Revue de Paléobiologie, *Genève* (juin 2005) 24 (1): 291-309 ISSN 1661-5468

Significant Miocene larger foraminifera from South Central Java

Marcelle K. BOUDAGHER-FADEL[1] & Stephen W. LOKIER[2]

Abstract

The Gunung Sewu area of South Central Java, Indonesia during Mid Miocene, Langhian-Serravallian (Tf1-Tf2), was deposited in a large area of warm, very shallow-marine water. Coralline algae and abundant larger benthic foraminifera dominate the carbonate lithologies. Larger benthic foraminifera from previously unstudied sections in South Central Java are described and figured. They have led to an understanding of sequence stratigraphic and facies relationship of Miocene carbonates in Indonesia. Thirteen larger foraminifera species are described and illustrated. A detailed biostratigraphical studies of The phylogeny *Katacycloclypeus annulatus* - *K. martini* and the gradual evolution from *Austrotrillina asmariensis* into *A. howchini* are recognised. Analysis of the larger benthic foraminifera has allowed accurate dating of the carbonate sections studied using the East Indian Letter Classification.

Key words

Larger foraminifera, Mid-Miocene, biostratigraphy, phylogeny, South Central Java.

I. INTRODUCTION

Larger benthic foraminifera were widely distributed in Tertiary carbonates in South Central Java. The larger foraminifera of the Netherland-East Indies have been the subject of a number of early works concerning their systematics, stratigraphy and biostratigraphy (e.g. Martin, 1880; Oppenoorth, 1918; van der Vlerk, 1924, 1925, 1928; Scheffen, 1932; Tan Sin Hok, 1932, 1935, 1936; Vaughan & Cole, 1941; Todd & Post, 1954).

Although the new evidence from Java confirms these earlier findings, our new contribution allows:

1. The recognition of the phylogeny of the taxa and their distribution in the palaeoenvironment represented by the studied samples.
2. An accurate stratigraphical correlation with an assessment of the controls on larger foraminifera occurrences. This, in turn, allows the true significance of biofacies to be established and understood.
3. This work has also enabled the recognition of a refined biostratigraphical correlation. Lines of evolution in larger foraminifera should be studied rather than simply relying on first and last occurrences. These lines of evolution allowed palaeoenvironmental specialisation into separate biocenoses and particular palaeoecological niches. Such evolutionary sequences have previously been established for *Lepidocyclina* (BouDagher-Fadel & Lord, 2000) and *Miogypsina* (BouDagher-Fadel *et al.*, 2000a), and are here clearly demonstrated in the sequence from *Austrotrillina asmariensis* to *A. howchini* and from *Cycloclypeus* to *Katacycloclypeus annulatus* and then to *K. martini*. Thus these evolved taxa must occur in the same sequence regardless of whether they were sampled from Papua, Indonesia or the Philippines. Prior to this research previous records of these species have been out of stratigraphic sequence.

Therefore, in distinguishing between the indicators of palaeoenvironments and biostratigraphical horizons we are able to trace an accurate stratigraphical correlation that is independent of biofacies.

II. STUDY AREA AND SAMPLES

In this study, larger benthic foraminifera have been analysed from five logged sections in the Gunung Sewu area of South Central Java, Indonesia (Fig. 1). This extensive Miocene carbonate platform developed in close proximity to an active volcanic arc (Lokier, 2000). The deposits associated with these events include the volcaniclastic Jaten and Wuni Formations, the siliciclastic and carbonate Nampol Formation, and the dominantly carbonate Kepek and Wonosari Formations.

The lower Mid Miocene Nampol Formation outcrops at the periphery of the area under investigation. The Nampol Formation is conformably overlain by, and grades upwards into, the contemporaneous pelagic-

---

[1] *Postgraduate Unit of Micropalaeontology, Department of Geological Sciences, University College London, Gower Street, London. WC1E 6BT, U.K. E-mail: m.fadel@ucl.ac.uk*

[2] *Badley Ashton and Associates Ltd., Winceby House, Winceby, Horncastle, Lincolnshire. LN9 6PB, UK. E-mail: sLokier@badley-ashton.co.uk*

carbonate dominated Kepek and shallow-water carbonate dominated Wonosari Formations. The Wonosari Formation outcrops throughout the area, and has been interpreted as being deposited in a distal, moderate to high energy, shallow-marine environment (Lokier, 2000). All of the samples examined during this study are derived from the Wonosari Formation. A well-developed, limited relief, cone karst topography, provides good exposures of limited thickness and lateral extent over an area of more than 100 km by 30 km. Local quarrying activity and isolated river sections along with a few small road cuttings complement these exposures. Limited burial of the lithologies under consideration has resulted in good preservation of bioclasts and sediments with very little recrystallisation or diagenesis.

The logging of successions in the field, along with detailed petrological and micropalaeontological analysis has revealed a diverse and abundant fauna that is dominated by coralline algae and larger benthic foraminifera, particularly *Miogypsina, Lepidocyclina, Katacycloclypeus* and *Amphistegina*. Rhodolith rudstones along with coralline algae and larger benthic foraminifera packstones and grainstones are the dominant lithologies throughout the Wonosari Formation. These lithologies are generally indicative of shallow-marine environments under moderate to high-energy conditions (Lokier, 2000). Occasional episodes of volcaniclastic input resulted from local or regional volcanic activity. Marls within the formation have been dated as Early to Mid Miocene using calcareous nannofossils (Lokier, 2000).

Stratigraphic logs of the five sections from which the samples were collected are displayed in Figure 2. The Djatirago section (TAN) outcrops as a series of karstic cliffs to the southeast of Pacitan (Fig. 1). This 359 m thick section is dominated by rhodolith rudstones and bioclastic packstones and grainstones succeeded by a thick (>50 m) volcaniclastic sequence that is largely devoid of skeletal allochems (Fig. 2). The Kali Baksoko section (BAK) outcrops within the Baksoko river between Donorojo & Pacitan (Fig. 1). The lowermost 42 m of this section lie within the mixed carbonate/volcaniclastic Nampol Formation (Fig. 2), which is conformably overlain by the bioclastic grainstone, packstone and wackestone lithologies of the Wonosari Formation. All of the samples from this section were derived from the Wonosari Formation. The Kali Sambi section (SAM) is a 177 m thick section outcropping in a series of cliffs on the eastern bank of the Sambi river (Fig. 1). The lower 125 m of this section are dominated by coralline algae and larger benthic foraminifera rudstones, packstones and grainstones (Fig. 2). These carbonate lithologies are overlain by interbedded carbonate, volcaniclastic and mixed carbonate-volcaniclastic lithologies. The 85 m thick Kederakon section (WB) outcrops in the west of the study area as a series of karstic hills on the road between Baron and Wonosari (Fig. 1). These carbonate lithologies are dominated by coralline algae rudstones, packstones and grainstones containing abundant larger benthic foraminifera (Fig. 2). The Sadeng section (SAD) is 100 m thick and outcrops in the centre of the study area as a series of karstic hills on the Rongkop to Sadeng road (Fig. 1). The carbonate lithologies within this section are again dominated by coralline algae and abundant larger benthic foraminifera (Fig. 2).

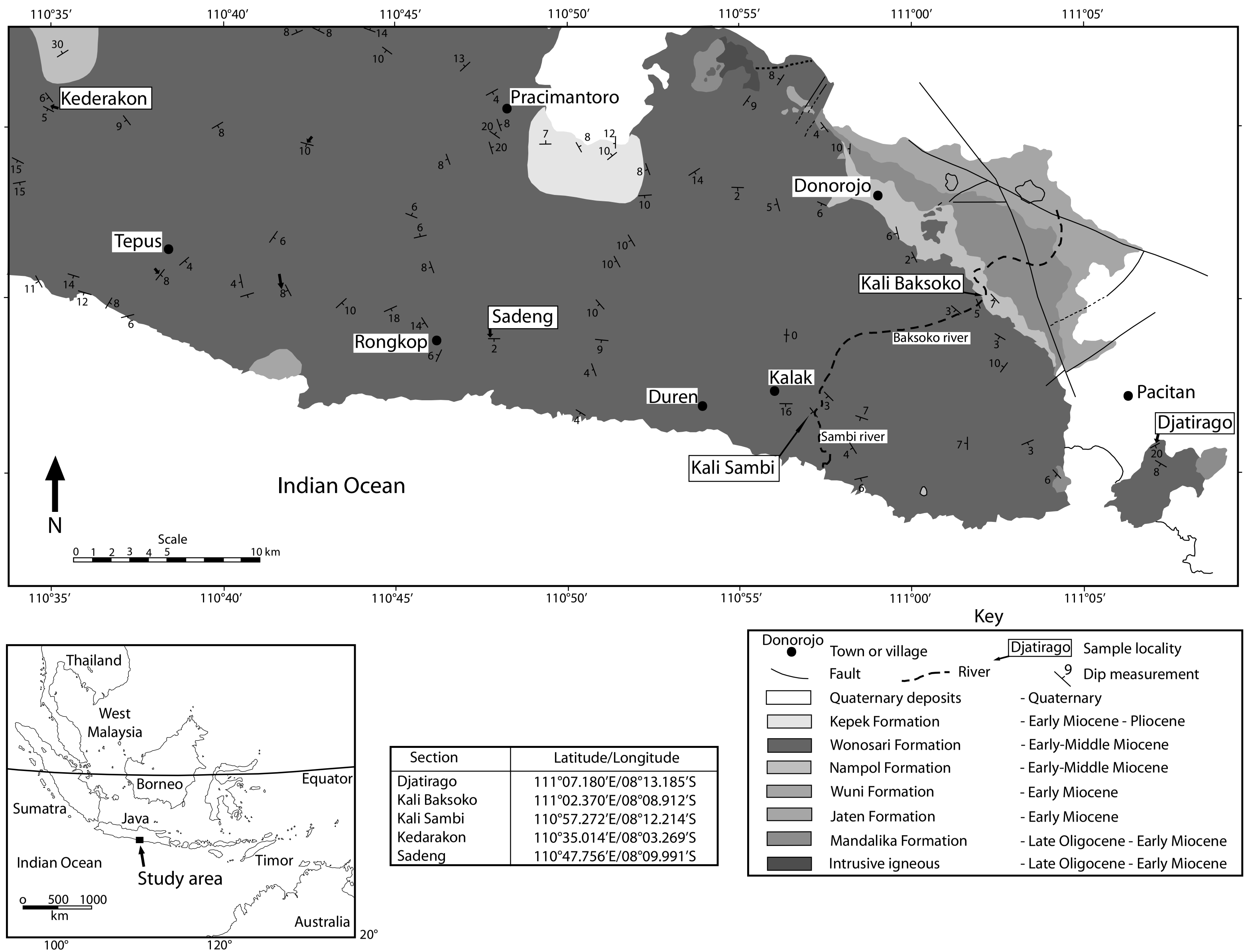
III. BIOSTRATIGRAPHIC INTRODUCTION

The nomenclatural revision of *Lepidocyclina* by BouDagher-Fadel & Banner (1997) makes the genus group name *Lepidocyclina sensu lato* available for the generic naming of microspheric forms. Megalospheric forms, however, are divisible into the essentially Palaeogene *Lepidocyclina (Lepidocyclina),* and the essentially Miocene *Lepidocyclina (Nephrolepidina).* The Palaeogene *Lepidocyclina (Lepidocyclina)* are 'isolepidine', having a protoconch and deuteroconch of nearly equal size and separated by a straight wall. *Lepidocyclina (Nephrolepidina),* in contrast, have a smaller proloculus followed by a much larger, reniform deuteroconch. The latter forms develop quadrate proloculi [e.g. figured here *Lepidocyclina (Nephrolepidina) rutteni quadrata,* Pl. III, fig. 5] in the later stages of many lineages (see BouDagher-Fadel & Lord, 2000). Studies of evolutionary trends within Miocene *Lepidocyclina* are demonstrated by BouDagher-Fadel & Wilson (2000). The so-called "letter stages" of the Oligo-Miocene of the tropical Far East have been redefined and correlated with the planktonic foraminiferal zones and the European stages by BouDagher-Fadel & Banner (1999). The top of the Tf is defined by the disappearance of *Austrotrillina*, while the top of the Tf2 by the disappearance of *Katacycloclypeus*. However, in this paper we emend the latter correlation by extending the age of *Katacycloclypeus* (*K. annulatus*) down into the Tf1 (Langhian) and that of *Flosculinella* up into the Tf2 (Serravallian).

