – Caudri, p. 72.
1970 *Nummulites fichteli* Michelotti, 1841 – Adams, p. 122.
1973 *Nummulites fichteli* Michelotti, 1841 – Bain & Binnekamp, p. 8.
1981c *Nummulites fichteli* Michelotti, 1841 (*partim*) – Hashimoto & Matsumaru, p. 75.
1993 *Nummulites fichteli* Michelotti, 1841 – Crotty & Engelhardt, p. 77.
1995 *Nummulites fichteli* Michelotti, 1841 – Racey, p. 44.

Material — > 30 specimens from Sungai Mesalai and Sungai Taballar (Kalimantan), including two axial and five equatorial sections of A-forms, and two axial and five equatorial sections of B-forms (RGM 19061-19070, RGM 19115-19120).

Description — A-form: test flat lenticular, diameter 2.5-5.5 mm, thickness 1-1.5 mm; D/T = 2.0-3.5. Septal filaments strongly reticulate. In equatorial section, spire regular, fairly uniform and tightly coiled (Figure 8). Chambers initially isometric, in the last few whorls 3x broader than high. Septa straight, inclined to the marginal cord. Marginal cord 1/5 of the chamber height in the first whorls, 1/3 in the last whorls. In axial section, pillars from the median layer do not reach the surface of the test. Proloculus 0.25-0.30 mm in diameter.

B-form: test flat lenticular, diameter 8-14 mm, D/T = 3.5-4.5. Septal filaments reticulate with occasional very fine granules on and between the septal filaments, especially towards the polar region. In equatorial section, spire is uniform and fairly tightly coiled (Figure 8). Marginal cord 1/2-1/3 of the chamber height. Chambers increasing in length from the inner towards the outer whorls, becoming up to 3x longer than high in outer whorls. Septa slightly inclined in the inner whorls, more inclined in the outer whorls.

Remarks — The Indonesian A-forms of this species are somewhat more tightly coiled than the European and Omani specimens figured by Schaub (1981) and Racey (1995), respectively. The B-forms match the European specimens, although the Indonesian specimens fall in the lower range of the variation shown in the coiling diagrams of Schaub (1981) and Racey (1995), *i.e.* they show less variation and are more tightly coiled than the western Tethyan specimens.

Whorl number	1	2	3	4	5	6	7	8
Radius (mm)	0.45	0.72	1.1	1.4	1.7	2.0	2.3	2.7
Chambers	7	12	15	18	22	22	24	-

Table 13. Whorl number, radius and number of chambers per whorl in the A-form of *Nummulites fichteli* Michelotti.

Whorl number	1	2	3	4	5	6	7	8	9	10	11
Radius (mm)	0.13	0.22	0.34	0.48	0.65	0.83	1.09	1.37	1.68	2.03	2.37
Chambers	-	16	18	22	24	24	23	24	26	28	28
Whorl number	12	13	14	15	16	17					
Radius (mm)	2.74	3.30	3.56	3.33	3.86	4.05					
Chambers	30	-	-	-	-	-					

Table 14. Whorl number, radius and number of chambers per whorl in the B-form of *Nummulites fichteli* Michelotti.

In addition to *N. fichteli* and *N. subbrongniarti*, Doornink (1932) recognised a third species of reticulate *Nummulites*, *N. absurda* Doornink (pp. 299, 300) from Java, distinguished from the other reticulate species by its larger and more irregularly shaped proloculus and the form of spire. So far, this species is only known from a single locality where it was found with 'typical' *N. fichteli* so that it cannot be excluded that this is an ecophenotypic variant of *N. fichteli*. The precursor of this species in Europe, *N. fabianii* Prever, 1905, has not been found in Indonesia, although it is widespread and often abundant in the Priabonian of Europe and the Middle East (Schaub, 1981; Racey, 1995, and references therein).

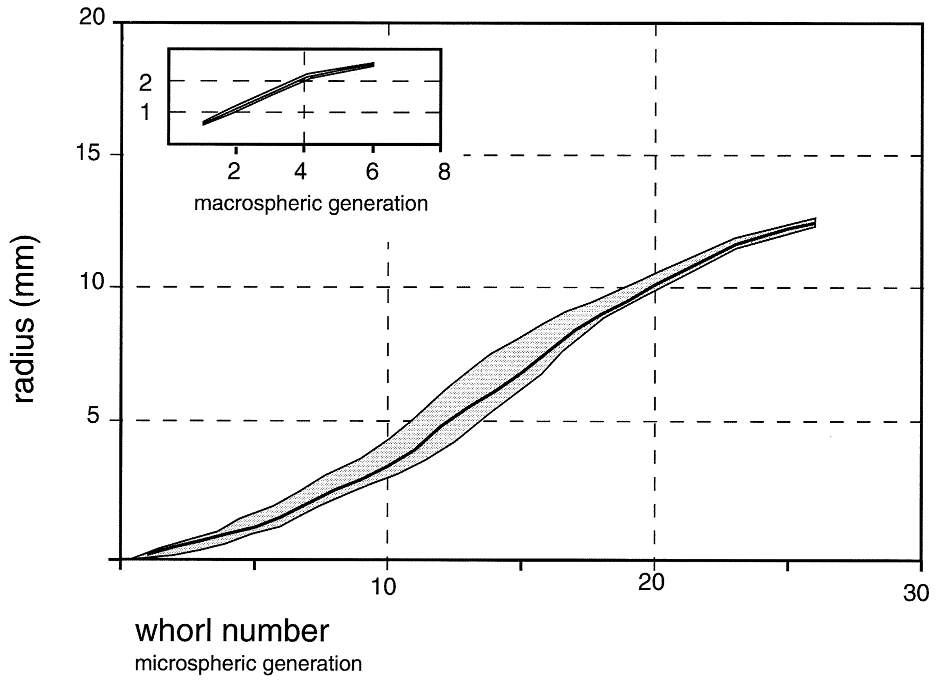


Figure 9. Coiling diagram of *Nummulites javanus* Verbeek, 1891.

Geographic distribution — Indonesia: Java, Sumatra, Borneo, Sulawesi, Sumba and Irian Jaya. Elsewhere: widely distributed throughout the Tethys. For records on distribution see Blondeau (1972), Schaub (1981) and Racey (1995). There are additional eastern Asiatic records from Mindanao (Hashimoto & Matsumaru, 1984), Mindoro and Luzon (Philippines; Cosico *et al.*, 1989) and Papua New Guinea (Bain & Binnekamp, 1973).

Stratigraphic range — Species typical of Tc and Td (Lower Oligocene) in the eastern Indian letter classification (Adams, 1970). The last appearance of this species is in zone P21a in the Kujung area of NE Java (dated as 29.4 Ma using strontium isotopes). A single, younger Sr date of 28.4 Ma has been obtained from the Pelang Limestone of central Java, but at this locality there are no independent planktonic foraminiferal data. The interpreted stratigraphic range is letter stage Tc to Td (Rupelian).

Nummulites javanus Verbeek, 1891
Figures 9, 26A-F; Tables 15, 16

*1891 *Nummulites javanus* var. , Verbeek, pp. 105, 106.
*1891 *Nummulites bagelensis* Verbeek, p. 107.
1896 *Nummulites javanus* Verbeek, 1891 — Verbeek & Fennema, p. 1096.
1896 *Nummulites bagelensis* Verbeek, 1891 — Verbeek & Fennema, p. 1101.
1905 *Nummulites bagelensis* Verbeek, 1891 – Deprat, p. 493.
1912a *Nummulites bagelensis* Verbeek, 1891 – Douvillé, p. 262.
1929 *Nummulites bagelensis* Verbeek, 1891 – Van der Vlerk, p. 18.
1929 *Nummulites javanus* Verbeek, 1891 – Gerth, p. 598.
1929 *Nummulites bagelensis* Verbeek, 1891 — Gerth, p. 598.
1931 *Camerina bagelensis* (Verbeek) – Umbgrove, p. 49.
1931 *Camerina javana* Verbeek, 1891 [*sic*] – Umbgrove, p. 50.
1932 *Camerina perforata* Denys de Montfort, 1808 – Doornink, p. 273.
1932 *Camerina bagelensis* Verbeek, 1891 – Doornink, p. 277.
1934 *Camerina javana* (Verbeek, 1891) – Caudri, p. 64.
1934 *Camerina perforata* Denys de Montfort, 1808 – Henrici, p. 21.
1934 *Camerina bagelensis* Verbeek, 1891 – Henrici, p. 25.
1948 *Camerina perforata* Denys de Montfort, 1808 – Van Andel, p. 1013.
1979 *Nummulites perforatus* (Denys de Montfort, 1808) – Hashimoto *et al.*, p. 155.
1981b *Nummulites perforatus* (Denys de Montfort, 1808) – Hashimoto & Matsumaru, p. 67.
1993 *Nummulites javanus* Verbeek, 1891 – Crotty & Engelhardt, p. 77.
1995 *Nummulites javanus* Verbeek, 1891 – Racey, p. 50.

Material — > 30 specimens including five equatorial and three axial sections of B-forms, and ten equatorial and two axial sections of A-forms from Karangsambung (central Java; RGM 202019, RGM 202022); > 30 specimens including ten equatorial and three axial sections of B-forms from Banten (western Java; RGM 202023); twenty specimens, including five equatorial sections of B-forms from Jiwo Hills (central Java; RGM 202018, RGM 202024); ten equatorial and three axial sections of B-forms and four equatorial and two axial sections of A-forms from several localities in Timor (Institut für Paläontologie, Universität Bonn).

Description — A-form: lenticular with a rounded periphery, diameter up to 4.5 mm, thickness up to 2 mm; D/T = 1.8 (1.5-3.1). Septal filaments gently curved, radiating from the centre with granules on and between septal filaments. In equatorial section, spire regular, comprising 4-5 whorls (Figure 9). First two whorls fairly lax, tightening in the 3rd-4th whorl. Septa oblique, curving gently in the proximal part, distally straight. Marginal cord 1/5 of chamber height. Chambers equidimensional to broader than high. Proloculus 0.55-0.8 mm in diameter.

Whorl number	1	2	3	4	5
Radius (mm)	0.6	1	1.6	1.9	2.2
Chambers	7	12	23	25	-

Table 15. Whorl number, radius and number of chambers per whorl in the A-form of *Nummulites javanus* Verbeek.

B-form: test lenticular, up to 30 mm in diameter, maximum thickness 9 mm; D/T = 3.1 (2.6-5.2). Septal filaments meandriform with fine granules on and between them, especially over the polar region. In equatorial section, spire regularly opening, tightening in the last whorls in some specimens giving it a tripartite appearance (Figure 9). Septa slightly oblique, straight to gently curved in the distal part. Chambers higher than broad in the first whorls, becoming 2-3x broader than high in the outer whorls. Marginal cord thick, 1/3-1/2 of the chamber height. In axial section, strongly pillared with thin pillars, especially over the centre of the test, with most pillars not reaching the test surface.

Whorl number	1	2	3	4	5	6	7	8	9	10	11	12	13
Radius (mm)	0.18	0.47	0.7	0.97	1.2	1.6	2.1	2.6	3.0	3.5	4.1	5	5.7
Whorl number	14	15	16	17	18	19	20	21	22	23	24	25	26
Radius (mm)	6.3	7.0	7.8	8.6	9.2	9.7	10.3	10.8	11.3	11.8	12.1	12.4	12.6

Table 16. Whorl number, radius and number of chambers per whorl in the B-form of *Nummulites javanus* Verbeek. Due to flexure of the test, the number of chambers per whorl could not be counted.

Remarks — Initially, all Indonesian 'larger' *Nummulites* were grouped under the name *N. javanus*. In his original description, Verbeek (1891) already described four varieties, α, β, χ and δ. α and χ are the larger forms, α has a rounded periphery, whilst χ is more flattened and has a sharp periphery. β and α are smaller, β is a thick form with a rounded periphery, whilst δ is a small, flat form with a very sharp periphery. Subsequently, there has been a lot of discussion about these 'species'. Doornink (1932) suggested that the two forms with the sharp periphery should be included in *N. gizehensis*, whilst the specimens with the rounded periphery, *i.e.*, var. δ and var. β, should be included in *N. perforatus*. The present study confirms that the large-sized *Nummulites* from Indonesia belong to two species, *N. boninensis* (equivalent to var. α of Verbeek) and *N. javanus* (equivalent to var. χ of Verbeek).

The smaller variety with the blunt edge has subsequently been identified as *N. laevigatus* (Bruguière, 1792) by Douvillé (1912a), as a transitional form between *N. laevigatus* and *N. perforatus* by Dollfus (1917), as *N. obtusus* Sowerby, 1840 by Gerth (1929), and as *N. perforatus* by Doornink (1932). Racey (1995) discussed the status of the smaller specimens with the blunt edge. The B-forms of *N. perforatus* have a tripartite spire, which is not seen in material from Java. In the middle, looser part of the spire *N. perforatus* also has occasional intercalatory whorls. *Nummulites javanus* has a gradually opening spire, with some very tight last whorls (usually three, sometimes up to five). In none of the specimens of *N. javanus* are intercalatory whorls present (pers. obs.; Racey, 1995). The spire of *N. obtusus* is also tripartite, but always has 3-4 intercalatory whorls, features absent in the Javanese specimens. *Nummulites laevigatus* has a gradually opening spire, which does not tighten in the outer whorls, and has a flatter test with sinuous septal filaments and can thus be differentiated from *N. javanus*.

Geographic distribution — Indonesia: Karangsambung and Jiwo (central Java, type localities), Bayah (western Java), Ralla, Tonasa (SW Sulawesi), Batu Gading, Melinau Gorge (Sarawak) and several localities in Sumba, Timor and West Papua. Elsewhere: Oman (Racey, 1995) and Papua New Guinea (Bain & Binnekamp, 1973).

Stratigraphic range — *Nummulites javanus* is assigned a Ta_3 age (Middle Eocene in Adams, 1970; Lutetian in Haak & Postuma, 1975), although Bartonian was not recognised in these studies. In Oman, Racey (1995) found *N. javanus* together with *N. perforatus* and *N. brongniarti* d'Archiac & Haime, 1853, in the 'Biarritzian', equivalent to the upper Lutetian to Bartonian (SBZ 17 of Serra-Kiel *et al.*, 1998; top P12-P14). Outcrops in Karangsambung (Java) yielding *N. javanus* could not be dated directly, although samples taken just above them have yielded planktonic foraminifera and nannoplankton indicative of a Middle Eocene (late Lutetian to early Bartonian, P12, upper NP15) age. Limestones with *N. javanus* and *Pellatispira* from Jiwo Hills (Watu Perahu) were successfully dated as P14 or older based on the presence of *Morozovella* sp. Overlying mudstones were also dated as Middle Eocene on nannofossils (see above). Samples from Ralla containing both *N. javanus* and *Pellatispira* were dated as Bartonian on the basis of associated dinoflagellates (H. Brinkhuis, pers. comm.). Crotty & Engelhardt (1993) also found samples containing pollen indicative of Bartonian age immediately above *N. javanus*-bearing rocks. The suggested stratigraphic range for this species in Indonesia is thus considered to be Middle Eocene (upper Lutetian to lower Bartonian).

Nummulites martini n. sp.
Figures 10, 24C-E, 25A-C; Tables 17, 18

1881 *Nummulites cf. lamarcki* d'Archiac & Haime, 1853 – Verbeek *et al.*, p. 39.
1881 *Nummulites cf. laevigata* Lamarck, 1801 [*sic*] – Verbeek *et al.*, p. 39.
1891 *Nummulites laevigatus* Lamarck, 1881 [*sic*] – Verbeek, p. 117.
1896 *Nummulites laevigata* Lamarck, 1801 [*sic*] – Verbeek & Fennema, p. 1104.
1912b *Nummulites vredenburgi* Prever, 1908 – Douvillé, p. 260.

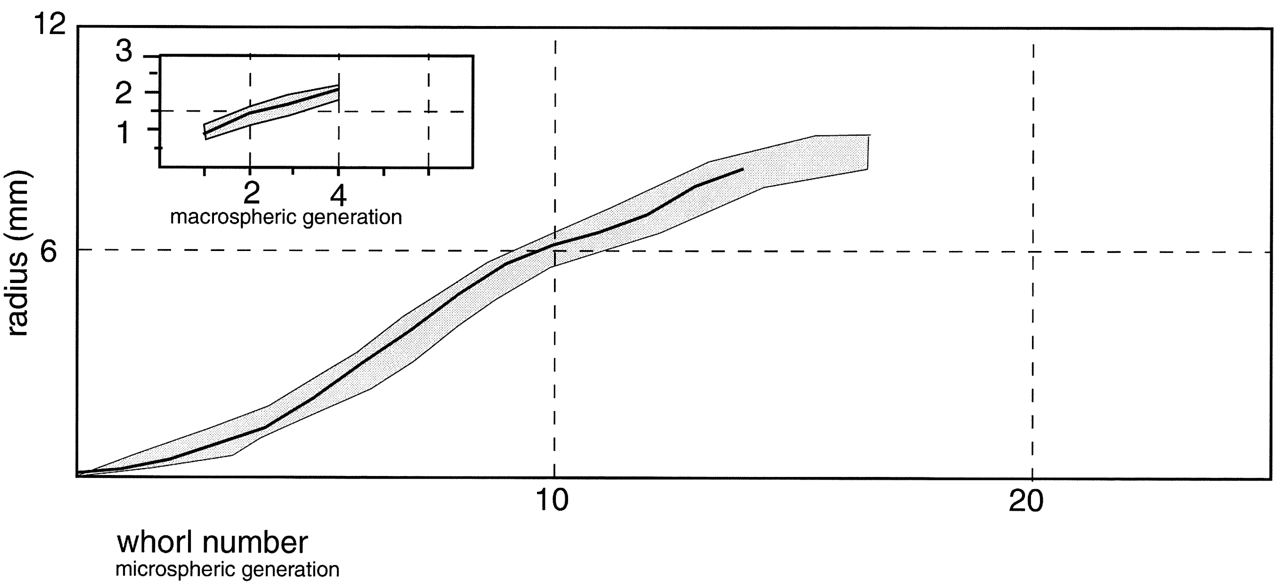


Figure 10. Coiling diagram of *Nummulites martini* n. sp.

1932 *Camerina laevigata* Bruguière, 1792 – Doornink, p. 279.
1934 *Camerina djokjokartae* (Martin, 1881) – Caudri, p. 67.
1995 *Nummulites acutus* (Sowerby, 1840) – Racey, p. 30.
non1972 *Nummulites acutus* (Sowerby, 1840) – Blondeau, p. 149.

Material — Numerous individuals from Nanggulan (Java), comprising twelve equatorial sections of A-forms, and ten of B-forms plus five axial sections of A-forms and five axial sections of B-forms. One equatorial section from Uwaki (western Timor) (Institut für Paläontologie, Universität Bonn).

Types — Holotype is RGM 3322B; paratypes are RGM 3322A, RGM 3325B, and RGM 3339A-F.

Type locality — Kali Puru, Nanggulan (central Java, Indonesia).

Type horizon — *Djokdjokartae* Beds of the Nanggulan Formation (upper Middle Eocene; uppermost Lutetian or basal Bartonian).

Diagnosis — Medium-sized *Nummulites*, septal filaments meandriform, densely covered by granules. Spiral laminae infrequently split in the polar region, not near the marginal cord. Coiling regular up to the 8th-10th whorl, then more irregular with thinning marginal cord. A-forms are difficult to distinguish from *N. djokdjokartae*, except that they are smaller and have fewer whorls.

Derivatio nominis — Named after Carl Martin (1851-1942), who pioneered the study of the Indonesian Cainozoic, and especially the type locality of this species.

Description — A-form: lenticular with rounded periphery. Diameter up to 4.5 mm, thickness up to 2.5 mm; D/T= 1.6-2.0. Trace of septal filaments radiating, S-shaped, occasionally branching with coarse granules on and between the septal filaments. In equatorial section, spire regular consisting of up to 4-4.5 whorls (Figure 10), with the first whorl wider than subsequent whorls. Marginal cord thick, 1/4-1/3 of chamber height. Chambers rectangular, initially almost isometric, becoming 1.5x broader than high. Septa perpendicular to marginal cord, curving backwards. In axial section, pillars occur over entire test surface from the centre to the periphery, and often reach the test surface to form granules. Proloculus 0.48-0.7 mm in diameter.

Whorl number	1	2	3	4
Radius (mm)	0.97	1.36	1.69	1.88
Chambers	8	17	22	-

Table 17. Whorl number, radius and number of chambers per whorl in the A-form of *Nummulites martini* n.sp.

B-form: test flat lenticular, with sharp to rounded periphery. Test diameter up to 18 mm, thickness up to 6 mm; D/T = 3.5-4.5. Septal filaments meandriform, with large granules on and between them. In equatorial section, spire regularly increasing in width, up to the 8th-10th whorl (Figure 10), after which the spire becomes irregular, with partial intercalatory whorls developed. Marginal cord thick in the first 8-10 whorls at about 1/4 of chamber height and thinner in remaining whorls. Chambers 2x higher than long in the first 4 whorls, about 1.5-2.0x higher than long in whorl 5-8 (10) and finally 1.5-2x longer than high in the later whorls. Septa straight, sharply curved backwards at the peripheral margin, perpendicular to marginal cord in first 8-10 whorls and curved in later whorls. In axial section, chamber height increases towards margin. Spiral laminae thickest near marginal cord, then much thinner, but lateral splitting of the spiral laminae is rare, occurring nearer to the central axis of the test than to the marginal cord. Alar prolongations very narrow. Pillars of varying size and shape, distributed from pole to periphery. Most pillars do not protrude to the surface of the test.

Whorl number	1	2	3	4	5	6	7	8	9
Radius (mm)	0.21	0.47	0.90	1.3	2.1	3.0	3.9	4.88	5.85
Chambers	9	12	22	27	27	33	38	48	64
Whorl number	10	11	12	13	14	15	16		
Radius (mm)	6.22	6.55	7.02	7.78	8.25	8.55	9.04		
Chambers	68	70	76	92	90	92			

Table 18. Whorl number, radius and number of chambers per whorl in the B-form of *Nummulites martini* n.sp.

Remarks — The A-form typically has 4-4.5, the B-form 14-17 whorls. In the Nanggulan section, A-forms are abundant, whilst B-forms are rare. *Nummulites martini* n. sp. differs from *N. djokdjokartae* in that it is slightly more loosely coiled, the chambers are isometric to twice as high as long (2-3x higher than long in *N. djokdjokartae*) and the lateral laminae thin, but do (usually) not split. If they split, it is in the polar region, whilst in *N. djokdjokartae* they split near the periphery. Additionally, the maximum size of *N. martini* n. sp. is 16-18 mm, while *N. djokdjokartae* may reach 25 mm.

In India and Indonesia, three species of the *N. laevigatus* lineage (*N. acutus*, *N. djokdjokartae* and. *N vredenburgi*) have been described, which were confused during the last century. The types of *Nummulites acutus*, mixed A- (which Sowerby regarded as juveniles) and B-forms are lost, except for the largest specimen that is preserved in the NHM collections (London). Samanta (1982) resampled the type area and studied the remaining type specimen of *N. acutus* and the type specimens of *N. vredenburgi* and discussed the differences between these two species, that both were synonymised with *N. djokdjokartae* by Umbgrove (1931).

