A revision of the biostratigraphy and strontium isotope dating of Oligocene-Miocene outcrops in East Java, Indonesia

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ABSTRACT

The biostratigraphic ranges of identified larger benthic and planktonic foraminifera from Tertiary exposures in East Java Basin have been tied to the ages constrained from the Strontium isotope dating of some of the most abundant large benthic foraminifera. Foraminiferal assemblages and Strontium data have provided precise age ranges of the different stratigraphic units. The age of the exposed Lower Kujung Formation is late Early Oligocene (Rupelian P20) to Late Oligocene (Te1-4), equivalent to 28.78- 28.27 Ma). The age of the exposed Upper Kujung Formation is Late Oligocene, Chattian (P22, Te1-4) to Early Miocene (Aquitanian, N5a, Te5), equivalent to 24.31-23.44 Ma. The age of the exposed Tuban Formation is late Early Miocene, (Burdigalian) to Middle Miocene (Langhian, N5b-N9, Te5-Tf1), equivalent to 20.80- 15.25 Ma. The age of the exposed Ngrayong Formation is late Middle Miocene (Serravallian, N12-N13, Tf2), equivalent to ~15.0-~13.0 Ma. Age boundaries between the lithostratigraphic units were determined as: Upper Kujung- Tuban (22 Ma), Tuban-Ngrayong (15.25 Ma) and Ngrayong -Bulu Member of the Wonocolo Formation (12.98 Ma).

INTRODUCTION

Larger benthic foraminifera (LBF) are very abundant in the Cenozoic deposits of the Indo-Pacific region. They have been described from many localities in Indonesia, The Philippines and Japan. Most LBF taxa have long stratigraphic ranges. However, well-established genera are morphologically distinct and have different stratigraphic ranges (see BouDagher-Fadel and Banner, 1999; BouDagher-Fadel, 2008). The co-occurrence of planktonic foraminifera and LBF in the same section is a rare opportunity to refine the biostratigraphic ranges of some of these LBF.

The main objectives of this paper are to refine the biostratigraphic framework of Oligocene-Miocene outcrops in the East Java Basin (EJB), to calibrate the stratigraphic ranges of the identified foram assemblages with the geochronology from their Strontium isotopic compositions, and to describe and illustrate the larger foraminifera species present in the NE Java outcrops. This paper builds on work of Sharaf et al. (2006).
Little work has been published on the Tertiary sequence in the East Java Basin. Previous paleontological studies in this area include Duyfjes (1936, 1938), Van Bemmelen (1949), Muhar (1957), Bolli (1966), Brouwer (1966), Van der Vlerk and Postuma (1967), Pringgoprawiro et al. (1977), Van Vessem (1978), Ardhana et al. (1993), Lunt et al. (2000) and Sharaf et al. (2006). We follow the lithostratigraphic nomenclature established by Bataafsche Petroleum Maatschappij/ BPM (1950) and JOB Pertamina-Tuban (1990) as cited by Ardhana et al. (1993). The results of our stratigraphic work on the Oligo-Miocene stratigraphy of NE Java Basin are very similar to that in the recent book 'The sedimentary geology of Java' (Lunt, 2013).

GEOLOGIC AND STRATIGRAPHIC SETTING

The study area is located within the Rembang and northern Randublatung physiographic zones of Van Bemmelen (1949) in NE Java. The Rembang Zone consists of series of E-W oriented hills with maximum elevation of about 500 m (Figure 1). Those hills generally represent anticlines that may or may not be faulted. The Randublatung Zone is south of the Rembang Zone and represents a physiographic depression that contains

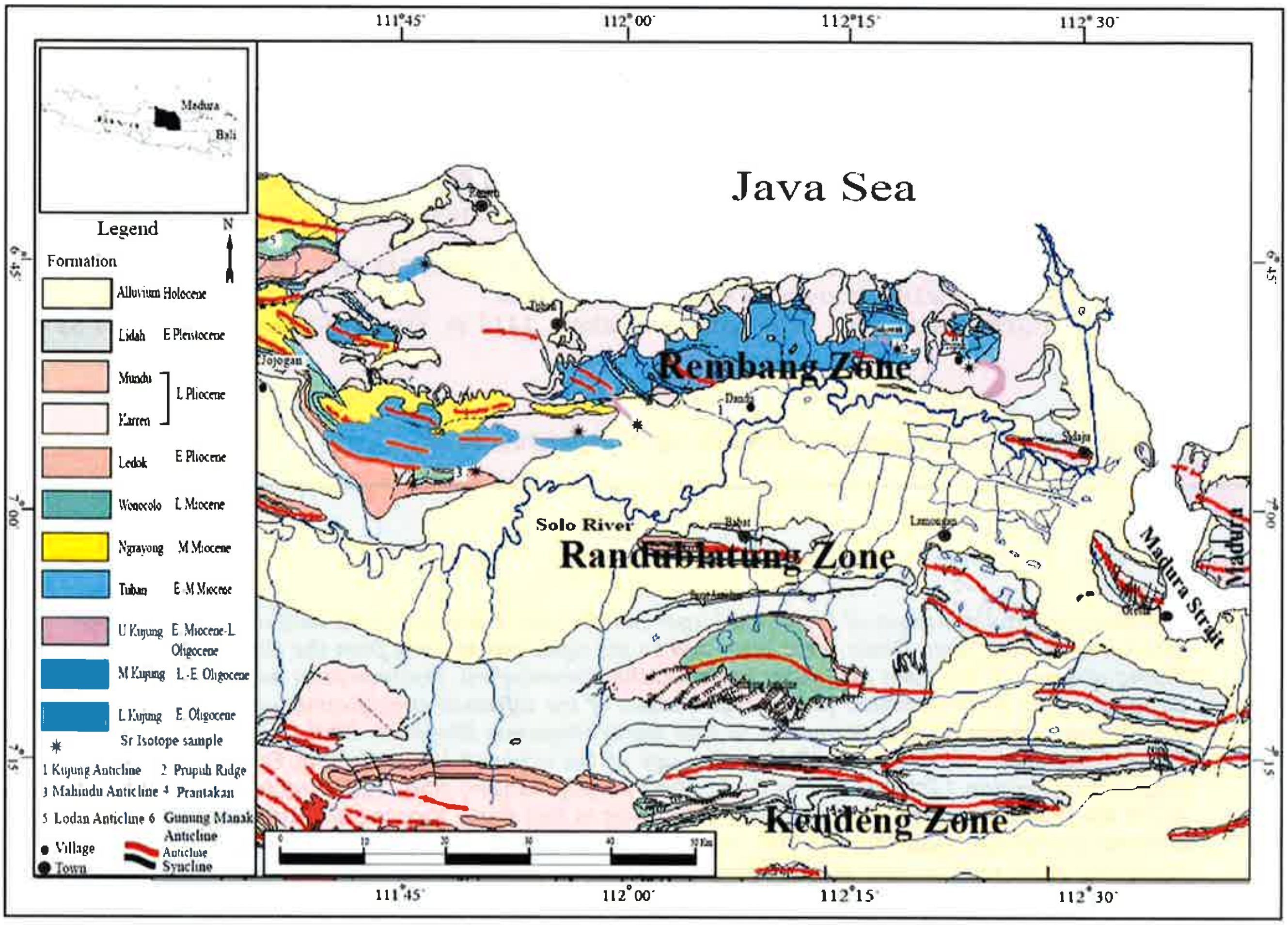

Figure 1. Geologic map of East Java showing the main stratigraphic units, main areas and localities of Sr isotope samples. Modified after Pringgoprawiro et al. (1992), Van Vessem (1992) and Sharaf et al. (2005).

folds such as Pegat and Ngimbang anticlines (Duyfjes, 1938).