IV. TERMINOLOGY

As the specimens studied here are from random thin sections of limestones, biometric measurements on isolated, solid specimens of larger foraminifera have rarely been possible. We attempt to combine the broad results gained by equatorial sections of the megalospheric nepiont of the Miogypsinidae (as published by Drooger, 1993) with those obtained by vertical sections of the whole test (as followed by Tan Sin Hok, 1936, 1937). We use as well the broad results gained by equatorial sections of the megalospheric nepiont of the lepidocyclinids (as published by Chaproniere, 1984; Van Vessem, 1978) with those obtained by vertical sections of the whole test (as followed by Cole, 1957, 1968). In *Miogypsina*,

Fig. 1: Geological map of the research area in south Central Java showing the principal formations and sample locations. Revised from the 1:100,000 scale Yogyakarta and Surakarta-Giritontro quadrangle maps of Rahardjo *et al.* (1995) and Surono *et al.* (1992).



Section	Latitude/Longitude
Djatirago	111°07.180′E/08°13.185′S
Kali Baksoko	111°02.370′E/08°08.912′S
Kali Sambi	110°57.272′E/08°12.214′S
Kedarakon	110°35.014′E/08°03.269′S
Sadeng	110°47.756′E/08°09.991′S

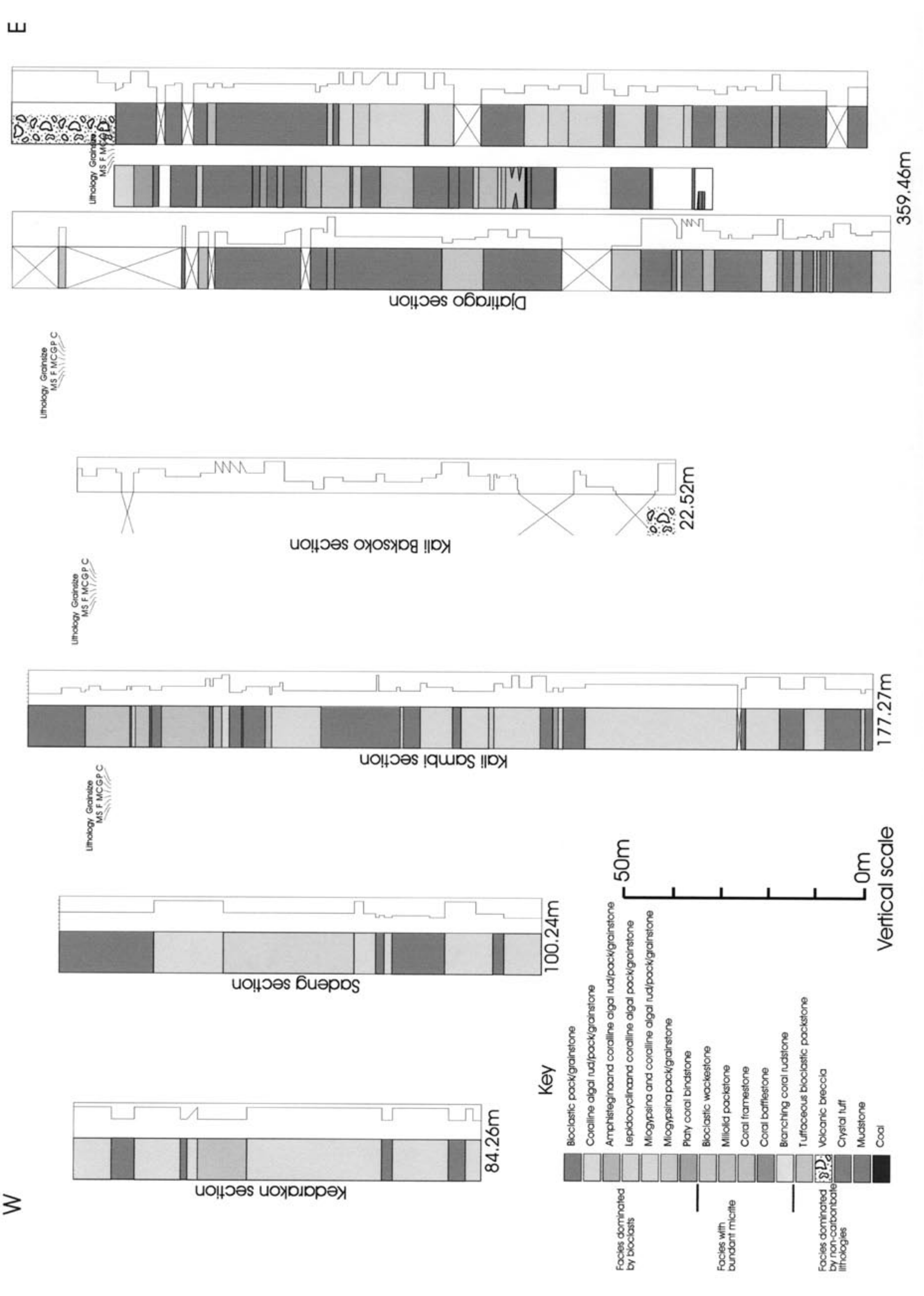


Fig. 2: Simplified stratigraphic s□

as in the different species of *Katacycloclypeus* and *Lepidocyclina,* the morphological dimensions of the protoconch and deuteroconch are given as the ratio of Diam. I (the diameter of the protoconch) over Diam. II (the diameter of the deuteroconch, which is the largest diameter of II parallel to the line taken as the diameter of the protoconch).

The photographs are focused as sharply as the sectioned specimens will allow and the photographs are magnified to show the detailed structures we believed to be significant.

A chamberlet is the division of the chamber as is seen in some species of *Nummulites* [(*Heterostegina* (*Vlerkina*), etc.]. The "cubicula" (*sensu* BANNER & HODGKINSON, 1991, p. 105) are separate little "chamberlets" which do not arise from the division of larger chambers and are the correct name for those structures inaccurately called by others as "lateral chamberlets". This applies particularly to the lateral structures of orbitoids and miogypsinids. The median layer is composed of true chamberlets which are known to be derived from the division of primary chambers phylogenetically or ontogenetically or both and does not have cubiculae. The "centrum" of the lateral layers was defined by EAMES *et al.* (1968).

The morphological dimensions of the alveoli of the miliolids are given as the ratio of depth over breadth rather than absolute measurements, because the alveoles change size as the test gets larger but the ratio remains the same.

At least 14 species of benthic foraminifera have been identified from within the Wonosari Formation, and it is considered that these can be used to refine both the age and palaeoenvironmental interpretations.

V. SYSTEMATIC PALAEONTOLOGY

Superfamily Miliolacea EHRENBERG, 1839
Family Austrotrillinidae LOEBLICH & TAPPAN, 1986
Genus *Austrotrillina* PARR, 1942
Austrotrillina asmariensis ADAMS, 1968
Pl. I, figs 1-2

1968. *Austrotrillina asmariensis* ADAMS, p. 82, pl. 1, figs 1-12.
1996. *Austrotrillina howchini* (SCHLUMBERGER).- MATSUMARU, pl. 84, figs 5,7 (not 3, 4, 6).
2000b. *Austrotrillina asmariensis* ADAMS.- BOUDAGHER-FADEL *et al.*, p. 345, pl. 1, fig. 1.

Material: 75 specimens, greatest diameter 1.00 mm; alveoles non-bifurcating, d/b=5; wall thickness between alveoles 14 μm.

Remarks: ADAMS (1968) distinguished his new species on its closely spaced, narrow alveoles, which were present in a single series and did not bifurcate peripherally as they would have done in the type species of this genus, *A. howchini* (SCHLUMBERGER). MATSUMARU (1996, pl. 84, figs 5, 7) illustrated specimens with narrow simple alveoli as *A. howchini*. However, *A. howchini* possess alveoles which bifurcate and MATSUMARU's specimens should be referred to as *A. asmariensis*. Pl. I, figs 1-2 are transitional forms where the alveoles in the later whorls are simple and undivided as in *A. asmariensis,* while the first whorls have thicker, bifurcating and more complex alveoli as in *A. howchini*.

Distribution: ADAMS (1968) obtained the type specimens of *A. asmariensis* from the post-nummulititic Asmari Limestone of Luristan, Iran. We consider these beds probably to be Late Oligocene in age. MATSUMARU (1996) recorded his specimens from the Lower Te, Chattian of the Minamizaki Limestone of Japan. BOUDAGHER-FADEL *et al.* (2000b) recorded similar forms from Sabah, North-East Borneo, from samples which also contained *Miogypsinoides dehaarti* VAN DER VLERK, which does not extend below the Upper Te (ADAMS, 1970) and which we believe to range from the middle Upper Te into the lower Tf1 (Aquitanian to latest Burdigalian). Therefore, *A. asmariensis* has a Tethyan stratigraphic range from Late Oligocene (Chattian) to Early Miocene (Burdigalian) and we believe it to be immediately ancestral to *A. howchini* of the later Early Miocene (Upper Burdigalian-Lower Langhian). It is common here in the Tf1 (Langhian) of Kali Sambi (SAM) in the Gunung Sewu area of South Central Java; sometimes occurring with *Katacycloclypeus annulatus*.

Austrotrillina howchini (SCHLUMBERGER, 1893)
Pl. I, fig. 3

1893. *Trillina howchini* SCHLUMBERGER, p. 119, text-fig. 1, p. 120, text-fig. 2, pl. 3, fig. 6.
1987. *Austrotrillina howchini* SCHLUMBERGER.- BARBERI *et al.*, pl. 7, fig. 6.

Material: 35 specimens, greatest diameter 1.00 mm; alveoles bifurcating, d/b=4; wall thickness between alveoles 10 μm.

Remarks: *A. howchini* not only has chambers which are triangular in transverse section, but also (and most importantly) has alveoles which bifurcate, the interior alveoles being divided peripherally into smaller alveoles, while those of *A. asmariensis* are narrow, non-bifurcating and closely packed. We believe that the narrow alveoles of *A. asmariensis* are direct ancestors of the bifurcating alveoles of *A. howchini*. Pl. I, figs 1-2 show advanced *A. asmariensis,* which has started gradually to acquire more complex and bifurcating alveoles in the walls of the early whorls. The last whorl still has simple alveoles. Pl. II, fig. 3 shows fully developed *A. howchini* which is also gaining triangularity.

An excellent section photographed by MATSUMARU (1996, pl. 84, fig. 3) from the Early "Te Stage" has broad alveoles in a single series and is referable to *Alveolina striata* TODD & POST, not *A. howchini* (SCHLUMBERGER) as identified by MATSUMARU (*op. cit.*).

Distribution: *A. howchini* was first described from the "Tertiary" of Australia. It was figured by Barberi *et al.* (1987) from the Tf1 (Upper Burdigalian-Langhian) of the carbonate sequence of the island of Sumbawa, Indonesia. Specimens are figured here from the upper Tf1, top of the Langhian of Kali Sambi section (SAM) in the Gunung Sewu area of South Central Java.

Superfamily Alveolinacea Ehrenberg, 1839
Family Alveolinidae Ehrenberg, 1839
Genus *Flosculinella* Schubert, 1910
Flosculinella bontangensis Rutten, 1913
Pl. I, fig. 4

1913. *Flosculinella bontangensis* Rutten, p. 221, pl. 14, figs 1-3, p.222, text-fig. 1, p. 223, text-fig. 2.
1987. *Flosculinella* cf. *bontangensis* Rutten.- Barberi *et al.*, pl. 7, fig. 1, 7-9.

Material: 92 specimens, greatest diameter 2 mm.
Remarks: *F. bontangensis* has an elongate test similar to *Borelis pygmaeus* Hanzawa, 1930 but with double rows of chamberlets.
Distribution: *F. bontangensis* was first described from the "Burdigalian" of Borneo. It was figured by Barberi *et al.* (1987) from the Tf1 (Upper Burdigalian-Langhian) of the carbonate sequence of the island of Sumbawa, Indonesia. Specimens figured here are from the Tf1, upper Burdigalian-Langhian and the Tf2, Serravallian of Kali Sambi section (SAM) in the Gunung Sewu area of South Central Java.