Samanta (1982) showed that *N. acutus* and *N. djokdjokartae* (= *N. vredenburgi*) are two distinct species that often have been confused, and did not find new specimens of *N. acutus*, so his description of that species is solely based on the type specimen. This reaches only 10 mm in diameter, the coiling pattern is tighter than the Indonesian specimens and the marginal cord does not thin or disappear, thus not justifying the synonymy of *N. acutus* and *N. djokdjokartae*.

Blondeau (1972) described and illustrated specimens under the name *N. acutus* that fit the description of Sowerby precisely. The maximum diameter is 13 mm, with only 12 whorls, all chambers isometric or only slightly higher than long, marginal cord not thinning in the outermost whorls, whilst the maximum diameter in Indonesia is 18 mm, specimens have up to 17 whorls and the initial chambers are higher than long. Blondeau showed Indonesian A-froms (*N. djokdjokartae*) as the accompanying macrospheric generation, but the microspheric forms shown by him originate from Madagascar and differ from the Indonesian B-forms. Thus, *N. acutus* is a different species, thus warranting the introduction of a new species name for the small Indonesian specimens.

The A- and B-forms shown by Racey (1995) as *N. acutus* are similar to *N. martini* n. sp. in size, coiling pattern and number of whorls, as well as external characters, and should be included in this species.

Geographic distribution — Indonesia: central Java, Timor. Elsewhere: Oman (Racey, 1995).

Stratigraphic range — In Oman, *N. martini* n. sp. (recorded as *N. acutus* by Racey, 1995) was found in middle Lutetian deposits, which are approximately equivalent to zone P11. In Indonesia, it is found in the oldest rocks containing larger foraminifera from the Nanggulan section, that have been dated as upper P12 (Lunt, 2000a, b), but also in the Nummulite Beds 2, which means that the range of *N. martini* n. sp. overlaps with that of *N. djokdjokartae.* The stratigraphic range in Indonesia is interpreted as letter stage Ta (P11-P12), correlating with the Lutetian Stage.

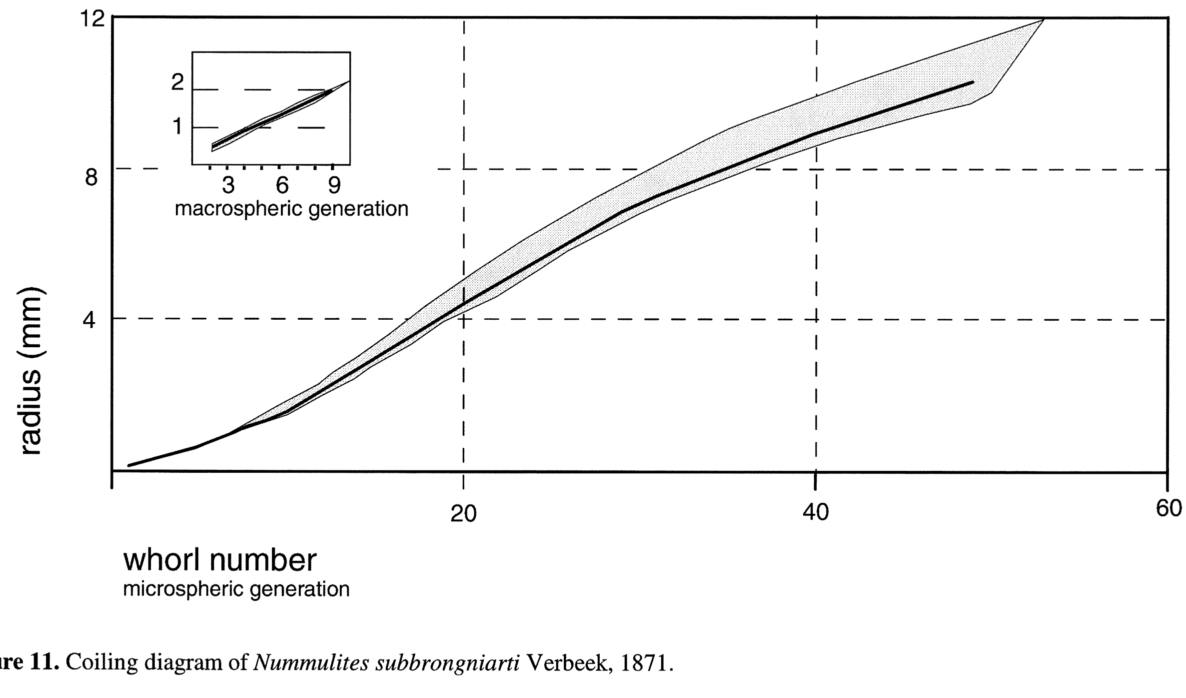


Figure 11. Coiling diagram of *Nummulites subbrongniarti* Verbeek, 1871.

Nummulites subbrongniarti Verbeek, 1871
Figures 11, 30A-C; Tables 19, 20

*1871 *Nummulites sub-brongniarti* Verbeek, p. 6.
1874 *Nummulites subbrongniarti* Verbeek – Verbeek, p. 152.
1929 *Camerina fichteli* Michelotti – Van der Vlerk, p. 18.
*1932 *Camerina divina* Doornink, p. 299.
1934 *Camerina divina* Doornink – Caudri, p. 78.

Material — Fifteen specimens, including one equatorial section of a B-form and five equatorial and one axial section of A-forms from Sungai Seilor (Borneo, RGM 10949, RGM 19051-19060); five specimens including five equatorial sections of A-forms from Tji Dengkol (Java; RGM 202025).

Description — A-form: lenticular test with a sharp margin, diameter 3.5-5.0 mm, thickness 1.6-2.4 mm; D/T = 2.1 (1.8-2.5). Septal filaments reticulate, comprising a rather coarse mesh. The equatorial section comprises 7-9 compact whorls of almost equal height (Figure 11). Marginal cord 1/3 of chamber height in initial whorls and approximately 1/2 chamber height in later whorls. Chambers 1.5x broader than high in the initial whorls, becoming 3-5x broader than high in the outer 3-4 whorls. In axial section, fine pillars diverge from the equatorial plane to the outer whorl. Proloculus 0.2-0.36 mm in diameter.

B-form: description based on the type description of Verbeek (1871) and figures in Hashimoto *et al.* (1973), together with data from a single thin section in the NNM collections. Test flattened lenticular, with a subrounded, often undulated periphery. Diameter up to 28 mm (commonly 14 mm), thickness up to 6 mm; D/T = 4-5. Septal filaments reticulate. In equatorial section, comprising up to 50-60 whorls in a diameter of 14 mm (Figure 11), with a wide range of variation both in diameter and number of whorls. Marginal cord in the inner whorls as high as the chamber height, in the latter whorls about 1/3 of the chamber height. Chambers up to 4x longer than high, especially in the outer whorls. Septa slightly inclined and straight.

Whorl number	1	2	3	4	5	6	7
Radius (mm)	0.6	0.78	0.98	1.19	1.42	1.67	1.89
Chambers	8	9	10	11	13	14	-

Table 19. Whorl number, radius and number of chambers per whorl in the A-form of *Nummulites subbrongniarti* Verbeek.

Whorl number	1	2	3	4	5	6	7	8	9	10
Radius (mm)	0.1	0.2	0.3	0.5	0.6	0.7	0.9	1.1	1.3	1.5
Whorl number	11	12	13	14	15	16	17	18	19	20
Radius (mm)	1.6	1.9	2.3	2.6	3.1	3.5	3.7	3.9	4.2	4.4
Whorl number	21	22	23	24	25	26	27	28	29	30
Radius (mm)	4.7	4.9	5.2	5.5	5.8	6.1	6.3	6.5	6.8	7.1
Whorl number	31	32	33	34	35	36	37	38	39	40
Radius (mm)	7.3	7.5	7.6	7.8	8.0	8.2	8.4	8.6	8.7	8.9
Whorl number	41	42	43	44	45	46	47	48	49	
Radius (mm)	9.0	9.1	9.3	9.4	9.5	9.6	9.7	9.8	10	

Table 20. Whorl number, radius and number of chambers per whorl in the B-form of *Nummulites subbrongniarti* Verbeek. Due to flexure of the test, number of chambers per whorl could not be counted.

Remarks — *Nummulites subbrongniarti* differs from *N. brongniarti* in being more tightly coiled in both A- and B-forms. Furthermore, *N. subbrongniarti* lacks granules on the surface of the test and has reticulate rather than subreticulate septal filaments.

Much confusion has arisen following Verbeek's original description. His drawings were not clear, and although he mentioned that the proloculus was small, but visible, this species was subsequently interpreted as an A-form. However, Verbeek's specimens are clearly B-forms, based on their size and the number of whorls. Starting with Douvillé (1905), several authors have regarded *N. subbrongniarti* as the Indonesian representative of *N. intermedius/fichteli*. Doornink (1932) restudied the Javanese *Nummulites* and acknowledged the existence of more than one species among the Oligocene reticulate *Nummulites*, describing two new species and discussing the status of N. subbrongniarti. He did not recognise *N. subbrongniarti*, but described *Camerina divina* from Java, which is an A-form similar to the A-form of *N. fichteli*, but has broader chambers (3-5x broader than high) in the outer whorls and has whorls of similar height. The reticulate septal filaments (mesh) on the test surface are coarser than in *N. fichteli* (see Caudri, 1934). Specimens figured and collected by Van der Vlerk (1929) match Doornink's description. Verbeek (1871) distinguished *N. subbrongniarti* from *N. fichteli* by its tighter coiling, larger number of whorls and longer chambers. He also mentioned the coarse mesh on the outer surface. The similar character distinguishing *C. divina* and *N. subbrongniarti* from *N. fichteli* indicate that these are in fact A- and B-forms of a single species *i.e.*, *N. subbrongniarti*. *Nummulites divina* must therefore be considered a junior synonym of *N. subbrongniarti.*

Hashimoto *et al.* (1973) restudied many reticulate nummulitids to examine the relationship between *N. subbrongniarti* and *N. fichteli*. Although they looked at many characters, they did not take the form of the spire into account and their fig. 11 clearly shows all the characters of *N. subbrongniarti*.

Nummulites subbrongniarti is closely related to *N. fichteli*. In India, Pakistan and Egypt, two other species occur that also are as closely related to *N. fichteli*, viz. *N. sublaevigatus* d'Archiac & Haime, 1853 and *N.* cf. *fichteli* (Sen Gupta, 2000), showing a radiation of the reticulate *Nummulites*-lineage following the Eocene-Oligocene boundary, but terminated prior to the Chattian.

Geographic distribution — Indonesia: Cijengkol (Java; Doornink, 1932), Sungai Seilor, Antjam, Borneo (Van der Vlerk, 1929), Pengaron, SE Kalimantan (Verbeek, 1871; Hashimoto *et al.*, 1973) and eastern Sumba (Caudri, 1934). Elsewhere: Mindoro (the Philippines).

Stratigraphic range — Co-occurring with *N. fichteli* and *P. pengaronensis* in SE Borneo in Tc faunas (Rupelian). Suggested stratigraphic range: Lower Rupelian (Tc).

Genus *Palaeonummulites* Schubert, 1908

Type species — *Nummulina pristina* Brady 1874, by monotypy.

Diagnosis — Planispiral, involute, semi-compressed to globular; spire moderately tightly coiled; whorls relatively few, generally no more than four or five in the A-form; coiling tight; chambers up to twice as high as long in equatorial section; primary septa and extensions ('filaments') only; septal sutures radial to sigmoidal; marginal cord finely to moderately strongly developed. Range: mid-Paleocene to Recent, with a cosmopolitan distribution.

Discussion — Distinguished from *Nummulites* by its simple septal filaments that are straight to sigmoidal. In *Nummulites*, secondary septal filaments are present.

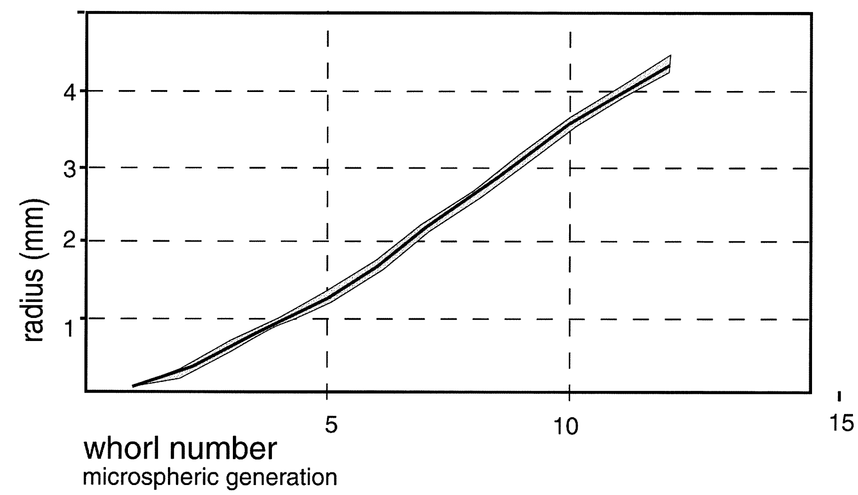


Figure 12. Coiling diagram of *Palaeonummulites beaumonti* (d'Archiac & Haime, 1853).

Palaeonummulites beaumonti (d'Archiac & Haime, 1853)
Figures 12, 29A-D; Table 21

*1853 *Nummulites beaumonti* d'Archiac and Haime, p. 133.
1874 *Nummulites biarritzensis* d'Archiac and Haime, 1853 – Verbeek, p. 155.
1874 *Nummulites striata* d'Orbigny var. f Verbeek, p. 157.
1912a *Nummulites kelatensis* Carter, 1861 – Douvillé, p. 262.
1929 *Nummulites kelatensis* Carter, 1861 – Van der Vlerk, p. 19.
1929 *Nummulites kelatensis* Carter, 1861 – Gerth, p. 598.
*1932 *Camerina densa* Doornink, p. 295.
*1932 *Camerina hoogenraadi* Doornink, p. 297.
1934 *Camerina kelatensis* (Carter?) Douvillé – Caudri, p. 53.
1934 *Camerina kelatensis* Carter, 1861 sensu Douvillé – Henrici, p. 30.
1940 *Nummulites beaumonti* d'Archiac and Haime – Davies, p. 206.
1972 *Nummulites beaumonti* d'Archiac and Haime – Blondeau, p. 149.
1981 *Nummulites beaumonti* d'Archiac and Haime – Schaub, p. 135.
1995 *Nummulites beaumonti* d'Archiac and Haime – Racey, p. 34.

Material — Five specimens from Nias, including one equatorial section of a B-form (RGM 202026); four specimens from Taballar including three equatorial sections and one axial section of B-forms (RGM 19112-19114); five specimens, including three equatorial and one axial section of B-forms from Timor (Institut für Paläontologie, Universität Bonn).

Description — A-form: not found.

B-form: test lenticular, with rounded margin. Test diameter 6.5-9.0 mm, thickness 3.5-4 mm; D/T = 2.1-3.1. Septal filaments straight, radiating and curving around a polar pillar. In equatorial section, spire regularly opening (Figure 12). Chambers numerous, uniform, rectangular, 1.5-2.0 higher than long in the initial whorls, equidimensional to slightly higher than broad in the outer whorls, with almost straight septa. Marginal cord about 1/4-1/5 of the chamber height. In axial section, alar prolongations thin, spiral laminae all of the same thickness. Fine pillars reach about halfway the exterior, mainly concentrated over the polar region and often buried.

Whorl number	1	2	3	4	5	6	7	8	9	10	11	12
Radius (mm)	0.11	0.26	0.59	0.93	1.25	1.67	2.21	2.59	3.07	3.55	3.97	4.33
Chambers		21	26	30	34	40	42	48	55	57	60	65

Table 21. Whorl number, radius and number of chambers per whorl in the B-form of *Nummulites beaumonti* (d'Archiac & Haime).

Remarks — According to Davies (1940) and Blondeau (1972), *N. kelatensis* Carter, 1861 is in part synonymous with *P. beaumonti*. Davies (1940) redescribed *N. kelatensis* from topotypes, whilst Racey (1995) restudied these and concluded that *N. kelatensis* is a smaller species with fewer whorls than *P. beaumonti*. Furthermore, in the description of *N. kelatensis*, Davies stated that the septal filaments are clearly twisted, while the septal filaments are nearly straight and only curved around the polar region in *P. beaumonti*. The buried pustules in the polar region are a good feature to help distinguish *P. beaumonti* from other species.

Specimens from all localities in Indonesia match the description of *P. beaumonti* in nearly all characters, and should therefore be included in that taxon, although they have previously been recorded under the name *N. kelatensis* (see synonymy).

Geographic distribution — Indonesia: Nias, Borneo, Java, Sumba and Timor, but rare at all localities. Elsewhere: Oman (Racey, 1995), Senegal, Libya (Blondeau, 1972), Egypt (De la Harpe, 1883), India (Nuttall, 1926a, b) and Pakistan (Davies, 1940).

Stratigraphic range — In Nias, *P. beaumonti* co-occurs with *Alveolina ovicula* Nuttall, 1925 and *Planocamerinoides* sp., indicating a (late) Lutetian age. In Timor, it co-occurs with *N. javanus* and planktonic foraminifera indicating a P12-P14 age. In Oman, it is restricted to the upper Lutetian (Racey, 1995), while in the western Tethys it is found in the upper Lutetian-Bartonian (Serra-Kiel *et al.*, 1998). The stratigraphic range in Indonesia of this species is therefore suggested to be upper Lutetian-Bartonian.

Palaeonummulites crasseornatus (Henrici, 1934)
Figures 13, 31A, B, H-J; Tables 22, 23

1932 *Camerina irregularis* Deshayes, 1838 – Doornink, p. 290.
1932 *Camerina orbignyi* (Galeotti) – Doornink, p. 289.
*1934 *Camerina crasseornata* Henrici, p. 32.
1934 *Camerina* aff. *irregularis* Deshayes, 1838 – Caudri, p. 62.

Material — Ten specimens, including four equatorial sections of B-forms from Nanggulan; > 30 specimens including five equatorial and three axial sections of both A- and B-forms from Timor (Technische Universiteit Delft); two specimens including one axial section of a B-form from Jatibungkus (RGM 202032).

Description — A-form: diameter up to 3 mm, thickness 1.5 mm. Involutely coiled with a pronounced marginal cord. From the coarsely granulated (70-130 ìm) centre straight septal filaments radiate. In equatorial section, spire regular, fairly constant in width (Figure 13). Chambers rectangular with rounded tops. Septa thin, perpendicular to the marginal cord, with intraseptal canal visible, slightly bent backwards. In axial section, a small umbilical plug is visible. The marginal cord is thick, and coarsely canalised. Proloculus 0.20-0.32 mm in diameter.

B-form: diameter up to 8 mm, thickness 1.7 mm; D/T = 3.4 (2.5-4.4). Test lenticular, involute. The centre of the test has a large number of coarse pillars, out of which 30-35 S-shaped septal filaments radiate. In equatorial section, the spire is irregular, showing large differences in whorl height within and between whorls (Figure 13).

Whorl number	1	2	3	4
Radius (mm)	0.42	0.93	1.7	2.6
Chambers	13	16	19	25

Table 22. Whorl number, radius and number of chambers per whorl in the A-form of *Palaeonummulites crasseornatus* (Henrici).

Test outline often elongated. Chambers rectangular, slightly bent backwards with rounded tops. Septa thin, perpendicular to the marginal cord and distally curved backwards, in outer whorls with intraseptal canal visible. Chambers higher than broad (up to 3x). In axial section, an umbilical plug (pillar) is visible. The marginal cord is swollen and coarsely canalised.

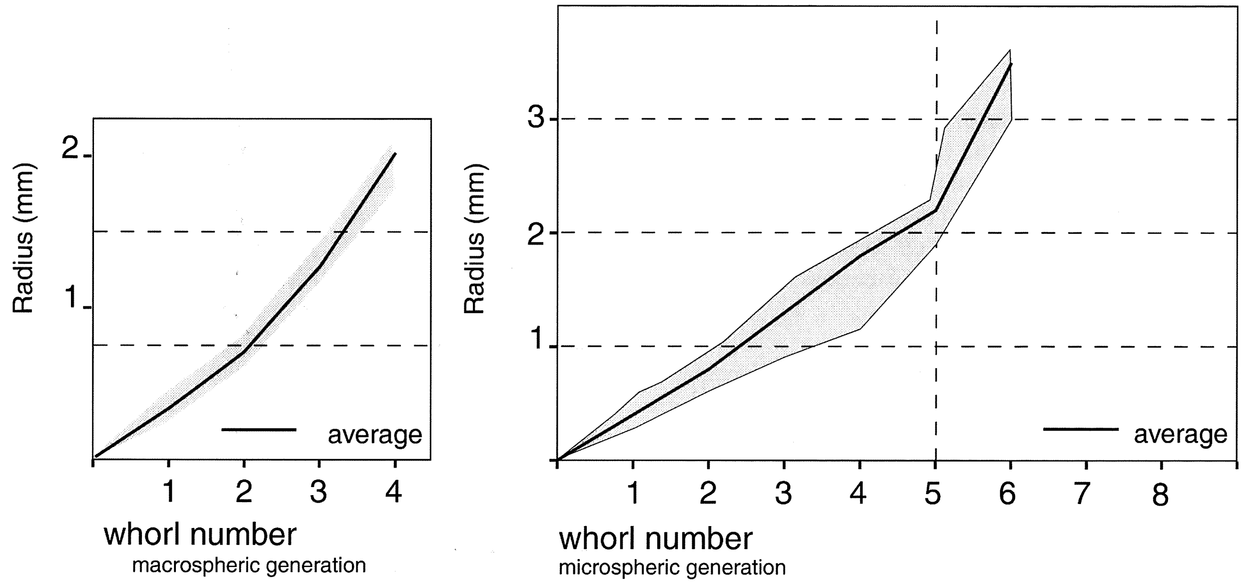


Figure 13. Coiling diagram of *Palaeonummulites crasseornatus* (Henrici, 1934).

Whorl number	1	2	3	4	5	6
Radius (mm)-Java	0.29	0.58	0.98	1.46	1.92	2.1
Chambers- Java	7	15	24	30	34	39

Table 23. Whorl number, radius and number of chambers per whorl in the B-form of *Palaeonummulites crasseornatus* (Henrici).

Remarks — There have been several records of *N. irregularis* (Deshayes, 1838) or related taxa from Tb strata in Indonesia, many of which should be assigned to other genera in our opinion. For example, the specimens figured by Provale (1908) as *N. heeri* De la Harpe, 1883 and *N. subheeri* De la Harpe,1883, are, in fact, *Operculina*, based on the rapidly opening spire and lack of alar prolongations, features which do not occur in *Nummulites* and are characteristic of *Operculina*.

Doornink (1932) first reported this species from Indonesia, as *Camerina orbignyi* (Galeotti, 1837), referring to a more complete description of *N. elegans* (Jones, 1887), which includes *N. prestwichianus* (Jones, 1887) and *N. elegans*. However, Jones (1887) showed that some of the specimens described by Sowerby as *N. elegans* were juveniles of *N. planulatus* Lamarck, 1804. In the descriptions of *N. elegans* and *N. prestwichianus*, no granulations in the centre of the test are mentioned, nor are they shown in the plates. Jones (1887) showed *N. prestwichianus* to lack granulations and have a poorly developed umbo in the centre of the test. In the Indonesian specimens no umbo is present, and in many specimens a polar depression is observed. Thus, neither *N. elegans* nor *N. prestwichianus* are identical with the Indonesian specimens. Boussac (1911) synonymised all these species under *N. orbignyi*, but did not give any supporting illustrations, although his description matches the previous one. Blondeau (1972) separated *N. orbignyi* and *N. prestwichianus* (= *N. elegans*). Both species differ from the Indonesian specimens by either the absence of granulations and the presence of an evolute last whorl (*N. orbignyi*) or by having a more robust test (*N. prestwichianus*).