Oligocene-Miocene outcrops in the EJB include carbonates, shale and sandstones that are rich in coralline algae, corals, larger benthic and planktonic foraminifera. The chronostratigraphy is based on a synthesis of all the paleontological data available and strontium isotope dating of selected field samples. The biostratigraphy from index foraminifera is in agreement with the ages constrained by strontium isotope analyses (Figure 2).

The Oligocene-Miocene stratigraphic units of interest of this work in East Java are the Kujung, Tuban and Ngrayong Formations and the Bulu Member of the Wonocolo Formation. The stratigraphic units are summarized below:

1. Kujung Formation

The Kujung Formation is the oldest exposed formation in the study area (Figure1). The age of the Kujung Formation has been established as latest Early Oligocene (Rupelian, P20) to Early Miocene (Aquitanian N4) (Najoan 1972; Duyfjes 1941; cited in Lunt et al. 2000). It is subdivided into three sedimentary packages. The exposed lower Kujung is represented by reefal carbonates (Darman and Sidi, 2000). The middle Kujung consists of interbedded shale and chalk lithologies rich in planktonic foraminifera. The upper Kujung forms a resistant ridge (Prupuh Ridge, near Prupuh village; Figure 1), which consists of interbedded chalky carbonates and graded-bedded grainstone with scour surfaces and load cast features (Sharaf et al., 2005). These lithologies are also known as the Prupuh Member carbonates (Figure 2).

2. Tuban Formation

The Tuban Formation is widely exposed along the EJB (Figure1). It has been dated as Burdigalian to Langhian (Ardhana et al., 1993). The Tuban lithologies are highly variable. The Tuban Formation is interpreted as a mixed carbonate-siliciclastic shelf with prograding deltas intertonguing with shelfal carbonates and buildups (Sharaf et al., 2005). The Tuban sandstone and carbonate lithologies are well exposed in western Rembang area, while the Tuban shale lithologies are thicker and more abundant in the eastern Rembang area. The Tuban carbonates are highly fossiliferous and are characterized by massive coral-rich beds, LBF- rich bedded shelf strata and red-algal thick-bedded carbonates. The Tuban shale consists of massive, featureless, green shale rich in planktonic foraminifera.

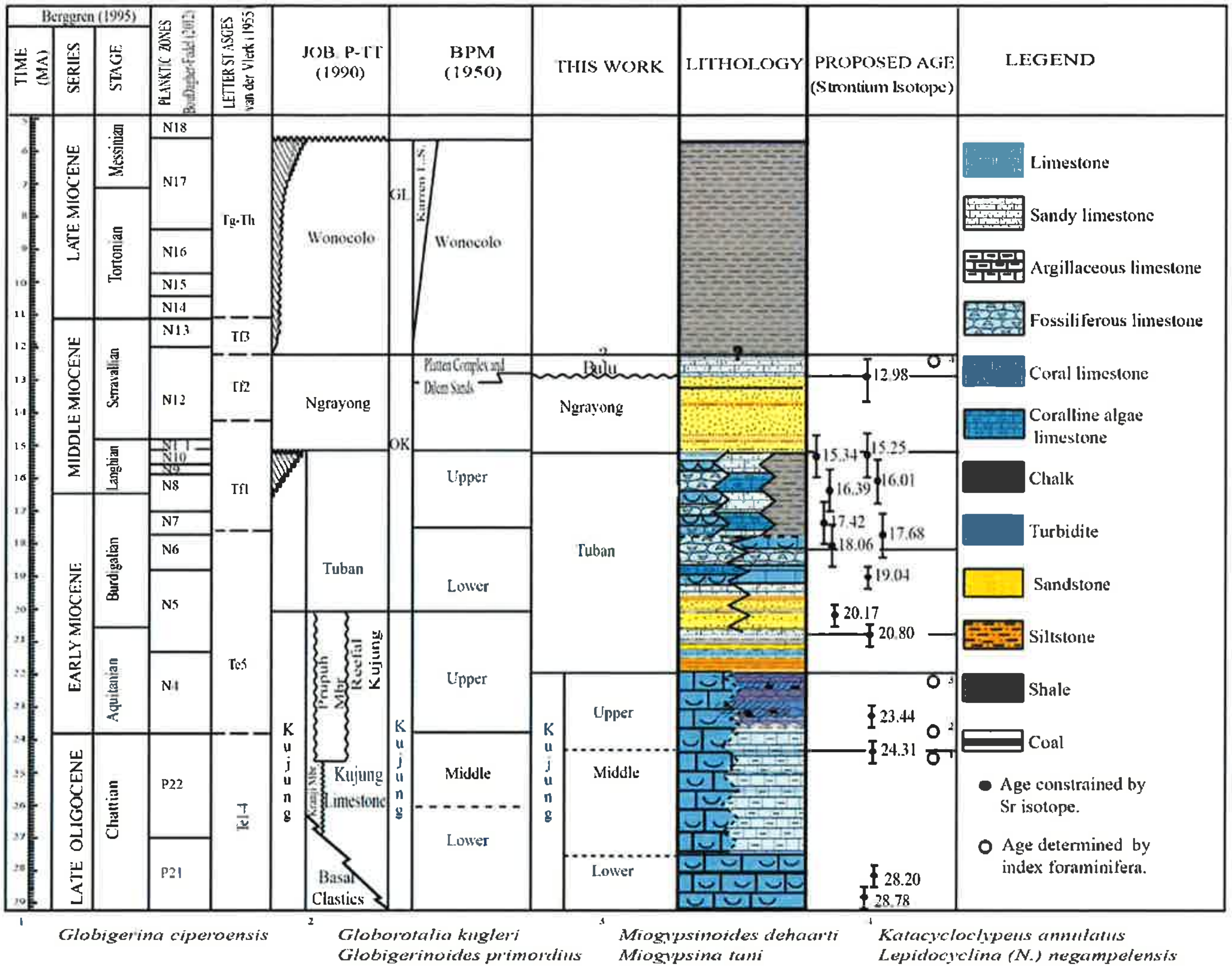

Figure 2. *Summary of stratigraphy and ages for stratigraphic units in East Java Basin. Modified after Sharaf et al. (2006).*

3. Ngrayong Formation

The Ngrayong Formation is well exposed in quarries and river banks along the Lodan Anticline and Prantakan River (Figure 1). The age of the Ngrayong unit is Middle Miocene (Ardhana et al. 1993, Lunt et al. 2000). The exposed Ngrayong succession is rarely fossiliferous. The formation consists at the base of argillaceous fine sand and shale, that grade upward into interbedded fine to medium-grained quartz sands with thin mudstones layers and coal seams. The Ngrayong Formation is interpreted as a prograding tidal delta (Sharaf et al., 2005).