Superfamily Nummulitacea De Blainville, 1827
Family Nummulitidae De Blainville, 1827
Genus *Katacycloclypeys* Tan Sin Hok, 1932

Tan Sin Hok (1932), in his description of *Katacycloclypeus*, assigned it as a new subgenus of *Cycloclypeus*. However, there is no direct evidence of intergradation, either in the modelling of the test nor in the embryonic structure between *Cycloclypeus* and *Katacycloclypeus*, also the stratigraphic range is quite different. *Katacycloclypeus* is confined to the Tf1-Tf2, Mid Miocene of the Indo-Pacific, while *Cycloclypeus* ranges from the Oligocene to Recent throughout all the tropics. Therefore we consider the two forms to be generically different.

Katacycloclypeus annulatus (Martin, 1880)
Pl. I, figs 5-7

1880. *Cycloclypeus annulatus* Martin, p. 157, pl. 28, figs 1a-1i.
1916. *Cycloclypeus annulatus* Martin.- Douvillé, p. 30, pl. 6, figs 2, 3 (not pl. 5, fig. 6; pl. 6, figs 1-4).
1963. *Cycloclypeus (Katacycloclypeus) annulatus* (Martin).- Cole, p. E19, pl. 6, fig. 13, 14; pl. 7, fig. 7; pl. 8, figs 4-6, 8-11; pl. 9, figs 14, 17.
2000. *Katacycloclypeus annulatus* (Martin).- BouDagher-Fadel & Wilson, p. 157, pl. 3, fig. 8, pl. 4, fig. 2.

Dimensions: Observed maximum diameter up to 6 mm (even on a broken specimen), 65 specimens from this work; Diam I/ Diam. II = 0.75.
Remarks: This species as typified by Martin, 1880, pl. 28, figs 1a and 1d, is characterised in having a large, thin test with a central umbo surrounded by several annular inflations of the solid lateral walls, each inflation is separated by broad, flat annuli from the next annular inflation (Pl. I, fig. 6). It also has a clearly trilocular embryont (Pl. I, fig. 5).
Distribution: *K. annulatus* was first described from the Early Miocene of West Java, Indonesia. Cole (1963) reported it from the Tertiary of Guam and Fiji. Similar forms were found in the Serravallian, Tf2, of eastern Sabah and the Darai Limestone of Papua New Guinea (BouDagher-Fadel *et al.,* in preparation) while those of BouDagher-Fadel & Wilson (2000) came from the lower Mid Miocene, Tf2 (early Serravallian) of Kalimantan. In this study it is found in the Tf1 (Langhian) and Tf2 (Serravallian) of Djatirago section (TAN) and Kederakon section (WB13) in the Gunung Sewu area of South Central Java.

Katacycloclypeus martini (van der Vlerk, 1923)
Pl. I, fig. 8-9, Pl. II, figs 1-7

1923. *Cycloclypeus martini* van der Vlerk, p. 139, pl. 1, figs 1, 2, pl. 2, figs 3, 4.
1932. *Cycloclypeus (Katacycloclypeus) transiens* Tan Sin Hok, p. 19, table II.
1945. *Cycloclypeus (Katacycloclypeus) martini* van der Vlerk.- Cole, p. 283, pl. 20, figs I, J.
1957. *Cycloclypeus (Katacycloclypeus) transiens* Tan Sin Hok.- Cole, p. 335, pl. 101, figs 11-4.
1963. *Cycloclypeus (Katacycloclypeus) martini* van der Vlerk.- Cole, p. E20, pl. 6, figs 1-4.

Material*:* Observed maximum diameter up to 7mm even on a broken specimen, 60 specimens from this work, Diam. I/Diam. II = 2.
Remarks: *K. martini* was typified by van der Vlerk (1923, pl. 2, figs 3, 4). It has a broad central umbo surrounded by few, broad, inflated annuli, not separated by broad depressions. It also differs from *K. annulatus* in having a two-chambered embryont, the third chamber present in *K. annulatus* being greatly reduced in size; a protoconch and a deuteroconch, as shown here in Pl. I, fig. 8 and Pl. II, fig. 3. In axial section it has very narrow constrictions with very broad swellings, the ratio being 1/4. Some specimens as in Pl. II, fig. 6 have very clear pillars similar to the pillared *K. transiensis*. We consider the latter as a variety of *martini* (Cole, 1957, pl. 101, figs 11-14, figured the same forms but with pillars as *K. transiens*). We think that there was an evolutionary sequence from *Cycloclypeus* to *Katacycloclypeus annulatus* (with widely separated annular inflations and a trilocular embryont)

and then to *K. martini* (with broad closely spaced annular inflations and a trilocular embryont). Both became extinct virtually simultaneously at the top of Tf2. Pl. I, fig. 9 is a broken specimen which shows the transition between *K. annulatus* and *A. martini*.

Distribution: This species was first described by van der Vlerk from the Early Miocene of Goenoeng Mlendong, near Kari Orang, Koeti, East Borneo. It was reported by Cole (1963) from Lau, Fiji (1945) and from Guam. Similar forms were found in the Serravallian, Tf2, of eastern Sabah and the Darai Limestone of Papua New Guinea (BouDagher-Fadel *et al.,* in preparation). In this study, it is figured from the Tf2 (Serravallian) of Kali Sambi section (SAM), Djatirago section (TAN), Kederakon section (WB) and Sadeng section (SAD) in the Gunung Sewu area of South Central Java.

Superfamily Asterigerinacea d'Orbigny, 1839
Family Lepidocyclinidae Scheffen, 1932
Subfamily Lepidocyclininae Scheffen, 1932
Genus *Lepidocyclina* Gümbel, 1870 *emend.* BouDagher-Fadel & Banner, 1997
Lepidocyclina delicata Scheffen, 1932
Pl. III, fig. 8

1932. *Lepidocyclina delicata* Scheffen, p. 18, pl. 1, fig. 4.
2000. *Lepidocyclina delicata* Scheffen.- BouDagher-Fadel & Wilson, p. 153, pl. 1, fig. 5.
2000b. *Lepidocyclina delicata* Scheffen.- BouDagher-Fadel *et al.*, p. 348, pl. 1, figs 7-8.

Material: 56 specimens from this work, maximum measured length 20 mm, centrum cubiculae (or "lateral chamberlets", see Biostratigraphic Introduction) up to 29 μm high and 78 μm broad; microgranular pillars maximum thickness 86 μm; hyaline pillars maximum thickness 57 μm.

Remarks: *Lepidocyclina delicata* is characterised by the dark, very finely, microgranular pillars which are restricted to the inner lateral layers of the centrum only. Beyond these pillars, hyaline, glossy radial pillars are to be found radiating from the inner layers of the centrum to the outer surface.

Distribution: *L. delicata* Scheffen ranges from middle Tf1 to Tf2 (Langhian to early Serravallian). It was first described from Java, Indonesia. BouDagher-Fadel *et al.* (2000b) record the occurrence of *L. delicata* in the Tf2 of the Darai Limestone in central south Papua-New Guinea. It has been found in Kalimantan with *Katacycloclypeus* in the early Serravallian (Tf2) by BouDagher-Fadel & Wilson (2000). In this study, it is figured from the Tf2 (Serravallian) of Sadeng section (SAD) in the Gunung Sewu area of South Central Java.

Lepidocyclina stillafera Scheffen, 1932
Pl. III, fig. 9

1932. *Lepidocyclina stillafera* Scheffen, p. 17, pl. 1, fig. 2.
2000. *Lepidocyclina stillafera* Scheffen.- BouDagher-Fadel & Wilson, p. 154, pl. 1, fig. 7.

Material: 60 specimens from this work, maximum measured length 3 mm; centrum cubiculae up to 29 μm high and 44 μm broad; pillars maximum thickness 35 μm.

Remarks: This species is characterised by short, club-shaped pillars scattered throughout the vertical section of the test. The pillars arise after two or three layers of cubiculae have been formed and then extend to the surface of the test.

Distribution: This species was first described from west Java Indonesia. BouDagher-Fadel & Wilson reported this species from the Tf1 of late Burdigalian to Langhian age, of eastern Borneo, Kalimantan. In this study, it is found in the Tf2 (Serravallian) of Kali Baksoko section (BAK) in the Gunung Sewu area of South Central Java.

Lepidocyclina stratifera Tan Sin Hok, 1935
Pl. III, fig. 3

1935. *Lepidocyclina stratifera* Tan Sin Hok, p. 9, pl. 1 (4), figs 1-3, pl. 2 (5), fig. 11, pl. 3 (6), fig. 9, pl. 4 (7), fig. 1, pl. 1, fig. 1.
1987. *Lepidocyclina (Nephrolepidina) stratifera* Tan Sin Hok.- Barberi *et al.*, pl. 4, figs 4, 11.
2000a. *Lepidocyclina (Nephrolepidina) stratifera* Tan Sin Hok.- BouDagher-Fadel & Wilson, p. 154, pl. 1, fig. 3, pl. 2, fig. 6.

Material*:* 85 specimens from this work, maximum measured length 4 mm, centrum cubiculae up to 40 μm high and 80 μm broad; pillars maximum thickness 160 μm.

Remarks: *L. stratifera* has a biconvex test which has many layers of low cubiculae in which their platforms are as thick or thicker than the cubicular lumena. Club-shaped hyaline pillars are developed from the outer periphery of the centrum to the surface of the test.

Distribution: *L. stratifera* was first described from Java, Indonesia being found together with *Miogypsina, Katacycloclypeus* and *Trybliolepidina*, an assemblage characteristic of middle Serravallian, Tf2 (see BouDagher-Fadel & Banner, 1999). Barberi *et al.* (1987) reported *L. stratifera* from the Tf1 (Burdigalian-Serravallian) of the carbonate sequence of the Island of Sumbawa, Indonesia. It was described by BouDagher-Fadel & Wilson (2000a) in the Tf1 of late Burdigalian to Langhian age, of eastern Borneo, Kalimantan. In this study, it is found in the Tf1 (Upper Burdigalian) and Tf2 (Serravallian) of Kali Baksoko section (BAK) in the Gunung Sewu area of South Central Java.

Subgenus *Lepidocyclina (Nephrolepidina)* Douvillé, 1911

emend. BouDagher-Fadel & Banner, 1997
Lepidocyclina (Nephrolepidina) oneatensis Cole, 1945
Pl. III, fig. 1

1945. *Lepidocyclina (Eulepidina) oneatensis* Cole, p. 292, pl. 26, figs A-J, pl. 28, fig. H.
1987. *Lepidocyclina (Nephrolepidina) cf. sumatrensis* (Brady).- Barberi *et al.*, pl. 3, fig. 8.
2000. *Lepidocyclina (Nephrolepidina) oneatensis* Cole.- BouDagher-Fadel *et al.*, p. 349, pl. 2, fig. 4.

Material : 62 specimens, greatest A-form diameter 8 mm ; centrum cubiculae up to 50 μm high and 200 μm broad ; lateral chamberlet walls maximum thickness 140 μm.

Remarks : Although Cole (1945) referred this species to the "subgenus" *Eulepidina*, the equatorial section which he figured (1945, pl. 26, figs A-D) showed the protoconch to be subquadrate (*sensu* BouDagher-Fadel & Banner, 1997), or "trybliolepidine" (*sensu* van der Vlerk & Postuma, 1967) and not that of the genus *Eulepidina.*

The biconvex and broadly flanged test possesses no true pillars but the vertical walls separating vertical stacks of lateral chamberlets (cubiculae) are commonly thickened, producing dichotomising and anastomosing lateral thickenings of characteristic appearance.