Schaub (1981, p. 160) mentioned that the granulated specimens from the Isle of Wight (southern England) were *N. aquitanicus* Benoist, 1889 although according to Schaub (1981), *N. aquitanicus* is much larger and more regularly coiled than *N. orbignyi*.

Doornink (1932) described specimens from central Java as *N. irregularis* on account of their similarity to *N. irregularis* material from India. His description refers to granules, a common morphological character of the Nummulitidae. However, *N. irregularis* does not have granules (Schaub, 1981; Racey, 1995). Granules are present in the Javanese specimens, and are formed by small pustules, comparable to those in Recent *Operculina ammonoides* Gronovius, 1781. The Javanese specimens, therefore, cannot be assigned to *N. irregularis*. The description given by Caudri (1934) is similar to that of the above-mentioned specimens. Although she did not give any measurements, she stated that the coiling is tighter than that of the Indian and European specimens.

The Javanese specimens studied herein exactly match the type specimens of *Camerina crasseornata*. In equatorial section, the septa are thinner and the chambers higher than in *P. taballarensis*. They are larger than both *P. thalicus* and *P. taballarensis*, have a more inflated test and more numerous, coarse pillars over the poles. In the largest B-forms, the last whorl is evolute and the coarse marginal cord forms a ridge that is visible on the test surface, a feature otherwise seen only in *Ranikothalia*. Unlike in the latter genus, the alar prolongations do not extend towards the poles in axial section and are much higher.

Nummulites kemmerlingi Caudri (1934, pp. 60-62) was recognised by Caudri from only seven specimens. It is very similar to *P. crasseornatus* but larger (8.5-15 mm). No specimens could be traced in museum collections and the material illustrated by Caudri (1934) is only slightly larger than the largest *P. crasseornatus* B-form described herein. Thus, *N. kemmerlingi* is regarded herein as a synonym of *P. crasseornatus*.

Geographic distribution — Indonesia: Java (Nanggulan, Jatibungkus Limestone), Timor (Henrici, 1934), Sumba (Caudri, 1934) and Sulawesi (Ralla Bridge section). Elsewhere: specimens from Pinugay Hill, Luzon, the Philippines (Hashimoto *et al.*, 1978c) resemble *P. crasseornatus*, although the figures provided are insufficient to allow positive identification.

Stratigraphic range — Recorded from Timor together with *Alveolina ovicula* and *N. javanus* (Ta Stage). In Java, *P. crasseornatus* is found in the *Discocyclina* Beds at Nanggulan (upper P12, upper NP16), at the Lutetian-Bartonian boundary. In the Jiwo Hills area, they are dated as P12-14, upper NP15-16, *i.e.* latest Lutetian to earliest Bartonian (Ta, Middle Eocene). *Palaeonummulites crasseornatus* is found in Sumba together with *P. beaumonti*, *P. taballarensis* and *Planocamerinoides orientalis*, indicative of a late Lutetian age. The stratigraphic range in Indonesia is therefore considered to be Middle Eocene (Ta, upper Lutetian-Bartonian).

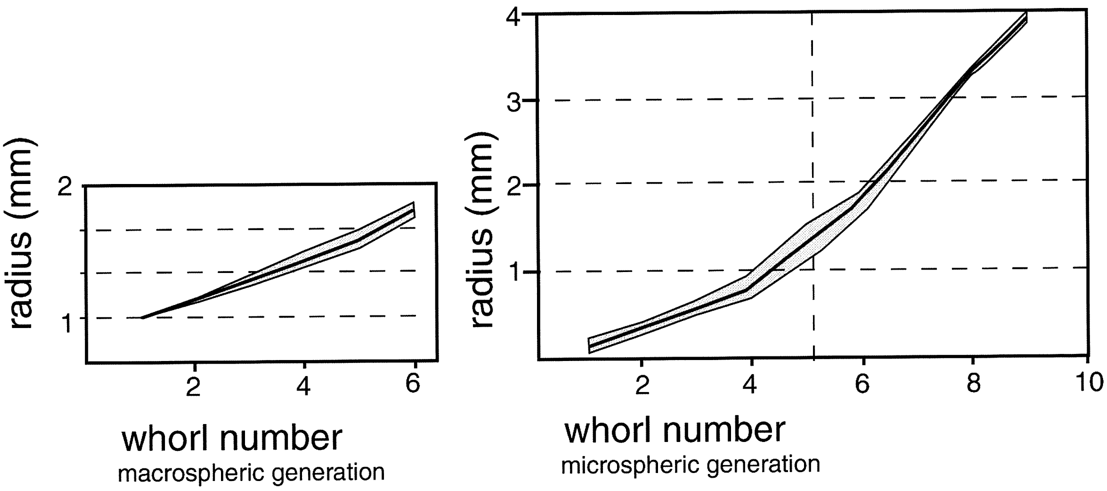


Figure 14. Coiling diagram of *Palaeonummulites pengaronensis* (Verbeek, 1871).

Palaeonummulites pengaronensis (Verbeek, 1871)
Figures 14, 28A-E; Tables 24, 25

- *1871 *Nummulites pengaronensis* Verbeek, p. 3.
- 1874 *Nummulites pengaronensis* Verbeek, 1871 – Verbeek, p. 145.
- *1891 *Nummulites nanggoelani* Verbeek, p. 161.
- 1896 *Nummulites nanggoelani* Verbeek, 1891 – Verbeek & Fennema, p. 1105.
- 1896 *Nummulites pengaronensis* Verbeek, 1871 – Verbeek & Fennema, p. 1107.
- 1905 *Nummulites nanggoulani* Verbeek, 1891 – Deprat, p. 494.
- 1912b *Nummulites pengaronensis* Verbeek, 1871 – Douvillé, p. 284.
- 1929 *Nummulites pengaronensis* Verbeek, 1871 – Van der Vlerk, p. 6.
- 1929 *Camerina nanggoelani* Verbeek, 1891 – Gerth, p. 598.
- 1931 *Camerina pengaronensis* Verbeek, 1871 – Umbgrove, p. 50.
- 1932 *Camerina pengaronensis* (Verbeek, 1871) – Doornink, p. 283.
- 1932 *Camerina pustulosa* Douvillé, 1919 – Doornink, p. 286.
- *1932 *Camerina gerthi* Doornink, p. 296.
- 1934 *Nummulites* cf. *pengaronensis* Verbeek, 1871 – Caudri, p. 52.
- 1934 *Camerina pengaronensis* (Verbeek, 1871) – Henrici, p. 29.
- 1949 *Nummulites pengaronensis* Verbeek, 1871 – Rutten in Van Bemmelen, p. 85.
- 1968 *Nummulites pengaronensis* Verbeek, 1871 – Samanta, p. 677.
- 1973 *Nummulites pengaronensis* Verbeek, 1871 – Binnekamp, p. 10.
- 1979 *Nummulites pengalonensis* [*sic*] Verbeek, 1871 – Hashimoto *et al.*, p. 155.
- 1981b *Nummulites cf. pengaronensis* Verbeek, 1871 – Hashimoto & Matsumaru, p. 68.

Material — Ten specimens, including five equatorial and two axial sections of B-forms from Pengaron (Borneo); fifteen specimens, including five equatorial sections of B-forms, and four equatorial and one axial sections of A-forms from Nanggulan (central Java; RGM 202026); numerous specimens from Sangiran, including ten equatorial and one axial of A-forms and one B-form (RGM 202027); ten specimens, including four equatorial sections of A-forms and four equatorial sections of B-forms from Nias; three equatorial and two axial sections of B-forms from Timor (Institut für Paläontologie, Universität Bonn).

Description — A-form: test biconical, with a sharp to rounded periphery, 3.1-4.1 mm (average 3.6 mm) in diameter and up to 3.2 mm thick; D/T = 1.8 (1.3-2.4). Septal filaments radiating, straight to slightly S-shaped. Polar usually with pillar present. In equatorial section, up to 5.5 whorls with a regularly opening spire (Figure 14) and has a thick marginal cord (1/3-1/4 of chamber height). Chambers slightly longer than high to equidimensional. Septa thin, perpendicular to marginal cord, curving backwards. Test is distinctly diamond shaped in axial section, with an umbilical plug (pillar) which is poorly developed in some specimens. Alar prolongations narrow. Proloculus small, 0.18-0.28 mm in diameter.

B-form: exterior similar to A-form with test diameter up to 9 mm, thickness up to 3 mm; D/T = 2.5 (1.8-3.2). Spire gradually opening, uniform (Figure 14) with marginal cord thin, about 1/5 of chamber height. Chambers higher than broad to isometric in the outer whorls. Septa perpendicular to the marginal cord, strongly curving backwards in the distal half. Biconical in axial section, with umbilical plug (pillar), alar prolongations narrow.

Whorl number	1	2	3	4	5
Radius (mm)	0.5	0.63	1.0	1.4	1.7
Chambers	8	14	19	24	30

Table 24. Whorl number, radius and number of chambers per whorl in the A-form of *Palaeonummulites pengaronensis* (Verbeek).

Whorl number	1	2	3	4	5	6	7	8	9
Radius (mm)	0.15	0.4	0.6	0.83	1.4	1.9	2.6	3.4	3.94
Chambers	-	23	27	35	33	46	-	-	-

Table 25. Whorl number, radius and number of chambers per whorl in the B-form of *Palaeonummulites pengaronensis* (Verbeek).

Remarks — There has been confusion about whether the type specimen of *P. pengaronensis* was an A-form or a B-form (see Doornink, 1932). The types were not available for study, although topotypes collected by Verbeek have been examined. The diameter of the B-forms is 6-9 mm, which is similar to the diameter of the types. The co-occurring A-forms are much smaller, being up to 4 mm in diameter. Both have a similar external morphology and chamber shape. The holotype is probably a B-form, as originally noted by Van der Vlerk (1929), who probably saw the types. In subsequent descriptions, the A- and B-forms have often been confused. *Palaeonummulites pengaronensis* is very similar to *N. striatus* (Bruguière, 1792), but is smaller with a smaller proloculus in the A-form. The fourth and fifth whorls are more tightly coiled in the A-forms. Both species have an axial pillar and a distinctive diamond-shaped test in axial section.

Doornink (1932, p. 296) described *Camerina gerthi* from Gamping, and noted that 'owing to the special character of this form, it is very difficult to name a species which may be related to it'. We found a similar facies, rich in *Pellatispira*, some *Sylvestriella*, *Discocyclina*, *Asterocyclina* and rare *Heterostegina* and *P. pengaronensis* B-form at Sangiran, with abundant globular *Palaeonummulites*, very similar to the ones figured by Doornink. In all measurements these are similar to *P. pengaronensis*, and thus *C. gerthi* is regarded as a junior synonym of that species.

Geographic distribution — Indonesia: western, central and eastern Java, Sumba, Borneo, Sulawesi, Timor and Nias (Sumatra). Elsewhere: Assam (eastern India; Samanta, 1968), New Caledonia (Deprat, 1905), Papua New Guinea (Binnekamp, 1973) and Saipan (Cole, 1954, 1957).

Stratigraphic range — Most abundant in the (?uppermost Bartonian and) Priabonian (*i.e.*, Tb, Upper Eocene), post-dating the extinction of Ta forms. Van der Vlerk (1929) reported *P. pengaronensis* with *N. fichteli* and *Heterostegina reticulata* Rütimeyer, 1850 in Borneo, which would indicate an Early Oligocene age. *Palaeonummulites pengaronensis* is also found together with *N. javanus* in Java and in Timor associated with *Cribrohantkenina* and *P. variolarius*, indicating a Late Eocene (P16) age. The stratigraphic range in Indonesia is assumed therefore to be upper Middle Eocene through Lower Oligocene (Ta to Tc, Lutetian to (lower) Rupelian).

Palaeonummulites songoensis n. sp.
Figures 15, 31C-G; Tables 26, 27

1932 *Camerina pustulosus* Douvillé, 1919 – Doornink, p. 286.

Material — Twenty-five individuals, including ten equatorial and four axial sections of B-forms from Nanggulan.

Types — Holotype is RGM 202000; paratypes are RGM 202001-202010, as well as Geologisch Museum Artis, nos O5743-1 and O5743-2.

Type locality — Kali Songo, Nanggulan (central Java, Indonesia).

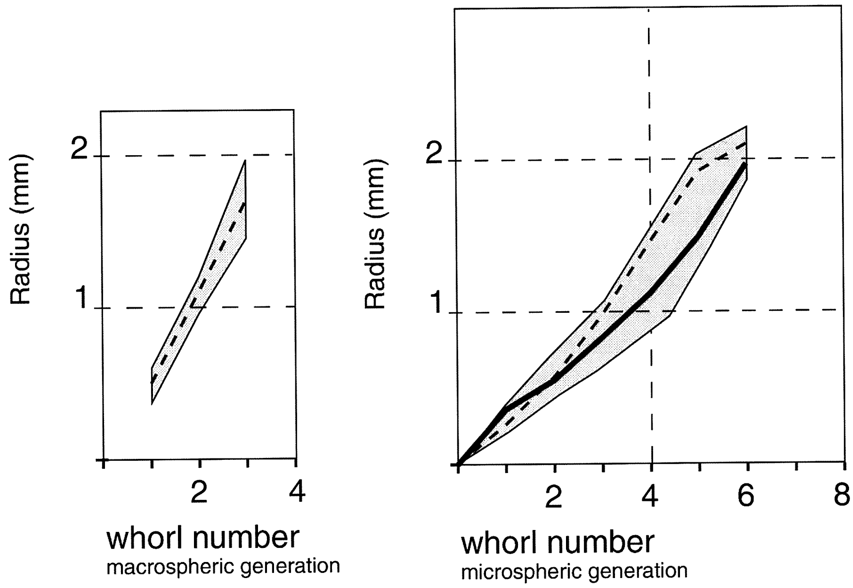


Figure 15. Coiling diagram of *Palaeonummulites songoensis* n. sp.

Type horizon — *Discocyclina* Beds of the Nanggulan Formation (Middle Eocene, uppermost Lutetian or basal Bartonian).

Diagnosis — A small, tightly coiled *Palaeonummulites*, with all whorls involutely coiled. Septa curved with large granules in the centre of the test. Marginal cord thick, 1/3 of the chamber height.

Description — A-form: test lenticular with a flattened periphery, diameter 3-4 mm, thickness 1.5-2.5 mm; D/T 1.5-2.4. Septal filaments slightly curved, radiating. Lateral surface covered by coarse pustules, concentrated in the umbonal region. In equatorial section, spire gradually opening (Figure 15). Septa thin, perpendicular to slightly inclined, straight and bent backwards in their basal part. Chambers 3-4x higher than broad. In axial section, pillars occur mainly over the umbonal region. Proloculus 0.2-0.3 mm in diameter.

B-form: test lenticular, involute throughout, sometimes with an umbonal depression. Diameter 4 to 6 mm, thickness up to 2 mm; D/T = 1.7-3.2 (12 measured specimens). Umbonal region covered by coarse pustules, 90-210 ìm in diameter. The number of granules and the surface area covered by these granules is variable. The granules mainly occupy the centre of the test and are arranged in a spiral in the outer half of the test.

Whorl number	1	2	3
Radius (mm)	0.5	1.1	1.7
Chambers	7	18	26

Table 26. Whorl number, radius and number of chambers per whorl in the A-form of *Palaeonummulites songoensis* n.sp.

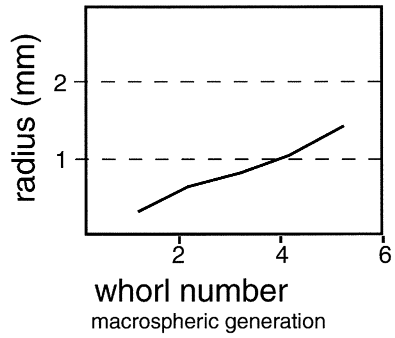
Smoothly curved septal filaments are seen mainly at the outer half of the test (Figure 31E). In equatorial section, the spire opens slowly, occasionally with some irregularities (Figure 15). Septa are thin, straight, and bent backwards in their upper part. Intraseptal canal clearly visible. Chambers 2-3x higher than broad, except in areas showing relatively low whorl height. In axial thin section, densely packed pillars occur over the umbonal region. Marginal cord thick, coarsely canalised.

Remarks — Doornink (1932) first recorded this species as *Camerina pustulosus* Douvillé, 1919.

Whorl number	1	2	3	4	5	6
Radius (mm) holotype	0.36	0.55	0.83	1.12	1.49	1.97
Chambers	8	17	26	31	32	39
Radius (mm) average	0.29	0.58	0.98	1.46	1.92	2.1
Chambers average	7	15	24	30	34	39
Number of measured specimens	5	5	5	5	3	1

Table 27. Whorl number, radius and number of chambers per whorl in the B-form of *Palaeonummulites songoensis* n.sp. The holotype is shown separately, as well as the average.

The European specimens of *N. pustulosus* show a superficial resemblance in external appearance, although the B-form is much larger, as is the proloculus size in the A-form and the chamber shape is much more regular than in *C. pustulosus*. The Javanese specimens show all the characteristics of the genus *Palaeonummulites*, although their marginal cord is more strongly developed and coiling is opener than given in the generic diagnosis by Haynes (1988). It has thin, straight septa with a relatively thick marginal cord. Especially there where the chambers are very high, the septa are bent backwards in their topmost quarter.



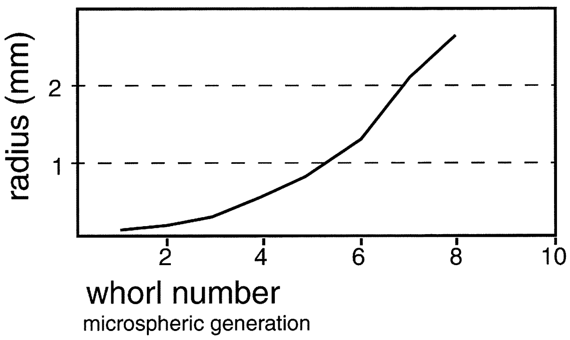


Figure 16. Coiling diagram of *Palaeonummulites* sp.

Geographic distribution — Known only from central Java (Jiwo, Kali Songo ['Kali Semah'] (Doornink, 1932)). Additional specimens have been found in samples from Kali Songo (RGM 20200) and 'Kali Semah' (B 8718, Geologisch Museum Artis).

Stratigraphic range — The few known localities that have been dated as zone P12 (late NP16, Middle Eocene, uppermost Lutetian or lowermost Bartonian) (see Lunt, 2000a; present paper).

Palaeonummulites sp.
Figures 16, 28F, G; Tables 28, 29

1908 *Nummulites guettardi* d'Archiac & Haime, 1853 – Osimo, p. 30.
1908 *Nummulites guettardi* d'Archiac & Haime, 1853 – Provale, p. 82.
1934 *Camerina guettardi* d'Archiac & Haime, 1853 – Henrici, p. 26.
1934 *Camerina* cf. *globula* Leymerie 1846 – Henrici, p. 28.

Material — Ten specimens from Timor, including four equatorial and three axial sections of A-forms and two equatorial sections of B-forms (Institut für Paläontologie, Universität Bonn).

Description — A-form: test lenticular, small with rounded periphery. Diameter up to 4 mm, thickness up to 2 mm; D/T on average 2.1. Polar pillar small with septal filaments radiating straight. In equatorial section, the spire is tight and regularly coiled (Figure 16). Chambers are higher than broad to equidimensional with marginal cord 1/10 of chamber height. Septa perpendicular, curved backwards. In axial section, a weak single polar pillar is present. Proloculus small 0.09-0.18 mm in diameter.
B-form: test lenticular, small with rounded periphery, diameter up to 6 mm, thickness up to 3.5 mm; D/T on average 2.0. Polar pillar small with septal filaments curving radially outwards from the polar area and straightening towards the margin. In equatorial section, spire compact, regular (Figure 16). Chambers higher than broad, with rounded tops. Septa curved backwards, almost perpendicular to marginal cord at base. Marginal cord thin, about 1/10 of chamber height. In axial section, a weakly developed polar pillar is present.

Remarks — This species most closely resembles *Camerina globula* Leymerie, 1846, from which it differs in having more and slightly tighter coiled whorls with fewer chambers in the A-form.

Whorl number	1	2	3	4	5
Radius (mm)	0.3	0.62	0.78	1.02	1.4
Chambers	9	14	21	24	28

Table 28. Whorl number, radius and number of chambers per whorl in the A-form of *Palaeonummulites* sp.

Whorl number	1	2	3	4	5	6	7	8	9
Radius (mm)	0.08	0.16	0.28	0.52	0.90	1.34	2.1	2.65	3.6
Chambers	12	18	24	26	30	34	38		

Table 29. Whorl number, radius and number of chambers per whorl in the B-form of *Palaeonummulites* sp.

The microspheric form is slightly larger and flatter than that of *C. globula*.

Geographic distribution — Indonesia: Timor (Henrici, 1934), Sumba (Caudri, 1934), Java, and Borneo.

Stratigraphic range — In Borneo and Timor, it was found together with *Orbitolites complanatus* Lamarck, 1801. These deposits are interpreted as early Lutetian in age. Suggested stratigraphic range in Indonesia: the older part of the Middle Eocene, Ta_{1-2} (?Ypresian-lower Lutetian).

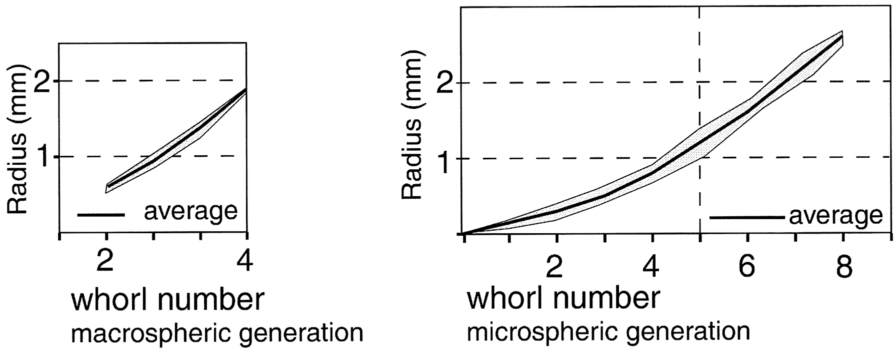


Figure 17. Coiling diagram of *Palaeonummulites taballarensis* (Caudri, 1934).

Palaeonummulites taballarensis (Caudri, 1934)
Figures 17, 31K-M; Tables 30, 31

1929 *Nummlites thalicus* Davies, 1927 - Van der Vlerk, p. 10.
1929 *Nummulites nuttalli* Davies, 1927 – Van der Vlerk, p. 10.
1932 *Nummulites variolarius* Lamarck, 1804 – Doornink, p. 287.
*1934 *Camerina borneensis* Caudri, p. 56.
*1934 *Camerina taballarensis* Caudri, p. 59.

Material — Numerous specimens, including eight equatorial and three axial sections of A-forms, plus four equatorial sections of B-forms from Sungai Taballar (Borneo; RGM 19126-19141).