4. Bulu Limestone Member of Wonocolo Formation

The Wonocolo Formation in the study area consists of a basal carbonate (Bulu Member), overlain by a thick succession of shale and marl with thin sandstone intervals. The Bulu Member forms a massive, resistant carbonate bench (10-20 m thick). The carbonate facies are mainly thick-bedded, rich in LBF and planar corals, and sandy fossiliferous. The Bulu Member truncates the underlying Ngrayong Formation; and is of Late Serravallian-Early Tortonian age, based on the presence of *Katacycloclypeus annulatus* (Plate 1, Figs. 9-10; Ardhana et al., 1993; Lunt et al., 2000 and Sharaf et al., 2006).

BIOSTRATIGRAPHY

Larger Benthic Foraminifera and long-range benthic foraminifera such as operculinids, amphisteginids, miliolids, textularids and lagenids are very abundant in the East Java Basin. Identified LBF assemblages show lateral variation in abundance from one locality to the other, confirming their facies dependence. In our definitions of stratigraphic ranges, we primarily use the planktonic foraminiferal zonal scheme of BouDagher-Fadel (2013), which is tied to the time scale of Gradstein et al. (2004). This scheme is developed from the calibration of the N-zonal scheme of Blow (1979), and the M-zonal scheme of Berggren (1973), which has been recently revised by Wade et al. (2011). In this paper the planktonic foraminiferal zonal scheme of BouDagher-Fadel (2013) is also correlated with the larger benthic zonation cited in BouDagher-Fadel & Banner (1999) and later revised by BouDagher-Fadel (2008).

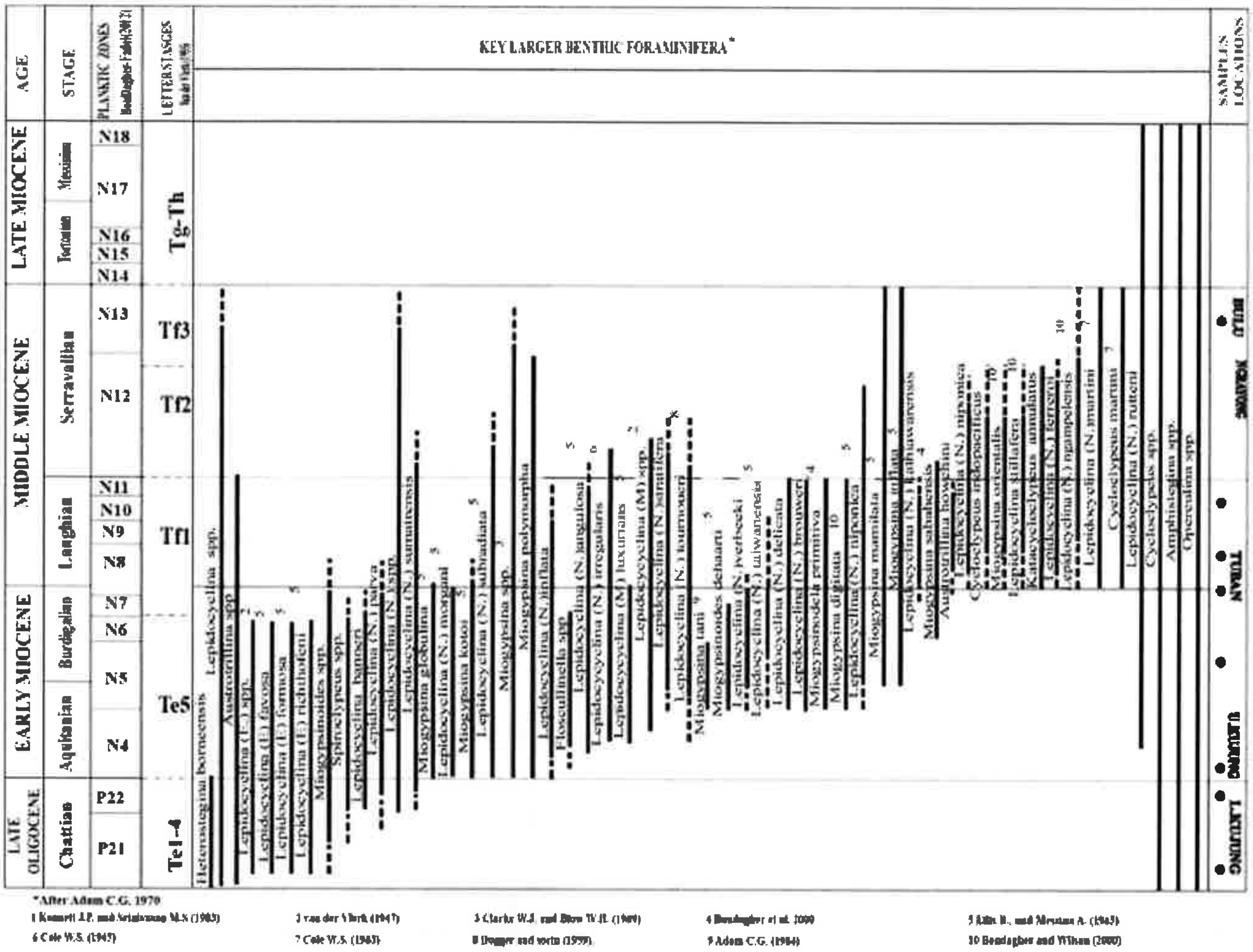

Figure 3. *Correlation between larger benthic foraminiferal assemblages identified from East Java and their stratigraphic ranges. Modified after Sharaf et al., (2006).*

Few index species have been described from the shale and chalk samples. Few exceptions are from the chalky beds of the Prupuh Ridge, the top of the Prantakan River and Mahindu outcrop, where the beds are rich in planktonic assemblages of long geologic range such as *Globigerina woodi, Globigerinoides sacculifer, Orbulina* sp. and *Orbulina suturalis*.

The LBF assemblage of the Upper Oligocene, Lower Kujung Fm, is dominated by *Spiroclypeus* sp., *Heterostegina borneensis, Eulepidina ephippioides, Eulepidina richthofeni, Lepidocyclina banneri, Lepidocyclina* sp., *Eulepidina formosa, Miogypsinoides* sp. and *Miogypsinella boninensis* and the index planktonic foraminifera *Globigerina ciperoensis* described from a shale sample near Dandu village, eastern Rembang area.