The specimen figured by Barberi *et al.* (1987) referred to forms as *L. (N.) sumatrensis* but in fact it has the anastomosing lateral thickenings of *L. (N.) oneatensis.*

Distribution *:* This species was first described as the form with the subquadrate protoconch from the Tf ("upper part of the lower Miocene") of Fiji (Oneata Island). Barberi *et al.* (1987) figured similar specimens from the Upper Te and Tf1 (Burdigalian-Serravallian). The specimens of BouDagher-Fadel *et al.* (2000b) were found in the Gomantong Limestone of the Upper Te, Late Oligocene-Early Miocene, of North East Borneo. In this study, it is found in the Tf1 (Upper Burdigalian) and Tf2 (Serravallian) of Kali Sambi section (SAM) in the Gunung Sewu area of South Central Java.

Lepidocyclina (*Nephrolepidina*) *parva* Oppenoorth, 1918
Pl. III, fig. 7

1918. *Lepidocyclina (Nephrolepidina) parva* Oppenoorth, p. 255, pl. 8, figs 11-12, pl. 9, fig. 9.
1957. *Lepidocyclina (Nephrolepidina) verrucosa* Scheffen.- Cole, p. 345, pl. 105, figs 11-17.

Material : 62 specimens from this work, maximum measured length 3.5 mm, centrum cubiculae up to 50 μm high and 175 μm broad ; lateral chamberlet walls maximum thickness 37 μm ; megalospheric nepiont ca. 225 μm.

Remarks : This species possesses heavy pillars which are scattered over the biconvex test ; it does not have the very heavy pillars and elongate cubiculae of *L. (N.) brouweri* (see BouDagher-Fadel & Lord, 2000). *L. (N.) parva* is distinctly different from *L. (N.) verrucosa* Scheffen, in that the latter possesses a single circle of strong pillars at the limits of the centrum of the test, so that, in axial section, the flattened surface of the centrum is delimited laterally by single, strong pillars.

Cole (1957, pl. 105, figs 11-17) referred to specimens from south Celebes as *L. (N.) verrucosa,* however, they lack the characteristics of the latter and they should be placed in *L. (N.) parva.*

L. (N.) angulosa Provale is very similar in structure to *L. (N.) parva* in that both possess a crown of strong pillars surrounding a flattened, pillar-free centrum. However, *L. (N.) angulosa* has a much broader, flatter centrum. The two taxa do not overlap morphologically or in range and no intermediate taxa have ever been recorded.

Distribution *:* Cole's specimens (1957, pl. 105, figs 11-17) were obtained from the upper Te of the south Celebes. In this study, it is found in the Tf1 (Upper Burdigalian) and Tf2 (Serravallian) of Kederakon section (WB) in the Gunung Sewu area of South Central Java.

Lepidocyclina (*Nephrolepidina*) *rutteni quadrata* BouDagher-Fadel & Banner, 1997
Pl. III, figs 4, 5

1923. *Lepidocyclina (Nephrolepidina) rutteni* van der Vlerk, p. 17, pl. 3, fig. 4a (not figs 1-4b-4f).
1997. *Lepidocyclina (Nephrolepidina) rutteni quadrata* BouDagher-Fadel & Banner, p. 9.

Material : 62 specimens from this work, maximum measured length 4 mm ; maximum measured length 3.5 mm, centrum cubiculae up to 54 μm high and 90 μm broad ; megalospheric nepiont ca. 200 μm, Diam. I/ Diam. II = 0.6.

Remarks : Our specimens have a quadrate proloculus similar to that figured by van der Vlerk (1924, pl. 3, fig. 4c) and should be recorded as a subspecies *quadrata* in accordance to the rules recommended by BouDagher-Fadel & Banner (1997).

Distribution : *L. rutteni s.l.* was first described from the "Vindobonian" of Java, Indonesia. In this study, the quadrate forms of *L. rutteni* are found in the Tf2 (Serravallian) of Kali Sambi section (SAM) in the Gunung Sewu area of South Central Java.

Lepidocyclina (*Nephrolepidina*) *sumatrensis* (Brady, 1875)
Pl. III, fig. 6

1875. *Orbitoides sumatrensis* Brady, p. 536, pl. 14, fig. 3a-c.
1957. *Lepidocyclina (Nephrolepidina) sumatrensis* (Brady).- Cole, p. 343, pl. 104, figs 1-9, pl. 105, fig. 18, pl. 106, fig. 5, pl. 109, figs 1-3.
1983. *Lepidocyclina (Nephrolepidina) sumatrensis* (Brady).- Chaproniere, p. 41, pl. 3, figs 11, 12, pl. 5, figs 9-12, pl. 6, figs 1-10.

1984. *Lepidocyclina (Nephrolepidina) sumatrensis* (Brady).- Chaproniere, p. 66, pl. 10, figs a-c, pl. 22, fig. 14, pl. 23, figs 1-7, pl. 26, figs 15, 16, fig. 21.
1987. *Lepidocyclina (Nephrolepidina)* cf. *sumatrensis* (Brady).- Barberi *et al.*, pl. 5, fig. 3, pl. 6, fig. 4.
2000. *Lepidocyclina (Nephrolepidina) sumatrensis* (Brady).- BouDagher-Fadel & Wilson, p. 156, pl. 2, fig. 4.
2000b. *Lepidocyclina (Nephrolepidina) sumatrensis* (Brady).- BouDagher-Fadel *et al.*, p. 352, pl. 3, fig. 2.

Material: 78 specimens from this work; greatest A-form diameter 2 mm; centrum cubiculae up to 34 μm high and 138 μm broad; pillars maximum thickness 69 μm; megalospheric nepiont ca. 310 μm; greatest B-form diameter 5 mm; centrum cubiculae up to 51 μm high and 310 μm broad; pillars maximum thickness 138 μm.

Remarks: The syntypes extant in the Natural History Museum have been examined. The whole specimen (NHM P36578) is the syntype drawn by Brady (1875, pl. 14, fig. 3a, b) and is contained in a sealed slide. The thin section partly drawn by Brady (1875, pl. 14, fig. 3c) is a section cut parallel to the equatorial plane, through the lateral chamberlets (cubiculae) (NHM P36585) but not through the median layer. There is one more syntype (NHM P 365690) of a similar section, not in the median layer, but this was broken on sectioning. None of these specimens is really suitable for the purpose, but we propose designating P.36578 as lectotype. The Brady specimens are not figured here.

This strongly biconvex species with a narrow equatorial flange was said by Brady (1875, p. 536) to be "granular" on its surface, which suggests the presence of many small, narrow pillars. This is confirmed by the examination of the syntypes. He also (*loc. cit.*) noted that the embryont was very small, but the syntypes indicate that the megalospheric embryont was never seen by Brady. However, BouDagher-Fadel *et al.* (2000b, pl. 3, fig. 2) figured a megalospheric form accompanied by a larger specimen, which may well be its microspheric partner in the same thin section. The characteristics of the megalospheric and microspheric forms are also well shown by Cole (1957, pl. 104, figs 1-9).

Distribution: Brady (1857) described *L. (N.) sumatrensis* from the "Early Tertiary" of Nias Island, west coast of Sumatra. Cole (1957) obtained his specimens from the Upper Te "Letter Stage" of Saipan, Chaproniere (1983, 1984) from the Oligocene-Miocene of Australia, while those of BouDagher-Fadel & Wilson (2000) were from the Tf1, upper Burdigalian to Langhian, of eastern Borneo, Kalimantan. The figured specimens of BouDagher-Fadel *et al.* (2000b) were from the Gomantong Limestone, upper Upper Te, Burdigalian, of north Borneo. In this study, *L. (N.) sumatrensis* is found in the Tf1 (Upper Burdigalian) and Tf2 (Serravallian) of Rongkop section (SAD) in the Gunung Sewu area of South Central Java.

Family Miogypsinidae Vaughan, 1929
Genus *Miogypsina* Sacco, 1893
Miogypsina kotoi Hanzawa, 1931
Pl. III, fig. 2

1931. *Miogypsina kotoi* Hanzawa, p. 154, pl. 25, figs 14-18.
2000. *Miogypsina kotoi* Hanzawa.- BouDagher-Fadel & Wilson, p. 157, pl. 3, figs 1-2.

Material: 98 specimens from this work, maximum measured length 2 mm Diam. I/Diam. II = 0.8.

Remarks: This species is distinguished in having ogival median chambers, small thick-walled, but strongly convex cubiculae; it has a biserial nepiont which is strongly asymmetrical.

Distribution: *Miogypsina kotoi* was first described from the Burdigalian of Japan. BouDagher-Fadel & Wilson (2000) reported it from the Tf1 late Burdigalian to Langhian, of eastern Borneo, Kalimantan. In this study, it is found in the Tf1 (Upper Burdigalian) and Tf2 (Serravallian) of Djatirago (TAN) the Gunung Sewu area of South Central Java.

VI. BIOSTRATIGRAPHICAL CORRELATION

The migration of the lepidocyclinids out of the Caribbean and into the main Tethyan ocean is an important event in the development of Indo-Pacific faunas, and appears to have occurred immediately after (or during) the mid Oligocene eustatic sea level fall. The latest published data (e.g. Berggren *et al.,* 1995) places this event in the middle of nannofossil Zone NP 24, the same age as the Pelang formation in Central Java. The mid-Oligocene sea level fall was possibly the event that shrank the open ocean barriers and/or, maybe more importantly, changed oceanic circulation to allow migration of these forms out of the Caribbean area.

The established view is that the arrival of the *Lepidocyclina*s in Asia was an early to mid Oligocene event, with some overlap of these forms with *Nummulites* (to give the Td faunas).

Many authors have suggested, based on the few reports of west African Early Oligocene lepidocyclines, that the migration was gradual, from west to east. We think that the earliest *Lepidocyclina (Nephrolepidina)* species in Tethys (from Iran to the Indo-Pacific) occurred in the Chattian but they were rare; it seems that they did not become widespread until the Aquitanian by which time *Lepidocyclina (Lepidocyclina)* had become extinct. *Lepidocyclina (L.)* of Tethys was almost certainly the direct descendant of *Lepidocyclina (L.)* of the Eocene and Oligocene of Central America but no intermediate forms are known.

In Central Java and Papua New Guinea there is less tectonic or facies contrast during the mid-Early Miocene period but the same faunal turnover can be seen. Not only do two locally important components of the larger foraminifera assemblages disappear but also there is subsequently a radiation of new forms. However, in eastern Indonesian and Papuan areas the relatively rare genus *Austrotrillina*, previously thought to be a Te marker, is seen to continue into the younger sediments. In addition some of the forms that radiated and became important in the Tf have occasional records alongside Te markers (e.g. *Flosculinella*, and *Marginopora*). The distinction between Te and Tf Letter Stages appears to become slightly less abrupt in areas away from the centre of Sundaland where there is maximum expression of the mid-Early Miocene tectono-stratigraphic event.

From the study of larger foraminifera in South Central Java Miocene larger foraminifera it became apparent that the top of the lower part of Lower Tf (Tf1) is defined by the extinction of the youngest species, *Austrotrillina howchini* (Pl. I, fig. 3), together with the extinction of *Flosculinella bontangensis* (Pl. I, fig. 4). *A. howchini* is rare in Sundaland after Te but frequent in Central Java and Papua New Guinea, where it survives until just after the *Orbulina* datum that is usually used to define the base Mid Miocene (BouDagher-Fadel & Banner, 1999). This extinction is here to mark the top of Tf1 (Fig. 3).

The fusiform miliolid *Flosculinella bontangensis* (Pl. I, fig. 4) grades into *Alveolinella* forms about the same time as the disappearance of *Austrotrillina*, occurring alongside *Alveolinella praequoy* within the upper part of Lower Tf2 (see Fig. 3). Also in Tf1 are forms such as *Miogypsina kotoi* (Pl. III, fig. 2) and the rare (especially in western Indonesia/Sundaland) *Pseudotaberina malabarica* (see Fig. 3). *Lepidocyclina delicata* (Pl. III, fig. 8), *L. stillafera* (Pl. III, fig. 9) and *L. stratifera* (Pl. III, fig. 3), all distinct forms in axial sections, co-exist within the Tf1 assemblages and continue to flourish along the Tf2 new arrivals.