Description — A-form: test involute, small, diameter 2.2-3.2 mm, thickness 1.5- 2.1 mm; D/T = 1.5. In the centre of the test, a cluster of pillars (usually fewer than 10) forms an umbo, with 24-25 straight septal filaments radiating towards the margin (often becoming slightly curved near the margin). In rare cases, some pillars that are arranged in a spiral over the polar region. Whorls open gradually (Figure 17) and are slightly tighter than in *P. thalicus* Davies, 1927. Thick marginal cord, about 0.3-1x chamber height. Chambers rectangular with rounded top, on average 1.25x higher than broad. Septa straight, thick with a clearly visible intraseptal canal oriented obliquely to the marginal cord. Proloculus 0.35-0.5 mm in diameter.
B-form: test lenticular, involute, last whorl partly evolute. Diameter up to 5 mm, thickness 2.3 mm; D/T = 2. Chamber walls in the last whorl are almost parallel, with a well-developed marginal cord. Large polar pillar and several smaller ones, arranged more or less in a spiral over the centre of the test. Spire opening gradually (Figure 17). Marginal cord about 0.2x chamber height in axial section. Septa straight with an intraseptal canal clearly visible. Chambers are about 1.5-2x higher than broad and have rounded tops.

Whorl number	1	2	3	4
Radius (mm)	0.62	0.97	1.37	1.88
Chambers	9	18	23	

Table 30. Whorl number, radius and number of chambers per whorl in the A-form of *Palaeonummulites taballarensis* (Caudri).

Whorl number	1	2	3	4	5	6	7	8
Radius (mm)	0.15	0.3	0.5	0.8	1.2	1.6	2.1	2.6
Chambers	8	9	13	19	25	33	34	40

Table 31. Whorl number, radius and number of chambers per whorl in the B-form of *Palaeonummulites taballarensis* (Caudri).

Remarks — The A-form differs from *N. nuttalli* in having thicker and straighter septa, higher chambers, tighter coiling and a larger proloculus. The B-form is characterised by its tighter spire, smaller number of chambers per whorl, less elongate chambers and a marginal cord which does not stand out in relief as strongly as is typical in B-forms of *N. nuttalli*.

There is a lot of confusion about the occurrence of this species outside the Indian subcontinent, especially in Indonesia. Van der Vlerk (1929) identified *Nummulites nuttalli* (B-form) and *N. thalicus* (A-form) from eastern Borneo. Davies described the B-form of *N. nuttalli* and the A-form (*N. thalicus*) from India. Later these were considered a species pair and Caudri (1934) used *N. nuttalli* as the type species of the genus *Ranikothalia*.

The A-form of *R. nuttalli*, as presented by Racey (1995), is more closely similar to *Palaeonummulites thalicus*, suggesting that *R. nuttalli* and *P. thalicus* do not belong to the same genus (Racey, 1995). The same pairing was also reported to occur in samples from eastern Borneo by Van der Vlerk (1929).

Caudri (1934) restudied Van der Vlerk's samples from Borneo and concluded that the B-forms were different from *R. nuttalli* in being smaller and more tightly coiled and described these as *Camerina borneensis*. Adams (1970) restudied paratypes of *R. nuttalli* (from India) and concluded that these are different from those found in Indonesia, and subscribed to Caudri's (1934) view.

After comparing the figured specimens of Van der Vlerk and additional material of *Ranikothalia* B-forms in Davies (1927), Caudri (1934) and Racey (1995), and after having studied topotypes of *C. borneensis*, we conclude that the B-form illustrated by Van der Vlerk is not *Ranikothalia nuttalli* and should be reassigned to *Palaeonummulites*.

Caudri (1934) reassigned the A-form from Borneo (*N. thalicus*, *sensu* Van der Vlerk) to *Camerina taballarensis*, whilst Adams (1970) agreed with the original identification of *N. thalicus* by Van der Vlerk. Racey (1995) re-examined the records of *R. nuttalli* and considered the A-forms of *C. borneensis* (including *C. taballarensis*) to be synonymous with *R. nuttalli*. However, because of the larger proloculus and tighter coiling of the Indonesian specimens, we do not agree that *C. taballarensis* (the A-form accompanying *C. borneensis*) is the same as *P. thalicus*. Thus, we conclude that both microspheric and macrospheric specimens should be assigned to a species other than *P. thalicus*. Although Caudri (1934) described *C. borneensis* first, it is more appropriate to use the name *P. taballarensis*, published in the same paper, but some pages further on, since most of the species are macrospheric forms and the microspheric forms are extremely rare. From the above it is clear that the only illustrated and documented record of *Ranikothalia* from the Indonesian region is erroneous and that these specimens should be reassigned to *Palaeonummulites*.

In the type sample from Sungai Taballar, one specimen (an axial section) has been found that has a much smaller proloculus and more pronounced pustules extending over a larger part of the test. It resembles *P. cuvillieri* Sander, 1962 from Oman (Racey, 1995), a species that is abundant in India in strata of similar age (Saraswati *et al.*, 2000). Since it is just a single specimen, and we have not been able to find additional material to obtain equatorial sections, we do not formally record *P. cuvillieri* from Indonesia here.

Geographic distribution — Known only from Borneo (Sungai Taballar; Van der Vlerk, 1929) and Sumba (Caudri, 1934). The fact that the only previously published records of *Ranikothalia* from the Indonesian region now prove reassignable to a different genus (*i.e.*, *Palaeonummulites*) has important palaeobiogeographic implications in that it lends support to the idea that the genus *Ranikothalia* is restricted to the Indian subcontinent and to the Middle East (see also Racey, 1995; Haynes *et al.*, in press).

Stratigraphic range — In Borneo, this species co-occurs with *P. beaumonti* and *P. variolarius*, indicating a middle to late Lutetian age. The stratigraphic range in Indonesia is interpreted to be Lutetian.

Palaeonummulites variolarius (Lamarck, 1804)
Figures 18, 29E-H; Tables 32, 33

*1804 *Lenticulites variolaria* Lamarck, p. 187.
1829 *Nummularia variolaria* (Lamarck, 1804) – J. de C. Sowerby, p. 76.
1840 *Nummulina variolaria* Lamarck, 1804 – Sowerby, p. 533
*1891 *Nummulites bagelensis* var. Ib, IIc and IId Verbeek, p. 67.
1896 *Nummulites bagelensis* var. Ib, IIc and IId Verbeek, 1891 – Verbeek & Fennem, p. 1101.
1905 *Nummulites variolarius* Sowerby, 1829 – Deprat, p. 495.
1912b *Camerina variolaria* (Sowerby, 1829) – Douvillé, p. 256.
1929 *Nummulites bagelensis* Verbeek, 1891 – Van der Vlerk, p. 18.
1929 *Nummulites variolarius* Sowerby, 1829 – Van der Vlerk, p. 21.
*1932 *Camerina semiglobula* Doornink, p. 292.
1932 *Camerina mamilla* Fichtel and Moll, 1798 – Doornink, p. 290.
1934 *Camerina bagelensis* Verbeek – Henrici, p. 25.
1934 *Camerina variolaria* Sowerby – Henrici, p. 27.
non 1932 *Nummulites variolarius* (Lamarck, 1804) – Doornink, p. 287 (= *P. taballarensis*).

Material — > 40 specimens, including ten equatorial and five axial sections of both A- and B-forms from Nanggulan (central Java; RGM 20129); > 40 specimens, including ten equatorial and five axial sections of both A- and B-forms from Ralla (Sulawesi; RGM 20130); twenty specimens including five equatorial sections of A-forms and ten equatorial sections of B-forms from Sungai Seilor and Taballar (RGM 19076-19105).

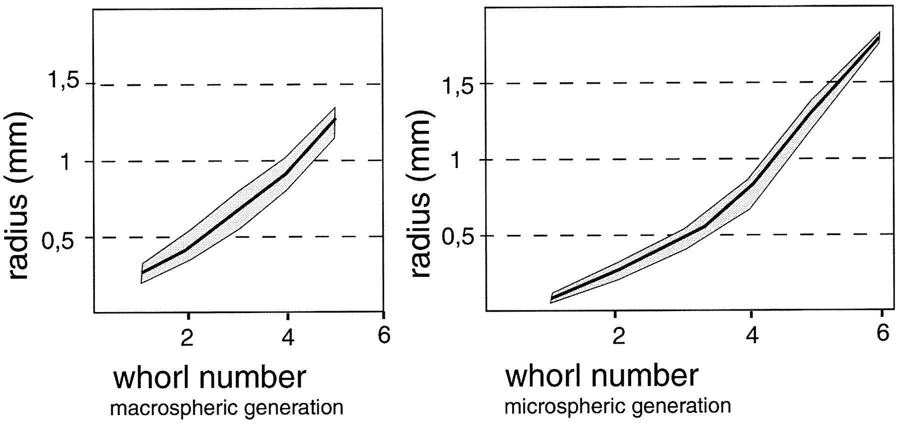


Figure 18. Coiling diagram of *Palaeonummulites variolarius* (Lamarck, 1804).

Description — A-form: small, biconical test up to 2.5 mm in diameter and up to 1.7 mm thick; D/T = average of 1.6. Septal filaments straight to S-shaped, radiating from a polar pillar occasionally developing secondary filaments. In equatorial section, tightly coiled, comprising up to five whorls that open very regularly (Figure 18). Chambers as high as broad or slightly higher than broad. Septa perpendicular to marginal cord, strongly curving backwards in their distal part. Marginal cord about 1/5 or less of the chamber height. In axial section, a clear umbilical pillar is present. Proloculus very small, 0.05-0.15 mm in diameter.

Whorl number	1	2	3	4	5
Radius (mm)	0.2	0.43	0.72	0.95	1.25
Chambers	7	11	13	16	20

Table 32. Whorl number, radius and number of chambers per whorl in the A-form of *Palaeonummulites variolarius* (Lamarck).

B-form: similar to the A-form, although slightly larger, up to 4 mm in diameter and up to 2.5 mm thick; D/T = 2.1 on average. Septal filaments straight to S-shaped with polar pillar. In equatorial section, comprising up to six whorls, that open gradually (Figure 18). Marginal cord quite thick, irregular. Septa oblique and curved in their distal part. Chambers in the first whorls higher than broad, isometric in the last whorls. Marginal cord 1/6 of the chamber height. In axial section, the polar pillar is more pronounced than in the A-form.

Whorl number	1	2	3	4	5	6
Radius (mm)	0.1	0.30	0.45	0.75	1.2	1.8
Chambers	8	12	14	18	26	30

Table 33. Whorl number, radius and number of chambers per whorl in the B-form of *Palaeonummulites variolarius* (Lamarck)

Remarks — This species may be confused with *P. globulus* (Leymerie, 1846), which Blondeau (1972) suggested was the precursor of *P. variolarius*. Both A- and B-forms of the present species are smaller than those of *P. globulus* and in axial section the polar pillar is less pronounced in the former. Furthermore, the A-form of *P. variolarius* is more tightly coiled and has fewer chambers in each whorl than *P. globulus*. The B-form of *P. globulus* has more whorls and is much larger than the B-form of *P. variolarius*.

The taxonomic status of the present species is unclear; it was first described by Lamarck (1804) without an accompanying illustration or type locality, who placed it in the genus *Lenticulites*, although he had erected the genus *Nummulites* just three years earlier (Lamarck, 1801). J. de C. Sowerby (1829), who referred in his record to Lamarck's description (1804), was the first to illustrate *P. variolarius*. Blondeau (1972) mentioned *P. variolarius* from a wide range of localities, including England, the Paris and Aquitaine basins (France), North Africa, the former Soviet Union and New Caledonia.

Specimens of *N. bagelensis* Ib, IIc and IId (*sensu* Verbeek) in the NNM collections all belong to the present species, as do specimens identified as *N. bagelensis* from Borneo by Van der Vlerk (1929).

Geographic distribution — Indonesia: widely distributed throughout Indonesia (Java, Borneo, Timor, Sulawesi, Nias, and Sumba). Elsewhere: only rarely included in studies dealing with Nummulitidae (see above). Blondeau (1972) recorded it from England, France, Belgium, the former Soviet Union, Egypt, Somalia, Mozambique and New Caledonia.

Stratigraphic range — The oldest occurrences are associated with *N. djokdjokartae*, or P12, whilst the youngest record in Java is from the *Discocyclina* Beds in the Nanggulan section, dated as upper Middle Eocene (P12, late NP16, lowermost Bartonian; see Lunt, 2000a, b). In Sulawesi (Ralla), it is found in P15-P17 sediments, and

in Timor in P16 sediments. Blondeau (1972) suggested a range from the Lutetian to Bartonian. The stratigraphic range in Indonesia is estimated to be Middle to Upper Eocene (Ta_3-Tb; middle Lutetian-Priabonian).
Genus *Planocamerinoides* Cole, 1957

Type species — *Nummularia exponens* J. de C. Sowerby *in* Stykes, 1840 by original designation

Diagnosis — Test planispiral, compressed, often with an inflated polar region and a marked central depression; spire tightly and uniformly coiled, many whorls, quasi-evolute, *i.e.* alar prolongations pinched off, although spiral sheet extends towards the poles; opening rate less than 1.5d; chambers regular more than 1.5x higher than broad, marginal cord finely developed and generally <1/4 chamber height. In axial cross-section, chambers are triangular, often increasing in height towards the periphery. A pronounced difference in diameter between the B-form and the A-form generation is usually noted in larger Eocene species.

Stratigraphic range — Upper Paleocene to Middle Eocene, common.

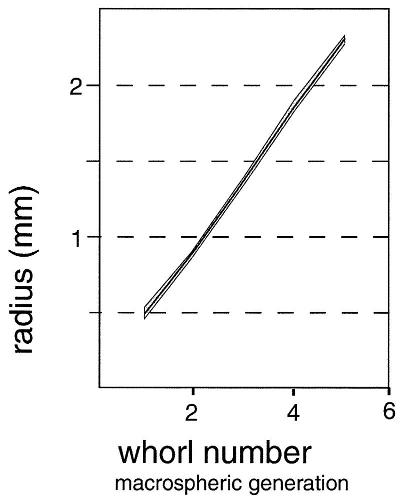


Figure 19. Coiling diagram of *Planocamerinoides orientalis* (Douvillé, 1912b).

Discussion — *Assilina* d'Orbigny, 1826 (type species: *Assilina depressa* d'Orbigny, 1850 differs from *Planocamerinoides* in having a completely evolute, flat to flatly lenticular test, often with a central depression, a more rapidly opening spire (approximately 2d) spire and a thicker marginal cord.

The taxa described below have traditionally been assigned to *Assilina*, which was broadly subdivided by Schaub (1981) into two main groups, the *A. exponens* and *A. spira* de Roissy, 1805 groups. All forms from Indonesia described below have been reassigned to *Planocamerinoides* as defined above, following Haynes (1988) and Haynes *et al.* (in press). *Planocamerinoides* broadly encompasses most of the species previously assigned by Schaub (1981) to the *Assilina exponens* group, whilst *Assilina* is used mainly for species previously assigned to the *Assilina spira* group by that author.

Planocamerinoides is a rare genus in Indonesia, confined to a limited number of localities, and usually occurring in indurated solid carbonates, making it difficult to isolate and describe specimens. One of the species discussed herein, *P. umbilicata*, is included despite the fact that we have not seen specimens. However, its unique morphology warrants recognition and inclusion here.

Another species that, if proved valid, should be referred to as *P. discoidea* (Caudri, 1934) is not included because of its current uncertain status. Specimens similar in appearance to *P. discoidea*, described by Caudri from Sumba, have also been found in Borneo (as *Assilina granulosa* d'Archiac var. *minor* Heim 1908; Yabe, 1921) and at Kali Worowari (Java). It is a small, macrospheric *Planocamerinoides* without umbonal depression, but with parallel sides. It co-occurs with *Palaeonummulites* sp. and should probably be assigned to *Operculina* rather than to *Planocamerinoides*.

Planocamerinoides orientalis (Douvillé, 1912b)
Figures 19, 30F; Table 34

*1912b *Assilina orientalis* Douvillé, p. 263.
1921 *Assilina orientalis* Douvillé, 1912 – Yabe, p. 105.
1934 *Assilina orientalis* Douvillé, 1912 – Caudri, p. 83.

Material — A single axial section of an A-form from Nias (**holotype**) and several oblique sections from the same locality (RGM 11879).

Description — A-form: test inflated lenticular with a sharp edge, diameter 5-5.8 mm, thickness 1.5-2.2 mm; D/T = 1.5-2.5. Some specimens show a poorly developed granulated umbo (*e.g.*, Caudri, 1934, pl. 2, fig. 1). The lateral surface of the test generally is smooth, while radiate, slightly curved septa are visible as septal ridges. In equatorial section (see Doornink, 1932, figs f, 17, 18) spire tight, opening very gradually. Chambers equidimensional, septa perpendicular, slightly recurved towards their tops. Marginal cord 1/4 of chamber height. In axial section, a very thick spiral sheet extends towards the poles and coarse pillars occur in the central part of the test which reach the lateral surface of the test. In axial section, chambers have a strongly tapering, arrowhead shape. Proloculus 0.15-0.25 mm in diameter.

B-form: not found.

Remarks — Easily recognised in axial section on account of the very robust appearance with thick spiral sheet and coarse pillars in the polar region.

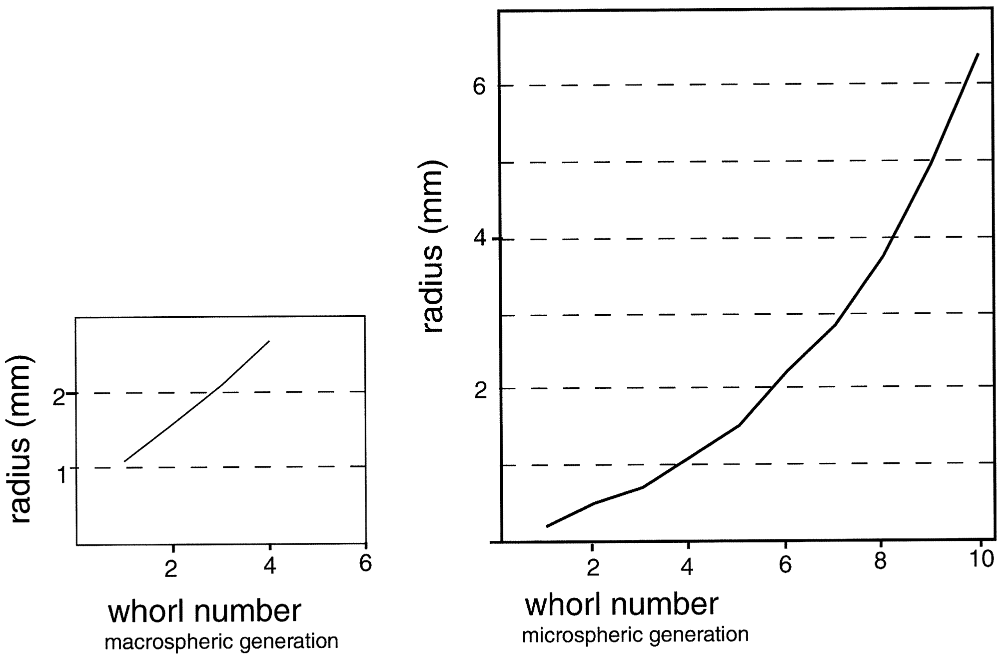


Figure 20. Coiling diagram of *Planocamerinoides* sp.

The Indonesian specimens are larger than *P. sublaminosa* (Gill, 1953), from the Lower Eocene of Pakistan (Gill, 1953; Akhtar & Butt, 1999), which reaches only 2-3.6 mm in diameter and are otherwise similar. *Planocamerinoides sublaminosa* may be the precursor of *P. orientalis*.

Whorl	1	2	3	4	5
Radius (mm)	0.5	0.9	1.4	1.9	2.3
Chambers	9	21	24	?	?

Table 34. Whorl number, radius and number of chambers per whorl in the A-form of *Planocamerinoides orientalis* (Douvillé).

Geographic distribution — Indonesia: Borneo, Java, Nias and Sumba. Elsewhere: NW Pakistan (Gill, 1953).

Stratigraphic range — Co-occurring with *P. beaumonti* in Nias (Douvillé, 1912b), with *Alveolina ovicula* and *P. beaumonti* in Sumba (Caudri, 1934); with *P. taballarensis* and *Discocyclina javana* (Verbeek, 1891) (small form) in Sumba (Caudri, 1934), and with *P. pengaronensis* in Borneo (Yabe, 1921). The suggested range for this species based on the associated microfauna in Indonesia is Ta (Middle Eocene, middle to upper Lutetian to possibly basal Bartonian).

Planocamerinoides sp.
Figures 20, 30G-K; Tables 35, 36

1896 *Assilina spira* de Roissy, 1805 – Verbeek & Fennema, p. 1102.
1896 *Nummulites (Assilina) leymeriei* d'Archiac & Haime, 1853 – Verbeek & Fennema, p. 1103.
1912b *Assilina granulosa* d'Archiac, 1847 – Douvillé, p. 263.
cf. 1921 *Assilina granulosa* d'Archiac var. *minor* Heim – Yabe, p. 105.
1932 *Assilina granulosa* d'Archiac – Doornink, p. 301.
1932 *Assilina spira* de Roissy – Doornink, p. 303.
1934 *Assilina* spec. *granulosa-exponens (partim)* – Caudri, p. 34.

Material — Five specimens from Jiwo, including two equatorial sections of B-forms and one of an A-form (RGM 20214).

Description — Of this rare species, the A-form has a test lenticular to flattened lenticular with a subrounded periphery, diameter 5-7 mm, thickness 1.5-2 mm; D/T = 3.2-4.0. Granules in central part of the test, which is occasionally slightly depressed. Septal ridges are visible in relief in the outer part of the test. In equatorial section, comprising up to 4.5 whorls of similar height. Chambers regularly spaced, of similar length in all whorls, slightly higher than broad. Marginal cord 1/3-1/4 of chamber height. In axial section, quasi-evolute with the alar prolongations pinched off by the spiral sheet which extends towards the poles in all whorls. Lateral sides of test parallel, without a polar depression. Proloculus 0.3-0.55 mm in diameter.

Whorl number	1	2	3	4
Radius (mm)	1.1	1.6	2.1	2.7
Chamber	11	20	24	32

Table 35. Whorl number, radius and number of chambers per whorl in the A-form of *Planocamerinoides* sp.

B-form: test flat with a sharp periphery, with spire and septa visible as ridges on the test surface. Test diameter up to 20 mm, thickness 1.5-2.5 mm; D/T = 4.8-5.2. Polar region finely pillared. In equatorial section, the spire opens regularly, and has rectangular chambers which are 1.5-2x higher than broad. Septa straight, perpendicular to slightly inclined, arcuate in the outermost part. Marginal cord 1/4 of chamber height. In axial section, the spiral sheet extends towards the poles, whilst the alar prolongations are pinched off. Lateral surface of the test parallel, without a polar depression.

Remarks — First reported by Verbeek & Fennema (1896) as *N. (Assilina) leymeriei* (A-form), which was assigned to *Assilina granulosa* by Doornink (1932). Schaub (1981) discussed the synonymy of *Assilina laxispira* De la Harpe, 1926, which included *Assilina granulosa*. However, *A. laxispira* is fully evolute and the spiral sheet is pinched off on the previous whorl. In the Indonesian specimens labelled *N. (A.) granulosa* and figured by Verbeek & Fennema (1896, fig. 93), the spiral sheet is not pinched off and clearly reaches towards the poles. The Indonesian specimens should therefore be reassigned to *Planocamerinoides* .