The Upper Kujung Formation is of Upper Oligocene-Lower Miocene age (Chattian-Aquitanian, P22-N4, Te1-4 -Te5) age. LBF assemblages are dominated by *Eulepidina formosa, Eulepidina ephippioides, L. (N.) parva, L. (N.) morgani, L. (N.) verbeeki, L. (N) sumatrensis, Miogypsina sabahensis, Miogypsinoides dehaarti, Spiroclypeus* sp. and *Flosculinella* sp.. The chalk beds are characterized by a planktonic assemblage of *Globoquadrina dehiscens, Globigerinoides quadrilobatus* and *Globigerinoides trilobus*. Two shale samples collected along Prupuh Ridge are rich in *Globorotalia kugleri* and *Globigerinoides primordius*.

The Tuban Formation sandy carbonates are of Early-Middle Miocene age (Burdigalian-Langhian, N5-N9, equivalent to upper Te5-Tf1), defined by *Eulepidina formosa* and *Miogypsina tani* (Figure 3). The Tuban carbonates are highly fossiliferous at the Prantakan area (Figure 1). The association at this area consists of *Austrotrillina howchini, Lepidocyclina (N.) ferreroi, L. (N.) martini, Eulepidina* sp., *L. delicata, L. (N.) stratifera, L. (N.) inflata, L. (N.) angulosa, L. (N.) brouweri, L (N.) tournoueri, L. (N.) irregularis, L. (N.) kathiawarensis, Miogypsina digitata,* and *Katacycloclypeus annulatus*. To the east, in the Mahindu area (Fig. 1), the dominant LBF's are *Lepidocyclina (N.) verbeeki, Miogypsina* sp., *Miogypsinoides* sp., and *Katacycloclypeus annulatus*. Farther to the west (Dermawu village, Fig. 1), the association consists of *Lepidocyclina (N.) verrucosa, L. (N.) ferreroi, L. (N.) sumatrensis* and *Katacycloclypeus annulatus*. The bed on top of the Tuban carbonates in the Mahindu area contains the planktonic foraminifers *Globorotalia praemenardii, Orbulina sp.* and *O. suturalis*.

The Late Serravallian Bulu Limestone assemblage (N12 and younger, stage Tf2) is characterized by dominance of *Katacycloclypeus annulatus, Lepidocyclina* (*N.*) *ngampelensis, Orbulina sp.* and *Orbulina suturalis.*

SYSTEMATIC DESCRIPTIONS OF LARGER BENTHIC FORAMINIFERA

The systematic taxonomy of Foraminifera is still undergoing active revision. The recognition of the Foraminifera as a class has emerged from biological research over the past two decades, including molecular systematics that is revealing the very early divergence of the Rhizaria, which includes the Granuloreticulosa from other protoctistan lineages (e.g., Pawlowski and Burki, 2009). Below, we follow Lee's (1990) elevation of the Order Foraminiferida to Class Foraminifera, and the concomitant elevating of the previously recognized suborders to ordinal level.

Class FORAMINIFERA Lee, 1990

Order ROTALIIDA Delage and Herouard, 1896

Superfamily ASTERIGERINOIDEA d'Orbigny, 1839

Family LEPIDOCYCLINIDAE Scheffen, 1932

Subfamily LEPIDOCYCLININAE Scheffen, 1932

Genus ***Eulepidina*** Douville, 1911

Eulepidina ephippioides (Jones and Chapman)

Orbitoides (*Lepidocyclina*) *ephippioides* Jones and Chapman, 1900, pl. 20, fig. 9, pl.21, fig. 1.

Eulepidina ephippioides (Jones and Chapman, BouDagher-Fadel and Price, 2010, Fig. 7. 1-6.

Dimensions: Maximum measured length 6mm.

Remarks: Many authors have combined American with similar Tethyan species on the basis of their morphological similarity, such as the American Oligocene species *E. favosa* and the Indo-Pacific species *E. ephippioides* (see BouDagher-Fadel and Price, 2010). *E. ephippioides* is a form described from the Indo-Pacific province with a small embryon (0.8 mm) but with the proloculus broadly attached to the median chambers. In this study it is found in the upper Oligocene and Lower Miocene, Lower Kujung.

Eulepidina formosa (Schlumberger)

Plate 2, fig. 9

Lepidocyclina formosa Schlumberger 1902, p. 251, pl. 7, figs. 1-3.

Eulepidina formosa BouDagher-Fadel and Price, 2010, Fig. 10.7.

Dimensions: Maximum measured length 5mm.

Remarks: Eulepidina formosa is characterized by the four angles of the test prolonged into tapering rays, the size of the deuteroconch is 0.8 mm.

Distribution: This species was originally described from the Miocene of Borneo. In this study it is found in the Lower Miocene deposits (Te5) of East Java.

Lepidocyclina (Lepidocyclina) Gumbel, 1870; emend. BouDagher-Fadel and Banner, 1997.

Lepidocyclina banneri BouDagher-Fadel, Noad and Lord, 2000

Plate 2, fig. 7

Lepidocyclina banneri BouDagher-Fadel, Noad and Lord 2000, p. 348, pl. 1, figs. 5-6.

Dimensions: Maximum measured length 4mm.

Remarks: This species is characterized by its possession of massive pillars in the centrum of the strongly biconvex test. Much narrower hyaline pillars are scattered over the whole of the lateral sides of the test. *L. banneri* is broadly biconvex in form in comparison with *L. delicata.*

Distribution: This species was originally described from the Gomantong Limestone from the Upper Te, Aquitanian-Burdigalian, of NW Borneo. In this study it is found in the Upper Chattian of the Lower Kujung Formation in East Java, Kujung area.

Lepidocyclina delicata Scheffen 1932

Plate 2, fig. 3-4

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

Dimensions: Maximum measured length 20mm.

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- early Serravallian). It was first described from Java. BouDagher-Fadel et al. (2000b) recorded *L. delicata* from 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 and Wilson (2000) and from the Tf2 (Serravallian) of the Sadeng section (SAD) in the Gunung Sewu area of South Central Java by BouDagher-Fadel et al. (2000b). In this study it was found in the Tf1 Letter stage of late Burdigalian- Langhian age of East Java, Gabalan outcrop, Rembang west.

Lepidocyclina stratifera Tan Sin Hok 1935

Plate 2, figs. 1, 2B

Lepidocyclina stratifera Tan Sin Hok 1935, 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.

Lepidocyclina (Nephrolepidina) stratifera Tan Sin Hok; Barberi et al. 1987, pl. 4, figs. 4, 11; BouDagher-Fadel and Wilson 2000, p. 154, pl. 1, fig. 3, pl.2, fig. 6; BouDagher-Fadel 2002, p. 164, pl. 3, fig. 10.

Maximum measured length 4mm.