The sub-zone Tf2 is relatively short lived (less than 3 Ma compared to just over 5 Ma for Tf1) but is well represented in Southeast Asia, especially western areas, as regional low stand and early transgressive conditions developed into late transgression (fewer clastic sources, more drowned land areas) and prograding highstand, with common carbonate development. Apart from the absence of *Miogypsinoides*, which faded away from faunas through the later Early Miocene, and *Austrotrillina*, which was never a major faunal component except in very specific facies, there are few features to distinguish Tf2 from Tf1. In Central Java a thick formational unit, the Dutch called the "Orbitoiden Kalk" or "OK" beds, represents the Tf2. It comprises larger foraminifera rich carbonates, usually interbedded with clastics, and containing an assemblage with *Lepidocyclina* spp., *Lepidocyclina (Nephrolepidina) rutteni quadrata* (Pl. III, figs 4, 5), *Miogypsina* spp., *Cycloclypeus* spp., *Katacycloclypeus martini, K. annulatus* and *Flosculinella bontangensis*.

The distinctive species *Katacycloclypeus annulatus* (Pl. I, figs 5-7) that evolved gradually from *Cycloclypeus*, is a common component of Tf2 assemblages. However, its occurrence in Central Java also overlaps (see above) with both *Miogypsinoides* as well as *Austrotrillina* in Tf1. On the other hand, it evolves in the Tf2 into *K. martini* (Pl. I, figs 8-9; Pl. II, figs 1-7). The two forms co-exist and disappear at the same time at the top of Tf2. The effects of top Tf2 are well illustrated in Central Java, and it is here that the extinction of the *Katacyclopeus annulatus, K. martini* and the miogypsinas (e.g. *Miogypsina kotoi*, Pl. III, fig. 2) and the whole faunal turnover can be best dated. The extinction of the genus *Katacycloclypeus*, often used as a subgenus of *Cycloclypeus*, is often used to define the top of "Letter Stage" Lower Tf, i.e. the top of Tf2 (BouDagher-Fadel & Banner, 1999), however, here the latter correlation is emended to extend the age of *Katacycloclypeus* (*K. annulatus*) down into the Tf1 (Langhian).

The Letter Stage Tf3 (or Upper Tf of some authors) is remarkable only by what is does not contain. Faunas of this age are depleted in larger foraminifera with only rare *Lepidocyclina,* sometimes *Cycloclypeus* and, in shallower settings, *Alveolinella quoyi, Marginopora, Operculina, Amphistegina* and a few other long ranging species. The end of the Tf Letter Stage was defined by BouDagher-Fadel & Banner (1999) on the extinction of *Lepidocyclina*.

The Letter Stages Tg and Th represent shallow marine biohermal carbonates that changed from mixed coral and coralline algal boundstones with larger foram grainstones to more dominant coral reefs with a marked increase in *Halimeda* green algae. The latter more often preserved in recognisable form, or as an increase in micrite and fine bioclastic products from the early breakdown of its aragonitic platelets. Larger foraminiferal grainstones are only rare after this event, as deeper photic *Cycloclypeus* facies or minor *Operculina/Amphistegina* or *Alveolinella* calcarenites. Most well and field sections encountering limestones of this later Miocene or Pliocene age in Southeast Asia do not sample rocks composed of larger foraminifera tests. Tertiary G is a period characterised by 35 to 45 % extant molluscs.

VII. PHYLOGENETIC RELATIONSHIPS

Like all fossils, from dinosaurs to dinoflagellates, the larger benthic foraminifera are biofacies bound, sometimes even regionally. They have biotopes closely associated with carbonate environments. Large scale changes in these biotopes occur in response to eustatic sea level fluctuations. They may be used throughout Tethys for biostratigraphic dating, but in regions of that area they may be more stratigraphically restricted than is true globally.

We believe that several lineages developed during the history of the evolution of *Lepidocyclina s.l.* (BouDagher-Fadel & Lord, 2000), *Miogypsina* (BouDagher-Fadel *et al.,* 2000a), and *Katacycloclypeus* and *Austrotrillina*

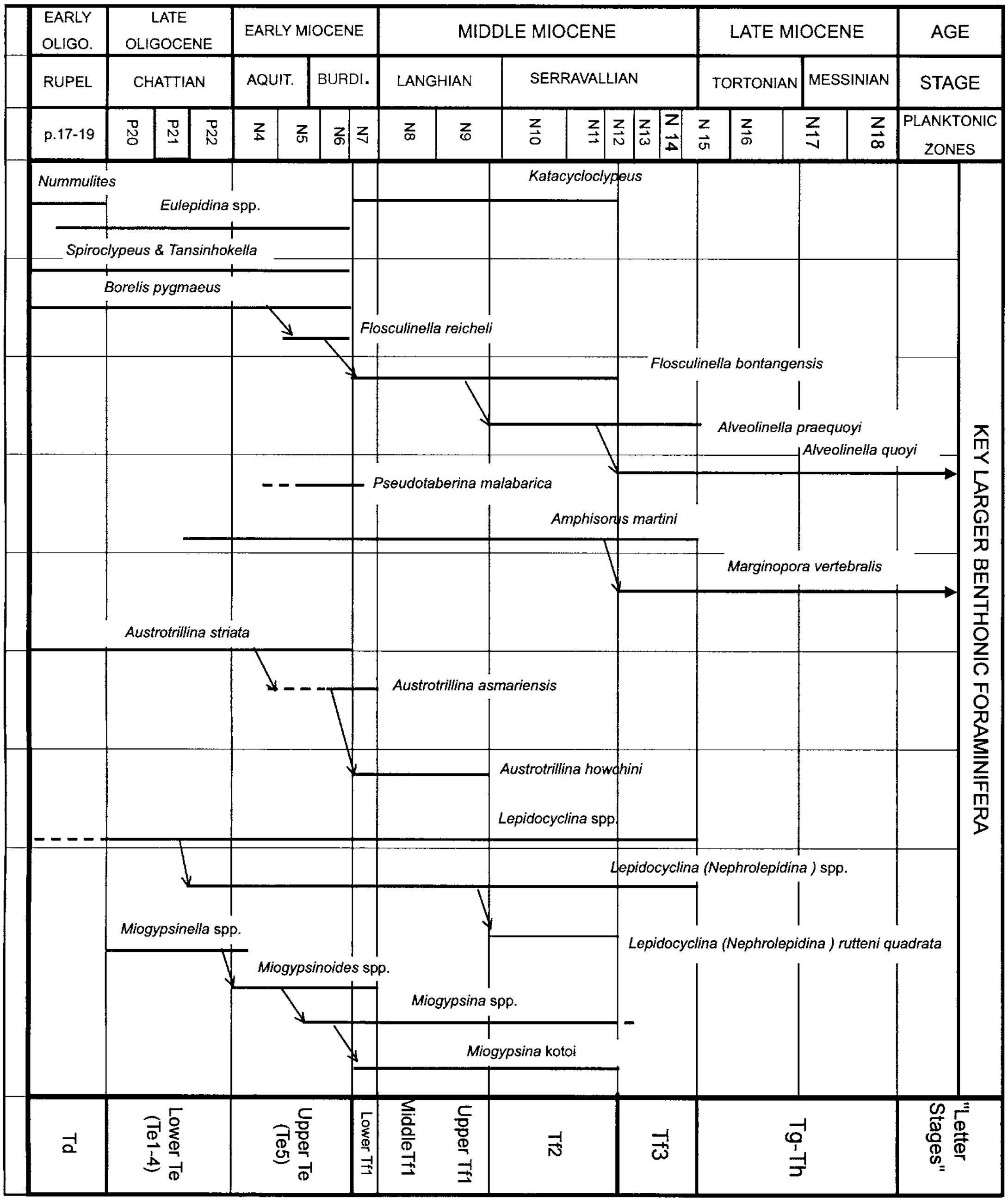


Fig. 3: Stratigraphic and phylogenetic distribution of the key larger benthic foraminiferal taxa in South Central Java. Planktonic foraminiferal zones modified from Banner & Blow (1965) and "letter stages" (Wonders & Adams, 1991) from BouDagher-Fadel & Banner, 1999) (not to scale).

(see Fig. 3) which have contrasting phylogenetic characteristics.

In the early stages of evolution of *Lepidocyclina s.l.*, the megalospheric and microspheric forms were similar in size and shape. However, in the interval high Te to Tf3 there was a marked development of large microspheric forms that bear few similarities with contemporary megalospheric forms, which were often smaller and less distinctive. In Tf3, for example, *L. gigantea* (Martin) became so large in Vietnam, Papua-New Guinea and East Africa that these microspheric lepidocyclinas characterize the so-called "Oyster Beds" in Vietnam. Their megalospheric partners are unknown but must have been small and undistinguished. Similar evolutionary patterns occurred in many lineages of *Lepidocyclina s.l.*, forming taxa such as *Lepidocyclina stillafera* (Pl. III, fig. 9) and *L. delicata* (Pl. III, fig. 8) with no confidently known megalospheric partners.

This evolutionary history curiously parallels that of the genus *Nummulites*. In the early and middle Eocene the microspheric and megalospheric generations of *Nummulites* were similar in size and shape but in the late Eocene to early Oligocene specimens of the microspheric generation were very large in size and dominate their (often associated) megalospheric partners. A famous example of this is the megalospheric *Nummulites fichteli* and the microspheric *Nummulites intermedius* which often occur together (see VLERK, 1929, p. 36, figs 30 a-b, 31 a-b; EAMES *et al.,* 1968, pl. 1). *Cycloclypeus* is a nummulitid with a nepionic morphology like *Heterostegina*, but with a final growth stage with cyclic chambers. The evolution of *Cyclocypeus* was studied in great detail by TAN SIN HOK (1932). However, the potential for biostratigraphic application of his detailed biometrical descriptions is severely limited by the uneven distribution of suitable *Cyclocypeus* material over the geological column, and also by the complex nature of the data. The oldest species would appear to be *C. koolhoveni*, possibly the direct ancestor of *C. oppenoorthi*. We note here that in general, the one *Cycloclypeus* lineage that could be continuous consists of species with very wide variations in internal morphological characters, and that the individual species, if at all separable, are very long-ranging. This, coupled with the fact that Recent *Cycloclypeus* are the deepest living larger foraminifera, is consistent with a model in which *Cycloclypeus* was only affected by the large mid-Oligocene sea level fall. However, in the Tf1 a lineage of *Cycloclypeus* evolved into forms with widely separated annular inflations and a trilocular embryont (*Katacycloclypeus annulatus*, Pl. I, fig. 5) which in turn gave rise in the Tf2 with a form with broad closely spaced annular inflations and a trilocular embryont (*K. martini*, Pl. I, fig. 8). *Katacycloclypeu*s is confined to the Tf1-Tf2, Upper Early Miocene to Mid Miocene of the Indo-Pacific, while *Cycloclypeus* ranges from the Eocene to Recent throughout all the tropics. It is suggested here that apparently, the annuli were no longer needed to focus the sparse sunlight at greater water depth into preferred areas of the equatorial layer and that, therefore, it seems likely that the top of Tf2 coincides with a sharp sea level drop in the Mid Miocene. It could be argued that the *Katacycloclypeus* morphotypes had ample time to migrate down slope to maintain their preferred water depth, but depth distribution was dictated by temperature rather than water depth, and the deeper water may have become too cold due to the cooling associated with the sea level fall.

Thus, the co-existence in Central Java and the apparent gradual evolution of *Cycloclypeus* to *Katacycloclypeus annulatus* (Pl. I, figs 5-7) and then to *K. martini* (Pl. I, figs 8, 9; Pl. II, figs 1-7), demonstrate clearly parallel evolutionary sequences. Primitive specimens of *K. martini* (Pl. I, fig. 9) showing the transition between both species occur together with *K. annulatus* in the same sample (e.g. sample TAN8). These specimens link the two species and demonstrate a gradual evolution from *K. annulatus* into *K. martini*. The evolutionary sequences mean that these evolved taxa must occur one after the other in the same sequence if one is sampling Papua, Indonesia or the Philippines. The division of the median chambers of *Cycloclypeus* and *Katacycloclypeus* (Pl. I, figs 5-9) has evolutionary parallels with the division of the cubiculae (or small chamberlets) of *Miogypsina* (Pl. III, fig. 2) where the illuminated chambers are also nests for diatoms (see BOUDAGHER-FADEL *et al.*, 2000). Each of the chambers cubiculae (or "lateral chamberlets" would act not only as a small convex lense for the focusing of sunlight, but could also act as greenhouse for the containment and development of symbiotic diatoms. The diatoms enable these forms to be competent in the supply of nutrients without pseudopodial activity in food-gathering (RÖTTGER, 1971).