Illustrations and descriptions in Verbeek & Fennema (1896) represent the only data available on the microspheric generation of this species in Indonesia.

Whorl number	1	2	3	4	5	6	7	8	9	10
Radius (mm)	0.2	0.5	0.7	1.1	1.5	2.2	2.8	3.7	4.9	6.3

Table 36. Whorl number, radius and number of chambers per whorl in the B-form of *Planocamerinoides* sp.

In both figures and description, it is clear that this species, originally recorded as *Assilina spira*, should be reassigned to *Planocamerinoides*. *Assilina spira* has no extending spiral laminae and is fully evolute, thus the Indonesian specimens should be reassigned to another species. All measurements and figures resemble *Pl. exponens*, although the size is in the lower part of the range given by Racey (1995). Schaub (1981) suggested that *Pl. exponens* is replaced by *Pl. cancellata* Nuttall, 1926 in the eastern Tethys. However, *Pl. cancellata* is even larger than *Pl. exponens* and more tightly coiled (Racey, 1995). The Indonesian specimens are rather small and have a slightly looser spire than *Pl. exponens*. Some of the specimens shown by Caudri (1934) match this species, for example her figs 6 and 7. At all localities the A- and B-forms co-occur and are therefore inferred to represent a microspheric-megalospheric pair.

Geographic distribution — Indonesia: Java, Borneo, Nias and Sumba.

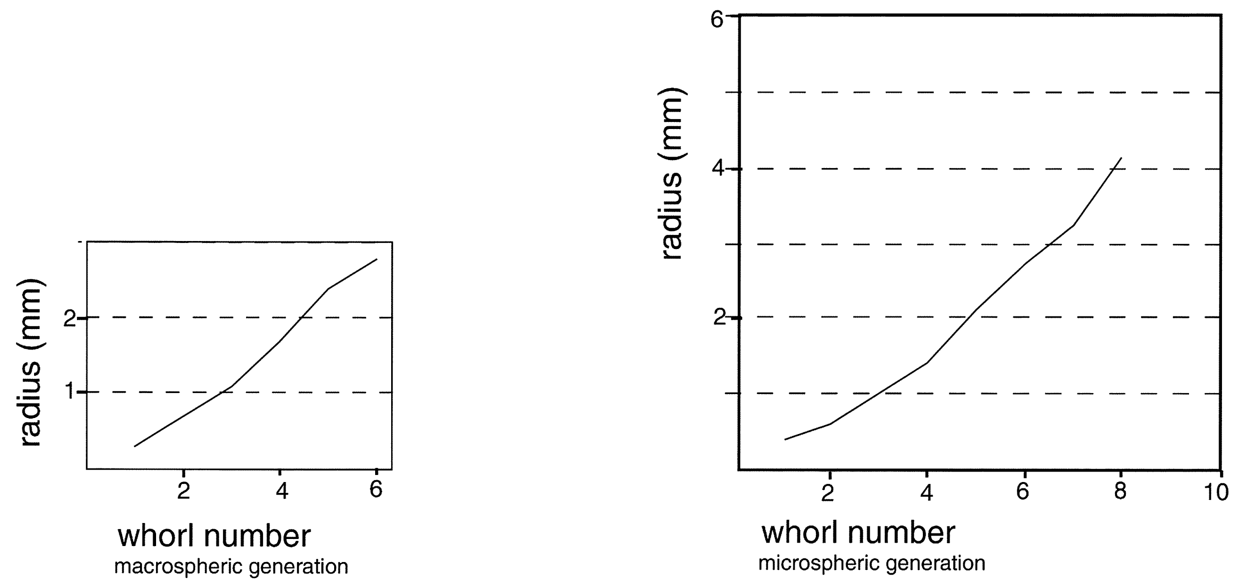


Figure 21. Coiling diagram of *Planocamerinoides umbilicata* (Rutten *in* Waterschoot van der Gracht, 1915).

Stratigraphic range — Co-occurring with *Nummulites javanus* at some Middle Eocene localities in eastern and central Java correlating with the upper Lutetian or lower Bartonian.

Planocamerinoides umbilicata (Rutten *in* Waterschoot van der Gracht, 1915)
Figures 21, 30L-P; Tables 37, 38

*1915 *Nummulites (Assilina) umbilicata* Rutten *in* Waterschoot van der Gracht, p. 60.
1934 *Assilina* spec. *granulosa-exponens* type (*partim*) – Caudri, p. 34.
non*1938 *Assilina umbilicata* de Cizancourt, p. 23.

Whorl	1	2	3	4	5	6
Radius (mm)	0.3	0.7	1.1	1.7	2.4	2.8

Table 37. Whorl number, radius and number of chambers per whorl in the A-form of *Planocamerinoides umbillicata* (Rutten *in* Waterschoot van der Gracht).

Material — For the present study, no specimens were available; consequently the description below is based on the drawings provided by Rutten (*in* Waterschoot van der Gracht, 1915), who on p. 60 of that paper gave an equatorial and an axial section of a microspheric form and an axial section of a macrospheric form, which are here reproduced in Figure 30M-P.

Description — A-form: not mentioned in the type description, apart from the remark that sometimes the first chamber is rather large. However, a figure of an A-form was provided by Rutten (*in* Waterschoot van der Gracht, 1915, p. 60, fig. 36), on which the following description is based.

Test lenticular with a polar depression and sharp periphery, diameter cannot be measured, thickness 2.1 mm; D/T unknown. The spire consists of six fairly tightly coiled whorls. In axial section, the spiral sheet extends over the previous whorl, although after the third whorl, the spiral sheet does not reach the central part of the test. Proloculus 0.25 mm in diameter.
B-form: test lenticular to flattened lenticular, with a distinct polar depression and sharp periphery, diameter up to 11 mm, thickness up to 2.5 mm; D/T = 4.4. Granulated in centre, with granules aligned along straight, radiating (septal) ridges in the peripheral part of the test. In equatorial section, very uniformly coiled, with chambers 2x broader than high to equidimensional. Septa straight, perpendicular. Up to 9 whorls in figured specimens and 11 whorls in the written description.

Remarks — Apart from the description by Rutten (*in* Waterschoot van der Gracht, 1915), little is known about this species.

Whorl	1	2	3	4	5	6	7	8
Radius (mm)	0.4	0.6	1	1.4	2.1	2.7	3.2	4.1
Chambers	8	17	22	24	31	34	37	38

Table 38. Whorl number, radius and number of chambers per whorl in the B-form of *Planocamerinoides umbillicata* (Rutten *in* Waterschoot van der Gracht).

The clear umbilical plug is not seen in any other Indonesian species of *Planocamerinoides* and it might well be a distinct species. Some of the specimens described by Caudri (1934) match the description of this species, although she did not provide any illustrations against which this can be confirmed. Caudri (1934) discussed the taxonomy of Indonesian assilinids, and concluded that the specimens from Java and Sumba probably comprised a group of closely similar species. The main characters she used were: test shape in axial section, chamber shape and, number of chambers in each whorl. Her main conclusion was that none of the specimens studied could be matched with *Pl. exponens* or *A. granulosa* (= *A. laxispira*) and that these species could not therefore be identified in the Indonesian specimens, a conclusion supported by the present study.

In 1938, de Cizancourt described the A- and B-form pair *Assilina umbilicata-A. subumbilicata* from the Lower Eocene of Afghanistan. As Schaub (1981) discussed, Rutten's species name has priority and the species described by de Cizancourt (1938) should be called *Pl. subumbilicata* (de Cizancourt, 1938). It has many features in common with *Pl. umbilicata*, is notably smaller with a maximum diameter of about 5.5 mm in the microspheric generation.

Planocamerinoides umbilicata falls within the group of *Pl. reicheli* as described by Schaub (1981, pp. 215-218), which is characterised by a spiral sheet which extends over the previous whorl, but does not reach the centre of the test. None of the species in this group figured by Schaub (1981) show such a clear umbilical depression as seen in *Pl. umbilicata*. This very characteristic test shape and coiling mode is the main reason why we regard this species to be valid, without having seen any new specimens.
Geographic distribution — Indonesia: Sulawesi and probably Sumba.

Stratigraphic range — In Sulawesi, this species co-occurs with *P. variolarius*, whilst in Sumba it was found in association with *P. beaumonti* and *Pl. orientalis* (see Caudri, 1934), suggesting a Middle Eocene age (Ta_3, late Lutetian).

Stratigraphy

The occurrence of a certain species is not always related to its stratigraphic range, but due to facies control. Although contemporaneous, it is remarkable that *N. djokdjokartae* and *N. javanus* have never been found to co-occur in any given sample. A range chart for taxa discussed in the present study is shown in Figure 22 and has been composed from the co-occurrence of species in the various sections as shown in Figures 4 and 5. Independent age determination of some localities using calcareous nannoplankton, planktonic foraminifera, dinoflagellates and, in the Oligocene, stable strontium isotopes, have been used in this age calibration. The species limits in Figure 22 reflect current knowledge and are likely to change as more data become available. As with the occurrence of studied sequences (Figure 5), the boundaries are chosen to coincide with the boundaries of the letter stages, as units of faunal stability. The interval of greatest uncertainty is the Ypresian to lower Lutetian, due mainly to a lack of sequences containing larger foraminifera. However, modern geological models (compare Netherwood, 2000) suggest most sedimentary basins in southeast Asia did not come into existence until the middle Middle Eocene (middle Lutetian), which means that lower Lutetian and older sections may not be present, or rare, and would be overlain by a major unconformity. In eastern Indonesia/Papua New Guinea where there are older Eocene and Paleocene sedimentary rocks, but they are invariably in deep marine facies and tend to lack larger foraminifera.

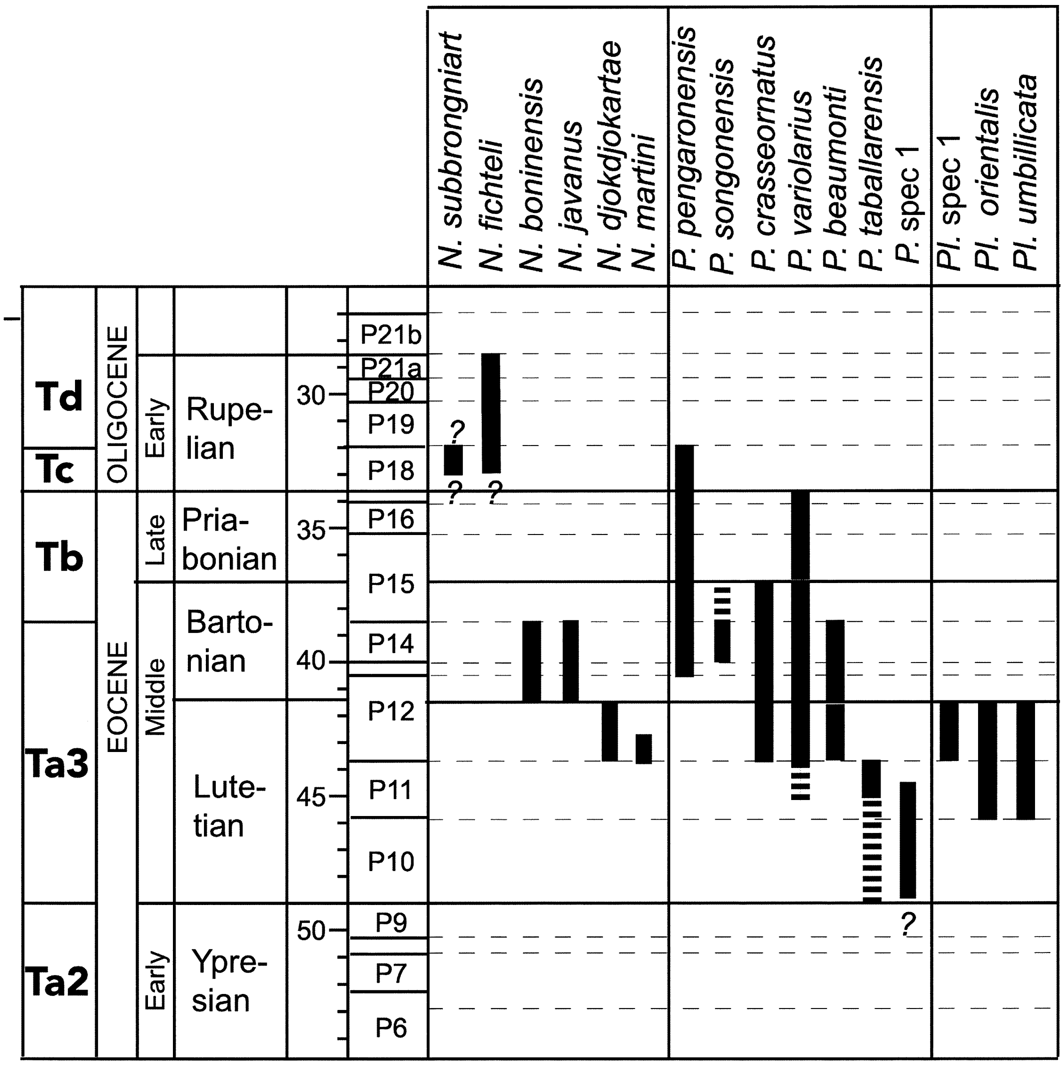


Figure 22. Stratigraphic ranges of the species of the genera *Nummulites*, *Palaeonummulites* and *Planocamerinoides* in Indonesia.

Conclusions

1 - Having reviewed available records of *Nummulites*, *Assilina* and *Ranikothalia* from the Indonesian Archipelago, including the sampling and analysis of several additional localities, it is concluded that six species of *Nummulites*, seven of *Palaeonummulites* and three of *Planocamerinoides* are valid. These are redescribed here and illustrated, many for the first time;

2 - Many of the taxa described and illustrated herein have

their age ranges significantly refined through the integration of new data from associated planktonic foraminifera, calcareous nannofossils, dinoflagellates and Sr isotopes (Oligocene only). These data have been integrated to produce a revised zonation which is shown in Figure 22;

3 - Far fewer Paleogene nummulitids are known from the Indonesian Archipelago than from the western Tethys. Moreover, unlike the western Tethyan region, there are no verifiable records of nummulitids older than Middle Eocene in the Indonesian Archipelago. Published records of *Nummulites*, *Assilina* and *Ranikothalia* suggested that 70+ species might be present. After reviewing the records, we conclude that only sixteen of these are valid and we have tabulated the various reinterpretations of the 'original' 70 taxa by geographic area in Tables 1-8;

4 - Indonesian *Nummulites* and *Palaeonummulites* show a more limited range of morphological variation than their coeval forms from the western Tethys. For example, the maximum size of the Middle Eocene Indonesian forms is about 45 mm, whilst in the western Tethys some species attain test diameters of up to 120 mm (Schaub, 1981). Tripartition of the spire and reversals in the direction of coiling, features which are relatively common in western Tethyan Middle Eocene species, have not been observed in the material studied. Intercalatory whorls (common in Middle Eocene Tethyan species) were only rarely observed in Indonesian material, being noted in *N. djokdjokartae*, *N. martini* n. sp. and *N. boninensis*. Likewise, the species of *Planocamerinoides* recorded from the region show far lower diversity and morphological variation than their western Tethyan counterparts;

5 - Several species previously described as *Nummulites* are reassigned to *Palaeonummulites*. These include *N. beaumonti*, *N. crasseornatus*, *N. pengaronensis* and *N. variolarius*. *Palaeonummulites taballarensis* was previously assigned to *Ranikothalia*, whilst one new species of *Palaeonummulites* is described. The first record of *Nummulites* s. str. in Indonesia is in the middle Middle Eocene, equivalent to the middle Lutetian Stage;

6 - All Indonesian species previously assigned to *Assilina*, for which material and/or illustrations were available, are reassigned to *Planocamerinoides*. It is tentatively concluded that *Assilina* s. str., as defined in Haynes *et al.* (in press) is not present in the Indonesian Archipelago and is therefore restricted to the Mediterranean, Middle East and Indian subcontinent. This may reflect absence of strata of pre-middle Middle Eocene age in the region, as mentioned above;

7 - records of *Ranikothalia*, especially of the species '*nuttalli*' from the Indonesian Archipelago are considered suspect and it is suggested that the genus is not in fact present in the region; previous records are reassigned to *Palaeonummulites*. *Ranikothalia* is considered to be restricted to the Indian subcontinent and the Middle East (see Haynes *et al.*, in press), for stratigraphic rather than palaeogeographic reasons.

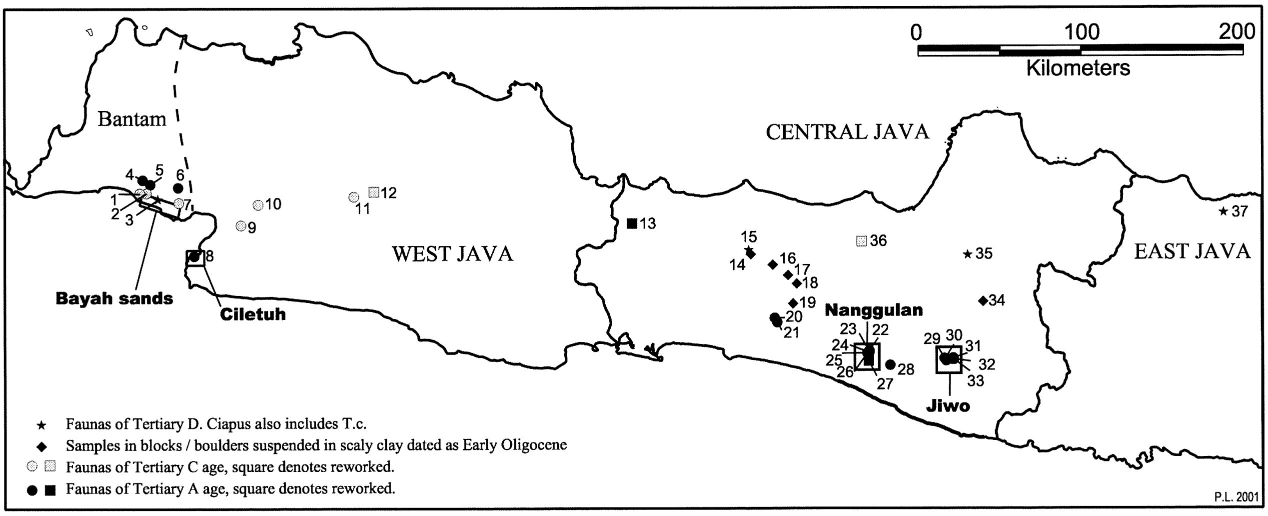


Figure 23. Localities of nummulitid-bearing strata in Java; numbers are explained in Appendix 1.

Acknowledgements

Ulrike Wielandt-Schuster (Landesamt für Geologie, Rohstoffe und Bergbau Baden-Württemberg, Freiburg) and Brian Rosen (The Natural History Museum, London) commented on and markedly improved earlier versions of this paper. Martin Langer (Paläontologisches Institut der Universität Bonn) allowed one of us (WR) to study the Wanner Collection, including the original specimens of Henrici, at the Institut für Paläontologie, Universität Bonn, where pictures were taken by Georg Oleschinski. Maaike van Tooren is thanked for allowing access to the Timor collection at the Geologisch Museum (Technische Universiteit Delft), while Jan Werner (Geologisch Museum, Artis) allowed us to study the Doornink specimens housed there. Hubert Vonhof (Vrije Universiteit, Amsterdam) assisted in interpretation of the Sr isotopes values.

AR thanks the BG Group for permission to publish, whilst Dr J.E. Whittaker and R.L. Hodgkinson (both The Natural History Museum, London) are thanked for providing both thin sections and data on Van der Vlerk's material from Tabellar. Dr D. Bayliss is thanked for his comments on this paper. PL is grateful to Coparex Banjumas for permission to publish.

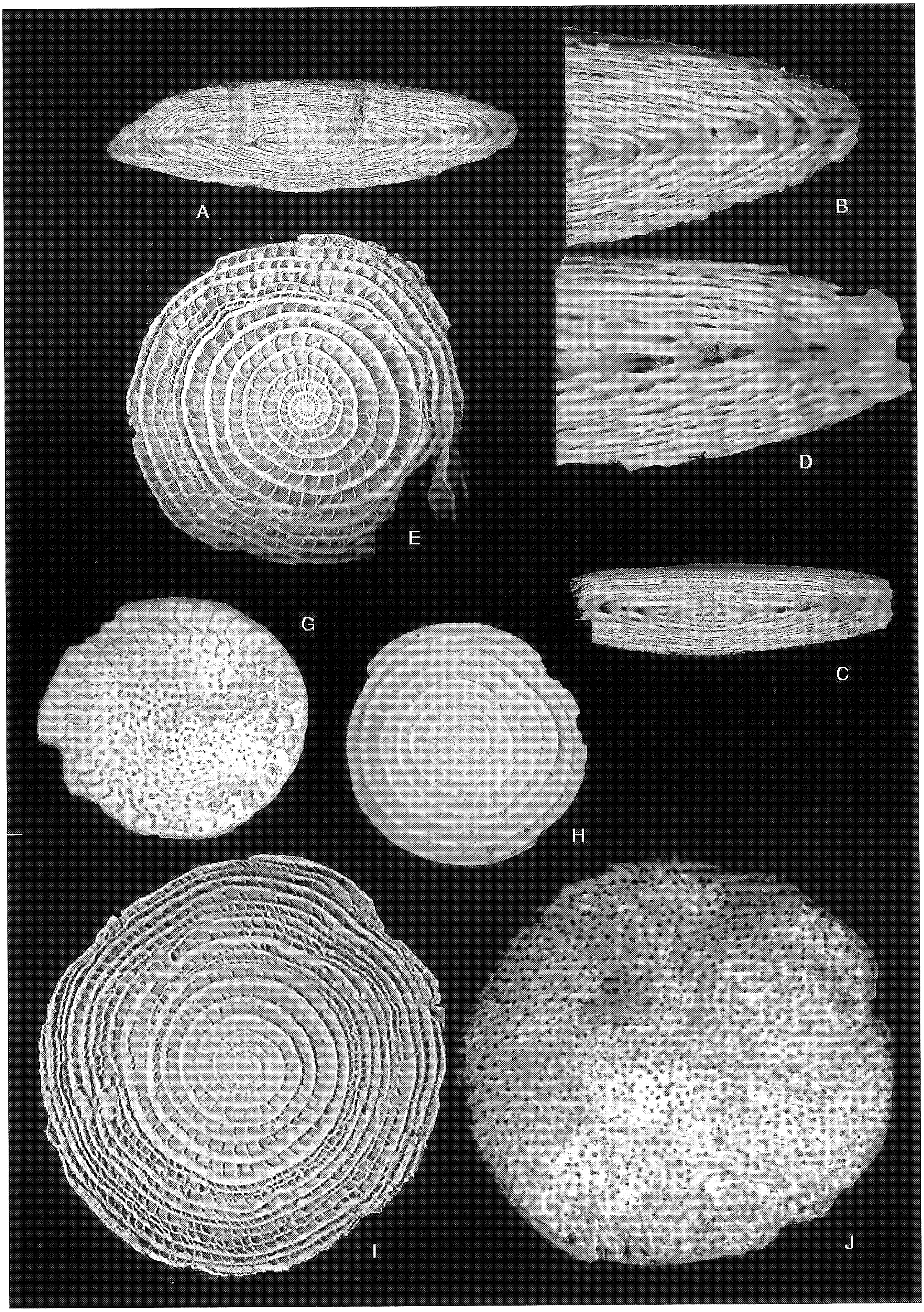

A
B
E
D
G
C
H
I
J

Figure 24A, B, G-J. *Nummulites djokdjokartae* (Martin, 1881); A, B - axial section of B-form, Kali Puru (Nanggulan) (RGM 47196A) (A x 5; B x 10); note the abundant splitting of the spiral laminae very near to the equatorial plane; G - external view of juvenile B-form, Kali Puru (Nanggulan) (RGM 3334B) (x 5); note straight peripheral part of the septal filaments; this specimen was labelled *N. vredenburgi* by Douvillé (1912a); H - equatorial section of juvenile B-form, Kali Puru (Nanggulan) (RGM 3334A) (x 5); this specimen was labelled *N. vredenburgi* by Douvillé (1912a); I - equatorial section of B-form, Kali Puru (Nanggulan) (RGM 3320C) (x 5) ; J - external view of B-form, Kali Puru (Nanggulan) (RGM 47196B) (x 5).