Remarks: L. stratifera has a biconvex test with many layers of low cubiculae, in which their platforms are as thick as 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. It was found together with *Miogypsina, Katacycloclypeus* and *Trybliolepidina*, an assemblage characteristic of Tf2, middle Serravallian. Barberi et al. (1987) reported *L. stratifera* from the Tf1 (Burdigalian-Langhian) of the carbonate sequence of the Island of Sumbawa, Indonesia. It was described by BouDagher- Fadel and Wilson (2000) in Tf1 of eastern Borneo, Kalimantan. BouDagher-Fadel (2002) recorded similar forms from the Tf1and Tf2 (Serravallian) of the Gunung Sewu area of South Central Java. In this study it was also found in the Tf1 Letter stage of Late Burdigalian-Langhian age in the Prantakan area.

Genus ***Lepidocyclina*** Douville, 1911.

Subgenus ***Nephrolepidina*** Douville, 1911

Lepidocyclina (Nephrolepidina) ferreroi Provale 1909

Plate 1, figure 4C, Plate 2, fig. 6

Lepidocyclina ferreroi Provale 1909, p.70, pl.2, figs 7-13.

Lepidocyclina (Nephrolepidina) ferreroi Provale.; Noad and Lord 2000, pl.2, figs 2-9.

Lepidocyclina (Nephrolepidina) ferreroi Provale; BouDagher-Fadel, Noad and Price, 2010, fig. 13.7.

Dimensions: Maximum measured length 3.6mm.

Remarks: The species is characterized in having a quadrate protoconch, a quadrilateral test, depressed medially but with a median layer which has 4 high, pillared, lateral lobes and high, numerous cubiculae with relatively thin wall.

Distribution: Lepidocyclina (Nephrolepidina) ferreroi with a quadrate protoconch were found in the Burdigalian-Langhian of SE Kalimantan. In this study it is found in the Tf1 Letter stage in the west Rembang and Mahindu areas.

Lepidocyclina (Nephrolepidina) kathiawarensis Chatterji 1961

Plate 2, fig. 2

Lepidocyclina (Nephrolepidina) kathiawarensis Chatterji 1961, p. 429, pl. 2, fig. 9.

Dimensions: Maximum measured length 4mm.

Remarks: This species is characterized by having a bilocular embryonic apparatus typical of a tryliolepidine type.

Distribution: This species was first described from the upper Burdigalian of western India. In this study it was found in Letter stageTf1in the Prantakan area.

Lepidocyclina (Nephrolepidina) ngampelensis Gerth

Lepidocyclina (Nephrolepidina) ngampelensis Gerth, *in* Caudri 1939, p. 159, pl. 1, figs. 3-4.

Dimensions: Maximum measured length 5mm.

Remarks: This species is characterized by very low, thick floored cubiculae, with strong pillars scattered along the centre of the test.

Distribution: This species was found in in the Serravallian (Tf2) of the Darai Limestone. Our specimens were found in the Tf2 of the Prantakan River section.

Lepidocyclina (Nephrolepidina) sumatrensis (Brady 1875)

Plate 2, fig. 10

Orbitoides sumatrensis Brady 1875 p. 536, pl. 14, fig. 3a-c.

Lepidocyclina (Nephrolepidina) sumatrensis (Brady). – Cole 1957, p.343, pl. 104, figs. 1-9, pl. 105, fig. 18, pl. 106, fig. 5, pl. 109, figs. 1-3; Chaproniere 1983, p. 41, pl. 3, figs. 11, 12, pl. 5, figs. 9-12, pl. 6, figs. 1-10; Chaproniere 1984, p. 66, pl. 10, figs. a-c, pl. 22, fig.14, pl. 23, figs. 1-7, pl. 26, figs. 15, 16, fig.21; Barberi et al. 1987, pl. 5, fig. 3, pl. 6, fig. 4; BouDagher-Fadel and Wilson 2000, p. 156, pl. 2, fig. 4; BouDagher-Fadel 2000b, p. 352, pl. 3, fig. 2.

Dimensions: Maximum measured length 5mm.

Remarks: This species is characterized by a strongly biconvex species with a narrow equatorial flange and with many small, narrow pillars.

Distribution: Brady (1857) described *L. (N.) sumatrensis* from the "Early Tertiary" of Nias Island, W Sumatra, Cole (1957) from the Upper Te of Saipan, Chaproniere (1983, 1984) from the Oligocene- Miocene of Australia, while those of BouDagher-Fadel and Wilson (2000) were from the Tf1 of East Kalimantan. The specimens of BouDagher-Fadel et al. (2000b) were from the Gomantong Limestone, Upper Te of north Borneo. BouDagher-Fadel et al. (2005) recorded *L. (N.) sumatrensis* from the Tf1 and Tf2 of Rongkop section (SAD) in the Gunung Sewu area of South Central Java. In this study it is found in the Tf1 of late Burdigalian- Langhian age in the East Dermawu, and Prantakan areas.

Lepidocyclina (Nephrolepidina) verrucosa Scheffen 1932

Plate 2, fig. 8D

Lepidocyclina verrucosa Scheffen 1932, p. 33, pl. 7, figs. 2-4, p. 13, fig. 4.

Lepidocyclina verrucosa Scheffen 1932; BouDagher-Fadel and Wilson 2000, p. 156, pl. 2, figs. 7-8.

Dimensions: Maximum measured length 3.5mm.

Remarks: This species is characterized by possessing pairs of pillars radiating from about the fifth layer of cubiculae to the surface, the pillars diverging at an angle of about 60°.

Distribution: L. (N.) verrucosa was first described from Tf2 of Java. BouDagher-Fadel and Wilson (2000) found similar forms in the Tf1 Letter stage of East Kalimantan and in Tf1 of the Darai Limestone in Papua. In this study it is found in the Tf1 letter stage (late Burdigalian- Langhian) of the East Dermawu outcrop.

Superfamily NUMMULITACEA de Blainville 1827

Family CYCLOCLYPIDAE BouDagher-Fadel, 2002

Genus ***KATACYCLOCLYPEUS*** Tan Sin Hok 1932

Katacycloclypeus annulatus (Martin 1880)

Plate 1, figs. 9-10

Cycloclypeus annulatus Martin 1880, p. 157, pl. 28, figs. 1a-1i; Douville 1916, p. 30, pl. 6, figs. 2,3 [not pl. 5, fig. 6, pl. 6, figs. 1-4).

Cycloclypeus (Katacycloclypeus) annulatus Martin; Cole 1963, p.E19, pl. 6, fig. 13, 14; pl. 7, fig. 7, pl. 8, figs. 4-6, 8-11, pl. 9, figs. 14, 17.

Katacycloclypeus annulatus (Martin); BouDagher-Fadel and Wilson 2000, p. 157, pl. 3, fig. 8, pl. 4, fig. 2; BouDagher-Fadel 2002, p. 168, pl. 3, fig. 1.