The miliolid genus *Austrotrillina* (Pl. I, figs 1-3) is essentially a *Quinqueloculina* with a distinctly alveolar wall, presumably to harbour symbiotic algae. The evolution in the Indopacific realm of *A. pauciloculata - striata - asmariensis - howchini* (Pl. I, fig. 3) is a straightforward lineage with gradually increasing number

---

Plate I

Figs 1-2: *Austrotrillina asmariensis* ADAMS, transitional forms; the alveoli in the later whorls are simple and undivided as in *A. asmariensis,* while the first whorls are thicker, with bifurcating alveoli as in *A. howchini,* Kali Sambi, sample SAM2, **1**, x73. **2**, x66

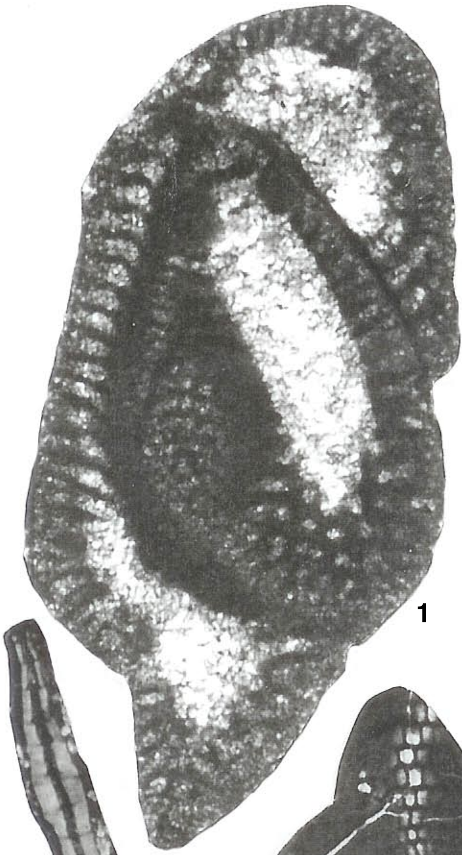
Fig. 3: *Austrotrillina howchini* (SCHLUMBERGER), advanced form showing the bifurcating alveoles and the more angular test, Kali Sambi, sample SAM23, X68.

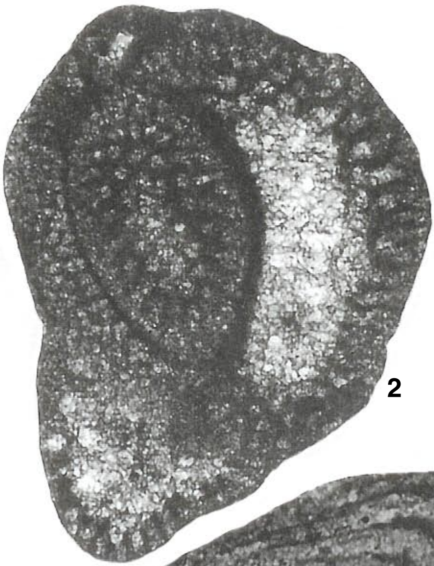
Fig. 4: Axial and equatorial sections of *Flosculinella bontangensis* (RUTTEN) showing two rows of chamberlets, Kali Sambi, sample SAM62, x30.

Figs 5-7: *Katacycloclypeus annulatus* (MARTIN), **5***,* Kali Sambi, sample SAM8, x45, **6,** Kederakon, sample WB13, x30, **7***,* Djatirago, sample TAN8, x33**.**

Figs 8, 9: *Katacycloclypeus martini* (VAN DER VLERK), Djatirago, sample TAN8, **8***,* x45, **9***,* A broken specimen showing the transition between *K. annulatus* and *K. martini,* Djatirago, sample TAN8, x33.

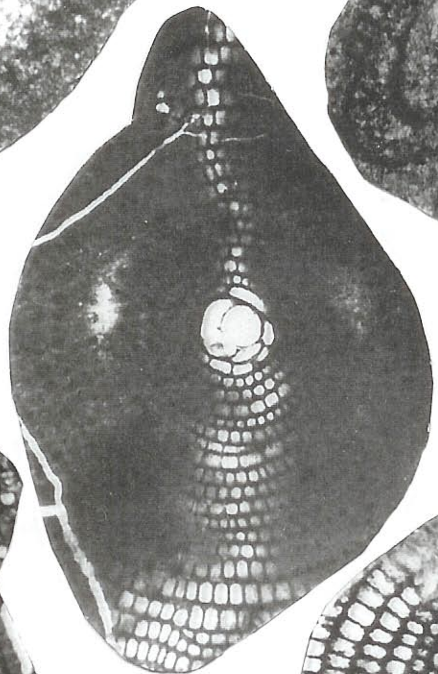
Plate I

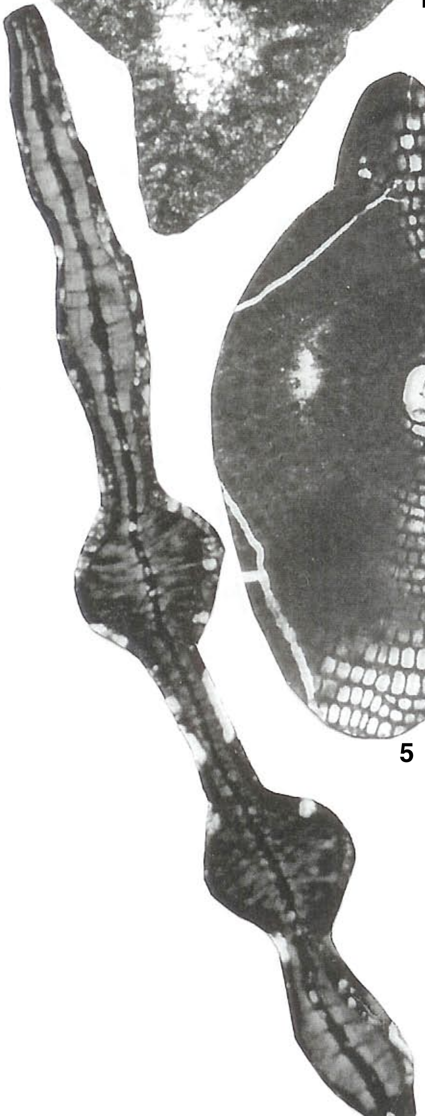

1

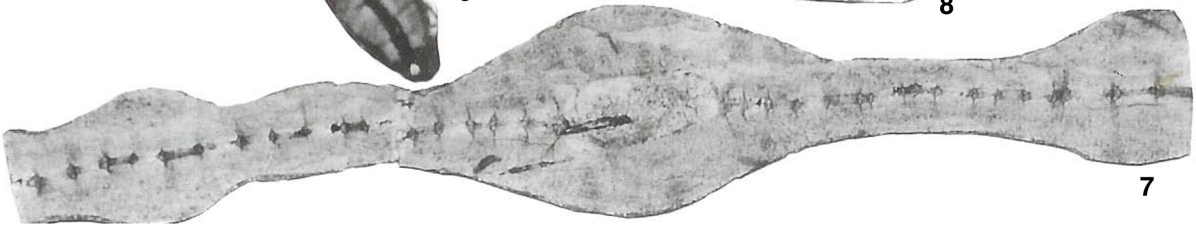

2

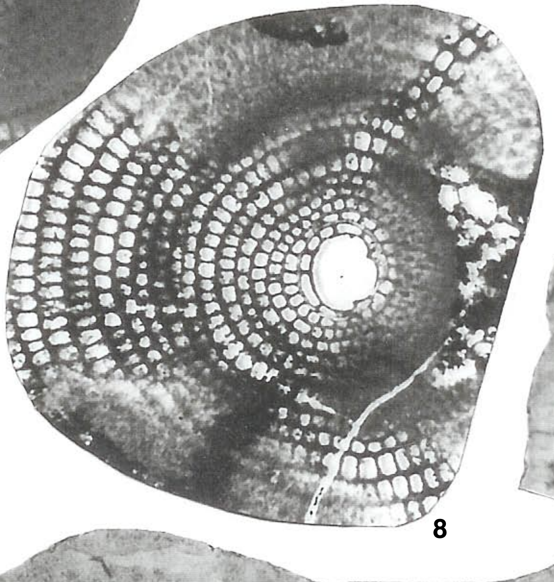

3

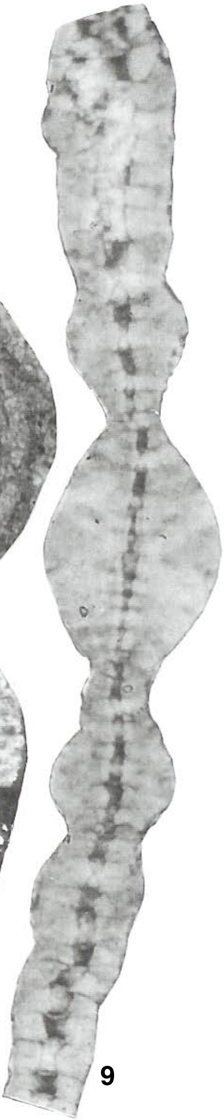

4


5


6


7


8


9

and complexity of alveolae. *A. asmariensis* is distinguished by its closely spaced, narrow alveoles, which were present in a single series and did not bifurcate peripherally as they would have done in *A. howchini* (Pl. I, fig. 3). In south central Java transitional forms (Pl. I, figs 1-2) where the alveoles in the later whorls are simple and undivided as in *A. asmariensis,* while the first whorls have thicker, bifurcating and more complex alveoli as in *A. howchini* co-exist with specimens typical of *A. asmariensis* with narrow alveoles. The gradual evolution from the primitive form *A. asmariensis* into more advanced form *A. howchini* occurred in the lower Tf1 (e.g. sample SAM2) and only the advanced form *A. howchini* persisted into the upper Tf1, where it disappears completely near the top.

BouDagher-Fadel & Banner (1999) summarised the ranges of the individual species in the context of "Letter Stages", and it would appear that the most distinct event is the extinction of the youngest species, *A. howchini* (Pl. I, fig. 3). This defines the top of the lower part of Lower Tf (Tf1), together with the extinction of *Flosculinella bontangensis* (Pl. I, fig. 4). In view of the lagoonal habitat of many miliolids, it would not at all be surprising if the extinction coincided with the onset of an early Mid Miocene sea level fall.

In the Te, the alveolinids included *Borelis pygmaeus,* in the upper Tf1 to Tf2 *Flosculinella bontangensis* and in the Tf3 *Alveolinella quoyi*. The Tf1 included the complex *Pseudotaberina* and in the Tf3 its analogue *Marginopora vertebralis*. In the Te to Tf1 the miliolids included species of the genus *Austrotrillina*. We believe that the lineage is a gradual evolution (Fig. 3) in which newly evolved taxa persisted to become contemporaneous with their descendants but occupied different ecological niches. For example, we believe that the evolution allowed palaeoenvironmental specialisation into separate distinct biocenoses and particular palaeoecological niches. There was, however, a gradual stratigraphic succession of species from a very simple Eocene *Borelis*, the only survivor of the terminal Mid Eocene extinction of alveolinids, mostly *Fasciolites*. The evolution has been very slow, with incremental increase in the length of the test from pole to pole, from globular trough ovoid to elongated spindle-shaped, and with an equally incremental increase in the number of secondary chamberlets ("mansardes") from zero in *Borelis* through one in *Flosculinella* to two or more in *Alveolinella*. BouDagher-Fadel & Banner (1999) summarised the ranges of individual species, and the series *Borelis pygmaeus* - *Flosculinella bontangensis* - *Alveolinella praequoyi* - *A. quoyi* seems to be the central evolutionary lineage (Fig. 3). *Borelis pygmaeus* persists to the top of the Te stage (BouDagher-Fadel & Banner, 1999) where it is suddenly replaced by *Flosculinella bontangensis* (Pl. I, fig. 4) which disappears in turn at the top of Tf2 (see Fig. 3). On the other hand, it evolved in the Upper Tf1 into *A. praequoyi* which continued in a parallel evolution to the top of Tf2. However, the occurrence of *Borelis pygmaeus* is environmentally controlled, as it is found mainly in very low hydrodynamic energy of a backreef (BouDagher-Fadel *et al.,* 2000b).