C-E. *Nummulites martini* n. sp.; C, D - axial section of B-form, Kali Puru (Nanggulan) (RGM 3322A) (C x 5; D x 10); note the rare splitting of the spiral laminae; if split, it is more in the polar region than in *N. djokdjokartae*; E - equatorial section of B-form, Kali Puru (Nanggulan) (RGM 3322B) (x 5).

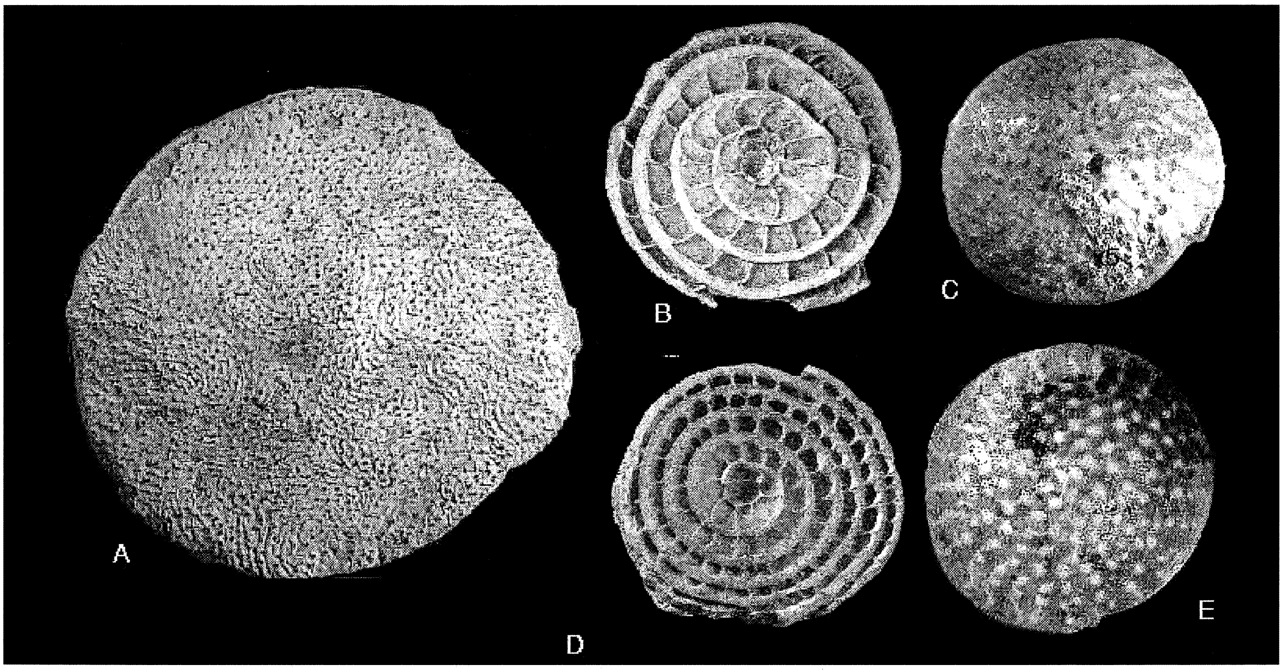
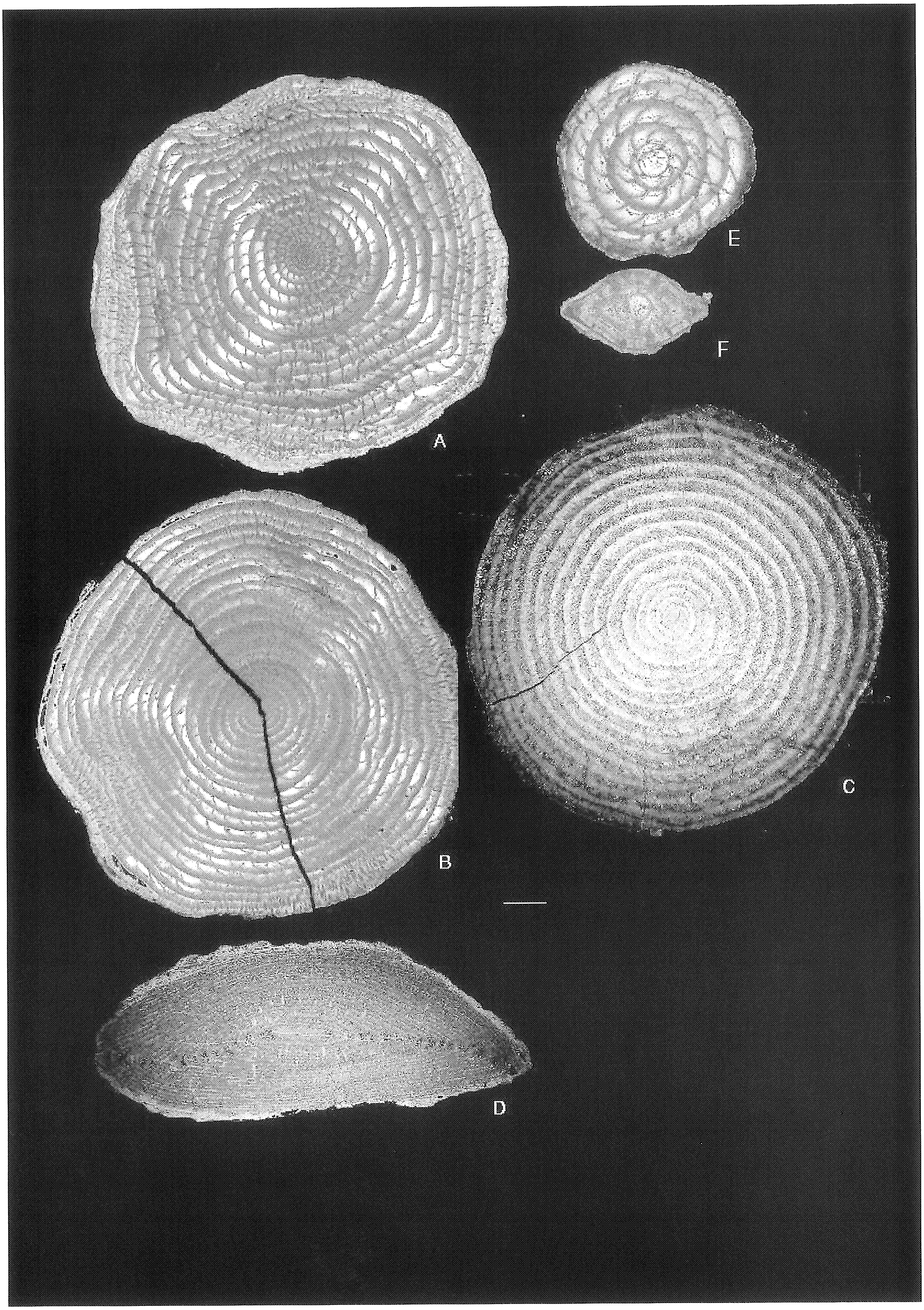


Figure 25A-C. *Nummulites martini* n. sp.; A - external view of B-form, Kali Bawang (Nanggulan) (RGM 3339) (x 5); B - equatorial section (split specimen) of A-form, Kali Puru (Nanggulan) (RGM 3325A) (x 10); C - external view of A-form, Kali Puru (Nanggulan) (RGM 3325B) (x 10).

D, E. *Nummulites djokdjokartae* (Martin, 1881); D - equatorial section (split specimen) of A-form, Kali Puru (Nanggulan) (RGM 3321A) (x 10); E - external view of A-form, Kali Puru (Nanggulan) (RGM 3332) (x 10).

Figure 26A-F. *Nummulites javanus* Verbeek, 1891 (with the exception of C and D, all specimens in collections of Institut für Paläontologie, Universität Bonn); A, B - equatorial section of B-form, Timor (x 5); C - equatorial section (split section) of B-form, Karangsambung (Java) (RGM 20119) (x 5); specimen from type locality, showing typical preservation with well-preserved marginal cord and very thin septa; D - axial section of B-form, Jetis (Java) (RGM 20118) (x 5); E - equatorial section of A-form, Timor (x 10); F - axial section of A-form, Timor (x 10).


A
B
C
D
E
F

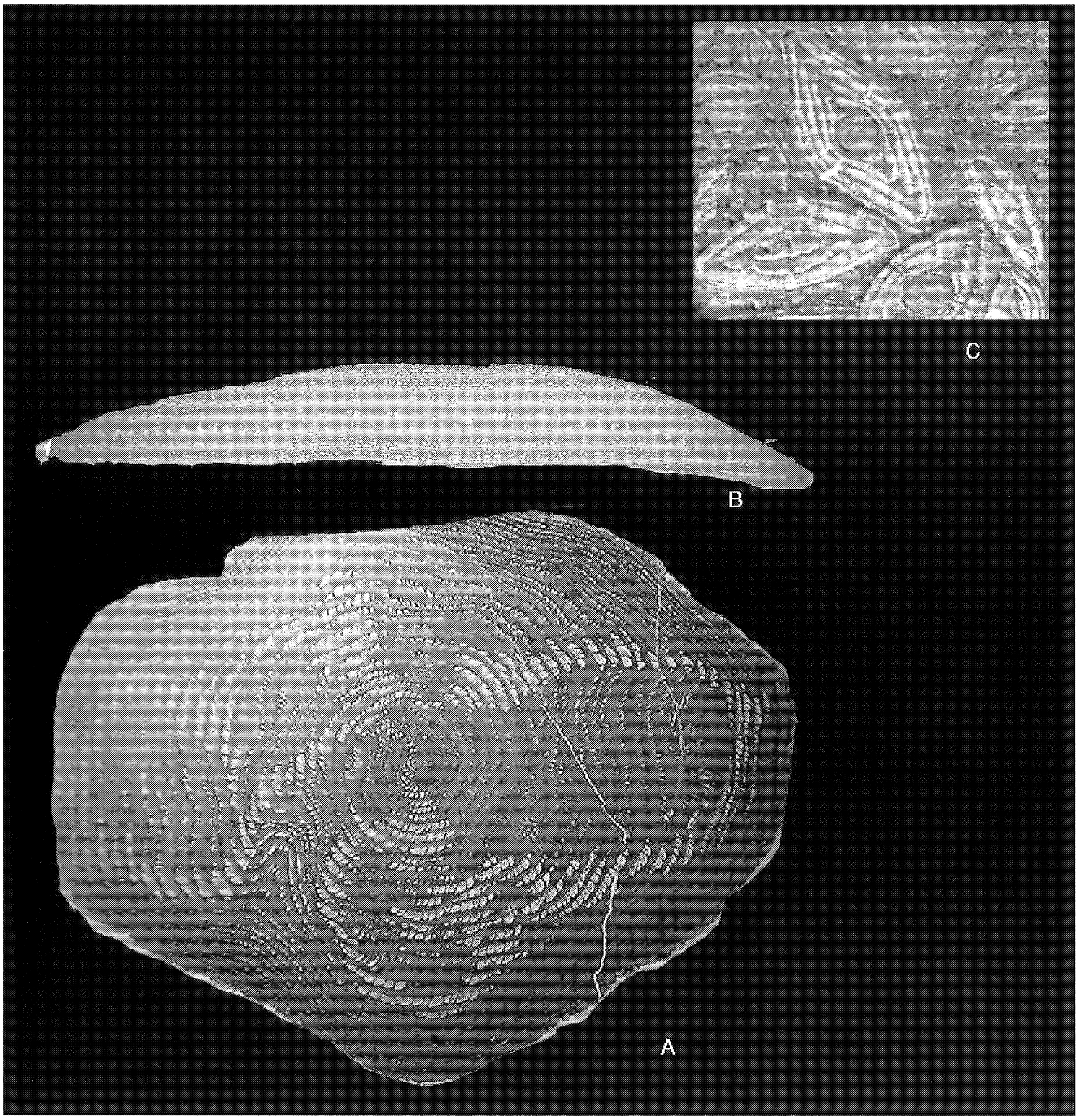


Figure 27A-C. *Nummulites boninensis* Hanzawa, 1947; A - equatorial section of B-form, Sungai Ular, SW Sulawesi (RGM 20117) (x 5); B - axial section of A-form, Timor (Universiteit Delft, KA 903) (x 10); C - axial section of B-form, Sungai Ular, SW Sulawesi (RGM 20116) (x 5).

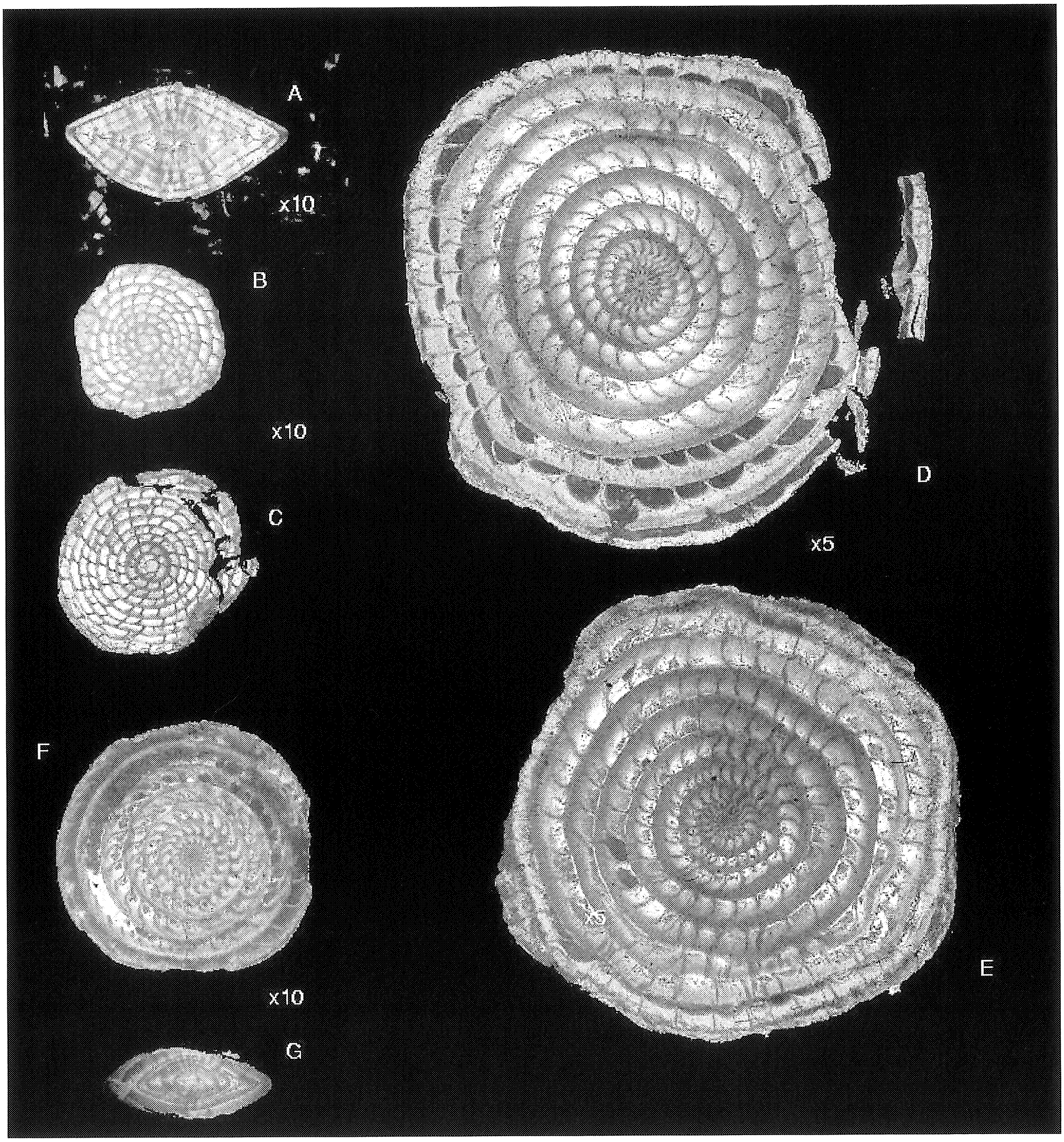


Figure 28A-E. *Palaeonummulites pengaronensis* (Verbeek, 1871); A - axial section of A-form, Timor (Institut für Paläontologie, Universität Bonn) (x 10); B - equatorial section of A-form, Sungai Temoe (Kalimantan) (RGM 19108) (x 10); C - equatorial section of A-form, Sungai Temoe (Kalimantan) (RGM 109) (x 10); D, E - equatorial section of B-forms, Timor (Institut für Paläontologie, Universität Bonn) (x 5).

F, G. *Palaeonummulites* sp.; F - equatorial section of B-form, Timor (Institut für Paläontologie, Universität Bonn) (x 10); G - axial section of B-form, Timor (same collection) (x 10).

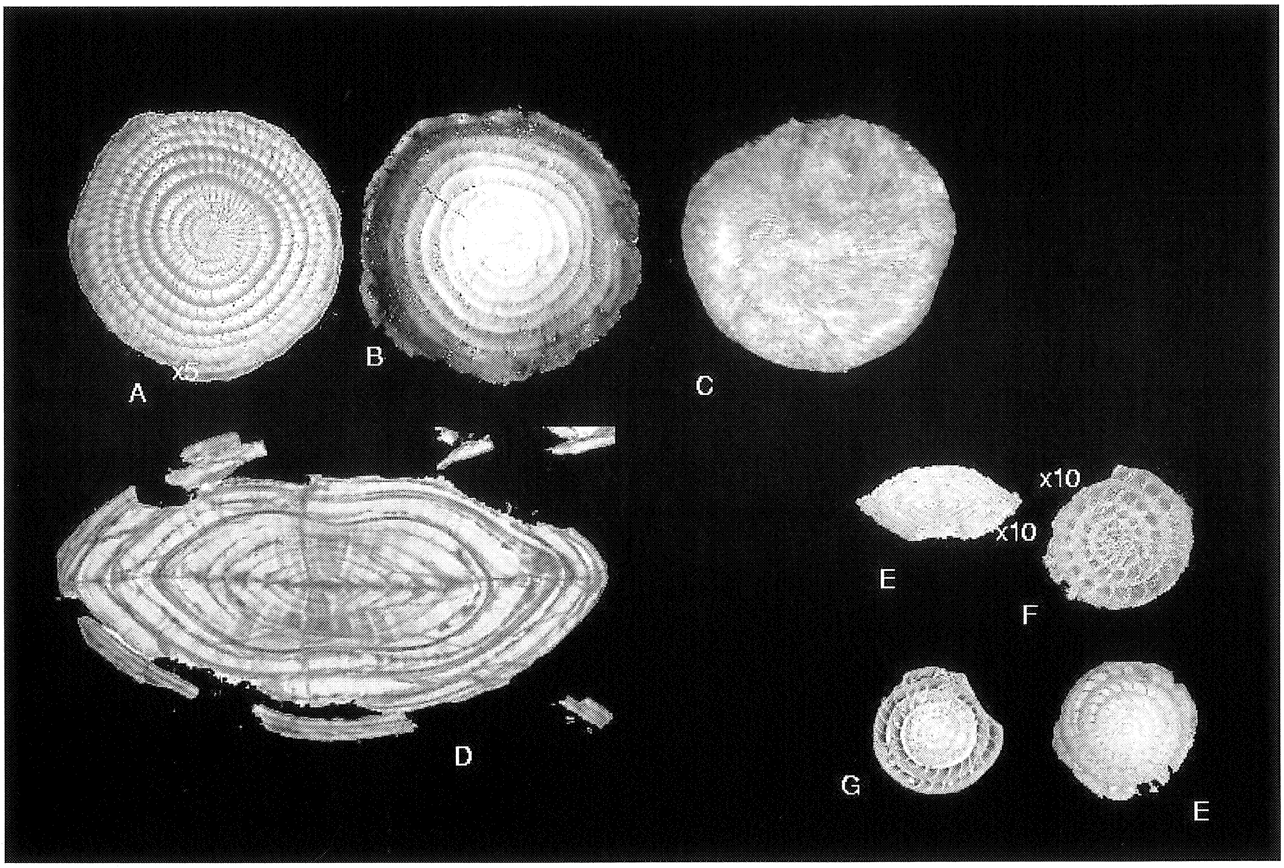


Figure 29A-D. *Palaeonummulites beaumonti* (d'Archiac & Haime, 1853); A - equatorial section of B-form, Timor (Institut für Paläontologie, Universität Bonn) (x 5); B - split specimen of B-form, Sungai Mangkalihat (Kalimantan) (RGM 19114) (x 5); C - exterior view of B-form; same specimen as B (x 5); D - axial section of B-form, Sungai Mangkalihat (Kalimantan) (RGM 19009) (x 10); note the pillars that stop halfway of the equatorial plane to the test outside.

E-H. *Palaeonummulites variolarius* (Lamarck, 1804); E - axial section of A-form, Sungai Mangkalihat (Kalimantan) (RGM 19124) (x 10); F - equatorial section of A-form, Sungai Mangkalihat (Kalimantan) (RGM 19122) (x 10); G - split specimen of A-form, Sungai Ular (SW Sulawesi) (RGM 202015) (x 10).

