

Age Refinement of the Sonde Molluscan Fauna, East Java, Indonesia

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Abstract. The Klitik Member of the Kalibeng Formation exposed along the Solo River in the Sonde area, East Java, Indonesia contains diverse molluscs that are a standard of the Neogene molluscan sequences in Indonesia vaguely dated as Late Pliocene. We investigated the molluscs and planktonic foraminifers in the Klitik Member exposed in a riverbank of the Solo River at Bangun, 2 km west of Sonde, which is one of the four classical fossil-collecting sites in the Sonde area. Our faunal analysis of the molluscs demonstrated that the mollusc-bearing beds at Bangun were deposited in an intertidal to upper sublittoral zone under the influence of oceanic water. Three sediment samples from the Klitik Member contain abundant planktonic foraminifers, and the mollusc-bearing beds at Bangun are assigned to a time interval between 3.95 Ma and 3.58 Ma, the latest Early or earliest Late Pliocene. These results are important for the understanding of the molluscan faunal evolution in the Southeast Asian archipelago.

Key words: Indonesia, Java, Kalibeng Formation, Mollusca, Planktonic foraminifer, Pliocene, Sonde.

Introduction

Tertiary molluscs in Indonesia are amongst the most diverse in the world, and represented by over 3,000 species (Skwarko, 1994; Skwarko *et al.*, 1994; Skwarko & Sufiati, 1999). In particular, the Tertiary molluscan sequence in Java, from the Eocene to Pleistocene, provides a standard in Indonesia as well as in the Philippines. The founder of the Tertiary molluscan paleontology and stratigraphy in Indonesia was Karl Martin, who in his long life made many fundamental contributions to these subjects (see Martin, 1919; Vlerk, 1931). One of his contributions to the Tertiary stratigraphy in Java is the age determinations of the mollusc-bearing beds (i.e., Nanggung-

lan, West Progo, Nyalindung, Tjilanang and Sonde beds) based upon the Lyellian method of determining percentages of modern species contained in the beds (Martin, 1919). This was the only available method in the early half of the 20th century, because the Cenozoic faunas in the East Indies belong to a bioprovince different from those of Europe where the international standard stratigraphic division was established. Oostingh (1938) further developed this subject and subdivided the Neogene molluscan fauna into five local stages with one hiatus, namely: Rembangian, Preangerian, Odengian, Odengian-Cheribonian hiatus, Cheribonian, Sondian and Bantamian from older to younger, with introduction of several index molluscs for each stage. An-

other important contribution to the stratigraphy in Indonesia was by Vlerk and Umgrove (1927) who proposed the Letter Classification based upon larger foraminifers, which divided the Tertiary beds into eight units indicated by alphabetical letters, ranging from Tertiary a for the oldest to Tertiary h for the youngest. Although this system was revised from time to time, it played an important tool for the age control and correlation of Tertiary strata in the East Indies (see Bemmel, 1970, pp. 83–89). These and later studies roughly correlated the mollusc-bearing beds in Java to the European standard stages as follows: the Rembangian, Preangerian, Odengian, Cheribonian, Sondian and Bantamian as early Middle Miocene, middle Miocene, Late Miocene, early Pliocene, late Pliocene and early Pleistocene, respectively (Bemmel, 1970, p. 82; but Shuto, 1977 provided slightly different correlation). Detailed correlation of these local stages with the international standard based upon planktonic microfossils is indispensable for the understanding of stratigraphy in Indonesia and faunal evolution in the tropical western Pacific, but such a study has not been done except for Robba (1996) who dated the Rembangian as a Middle Miocene in age.