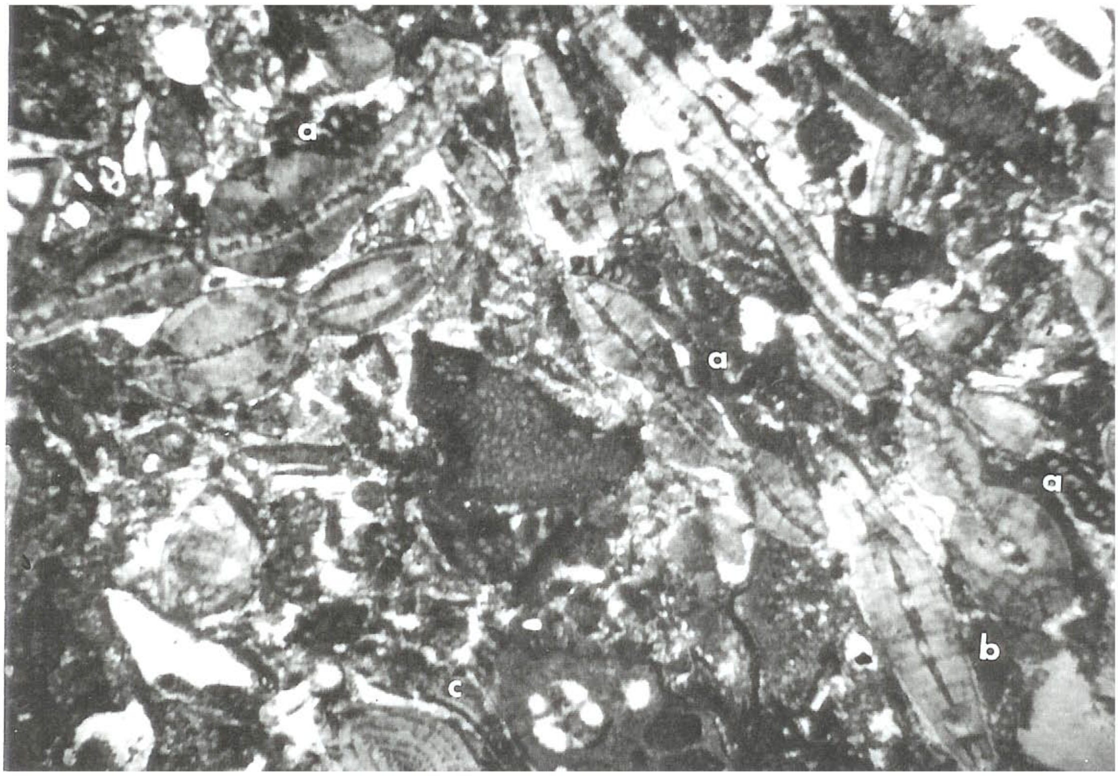
Recent alveolinids have a wide range in carbonate habitat, both in deep lagoons and in fore-reef settings, down to about 80 m. This, together with the fact that alveolinids are miliolids with a tolerance to salinity and temperature fluctuations, probably makes the group less sensitive to smaller sea level changes. We suspect that the Eocene alveolinids became extinct at the onset of Late Eocene rapid sea level changes, which led to the disappearance of vast carbonate platform to and lagoonal areas. In our own experience, Oligocene and Miocene alveolinids also had a wide range of habitats, but were particularly common in deeper lagoonal settings. Their response to sea level changes might therefore be similar to that of other miliolids, were it not that extinctions during sea level falls are unlikely due to the group's wide ecological niche. Obliteration of the lagoonal habitat during sea level falls may have caused reduction of population sizes and increase in the rate of evolution. The appearance of *Flosculinella* within the Early Miocene (Upper Te) and of *Flosculinella* in the early Mid Miocene (just before the top of Te) may have been the result of smaller population size coupled with an already existing tendency to increase the number of rows of chamberlets. Whatever the biological advantage of increased complexity in chamber subdivision may have been, it is a feature of alveolinid foraminifera from the Carboniferous onward and a well-established evolutionary trend. It may be analogous in function to the increased complexity of the *Austrotrillina* wall, probably increasing the efficiency of symbiosis with algae and diatoms.

Alveolinella praequoyi has early whorls akin to

Plate II

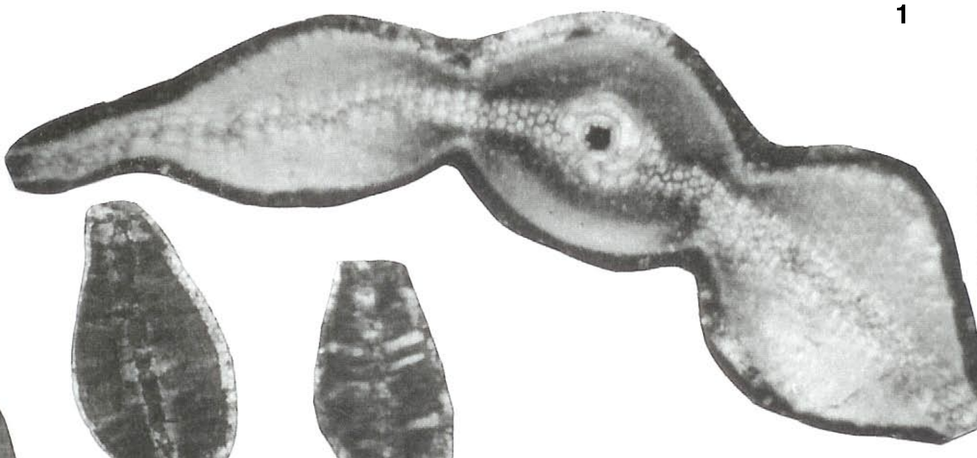
Figs 1-7: *Katacycloclypeus martini* (van der Vlerk), **1**. Thin section photomicrograph of assemblage type two where (a) *Katacycloclypeus martini* is dominant, (b) *Cycloclypeus* sp., (c) *Amphistegina* sp., Kali Sambi, sample SAM30, x24, **2**. Kali Sambi, sample SAM70, x65. **3**. Kali Sambi, sample SAM70, x38. *4*. Kali Sambi, sample SAM70, x56, **5-6**. specimens with pillars scattered all over their tests. **5.** Sadeng, sample SAD8, x41, **6.** Kali Sambi, sample SAM30, x42, **7**. Thin section photomicrograph showing continuous evolution with intermediate forms of (a) *Katacycloclypeus martini*, (b) *Amphistegina* sp., Kederakon, sample WB10, x20.

Plate II

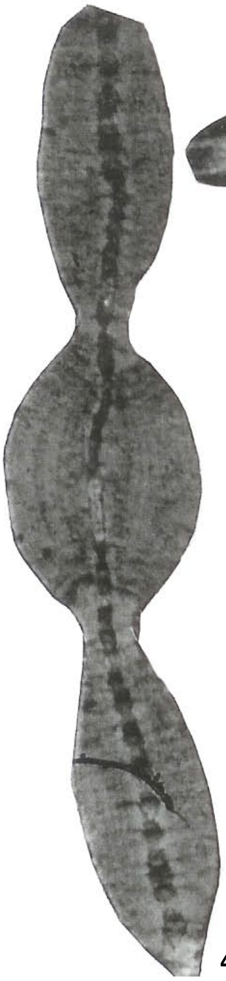


1

2



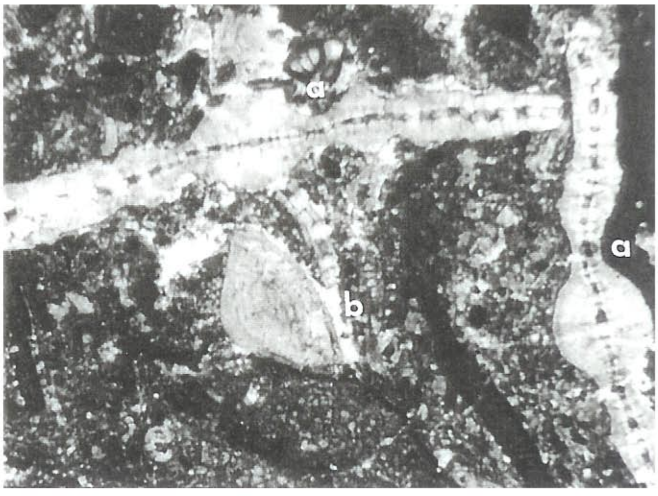
3



4

5

6



7

Flosculinella bontangensis (Pl. I, fig. 4) but in later whorls the chamberlets of each whorl are covered by at least 2 layers of smaller chamberlets. In *Alveolinella quoyi*, in the Tf3 stage all of the whorls have a multiple layer of chamberlets. Therefore, we here conclude that these are parallel lineages, which have each developed with the acquisition of an additional row of chamberlets in the *Borelis-Flosculinella* descent (see Fig. 3). This must have occurred at least twice during Te-Tf (early to Mid Miocene). This evolution is parallel to that described by BouDagher-Fadel & Lord (2000) in the evolution the *Lepidocyclina sensu lato*.

VIII. CONCLUSIONS

The extensive Miocene carbonate platform of the Gunung Sewu area of South Central Java (Fig. 1) was deposited in warm, very shallow-marine water (Lokier, 2000). Two distinctive assemblages are found, the first is Langhian (Tf1) and the second is Serravalian (Tf2) in age.

The base of the Langhian assemblage is dominated by miogypsinids (e.g. *Miogypsina kotoi*, *Miogypsinodella primitiva* BouDagher-Fadel *et al.* (2000, pl. 3, fig. 5), *Lepidocyclina* spp. and miliolids (e.g. *Austrotrillina asmariensis* (e.g. samples SAM2, SAM 23, BAK51, TAN74). At the top of Tf1, *A. asmariensis* grade gradually and is replaced eventually by *A. howchini*, the disappearance of which marks the boundary between Tf1 and Tf2 (SAM23). *Katacycloclypeus annulatus* is common in these assemblages. This assemblage indicates a low-energy backreef shelf environment where alveolinids, miogypsinids and miliolids were abundant. The lower Tf1 included the complex *Pseudotaberina.* In most examples, the studied larger benthic foraminifera were close to life position or had undergone only minor transportation and abrasion.

The Serravallian assemblage is dominated by *Katacycloclypeus martini, Lepidocyclina* spp., *Lepidocyclina (Nephrolepidina) rutteni quadrata* and alveolinids such as, *Flosculinella bontangensis* (e.g. SAM 30, Pl. II, fig. 1, SAM 62). *Katacycloclypeus annulatus* is also present but is rare. The top of this horizon is marked by the disappearance of *Katacycloclypeus* spp. This assemblage indicates a forereef shelf environment containing faunas dominated by cycloclypids, lepidocyclinids.

The region was one of patch reefs in which the areas attacked by oceanic swell may be called "forereef" and those sheltered from most oceanic wave energies may be called "backreef". The energy distribution produced characteristic carbonate lithofacies and allowed distinctive assemblages of foraminifera to flourish. The reef itself, being shallowest, produced characteristic bioherms and calcirudites of corals and algae, cemented by sparitic matrix as the lime muds were flushed away by wave action. The region was one of patch reefs in which the areas attacked by oceanic swell may be called "forereef" and those sheltered from most oceanic wave energies may be called "backreef". The energy distribution produced characteristic carbonate lithofacies and allowed distinctive assemblages of foraminifera to flourish. The reef itself, being shallowest, produced characteristic bioherms and calcirudites of corals and algae, cemented by sparitic matrix as the lime muds were flushed away by wave action. On either side of the reef, in the forereef and backreef shelves, biostromes of corals and algae were cemented by sparite and micrite carbonates. Distally from the reefs, coral debris diminished and micrite increased, cementing the calcarenitic biogenic debris. Below fair weather wavebase, micrite would accumulate which contained scattered larger foraminifera swept in from the reef shelves (*cf.* BouDagher-Fadel *et al.*, 2000b).