Dimensions: Maximum measured length up to 6mm (even on a broken specimen)

Remarks: This species is characterized by having a large, thin test with a central umbo surrounded by several widely spaced annular inflations of the solid lateral walls.

Distribution: K. annulatus was first described from the lower Miocene of West Java. Cole (1963) reported it from the Tertiary of Guam and Fiji. Similar forms were found in the Tf2, of eastern Sabah and the Darai Limestone of Papua New Guinea, while those of BouDagher-Fadel and Wilson (2000) came from the Tf2 (lower Serravallian) of Kalimantan. BouDagher-Fadel (2002) recorded this form the lower Miocene of the Tacipi Formation, Sulawesi. In this study, similar forms occurred in the Tf2 (lower Serravallian) of the Prantakan outcrop (sample PR.2), Prantakan River and Mahindu areas.

Family MIOGYPSINIDAE Vaughan 1929

Genus **MIOGYPSINELLA** Hanzawa 1940

Miogypsinella boninensis Matsumaru 1996

Plate1, fig. 1

Miogypsinella boninensis Matsumaru 1996, p. 50, pl. 5, figs. 1-7; pl. 6, figs. 1-12; pl. 7, figs 1-16; Fig. 23-4; BouDagher-Fadelet al. 2000, p. 144, pl. 2, figs. 1, 2, 4.

Dimensions: Maximum measured length 1mm.

Remarks: M. boninensis is characterised by having a biconvex test with several umbilical plug-pillars. The embryonic chambers near the apex are followed by nepionic chambers disposed in a trochoid spire.

Distribution: This form was first described from the Upper Oligocene of Japan. In this study, similar forms occur in the Lower Te (Upper Oligocene) of NE Borneo (BouDagher-Fadel, Lord and Banner 2000). This species is here found in the Lower Te of the Kujung area.

Genus ***MIOGYPSINOIDES*** Yabe and Hanzawa 1928

***Miogypsinoides dehaarti* (Van Der Vlerk 1924)**

Plate 1, figs. 2, 3

Miogypsina dehaarti Van Der Vlerk 1924, p. 429-431, Figs. 1-3.

Miogypsinoides dehaarti (Van Der Vlerk); Cole 1957, p. 339, pl. 111, figs. 5-16; Van Der Vlerk 1966, pl. 1, figs. 1-6, pl. 2, figs. 1-3.

Miogypsina (*Miogypsinoides*) *dehaarti* Van Der Vlerk; Raju 1974, p. 80, pl. 1, figs. 19-25; pl. 3, fig. 8; pl. 4, figs. 2-4. BouDagher-Fadel, Lord and Banner 2000, p. 145, pl. 2, fig. 5.

Miogypsinoides dehaarti (Van Der Vlerk); BouDagher-Fadel and Price 2013, figs. A2r and s; figs. A3a, b and n; fig. A4d.

Dimensions: Maximum measured length 1.5mm.

Remarks: M. dehaarti has very thick lateral walls and is smooth exteriorly lacking pillars. The equatorial chambers are ogival in shape. The large spherical proloculus is followed by an equally large deuteroconch.

Distribution. This species was first described from the Early Miocene of Larat, Molluccas, East Indonesia.It was subsequently found in the late Aquitanian and Burdigalian of Borneo, Cyprus (BouDagher-Fadel and Lord 2006) and Turkey (Matsumaru et al. 2010). Raju (1974) registered the occurrence of this species in the Indo-Pacific and Mediterranean regions. BouDagher-Fadel et al. (2000c) found similar forms in the Upper Te of NE Borneo, and is known in Papua New Guinea to range up into Tf1 (lower Langhian). It was also figured from the Middle Burdigalian, Subis Formation in Borneo, late Burdigalian of the Castelsardo section in N Sardinia and late Aquitanian of Sulawesi (BouDagher-Fadel 2008, BouDagher-Fadel and Price 2013). This species is here found in the Lower Te5 (Lower Aquitanian) of the Prupuh outcrop.

Genus ***MIOGYPSINA*** Sacco 1893

Miogypsina digitata Tan Sin Hok 1937

Plate 1, fig. 8

Miogypsina (Miogypsina) kotoi Hanzawa forma *digitata* Tan Sin Hok 1937, p. 101, pl. 2, figs. 1-5, fig. 1a.

Miogypsina digitata Tan Sin Hok; BouDagher-Fadel, Lord and Banner 2000, p.146, pl.3, fig.7.

Dimensions: Maximum measured length 1mm.

Remarks: This form is characterized by having oval median chambers and numerous fine pillars.

Distribution: It was found by BouDagher-Fadel et al. (2000c) in the lower Burdigalian, Upper Te, of North East Borneo. In this study it is found in the Tf1 Letter stage (upper Burdigalian) of East Java.

Miogypsina kotoi Hanzawa 1931

Plate 1, fig. 6

Miogypsina kotoi Hanzawa 1931, p.154, pl.25, figs 14-18.; *Miogypsina kotoi* Hanzawa, BouDagher-Fadel 2008, p. 484, plate 719, figs. 6 and 8.BouDagher-Fadel and Price 2013, figs A3c- d and figs A6a-b.

Dimensions: Maximum measured length 2.5 mm.

Remarks: This species is distinguished in having oval median chambers, small thick-walled, but strongly convex cubicula. It has a biserial nepiont that is strongly asymmetrical, with biometric factor between 30 and 40. It is distinguished in having ogival median chambers, which are small, thick-walled and strongly convex.

Distribution: Miogypsina kotoi was first described from the Burdigalian of Japan. BouDagher-Fadel and Wilson (2000) and BouDagher-Fadel (2008) reported it from the Tf1 of East Kalimantan. BouDagher-Fadel and Lokier (2005) recorded similar forms from the Tf1 and Tf2 (Serravallian) of Djatirago and the Gunung Sewu area of South Central Java. It is also recorded from the Early Miocene (Middle Burdigalian) of Kalimantan and Borneo (BouDagher-Fadel and Price, 2013). In this study it is found in the Tf1 Letter stage (late Burdigalian- Langhian) of Prantakan River.

Miogypsina sabahensis BouDagher-Fadel, Lord and Banner 2000

Miogypsina sabahensis BouDagher-Fadel, Lord and Banner 2000, p. 147, pl.3, figs. 4-6.

Dimensions: Maximum measured length 1.6mm.

Remarks: This species is characterized by having massive and heavy pillars when seen in vertical section.

Distribution: M. sabahensis was first described from the Upper Te of Burdigalian age of E Sabah and in the Tf1 (Burdigalian-Langhian) of Kalimantan (BouDagher-Fadel et al. 2000c). This species is found here in Te5, lower Miocene of the Prupuh outcrop.