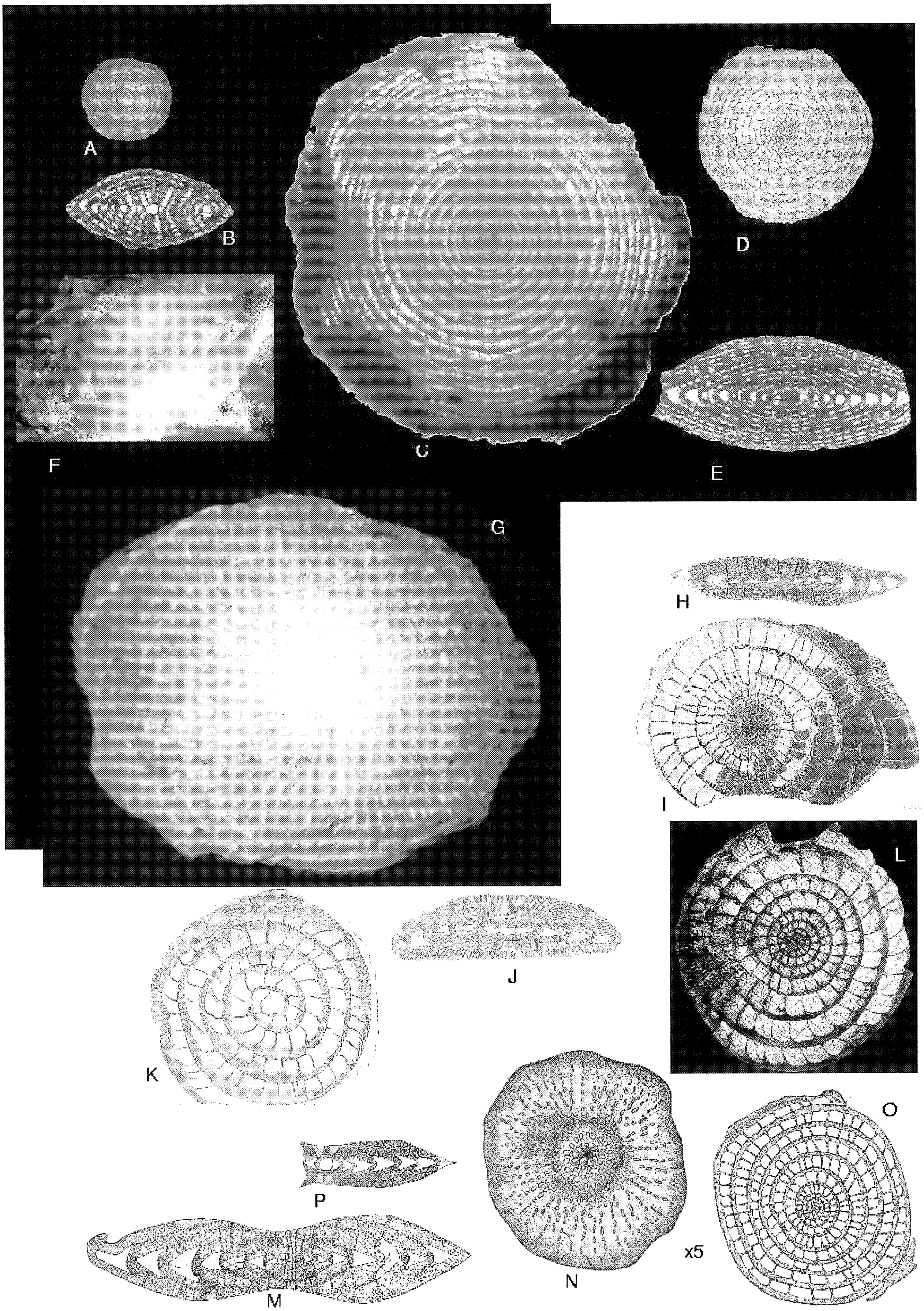
Figure 30A-C. *Nummulites subbrongniarti* Verbeek, 1871; A - equatorial section of A-form, Sungai Seilor (Kalimantan) (RGM 19056) (x 10); B - axial section of A-form, Sungai Seilor (Kalimantan) (RGM 19057) (x 10); C - axial section of B-form, Sungai Temoe (Kalimantan) (RGM 10949) (x 5).

D, E. *Nummulites fichteli* Michelotti, 1841; D - equatorial section of B-form, Sungai Seilor (Kalimantan) (RGM 19118A) (x 5); E - axial section of B-form, Sungai Seilor (Kalimantan) (RGM 19118B) (x 5).

F. *Planocamerinoides orientalis* (Douvillé, 1912b), axial section of A-form (**holotype**), Nias (RGM 11879) (x 5).

G-K. *Planocamerinoides* sp.; G - external view of B-form, Pengging (Java), RGM 20214 (x 5); H - drawing of axial section (Verbeek & Fennema, 1896, fig. 89, as *Nummulites (Assilina) spira* de Roissy) (x 5); I - drawing of equatorial section (Verbeek & Fennema, 1896, fig. 87, as *Nummulites (Assilina) spira* de Roissy) (x 5); J - drawing of axial section of A-form (Verbeek & Fennema, 1896, fig. 93, as *Nummulites (Assilina) leymeriei* d'Archiac & Haime) (x 10); K - drawing of equatorial section of A-form (Verbeek & Fennema, 1896, fig. 92, as *Nummulites (Assilina) leymeriei* d'Archiac & Haime) (x 10).

L-P. *Planocamerinoides umbilicata* (Rutten *in* van Waterschoot van der Gracht, 1915); L - equatorial section of B-form, Sumba; same specimen as Caudri (1934, pl. 1, fig. 2) (x 5); M-P - drawings reproduced from type description; M - axial section B-form (x 5), N - external view of B-form (x 5), O - equatorial section of B-form (x 5), P - axial section of A-form (x 10).


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
x5

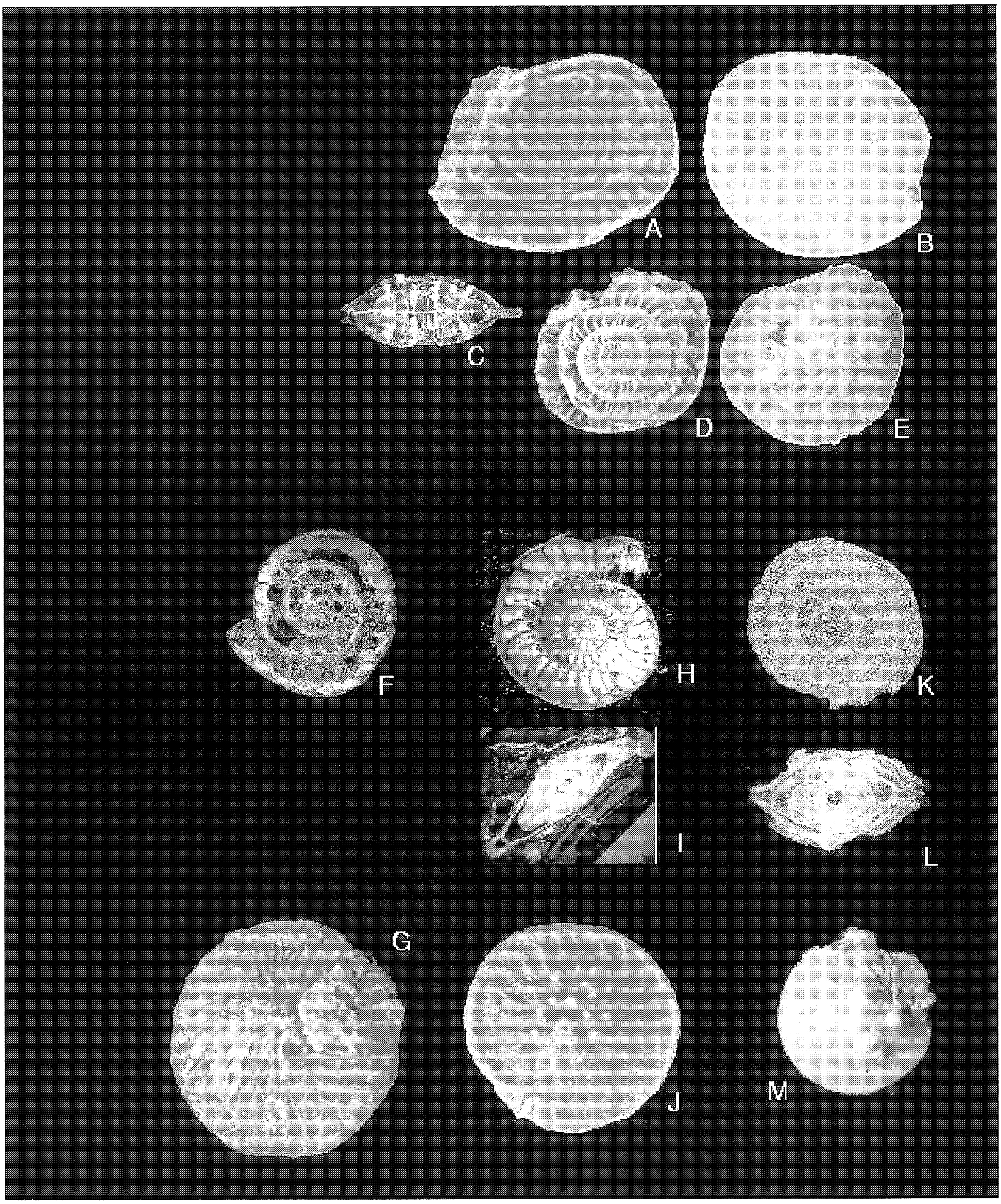


Figure 31A, B, H-J. *Palaeonummulites crasseornatus* (Henrici, 1934); A - equatorial section of B-form, Miomaffo (Timor) (RGM 202012) (x 5); B - external view of B-form, Miomaffo (Timor) (RGM 202013) (x 5); H - equatorial section of A-form, Miomaffo (Timor) (RGM 202014) (x 10); I - axial thin section of A-form (x 10), Jati Bungkus, Karangsambung (Java) - specimen in P. Lunt Colln; J - external view of A-form, Miomaffo (Timor) (RGM 202011) (x 10).

C-G. *Palaeonummulites songoensis* n. sp.; C - axial section of B-form, O5743-2 (Geologisch Museum Artis, Amsterdam) (x 5); D - equatorial section (split specimen) of B-form, Kali Songo (Nanggulan) (**holotype**, RGM 202000) (x 5); E - external view of B-form, Kali Songo (Nanggulan) (RGM 202005) (x 5); F - equatorial section of A-form, Kali Semah (Nanggulan), O5743-1 (Geologisch Museum Artis, Amsterdam) (x 10); G - external view of A-form, Kali Songo (Nanggulan) (RGM 202006) (x 10).

K-M. *Palaeonummulites taballarensis* (Caudri, 1934); K - equatorial section of A-form, Sungai Taballar, Kalimantan (RGM 19132) (x 10); L - axial section of A-form, Sungai Taballar, Kalimantan (RGM 19139) (x 10); M - equatorial view of A-form, Sungai Taballar, Kalimantan (RGM 19141) (x 10).

References

Adams, C.G. 1965. The foraminifera and stratigraphy of the Melinau Limestone, Sarawak, and its importance in Tertiary correlation. *Quarterly Journal of the Geological Society London* 121, 283-338.

Adams, C.G. 1970. A reconsideration of the East Indian letter classification of the Tertiary. *Bulletin of the British Museum (Natural History)*, Geology 19, 1-137.

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

Akhtar, M. & Butt, A.A. 1999. Lower Tertiary biostratigraphy of the Kala Chitta Range, northern Pakistan. *Revue de Paléobiologie* 18, 123-146.

Archiac, A. d' 1846. Description des fossiles recueillis par M. Thorent, dans les couches à Nummulites des environs de Bayonne. *Mémoires de la Société géologique de France* (2)2(4), 189-217.

Archiac, A. d' & Haime, J. 1853. *Description des animaux fossiles du Groupe nummulitique de l'Inde; précedée d'un résumé géologique et d'une monographie des Nummulites*, 373 pp. Paris (Gide & Baudry) [not seen].

Bain, J.H.C. & Binnekamp, J.G. 1973. The foraminifera and stratigraphy of the Chimbu Limestone, New Guinea. *Bureau of Mineral Resources and Mines, Geological Papers Bulletin* 139, 1-12.

Bakx, L.A.J. 1932. De genera Fasciolites en Neoalveolina in het Indo-Pacifische gebied. *Verhandelingen van het Koninklijk Nederlandsch Geologisch-Mijnbouwkundig Genootschap voor Nederland en Koloniën* 9, 205-267.

Bemmelen, R.W. van 1949. *Geology of Indonesia*, 732 pp. The Hague (Government Printing Office).

Benoist, A.H. 1889. Étude sur les Nummulites et les Assilines du sud ouest de la France. Recueillis dans divers gisements tertiaires de la Chalosse et du Bordelais. *Bulletin de la Société des Sciences Borda* 14, 3-22.

Berggren, W.A., Kent, D.V., Swisher III, C.C. & Aubry, M.-P. 1995. A revised Cenozoic geochronology and chronostratigraphy. *Society of Economic Petrologists and Mineralogists, Special Publication* 54, 129-212.

Binnekamp, J.G. 1973. Tertiary larger foraminifera from New Britain, PNG. *Bureau of Mineral Resources and Mines Geological Papers, Bulletin* 140, 1-27.

Blainville, H.M. Ducrotay de 1827. *Manuel de malacologie et de conchyliologie*, 350 pp. Paris (F.G. Levrault).

Blondeau, A. 1972. *Les Nummulites*, 255 pp. Paris (Vuibert).

Boubée, N. 1832. Présentation à la Société de deux nouvelles espèces de *Nummulites*. *Bulletin de la Société géologique de France* (1), 2, 444-445.

Boudagher-Fadel, M.K. & Banner, F. 1999. Revision of the stratigraphic significance of the Oligocene-Miocene 'Letter-Stages'. *Revue de Micropaléontologie* 42, 93-97.

Boussac, J. 1911. Études paléontologiques sur le Nummulitique alpin. *Mémoires pour servir à l'Explication de la Carte géologique de France*, 439 pp. Paris (Imprimerie nationale).

Brady, H.B. 1874. On a true Carboniferous nummulite. *Annals and Magazine of Natural History* (4)13, 222-231.

Bruguière, J.G. 1792. Histoire naturelle des Vers. *In: Encyclopédie méthodique* 1, 345-757, Paris [not seen.]

Carter, H.J. 1861. Further observations on the structure of foraminifera and on the larger fossilized forms of Sind, including a new genus and species. *Annals and Magazine of Natural History* (11)2, 1-161.

Caudri, C.M.B. 1934. *Tertiary deposits of Sumba*, 223 pp. Amsterdam (H.J. Paris).

Cizancourt, M. de 1938. *Nummulites* et Assilines du flysch de Gardez et du Khost, Afghanistan Oriental. *Mémoires de la Société géologique de la France,* n.s. 17(39), 1-28.

Cole, W.S. 1954. Larger foraminifera and smaller diagnostic foraminifera from Bikini drill holes. *United States Geological Survey, Professional Paper* 260-O, O569-O608.

Cole, W.S. 1956. Larger foraminifera [of Saipan Mariana Islands]. *United States Geological Survey, Professional Paper* 280-I, I321-I357.

Cole, W.S. 1957. Larger foraminifera from Eniwetok drill holes. *United States Geological Survey, Professional Paper*, 260-V, V743-V784.

Cole, W.S. 1963. Tertiary foraminifera from Guam. *United States Geological Survey, Professional Paper* 403-E, E1-E28.

Cole, W.S. & Bridges, J. 1953. Geology and larger foraminifera from Saipan Island. *United States Geological Survey, Professional Paper* 253, 1-45.

Cosico, R., Gramann, F. & Porth, H. 1989. Larger Foraminifera from the Visayan Basin and adjacent areas of the Philippines (Eocene through Miocene). *Geologisches Jahrbuch* B70, 147-205.

Crotty, K.J. & Engelhardt, D.W. 1993. Larger foraminifera and palynomorphs of the upper Malawa and lower Tonasa formations, southwestern Sulawesi island, Indonesia. *Proceedings of the International Symposium on Biostratigraphy of mainland southeast Asia: Facies and paleontology*, 71-82. Jakarta (IPA).

Davies, A.M. 1927. The Ranikot beds of Thal (north-west frontier provinces of India). *Quarterly Journal of the Geological Society London* 83, 260-290.

Davies, A.M. 1940. The upper Kirthar beds of North-West India. *Quarterly Journal of the Geological Society London* 96, 199-230.

Delage, Y. & Hérouard, E. 1896. *Traité de Zoologie concrète, 1, La cellule et les protozoaires*, 251 pp. Paris, (Schleicher Frères).

De la Harpe, P. 1877. Notes sur les Nummulites des Alpes occidentales. *Actes de la Société helvétique des Sciences naturelles* 60, 227-323.

De la Harpe, P. 1881-1883. Étude sur les *Nummulites* de la Suisse et révision des espèces éocènes des genres *Nummulites* et *Assilina*. *Mémoires de la Société paléontologique de la Suisse* 7-10, 4-180.

De la Harpe, P. 1926. Matériaux pour servir à une monographie des Nummulites et Assilines. *A Magyar Allami Földtani Intézet évi Jelentése* 27, 1-102.

Denys de Montfort, P. 1808. *Conchyliologie systématique et classification méthodologique des coquilles*, 1, 409 pp. Paris (F. Schoell).

Deprat, J. 1905. Les dépôts éocènes néo-caledoniens; leur analogie avec ceux de la région de la Sonde. *Bulletin de la Société géologique de France* 5, 485-516.

Deshayes, G.P. 1838. Description des coquilles fossiles recueillis en Crimée par M. de Verneuil. In: Verneuil, E. de (ed.). Mémoire géologique sur la Crimée. *Mémoires de la Société géologique de France* (3)1, 37-69.

Dollfus, G.F. 1917. Paléontologie du voyage à l'île de Celebes de M.E. Abendanon. In: Abendanon, M.E. (ed.). *Geologische en*

Geografische Doorkruisingen van Midden Celebes III, 955-958. Den Haag (Koninklijk Nederlands Aardrijkskundig Genootschap).

Doornink, H.W. 1932. Tertiary Nummulitidae from Java. *Verhandelingen van het Geologisch en Mijnbouwkundig Genootschap voor Nederland en Koloniën* 9, 267-315.

Douvillé, H. 1905. Les foraminifères dans la Tertiaire de Bornéo. *Bulletin de la Société géologique de France* (5)4, 434-464.

Douvillé, H. 1911. Les foraminifères dans la Tertiaire de la Philippine. *Philippines Journal of Science* D6, 53-80.

Douvillé, H. 1912a. Les foraminifères de l'île de Nias. *Sammlungen Geologisches Reichsmuseums Leiden* 8, 253-278.

Douvillé, H. 1912b. Quelques foraminifères de Java. *Sammlungen Geologisches Reichsmuseums Leiden* 8, 279-294.

Douvillé, H. 1919. L'Eocène inférieur en Aquitaine et dans les Pyrénèes. *Mémoires pour servir à l'explication de la Carte géologique détaillée de la France*, 84 pp. Paris (Imprimerie nationale).

Drooger, C.W., Marks, P. & Papp, A. 1971. Smaller radiate Nummulites of north western Europe. *Utrecht Micropaleontological Bulletins* 5, 1-137.

Eichwald, C.E. von 1830. *Zoologia specialis*, 323 pp. Vilnae (D.E. Eichwaldus).

Fichtel, L. von & Moll, J.P.C. von 1798. *Testacea microscopia aliaque minuta ex generibus Argonauta et Nautilus*, 123 pp. Wien (Anton Pichler).

Forskål, L.P. 1775. *Descriptiones animalium, quae in itinere oriental osseravit Petrus Forskål*, 164 pp. Haumiae (Copenhagen, Carsten Niebuhr).

Galeotti, 1837 - .

Gerth, H. 1929. The stratigraphical distribution of the larger Foraminifera in the Tertiary of Java. *Proceedings of the Fourth Pacific Science Congress*, 591-599. Jakarta.

Gill, W.D. 1953. The genus Assilina in the Laki (Lower Eocene) of the Kohat-Potwar Basin, northwest Pakistan. *Contributions of the Cushman Foundation for foraminiferal Research* 4, 76-86.

Gronovius, L.T. 1781. *Zoophylacii Gronoviani* 3, 241-380. Leiden (Theodorus Haak et Soc.).

Haak, R. & Postuma, J.A. 1975. The relation between the tropical planktonic foraminiferal zonation and the Tertiary Far East Letter classification. *Geologie en Mijnbouw* 54, 195-198.

Hanzawa, S. 1947. Eocene Foraminifera from Haha-Jima (Hillsborough Island). *Journal of Paleontology* 21, 254-259.

Hanzawa, S. 1957. Cenozoic foraminifera from Micronesia. *Geological Society of America Memoir* 66, 163 pp.

Hashimoto, W., Alcantara, P.M., Aoki, N., Balce, G.R. & David, P.P. 1978a. *Nummulites* from the Lubingan Crystalline Schist of Bongabon, Nueva Ecija and their significance on the geologic development of the Philippines. *Proceedings of the Japanese Academy* B54, 1-4.

Hashimoto, W., Aoki, N., David, P.P., Balce, G.G. & Alcantara, P.M. 1978b. Discovery of *Nummulites* from the Lubingan crystalline schist exposed east of Bongabon, Nueva Ecija, Philippines and its significance on the geologic development of the Philippines. *Geology and Palaeontology of Southeast Asia* 19, 57-63.

Hashimoto, W., Kitamura, N., Balce, G.R., Matsumaru, K., Kurihara, K. & Aliate, Z. 1979. Larger foraminifera from the Philippines, part X. Stratigraphic and faunal breaks between the Maybangain and Kinabuan formations in the Tanay Region, Rixal, Philippines. *Geology and Palaeontology of Southeast Asia* 20, 143-157.

Hashimoto, W., Kurihara, K. & Masuda, F. 1973. A study on some reticulate *Nummulites* from Kalimantan Selatan, Indonesia. *Geology and Palaeontology of Southeast Asia* 13, 73-90.

Hashimoto, W. & Matsumaru, K. 1978. Larger Foraminifera from the Philippines, 9. Larger Foraminifera found from the Zigzag Limestone, south of Baguio, Benguet, Luzon, Philippines. *Geology and Palaeontology of Southeast Asia* 19, 89-96.

Hashimoto, W. & Matsumaru, K. 1981a. Larger Foraminifera from the Philippines, 12. Eocene Limestone from southeastern Luzon. *Geology and Palaeontology of Southeast Asia* 22, 63-73.

Hashimoto, W. & Matsumaru, K. 1981b. Geological significance of the discovery of *Nummulites* fichteli (Michelotti) from the Sagada plateaux, Bontoc, Mountain Province, Northern Luzon, Philippines. *Geology and Palaeontology of Southeast Asia* 22, 75-82.

Hashimoto, W. & Matsumaru, K. 1984. Mesozoic and Cenozoic Larger Foraminifera of the Philippines and a reference to those found from Borneo by the APRSA's palaeontological reconnaissance. *Geology and Palaeontology of Southeast Asia* 25, 147-166.

Hashimoto, W., Matsumaru, K. & Kurihara, K. 1978c. Larger Foraminifera from the Philippines, 6. Larger Foraminifera found from the Pinugay Hill Limestone, Tanay, Rizal, central Luzon. *Geology and Palaeontology of Southeast Asia* 19, 65-72.

Haynes, J.R. 1988. Massively cordate nummulitids (Foraminifera) at the Palaeocene/Eocene boundary in Tethys. *Indian Journal of Geology* 60, 215-247.

Haynes, J.R., Racey, A. & Whittaker, J.E. in press. A revision of the Early Palaeogene nummulitids from northern Oman, with implications for their classification. *Journal of Systematic Palaeontology.*

Heim, A. 1908. Die Nummuliten und Flyschbildungen der Schweizeralpen. *Abhandlungen der Schweizerischen Paläontologischen Gesellschaft* 35, 1-301.

Henrici, H. 1934. Foraminiferen aus dem Eocän und Altmiocän von Timor. *Palaeontographica* 4, 1-56.

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

Howarth, R.J. & McArthur, J.M. 1997. Statistics for strontium isotope stratigraphy: a robust LOWESS Fit to the marine isotope curve for 0-206 Ma, with look-up table for derivation of numeric age. *Journal of Geology* 105, 441-456.