Martin-Icke (1911) and Martin (1919, p. 141) described four localities (Padasmalang, Sonde, Pengkol and Rangun) where they reported the occurrence of diverse Pliocene marine molluscs. Sonde is a small village along the Solo River, about 13 km west-northwest of Ngawi, East Java, one of the classical fossil localities of Pliocene molluscs in Java, from which the name Sondian stage was derived (Fig. 1). Although Sonde is not the type locality of the Sondian stage (type locality is the Tjimantjeuri Beds in Bantam province, West Java; Oostingh, 1938), a majority of the Sondian molluscs described by Martin (1891–1922), which were collected by R. D. M. Verbeek, came from this site. Verbeek's Sonde locality appears to be on the left bank of the Solo River just south of Sonde, but the outcrops there are now covered with talus deposits and thick vegetation. Martin-Icke (1911) and Martin

(1919, p. 141) mentioned "Rangun" west of Sonde as an equivalent of the beds at Sonde and listed 150 species of molluscs. Most probably, "Rangun" is Bangun in Kecamatan Kedunggalar, a small village about 2 km west of Sonde (Fig. 1B). To the south of Bangun on the right bank of the Solo River, highly fossiliferous sandstone beds mapped as the Klitik Member of the Kalibeng Formation are exposed (Datun *et al.*, 1996), where a continuous sedimentary succession from the uppermost part of the Kalibeng Formation to the Pucagan Formation is observed. The Bangun locality is also considered to be identical with "R. Solo near Bangoenredjo Kidol", where Regteren Altena (1938, 1941, 1942, 1950) and Schilder (1941) reported diverse molluscs. Padasmalang and Pengkol localities are located about 2.3 km and 3.0 km east of Sonde also along the Solo River. Martin-Icke (1911) reported diverse molluscs from these localities, many of which are common to those we reported in this paper.

The Upper Kalibeng Formation (=Klitik Member) was dated as Blow's (1969) N20 to N21 along the Solo River north of Ngawi (Gorsel & Troelstra, 1981) and as calcareous nannofossil Zone NN16 in the Sangiran area, Central Java (Siesser *et al.*, 1984). However, detailed age of the Klitik Member in the Sonde area still remains unstudied.

The purpose of this study is to document the sedimentary succession of the mollusc-bearing beds at the Bangun locality, its faunal composition, sedimentary environment, and detailed age determination by planktonic foraminifers.

Geologic Setting and Collecting Locality

Duyfjes (1936) gave the first detailed description of the Neogene lithostratigraphy in the Kendeng Hills, an east-west aligned area between Trinil and Surabaya, East Java (Fig. 1A). He recognized five stratigraphic units in this area: the Lower Kalibeng, Upper Kalibeng, Pucagan, Kabuh, and Notopuro formations, in ascending order. The former two units are of marine origin,