Miogypsina tani Drooger 1952

Plate 1, fig. 5, Plate 5, fig. 5b

Miogypsina (Miogypsina) tani Drooger 1952, p. 26, 51, 52, pl. 2, figs. 20-24; Raju 1974, p. 82, pl. 1, figs. 26-30; pl. 5, fig. 5; Wildenborg 1991, p. 113, pl. 4, figs. 1, 2, tabs. 19; BouDagher-Fadel, Lord and Banner 2000, p.147, pl.3, figs 4-6; BouDagher-Fadel 2008, p. 437, plate 7.8, fig. 1; BouDagher-Fadel and Price 2013, p. 574, pl. 3, fig 19.

Dimensions: Maximum measured length 3mm.

Remarks: This species is distinguished by having a long megalospheric nepionic coil of auxiliary chambers, low cubiculae with inflated roofs and many scattered pillars.

Distribution: This species was first described from Costa Rica. Similar forms have a wide distribution in the American, Mediterranean and Indo-Pacific regions. It was found in the Upper Te (Aquitanian) of Italy and southern Spain (Raju 1974) and Borneo (BouDagher-Fadel et al., 2000c). It was recorded in the Tf1 letter stage of East Java and the Early Langhian of Sumatra (BouDagher-Fadel 2008). It was also reported from the late Burdigalian of Corsica (Ferrandini et al.2010), the Early Miocene (Aquitanian) of onshore and offshore Brazil (De Mello e Sousa et al. 2003, BouDagher- Fadel and Price 2010). It is here figured from the Middle Burdigalian Subis Formation, Borneo (BouDagher-Fadel and Price, 2013). In this study it is found in the Lower Tf1 Letter stage of late Burdigalian age in the West Rembang and Mahindu areas.

Genus ***Lepidosemicyclina*** Rutten 1911

Lepidosemicyclina banneri BouDagher-Fadel and Price, 2013

Lepidosemicyclina banneri BouDagher-Fadel and Price, 2013, p. 206, Fig. A6q–w.

Miogypsina tani Drooger; Sharaf et al., 2006, pl. 3, fig. 1b.

Dimensions: Maximum measured length 6 mm.

Description: An elongated *Lepidosemicyclina* with a circular protoconch occupying a place between centre and edge of the test, and a smaller reniform deuteroconch that lines up with the protoconch closer to the apex of the test. In axial view chambers are very small, supported by pillars and stacked in irregular rows on the median chambers. In equatorial view, chambers are irregular and hexagonal in shape.

Distribution: Mahindu area.

STRONTIUM ISOTOPE CHRONOSTRATIGRAPHY

Strontium isotope chronostratigraphy was used to calibrate the biostratigraphic ages of the exposed Oligocene-Miocene outcrops in the EJB (Figure 2) Strontium isotope data from the lower Kujung Formation, provides an age range of 28.78± 0.74 Ma to 28.20± 0.74 Ma corresponding to Early to Late Oligocene, latest Rupelian- respectively, (Early P21) (see BouDagher-Fadel, 2013). The index planktonic foraminifera *Globigerina ciperoensis* from the middle Kujung shale/chalk indicates correlation with Zone of P22 for this interval. Strontium isotope dating of two samples from the upper Kujung (Sukowati village and west of Dandu village, gives ages of 23.44± 0.74 Ma and 24.31± 0.74 Ma (Late Oligocene), correlating with Zone (P22).

The oldest sandy carbonate unit exposed of Tuban Formation has an age of 20.80 ± 0.74 Ma. Tuban carbonates yield an age of 20.17±0.74 Ma (base of Burdigalian, N5) to 15.25 ±1.36 (base of Langhian, N9). Two samples separating the Tuban carbonates from the Ngrayong Formation yield ages of 15.34 ±1.36 Ma and 15.25±1.36 Ma. The Bulu Member from the base of the section at Prantakan River reveals an age of

12.98±1.36 Ma corresponding to the Serravallian age (N12).

CONCLUSIONS

The age of exposed Lower Kujung Formation is late Early Oligocene, Rupelian P20-Late Oligocene,Chattian, P21 respectively) based on identified foraminifera and strontium dating. The faunal assemblage in Prupuh Ridge area indicates that the exposed Upper Kujung (shale, chalk and turbidites) are rich in larger benthic and planktonic foraminifera with stratigraphic range of Early Miocene Aquitanian age (Te5) which is equivalent to Zone N4 of Blow (1969; see BouDagher-Fadel, 2008; BouDagher-Fadel, 2013). Strontium isotope dating of the Prupuh carbonates exposed at Sukowati village and along the western side of Prupuh Ridge gives an age of Late Oligocene (Chattian) to Early Miocene (Aquitanian) equivalent to Zones P22 to N5a (see BouDagher-Fadel, 2013). The Tuban outcrops have a long stratigraphic range from Upper Te5-Tf1 (Burdigalian- Langhian, see BouDagher-Fadel, 2008), which is equivalent to Zones N5b-N9 (BouDagher-Fadel, 2013). The studied carbonate beds from Mahindu and Prantakan outcrops confirmed the presence of *Orbulina* sp. and *Orbulina O. suturalis* suggesting an age of late Langhian (N9, see BouDagher-Fadel , 2013) for the top of the Tuban. This is consistent with the age constrained from strontium dating of the shale unit at the top of Prantakan outcrop.

The Bulu Member of the Wonocolo Formation is characterized by faunal assemblage of late Mid –Late Miocene age (Serravallian –Tortonian). The strontium dating of the Bulu carbonates exposed at Prantakan River is consistent with the age range obtained from the LBF.

The co-occurrence of both coralgal benthic planktonic foraminifera rocks in the carbonate facies of the Oligocene and Miocene of EJB is a rare opportunity for correlating the biostratigraphic framework of this region.

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Plate 1

Fig. 1. *Miogypsinella boninensis* Matsumaru 1996. Equatorial slice of a megalospheric section. Sample loc. 06° 58' 33.6" S, 112° 08' 52.6" E, Dandu village, Kujung anticline, x80.

Figs 2-3. *Miogypsinoides dehaarti* (Van Der Vlerk). Vertical axial sections showing the solid lateral walls. Sample loc. 06° 55' 13.9"S, 112° 26' 56.8" E, Prupuh section, 2, megalospheric form, x50; 5, microspheric form, x20.

Fig. 4. A. *Lepidosemicyclina banneri* BouDagher-Fadel and Price. B, *Cycloclypeus* sp. C. *Lepidocyclina* (*Nephrolepidina*) *ferreroi* Provale. Sample loc. 06° 58' 33.6" S, 112° 08' 52.6" E, Prantakan section, x7.

Fig. 5. *Miogypsina tani* Drooger. Sample loc. 06° 58' 33.6" S, 112° 08' 52.6" E, Prantakan section, x5.

Fig. 6. *Miogypsina kotoi* Hanzawa, Sample loc. 06° 55' 29.5"S, 111° 52' 34.4"E, Hargorento village, x13.

Fig. 7. *Katacycloclypeus martini* (Van Der Vlerk), Sample loc. 06° 57' 02.2"S, 112° 29' 49.4"E, Bungah area, x16.