The stratigraphic value of all of these taxa is outlined in BouDagher-Fadel & Banner (1999). The latter had postulated that *Borelis pygmaeus* persists to the top of the Te stage. However, we now believe that it is suddenly replaced by *Flosculinella bontangensis* in the lower part of Tf1 by acquiring an additional row of chamberlets. On the other hand, BouDagher-Fadel & Banner (*op. cit.*) restricted *Flosculinella* to the Tf1, but as demonstrated here *F. bontangensis* persists into the Tf2 (e.g. sample SAM62) where it evolves into *Alveolinella praequoyi*.

We conclude that the Early Miocene carbonate platform

Plate III

Fig. 1 : *Lepidocyclina (Nephrolepidina) oneatensis* Cole, microspheric form, Kederakon, sample WB14, x50.
Fig. 2 : *Miogypsina kotoi* Hanzawa, sample TAN74, x31.
Fig. 3 : *Lepidocyclina stratifera* Tan Sin Hok, Kali Baksoko, sample BAK51, x25.
Figs 4-5 : *Lepidocyclina (Nephrolepidina) rutteni quadrata* BouDagher-Fadel & Banner, Kali Sambi, sample SAM70, **4**. axial section, x55, **5.** equatorial section showing the subquadrate protoconch, X65.
Fig. 6 : *Lepidocyclina (Nephrolepidina) sumatrensis* (Brady), Sadeng, sample SAD12, 55.
Fig. 7 : *Lepidocyclina (Nephrolepidina) parva* Oppenoorth, Kederakon, sample WB14, x40.
Fig. 8 : *Lepidocyclina delicata* Scheffen, Sadeng, sample SAD12, x25.
Fig. 9 : *Lepidocyclina stillafera* Scheffen, Kali Baksoko, sample BAK51, x53.

Plate III

of the Gunung Sewu area of South Central Java were deposited in areas sheltered from most oceanic wave energies. On the other hand, the Mid Miocene carbonate platform was deposited in areas attacked by oceanic swell. In both of these environments biostromes of coralline algae, and occasionally of corals, were cemented by sparite and micrite carbonates.

ACKNOWLEDGEMENTS

We would like to acknowledge the financial support of the London University South East Asia Research Group and its consortium companies. We are indebted to many people in Indonesia for their help during fieldwork, special thanks go to GRDC and Dr Fauzie Hasibuan. Terima kasih banyak. LASMO provided essential logistical support in Kalimantan. Professors A.R. Lord and F.T. Banner (Department of Geological Sciences, University College London) kindly commented on a preliminary version of this paper.

REFERENCES

Adams, C.G. (1968) - A revision of the foraminiferal genus *Austrotrillina* Parr. *Bulletin of the British Museum (Natural History) Geology*, 16 : 71-97.

Adams, C.G. (1970) - A reconsideration of the Indian Letter classification of the Tertiary. *Bulletin of the British Museum (Natural History) Geology,* 19 : 85-137.

Banner, F.T. & W.H. Blow (1965) - Progress in the planktonic foraminiferal biostratigraphy of the Neogene. *Nature,* London, 208 : 1164-1166.

Banner, F.T. & R.L. Hodgkinson (1991) - A revision of the foraminiferal subfamily Heterosteginінae. *Revista Española de Micropaleontologïa*, 23 : 101-140.

Barberi, F., B. Bigioggero, A. Boriani, M. Cattaneo, A. Cavallini, R. Cioni, C. Eva, R. Gelmini, F. Giorgetti, S. Iaccarino, F. Innocenti, G. Marinelli, D. Slejko & A. Sudradjat (1987) - The Island of Sumbawa : A major structural discontinuity in the Indonesian Arc. *Bolletino della Società Geologica Italiana,* 106 : 547-60.

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

BouDagher-Fadel, M.K., N.A. Ascaria, S. Lockier, J. Noad & A. Samuel (in prep.) - Late Oligocene - Earliest Miocene reefal limestones in the Far East. *Journal of Foraminiferal Research, Special Publication.*

BouDagher-Fadel, M.K. & F.T. Banner (1997) - The revision of some genus-group names in Tethyan Lepidocyclininae. *Paleopelagos,* 7 : 3-16.

BouDagher-Fadel, M.K. & F.T. Banner (1999) - Revision of the stratigraphic significance of the Tertiary "Letter-Stages". *Revue de Micropaléontologie,* 42 : 93-97.

BouDagher-Fadel, M.K. & A.R. Lord (2000) - The evolution of *Lepidocyclina* (*L.*) *isolepidinoides*, *L.* (*Nephrolepidina*) *nephrolepidinoides*, *L.* (*N.*) *brouweri* in the Late Oligocene-Miocene of the Far East. *Journal of Foraminiferal Research*, 30 : 71-76.

BouDagher-Fadel, M.K., A.R. Lord & F.T. Banner (2000a) - Some Miogypsinidae (Foraminifera) in the Miocene of Borneo and nearby countries. *Revue de Paléobiologie*, 19(1) : 137-156.

BouDagher-Fadel, M.K., J.J. Noad & A.R. Lord (2000b) - Larger foraminifera from Late Oligocene - Earliest Miocene reefal limestones of North East Borneo. *Revista Española de Micropaleontología,* 32 : 341-361.

BouDagher-Fadel, M.K. & M. Wilson (2000) - A revision of some larger Foraminifera of the Miocene of South-East Kalimantan. *Micropaleontogy,* 46 : 153-165.

Brady, H.B. (1875) - On some fossil foraminifera from the West-Coast district, Sumatra, *Geological Magazine,* new series 4 : 534-536.

Chaproniere, G.C.H. (1983) - Tertiary larger foraminiferids from the northwestern margin of the Queensland Plateau, Australia. *Bureau of Mineral Resources, Australia, Bulletin,* 217 : 31-57.

Chaproniere, G.C.H. (1984) - Oligocene and Miocene larger Foraminiferida from Australia and New Zealand. *Bureau of Mineral Resources, Australia, Bulletin,* 188 : 1-98.

Cole, W.S. (1945) - Larger Foraminifera of Lau Fiji. *Bulletins of Bishop Museum*, 181 : 272-297.

Cole, W.S. (1957) - Larger Foraminifera, *In* : Geology of Saipan, Mariana Islands : Paleontology. *Professional Papers U.S. Geological Survey,* U.S.A., 280-I(3) : 321-360.

Cole, W.S. (1963) - Tertiary larger foraminifera from Guam. *Professional Papers U.S. Geological Survey,* 403-E : E1-E28.

Cole, W.S. (1968) - More on variation in the genus *Lepidocyclina* (larger foraminifera). *Bulletins of American Paleontology*, 54 : 295-325.

Douvillé, H. (1916) - Les foraminifères des Couches de Rembang. *Sammlungen des Geologischen Reichs-Museums in Leiden*, series 1, 10 : 19-35.

Drooger, C.W. (1993) - Radial Foraminifera, Morphometrics and Evolution. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen,* Amesterdam, 41 : 1-241.

Eames, F.E., W.J. Clarke, F.T. Banner, A.W.H. Smout & W.H. Blow (1968) - Some larger foraminifera from the Tertiary of Central America, *Palaeontology*, 11 : 283-305.

Hanzawa, S. (1931) - Note on Tertiary foraminiferous rocks from the Kwanto Mountainland, Japan. *Science Reports of the Tohoku University*, 12 : 141-157.

Lokier, S.W. (2000) - The Miocene Wonosari Formation, Java, Indonesia : Volcaniclastic influences on carbonate platform development. PhD Thesis. Royal Holloway, University of London : 1-648.

Matsumaru, K. (1996) - Tertiary Larger Foraminifera (Foraminiferida) from the Ogasawara Islands, Japan. *Paleontological Society of Japan, Special Papers*, 36 : 1-239.

Martin, K. (1880) - *Die Tertiärschichten auf Java,* Lief 3, *Paläontologischen Theil* (1879-1880). *E.J. Brill* (ed.) : 150-164.

Oppenoorth, W.F. (1918) - Foraminiferen van de Noordkust van Atjeh. *Verhandlungen der Geologischen van de Mijnbouw in Nederland,* 2 : 249-258.

Rahardjo, W., Sukandarrumidi & H.M.D. Rosidi (1995) -

Geological Map of the Yogyakarta Sheet. Jawa. 1 :100,000. Geological Research and Development Centre.

Röttger, R. (1971) - Die Bedeutung der Symbiose von *Heterostegina depressa* (Foraminifera, Nummulitidae) für hohe Siedlungsdichte und Karbonatproduction. *Sonderdruck aus Verhandlungsbericht der Deutschen Zoologischen Gesellschaf, Jahresversammlung, Gustav Fischer Verlag,* 65 : 42-47.

Rutten, L.M.R. (1913) - Studien über Foraminiferen aus Ost-Asien, 3, Eine neue *Alveolinella* von Ost-Borneo. *Sammlung des Geologischen Reichsmuseums in Leiden*, ser.1, 9 : 219-224.

Scheffen, W. (1932) - Ostindische Lepidocyclinen.- Teil I. *Dienst van den Mijnbouw in Nederlandsch-Indië, Wetenschappelijke Medeelingen*, 21 : 1-25.

Schlumberger, C. (1893) - Notes sur les genres *Trillina* et *Linderina*. *Bulletin de la Société Géologique de France,* sér. 3, 21 : 118-123.

Surono, B. Toha & I. Sudarno (1992) - Geological Map of the Surakarta-Giritontro Quadrangles, Jawa. 1 :100,000. *Geological Research and Development Centre*.

Tan Sin Hok (1932) - On the genus *Cycloclypeus* Carpenter, Part 1.- and an appendix on the Heterostegines of Timanggoe, S. Bantam, Java. *Dienst van den Mijnbouw in Nederlandsch-Indië, Wetenschappelijke Medeelingen,* 19 : 1-194.

Tan Sin Hok (1935) - Die peri-embryonalen Aquatorialkammern bei einigen Orbitoiden. *Ingenieur in Nederlandsch-Indië, IV, Mijnbouw en Geologie,* 4(2) : 113-126.

Tan Sin Hok (1936) - *Lepidocyclina zeilmansi* n.sp., eine neue Polylepidine von Zentral Borneo, nebst Bemerkungen über die verschiedenen Einteiungsweisen der Lepidocyclinen. *Ingenieur in Nederlandsch-Indië, IV, Mijnbouw en Geologie,* 3(1) : 7-14.

Tan Sin Hok (1937) - Weitere Untersuchungen Über die Miogypsiniden.- IIp. *Ingenieur in Nederlandsch-Indië, IV, Mijnbouw en Geologie,* 4(6) : 35-45.

Todd, R. & R. Post (1954) - Smaller Foraminifera from Bikini Drill Holes. *Geological Survey Professional Paper, 260-O. U.S. Government Printing Office, Washington,* 260N : 547-568.

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

Vessem, E.J. Van (1978) - Study of Lepidocyclinidae from Southeast Asia, particularly from Java and Borneo. *Utrecht Micropaleontological Bulletins,* 19 : 1-163.

Vlerk, I.M. van der (1923) - Een nieuwe Cycloclypeussoort van Oost-Borneo. *Sammlung des Geologischen Reichsmuseums in Leiden*, ser.1, 10 : 136-140.

Vlerk, I.M. van der (1924) - *Miogypsina dehaarti,* nov. species de Larat (Moluques). *Eclogae Geologicae Helvetiae*, 21 : 182-211.

Vlerk, I.M. van der (1925) - A study of Tertiary foraminifera from the Tidoengsche Landen (E. Borneo). *Wetenschappelijke Mededeelingen van de Dienst van de Mijnbouw in Nederlandsch-Oost-Indië,* 3 : 13-32.

Vlerk, I.M. van der (1928) - The genus *Lepidocyclina* in the Far East, *Eclogae Geologicae Helvetiae*, 21 : 182-211.

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

W Vlerk, I.M. van der, A.A.H. & C.G. A Vlerk, I.M. van der (1991) - The biostratigraphical and evolutionary significance of *Alveolinella praequoyi* sp. nov. from Papua New Guinea. *Bulletin of the British Museum (Natural History) (Geology)*, 47 : 169-175.

Accepté octobre 2004