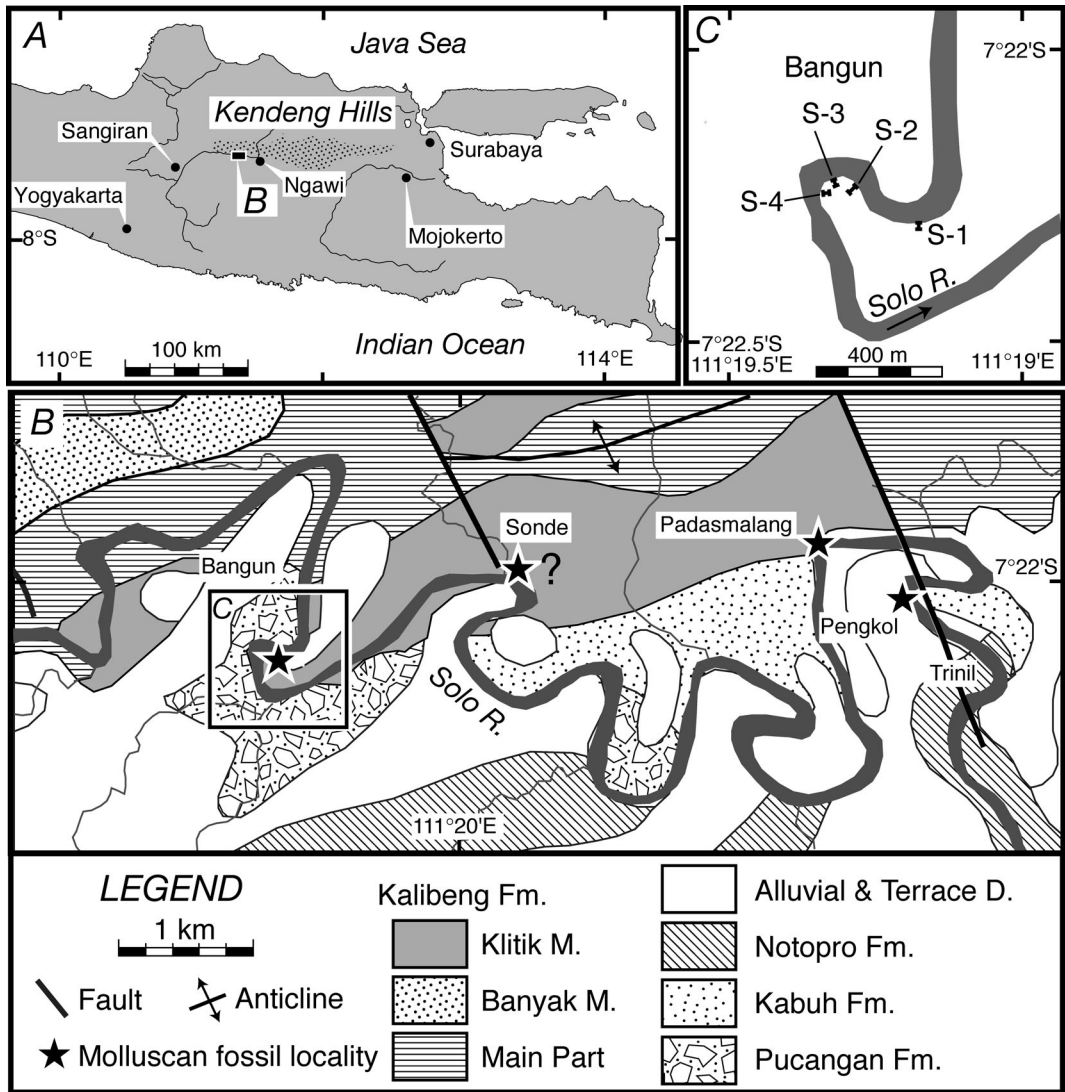


Fig. 1. A. Index map of Central and East Java. B. Geologic map of the Sonde area modified from Datun *et al.* (1996), showing the four classical fossil-collecting sites. Locations of Padasmalang and Pengkol are based on Carthaus (1911, pl. 6). C. Route of the section measurement at the Bangun locality.

whereas the latter three units are largely of non-marine origin and consist mainly of volcanoclastics. The Pucangan and Kabuh formations are well known for the hominid fossil *Homo erectus*.

Figure 2 shows the stratigraphic sections at Bangun, where a 14-m-thick Neogene sedimentary sequence is exposed. Except for the uppermost conglomerate of the Pucangan Formation, the marine sequence at Bangun is referable to the Upper Kalibeng Formation of Duyfjes (1936).

This unit was later separated from the main part of the Kalibeng Formation and named the Klitik Member (Datun *et al.*, 1996), which we follow in this paper. The lower half of the section (S-1 in Fig. 2) consists of a massive siltstone bed, a pebble- to cobble-sized limestone conglomerate bed, a medium-grained sandstone bed, and a biocalcarenite bed, in ascending order (Fig. 3A). The biocalcarenite bed commonly contains larger foraminifers (mostly *Operculina* sp.), molluscs