Fig. 8. *Miogypsina digitata* Drooger. Sample loc. 06° 55' 13.9"S, 112° 26' 56.8" E, Prupuh section, x25.

Fig. 9-10. *Katacycloclypeus annulatus* Martin. Axial section, Sample loc. 07° 02' 11.4"S, 111° 55' 23.2"E, x14; 10. Equatorial sections. Sample loc. 06° 55' 39.6" S, 112° 27' 32.7" E, Pantjn area, x25.

Fig. 11. *Spiroclypeus* sp. Axial section. Sample loc. 06° 54' 27.1"S, 112° 23' 51.9"E, x20.

Plate 1

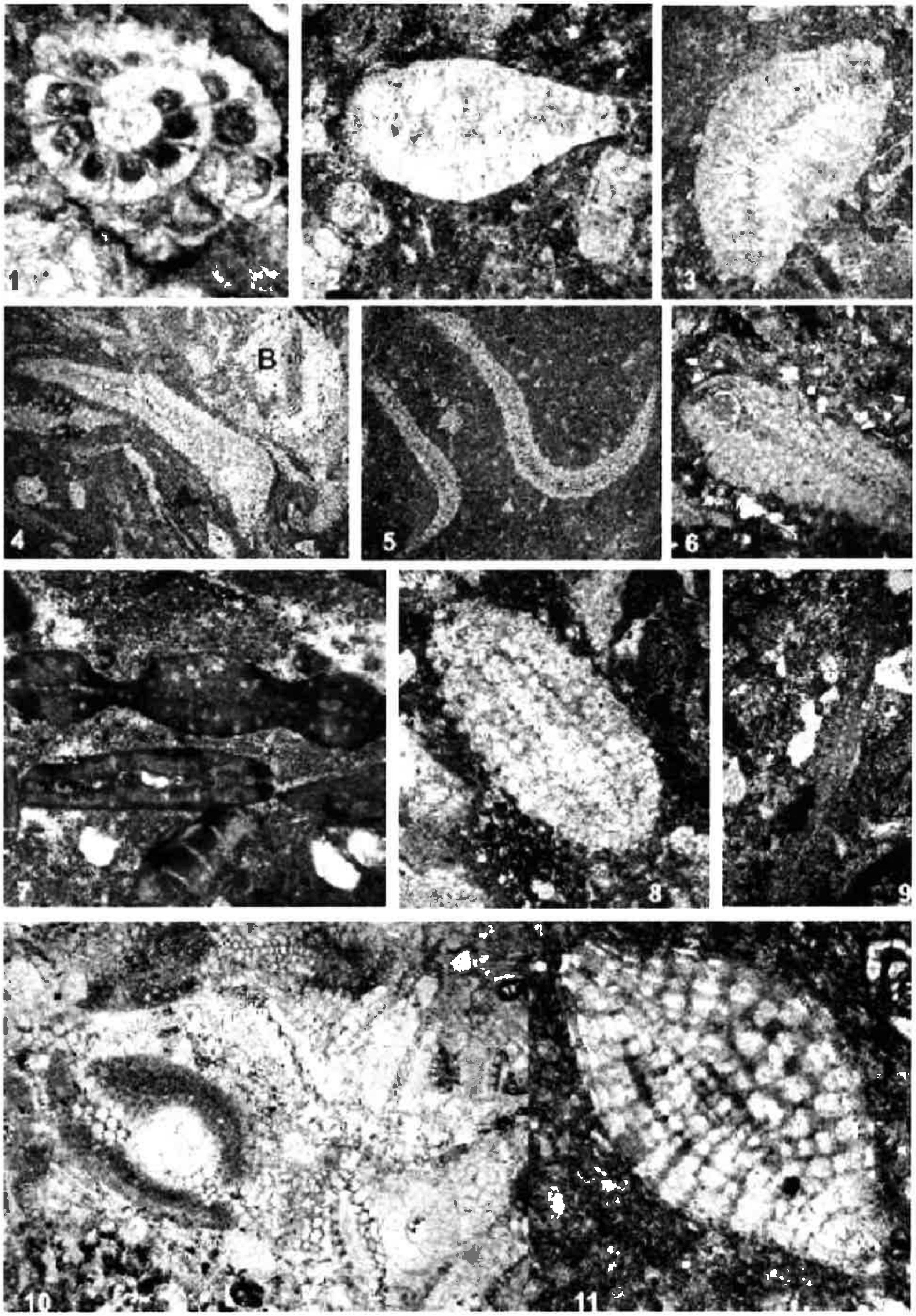

Plate 2

Fig. 1. *Lepidocyclina stratifera* Tan Sin Hok, Sample loc. 06° 58' 33.6" S, 112° 08' 52.6" E, Prantakan section, x11.

Fig. 2. *Lepidocyclina (Nephrolepidina) kathiawarensis* Chatterji, oblique equatorial section showing a quadrate protoconch strongly embraced by a deuteroconch. Pillars are present only towards the periphery in our specimens, however towards both ends of the test. B) *Lepidocyclina stratifera* Tan Sin Hok. Sample loc. 06° 58' 33.6" S, 112° 08' 52.6" E, Prantakan section, x10.

Figs 3-4. *Lepidocyclina delicata* Scheffen, 3. Oblique equatorial section, 4. Axial section. Sample loc. 07° 01' 14.8"S, 111° 55' 44.7"E, Mahindu section, x10.

Figs 5. A) Vertical axial section. *Lepidocyclina* (*Nephrolepidina*) *subradiata* (Douvillé). B) *Miogypsina tani* Drooger. ×12.

Fig. 6. Thin section photomicrograph of *Lepidocyclina* (*Nephrolepidina*) *ferreroi* Provale. Sample loc. 06° 58' 33.6" S, 112° 08' 52.6" E, Prantakan section, x23.

Fig. 7. *Lepidocyclina banneri* BouDagher-Fadel, Noad and Lord. Axial section showing massive pillars in centrum. Sample loc. 06° 54' 27.1"S, 112° 23' 51.9" E, Kujung Anticline, x20.

Fig. 8. A. *Amphistegina* sp., B. *Lepidocyclina (Nephrolepidina) oneatensis* COLE, C. *Lepidocyclina* (*Nephrolepidina*) *sumatrensis* (Brady). D. *Lepidocyclina* (*Nephrolepidina*) *verrucosa* (Scheffen).Sample loc. 7° 1' 6.02'' S, 112° 1' 56.35'' E. East Dermawu section, ×39.

Fig. 9. *Eulepidina formosa* (Schlumberger). Sample loc. 06° 55' 29.5"S, 111° 52' 34.4"E, Hargorento village, x10.

Fig. 10. *Lepidocyclina* (*Nephrolepidina*) *sumatrensis* (Brady), Sample loc. 7° 1' 20.17'' S, 111° 51' 14.4'' E, Prantakan River, x40.

Plate 2