Joly, N. & Leymerie, A. 1848. Mémoire sur les nummulites considérées zoologiquement et géologiquement. *Mémoire de l'Académie des Sciences de Toulouse* (3) 4, 1-70.

Jones, T.R. 1887. Notes on *Nummulites elegans* and other English *Nummulites. Quarterly Journal of the Geological Society London* 43, 132-150.

Khan, M.A. & Drooger, C.W. 1970. On variation in *Nummulites* assemblages. *Verhandelingen van de Koninklijke Nederlandse Academie voor Wetenschappen* (B)74, 97-121.

Lamarck, J.B. de 1801. *Système des animaux sans vertèbres*, 432 pp. Paris (The author).

Lamarck, J.B. de 1804. Suite des mémoires sur les fossiles des environs de Paris. *Annales du Muséum national de l'Histoire naturelle* 5, 1-241.

Leupold, W. & van der Vlerk, I.M. 1931. The Tertiary. *Leidsche Geologische Mededeelingen* 5, 54-78.

Leymerie, A. 1846. Mémoire sur le terrain à *Nummulites* (épicrétacé) des Corbières et de la Montagne Noire. *Mémoires de la Société géologique de France* (1)2, 5-41.

Loeblich, A.R. Jr. & Tappan, H. 1987. *Foraminiferal genera and their classification*, 970 pp. New York (van Nostrand Reinhold Company).

Lunt, P. 2000a. Review of the Eocene and Oligocene outcrops in the Nanggulan area, south central Java. *Bali 2000 AAPG/IPA fieldtrip - Appendix on the Nanggulan outcrops*, 19 pp.

Lunt, P. 2000b. *Biogeography of some Eocene larger foraminifera, and their potential in distinguishing geological plates* [http//www.nummulites.net/pal/lunt_2000.pdf], 11 pp.

Martin, K. 1881. Tertiaer-Versteinerungen vom östlichen Java. *Sammlungen Geologisches Reichsmuseums Leiden* 1, 105-130.

Martin, K. 1915. Die Fauna des Obereocäns von Nanggulan, auf Java. *Sammlungen Geologisches Reichsmuseums Leiden*, n.s. (2)5, 194-200.

Matsumaru, K. 1984. Larger foraminiferal associations useful for the correlation of the Eocene and Oligocene sediments in the Ogasawara Islands, Japan, and an examiniation of *Nummulites boninensis* Hanzawa. *Benthos '83 - 2nd International Symposium Benthic Foraminifera* (Pau, April 1983), 415-422.

Matsumaru, K. 1994. A megalospheric schizont of *Nummulites perforatus* (Montfort) from upper Lutetian of the Yusan Formation, Haha-Jima (Hillsborough Island), Ogasawara Islands, Japan. *Revue de Micropaléontologie* 37, 161-165.

Matsumaru, K. 1996. Tertiary larger foraminifera (foraminiferida) from the Ogasawara Islands, Japan. *Palaeontological Society of Japan, Special Papers* 36, 1-239.

Michelotti, G. 1841. Saggio storico del rizpodi carracteristici dei terreni supracretacei. *Memorie della Società italiana della Scienze Modena* 22, 1-296.

Nagappa, Y. 1959. Foraminiferal biostratigraphy of the Cretaceous-Eocene succession in the India-Pakistan-Burma region. *Micropaleontology* 5, 145-192.

Netherwood, R. 2000. *The petroleum geology of Indonesia*, 174-227. Jakarta (Schlumberger).

Newton, R.B. & Holland, R. 1899. On some Tertiary foraminifera from Borneo and their comparison with similar forms from Sumatra. *Annals and Magazines of Natural History* (3)7, 245-264.

Nuttall, W.L.F. 1925. The stratigraphy of the Laki series (Lower Eocene) of parts of Sind and Baluchistan (India); with a description of the larger foraminifera contained in those beds. *Quarterly Journal of the Geological Society of London* 81, 417- 453.

Nuttall, W.L.F. 1926a. The zonal distribution and description of the larger foraminifera of the Middle and Lower Kirthar series (Middle Eocene) of parts of western India. *Records of the Geological Survey of India* 59, 115-164.

Nuttall, W.L.F. 1926b. The zonal distribution of the larger foraminifera of the Eocene of western India. *Geological Magazine* 63, 495-504.

Okada, H. 1981. Calcareous nannofossils of Cenozoic formations in central Java. *In*: Saito, H. (ed.). *Micropaleontology, petrography and lithostratigraphy of Cenozoic rocks of the Yogyakarta Region, central Java*, 65-78. Jogjakarta (Department of Earth Sciences, Yamagata University).

Orbigny, A. d'. 1826. Tableau méthodologique de la classe des Céphalopodes. *Annales des Sciences naturelles* 7, 245-314.

Orbigny, A. d'. 1850. *Prodrome de Paléontologie stratigraphie universelle des animaux mollusques et rayonnés*, 1-2 Paris (Renard).

Osimo, G. 1908. Di alcuni foraminiferi dell' Eocene superiore di Celebes. *Rivista italiana di Paleontologia* 14, 28-54.

Paltrinieri, F., Sri Sajekti & Suminta 1976. Biostratigraphy in the Jatibungkus section (Lokulo area) in central Java. *Proceedings of the Fifth IPA Convention*, 195-203. Jakarta (IPA).

Pecheux, M.J.F. 1995. Ecomorphology of a Recent large foraminifer, *Operculina ammonoides. Geobios* 28, 529-566.

Prever, P.L. 1905. *Le Nummuliti della Forca di Presta nell' Appennino centrale e dei dintorni di potenza nell'Appeninno meridionale*. Schweizerische Palaeontologische Gesellschaft. Basel, 121 pp.

Provale, I. 1908. Di alcune Nummulitine ed Orbitoidine dell'Isola di Borneo. *Rivista italiana di Paleontologia* 14, 55-88.

Provale, I. 1909. Di alcuni Nummulitine ed Orbitoidine dell'Isola di Borneo. *Rivista italiana di Paleontologia* 15, 65-113.

Racey, A. 1992. The relative taxonomic value of morphological characters in the genus Nummulites (Foraminiferida). *Journal of Micropalaeontology* 11, 197-209.

Racey, A. 1995. Lithostratigraphy and larger foraminiferal (nummulitid) biostratigraphy of the Tertiary of northern Oman. *Micropaleontology* 41, 1-123.

Roissy, F. de 1805. *Histoire naturelle générale et particulière des mollusques*, 5, 450 pp. Paris (Dufart) [not seen].

Rütimeyer, L. 1850. Über das Schweizerischen Nummuliten-Terrain, mit besonderer Berücksichtigung des Gebirges zwischen dem Thunersee und der Emme. *Neue Denkschrifte der Schweizerischen Naturforschenden Gesellschaft* 11, 1-120.

Samanta, B.K. 1968. *Nummulites* (foraminifera) from the upper Eocene Kopili Formation of Assam, India. *Palaeontology* 11, 669-682.

Samanta, B.K. 1982. A restudy of two middle Eocene species of *Nummulites* (Foraminiferida) from Cutch, Gujarat. *Bulletin of the Indian Geological Association* 15, 21-50.

Sander, N.J. 1962. Apercu paléontologique et stratigraphique du Paléogène en Arabie Sauoudate orientale. *Révue de Micropaléontologie* 5, 3-40.

Saraswati, P.K., Patra, P.K. & Banerji, R.K. 2000. Biometric study of some Eocene *Nummulites* and *Assilina* from Kutch and Jaiasalmer, India. *Journal of the Palaeontological Society of India* 45, 91-122.

Schaub, H. 1981. Nummulites et assilines de la Tethys paléogène. Taxinomie, phylogénèse et biostratigraphie. *Schweizerische Paläontologische Abhandlungen* 104, 1-238.

Schaub, H. 1995. *Nummulites* of Israel. *Schweizerische Paläontologische Abhandlungen* 117, 19-32.

Schubert, R.J. 1908. Beiträge zu einer natürlichen Systematik der Foraminiferen. *Jahrbuch der Geologischen Reichsanstalt* 58, 345-386.

Sen Gupta, S. 2000. Problems of classifying Early Oligocene Reticulate *Nummulites* (Foraminiferida) from southwestern Kutch, Gujarat. *Journal of the Geological Society of India* 56, 673-677.

Serra-Kiel, J., Hottinger, L., Caus, E., Drobne, K., Fernandez, C., Jauhri, A.K., Less, G., Pavlovec, R., Pignatti, J., Samso, J.M., Schaub, H., Sirel, E., Strougo, A., Tambareau, Y., Tosquella,

Y. & Zakrevskaya, E. 1998. Larger foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene. *Bulletin de la Société géologique de France* 169, 281-299.

Sowerby, J. de C. 1829. *Mineral Conchology*, 6, 73-76. London (The author).

Sowerby, J. de C. 1840. *In*: Stykes, W.H. A notice respecting some fossils collected in Cutch by Capt. Walter Smee, of the Bombay army. *Transactions of the Geological Society London* 5, 317-329.

Tan Sin Hok, 1932. On the genus *Cycloclypeus* Carpenter and an appendix on the *Heterostegines* of Tjimanggoe, S. Bantan, Java. *Wetenschappelijke Mededeelingen van de Dienst van de Mijnbouw in Nederlands Oost-Indië* 19, 3-141

Tobler, A. 1923. Unsere palaeontologischen Kenntnisse von Sumatra. *Eclogae geologicae Helvetiae* 18, 313-342.

Umbgrove, J.H.F. 1931. Tertiary foraminifera. *Leidsche Geologische Mededeelingen* 5, 35-92.

Van Andel, T. 1948. Some remarks on *Nummulites javanus* Verb. and *Nummulites perforatus* de Montf. *Proceedings of the Koninklijke Nederlandse Academie van Wetenschappen* 51, 1013-1023.

Van Dijk, P. 1872. Geologische beschrijving der residentie Djokjakarta. *Jaarboek Mijnwezen Nederlands Oost-Indië* 1872, 149-192.

Van der Vlerk, I.M. 1923. Een overgangsvorm tusschen *Orthophragmina* en *Lepidocyclina* uit het Tertiair van Java. *Verhandelingen van het Koninklijk Nederlandsch Geologisch-Mijnbouwkundig Genootschap voor Nederland en Koloniën* 7, 91-98.

Van der Vlerk, I.M. 1929. Groote foraminiferen van NO Borneo. *Wetenschappelijke Mededeelingen, Dienst Mijnbouw Bandung* 9, 1-44.

Van der Vlerk, I.M. 1955. Correlation of the Tertiary of the Far East and Europe. *Micropaleontology* 1, 72-75.

Van der Vlerk, I.M. & Dozy, J.J. 1934. The Tertiary rocks of the Celebes Expedition 1929. *Verhandelingen van het Koninklijk Nederlandsch Geologisch-Mijnbouwkundig Genootschap voor Nederland en Koloniën* 10, 183-217.

Van der Vlerk, I.M. & Umbgrove, J.H.L. 1927. Tertiaire gidsforaminiferen uit Nederlandsch Oost-Indië. *Wetenschappelijke Mededeelingen, Dienst Mijnbouw Bandung* 6, 1-31.

Verbeek, R.D.M. 1871. Die Nummuliten des Borneo-Kalksteines. *Neues Jahrbuch für Mineralogie und Geologie* B9, 1-14.

Verbeek, R.D.M. 1891. Voorlopig bericht over den Nummulieten, Orbitoiden en Alveolinen van Java, en over den ouderdom der gesteenten waarin zij optreden. *Natuurkundig Tijdschrift voor Nederlandsch Oost-Indië* 51 (12): 101-139.

Verbeek, R.D.M. 1874. De nummuliten uit den Eocenen kalksteen van Borneo. *Jaarboek Nederlandsch Oost-Indië* 2, 133-161.

Verbeek, R.D.M. 1891. Voorlopig bericht over den Nummulieten, Orbitoiden en Alveolinen van Java, en over den ouderdom der gesteenten waarin zij optreden. *Natuurkundig Tijdschrift voor Nederlandsch Oost-Indië* 51(12), 101-139.

Verbeek, R.D.M., Boettger, O. & Fritsch, K. von 1881. Die Tertiärformation von Sumatra und ihre Tierreste. *Jaarboek van het Mijnwezen in Nederlandsch Oost-Indië* 2(2), 3-210.

Verbeek, R.D.M. & Fennema, R. 1896. *Geologische beschrijving van Java en Madura*, 1155 pp. Amsterdam (John G. Stemler Cz).

Vredenburg, E.W. 1906. *Nummulites douvillei*, an undescribed species from Kachh with remarks on the zonal distribution of Indian *Nummulites*. *Records of the Geological Survey of India* 34, 79-95.

Vredenburg, E.W. 1908. *Nummulites vredenburgi* Prever, nom. mut. *Records of the Geological Survey of India* 36, 239.

Wanner, J. 1907. Zur Geologie von West-Buru. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie* Beil.-Bd. 24, 133-160.

Wanner, J. 1910. Beiträge zur geologischen Kenntnis der Insel Misol. *Tijdschrift van het Koninklijk Nederlands Aardrijkskundig Genootschap* 2(27), 469-500.

Wanner, J. 1912. Beiträge zur Geologie des Ostarmes der Insel Celebes. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie* Beil.-Bd. 29, 739-778.

Wanner, J. 1922. Geologische Ergebnisse der Reisen K. Deningers in den Molukken. I. Beiträge zur Geologie der Insel Buru. *Palaeontographica*, Suppl. (4)3(3)1, 59-112.

Waterschoot van der Gracht, J.M. 1915. Bijdrage tot de geologie van Centraal-Celebes. *Jaarboek van het Mijnwezen in Nederlandsch Oost-Indië* 43, 16-73.

Wilson, M.E.J. 1995. *The Tonasa Limestone formation, Sulawesi, Indonesia: development of a Tertiary carbonate platform*, 560 pp. London (Royal Holloway University) [unpubl.].

Yabe, H. 1921. Notes on some Eocene foraminifera. *Science Reports of the Tohoku Imperial University* (2)5, 97-108.

Appendix 1

On the location of *Nummulites* bearing sediments in Java

Many of the classic works on the geology and palaeontology of Java refer to locations that are now hard to find. Spellings are variable, and there are few good maps. Also the original geological maps of Java were marked in degrees of longitude from a Batavia datum, to which 106° 48' 27.79' E (or 106.8077194°E) has to be added to convert to degrees east of the Greenwich meridian.

Although it is not acceptable to change the spelling of proper names of defined objects, such as species, it is permitted and necessary to transliterate the names of locations to modern usage, as modern names are consistently spelt and are used on modern maps. In the past, places names such as "Yogyakarta" have had considerable and confusing variations in spelling (Djogjakarta, Djocjakarta, Jogjakarta, Djokja, Jogja, found in geological papers).

Some recurring root words:

Batu (Indonesian) = Watu (Javanese) = rock or stone
Gamping (Javanese) = limestone, flat limestone rather than Karang (ridges)
Gunung = mountain or hill
Kali = (Javanese) river or stream (Central and East Java)
Kapur (Indon.) = limestone [batu kapur]
Karang (Indon.) = a cliff or small ridge, or reef as in ridges of hard stone along a beach, (rather than a biohermal biological community)
Ci (Tji) (Sundanese) as prefix = river or stream in (West and west Central Java), hence Cijengkol (previously Tji Djengkol).

Geography and names

In general, in the province of West Java Sundanese names have been used, while in the provinces of Central and East Java Javanese names have been used.

	region	locality	GPS locality	synonyms	remarks	age
	Bayah (Bantam)	Cisiih	E 106.217403 S 06.830558		Valley adjacent to (east of) the Cihara yielding mid Eocene fossils	Ta
1	Bayah (Bantam)	Cimanggu	E 106.115903 S 06.864117		See also Tan Sin Hok's 1932 monograph, on *Cycloclypeus & Heterostegina.*	Tc
2	Bayah (Bantam)	Cijengkol	E 106. 16965 S 06.86633	Tji Djengkol	Western Cijengkol	Tc
3	Bayah (Bantam)	Ciapus	E 106.216637 S 06.8821152	probably Tji Nongnang and Tji Sukarama of Doornink (1932)	Also part of the western Cijengkol area, along with lower Cihara [E 106.1311, S 6.8488] and other locations. See also Tan Sin Hok's 1932 monograph, on *Cycloclypeus & Heterostegina.*	Tc,Td
4	Bayah (Bantam)	Cihaur/ Cipager tributary	E 106.1453 S 06.7884	Tji Pager		Ta
5	Bayah (Bantam)	Cimuncang	E 106.184543 S 06.803252	Tjimoentjang	A tributary of the Cihara, important as yielding the location where "*Assilina*" (*Planocamerinoides*) was recorded, indicating a Ta age	Ta
6	Bayah (Bantam)	Cicarucup	E 106.340792 S 06.820144	Tjitjaroetjoep	includes Citukangkarang [Tji Tjukang Karang] previously considered Late Eocene, with *N. djokdjokartae.*	Ta
7	Bayah (Bantam)	Cijengkol-Cihideung	E 106.3452023 S 06.9040947	Tjidikit-leutik	eastern limit of Cijengkol formation, with *N. fichteli-intermedius* at the Cihideung section	Tc
8	Ciletuh (SW Priangan)	Ciletuh	E 106.4622620 S 07.22573046	Tjileteuh Bay, Tjikaramat, and Tjiboelakan	Main *Nummulites* location is at Cikaramat, but also in Cibulakan [106.4298418, 07.23836033], and traces in conglomerate boulders at Cikepuh [106.385806, 7.2416139]	Ta
9	Cimandiri (W. Priangan)	Cikalong	E 106.69396 S 07.030784	Tji Kalong, Cimandiri	Exact location of *Nummulites* not known.	Tc
10	Cibadak-Bandung ridge	Batu Asih	E 106.790517 S 06.9144079		Related outcrops with *Nummulites* extend as far as 12kms ESE at Cipeundeui (c. E 106.88317, S 06.9541).	Tc
11	Cibadak-Bandung ridge	Cikosan	c. E 107.32 c. S 06.8716	west of Tji Tarum / Citarum		Tc
12	Cibadak-Bandung ridge	Cibogo	E 107.43473 S 06.84456		reworked into Miocene limestone	Tc
13	N. Central Java	Pemali Beds,	E 108.877571		*N. djokdjokartae* reworked into Pliocene Pemali	Ta

		type location	S 07.021350		Beds	
14	N Serayu mountains	Sigugur Lst	E 109.5302 S 07.174711		in places as old as Td with *Nummulites*. (Td-Te)	Td
15	N Serayu mountains	Sigugur Eocene	E 109.53969 S 07.1862304		mudstone yielding boulders of Eocene *Nummulites* related to Kali Bongbong, Kali Bodas and Worawari (Bagelen Beds).	Ta
16	N Serayu mountains	Kali Bongbong	N 109.6613678 S 07.251677	possibly Kali Bening	related to Worowari Bagelen Beds	Ta
17	N Serayu mountains	Kali Bodas	N 109.74652 S 07.30946		related to Worowari Bagelen Beds	Ta
18	N Serayu mountains	Worowari	N 109.795824 S 07.356925	Bagelen	type location of the Bagelen Beds and *Nummulites bagelensis*. Red - green, ferric-ferrous scaly clay with deep marine, *Cyclammina*, *Ammodiscus*, *Glomospira* faunas. Sparse calcareous fossils have dated the host mudstone as Early Oligocene, but with numerous small to very large boulders of Eocene and basement lithologies.	Ta
19	N. Lukulo [Loh Uloh, Loh Oelo]	Kali Gua	E 109.7746592 S 07.46626176		Related to Worowari Bagelen Beds. Sample in block/boulder suspended in scaly clay dated as Early Oligocene.	Ta
	S. Lukulo	Kali Gorang	E 109.593236 S 07.528869	Kali Soeroean	Obscure location only shown on maps of Verbeek & Fennema. Important location in type descriptions of some forms of *N. javanus -bagelensis*.	
20	Karangsambung, S. Lukulo	Karangsambung	E 109.671201 S 07.545968		LIPI Fieldstation, above *N. javanus* limestone, next to road	Ta
21	Karangsambung, S. Lukulo	Jatibungkus	E 109.685897 S 07569221		see remarks on *P. crasseornatus*	Ta
22	Nanggulan	Kali Santen	E 110.20118 S 07.72676	Kali Anten		Ta
23	Nanggulan	Kali Watu Puru,	E 110. 1969316 S 07.732182		in the lowest part also called Kali Semah	Ta
24	Nanggulan	Kali Songo	E 110.200102 S 07.36438	Songgo	one of the main stream sections in the centre of Nanggulan	Ta
25	Nanggulan	Kali Kunir	E 110.188324 S 07.739183		stream section in a western tributary of Kali Songo	Ta
26	Nanggulan	Kali Seputih & 'Kali Semah'	E 110.18903 S 07.7414368			Ta
27	Nanggulan	Niten	E 110.196778 S 07.78238		reworked into basal Sentolo fm	Tb
	Nanggulan	Kali Balong	E 110.19600 S 07.72767		upper part of the Kali Kotes	Ta
	Nanggulan	Kali Kotes	E 110.200926 S 07.728514	Kali Kottes		Ta
28	West of Yogya	Gunung Gamping	E 110.6727812 S 07.7752116	G. Gamping, Djokja in Doornink (1932)	apparently lost due to complete use of limestone for building. Reefal limestone locally rich in *Pellatispira*. Not related to Gamping Beds.	Tb
29	Jiwo Hills	Gunung Wungkal	E 110.6206963 S 07.768430	Woengkal	small quarry, fallen into disuse. Type location of Wungkal Beds.	Ta
30	Jiwo Hills	Gunung Cakaran	E 110.6225534 S 07.772625			Ta
31	Jiwo Hills	Watu Perahu	E 110.6695416 S 07.767167	Gunung Jokotuwa-Tegalsari		Ta
32	Jiwo Hills	Pendul & Padasan sections	E 110.669578 S 07.7719238	G. Pendoel		Ta
32	Jiwo Hills	Padasan	E 110.662731 S 07.769231		small outcrop, almost as western extension of Watu Perahu section	Ta
33	Jiwo Hills	Gamping	E 110.6727812 S 07.7752116	Kampung Gamping Ketjil	Type location of the Gamping Beds, previously considered Late Eocene.	Ta
	Jiwo Hills	Kali Dowo	E 110.663025 S 07.774994		small location just W of G. Pendul. Gunung Konang, given as the first named location for type localities of *N. javanus* forms is the hill (of basement lithologies) just west of Kali Dowo.	Ta
	Jiwo Hills	Gunung Jabalkat	E 110.63062 S 07.782070			Ta
34		Sangiran	E 110.83730 S 07.455967		At the centre of this uplift are / were boulders of limestone with *Nummulites*, *Pellatispira* and *Biplanispira*, but these are now reduced to rubble by	

					over-enthusiastic collectors. May be genetically related to Bagelen Beds, with limestone boulders suspended in scaly clay.	
35		Pelang	E 110.75076 S 07.194626		unpublished, Td with common *N. fichteli*	Td
36		Lutut	E 110.15888 S 07.12198		*N. fichteli-intermedius* commonly reworked into Early Miocene Lutut beds	Tc
37		Kujung	N 112.181531 S 06.961767		an old Dutch bore with reported Td *Nummulites*. Recent field work within a few kilometres of the suspected location has found *Nummulites* (Td) on the surface	Td