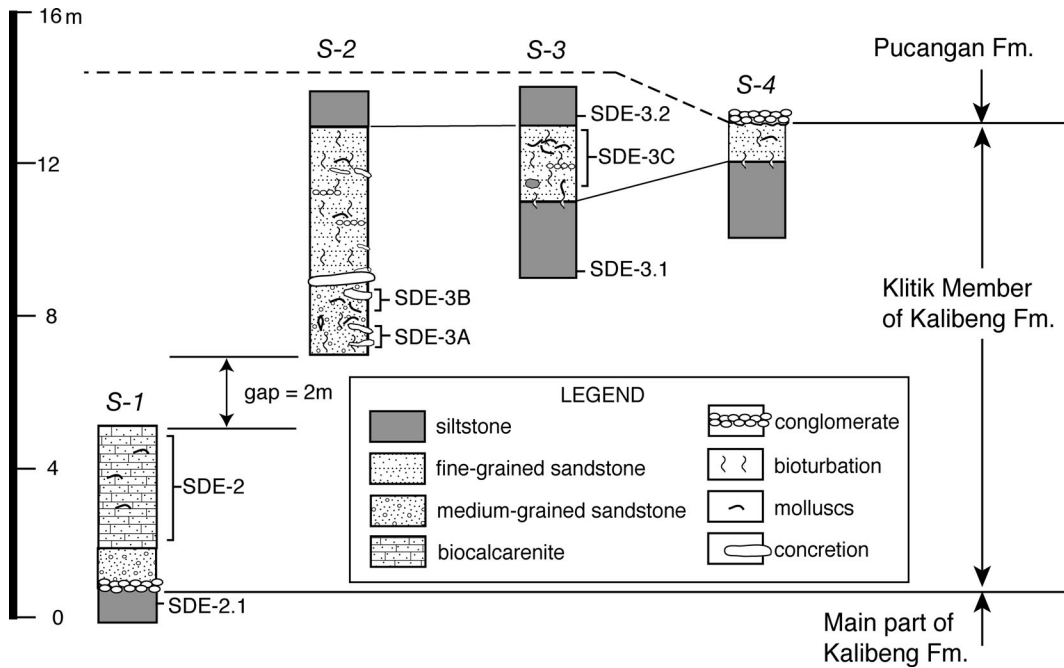


Fig. 2. Columnar sections and sampling horizons (with prefix SDE) at the Bangun locality, East Java. Route of the section measurement is shown in Fig. 1C.

and corals, of which the latter two fossil groups are dissolved and preserved as casts and molds except for pectinid bivalves. The upper half of the sections (S-2, 3 and 4 in Fig. 2) consist of massive siltstone, muddy medium-grained sandstone and fine-grained sandstone (Fig. 3B). The siltstone is massive, olive-grey in color and contains abundant planktonic foraminifers. The latter two lithofacies are massive, bioturbated and commonly associated with tube-shaped burrows and calcareous concretions, and contain well-preserved molluscs and corals (Fig. 3C, D). The contact between the siltstone and the fine-grained sandstone is sharp with intensive burrows of *Thalassinoides* isp. (Fig. 3E). The fine-grained sandstone is commonly unconsolidated with abrupt lateral changes in thickness, often showing lenticular geometry (Fig. 3E). The Klitik Member is unconformably overlain by the conglomerate of the Pucangan Formation observed at section S-4 (Figs. 2, 3F).

Molluscan assemblage and depositional environment

The lithofacies of the Klitik Member described above indicate deposition of the member in a shallow marine setting which exhibits marked contrast to the underlying deep marine (400–1000 m deep according to Gorsel & Troelstra, 1981), main part of the Kalibeng Formation, indicating an abrupt shallowing of the sedimentary basin. The abundant occurrence of planktonic foraminifers suggests that the Klitik Member was deposited under a strong influence of oceanic water. Analysis of the molluscan assemblages of the Klitik Member gives additional data on the depositional environments of this member. Our extensive collecting recognized over 150 species of molluscs from three beds SDE-3A, SDE-3B and SDE-3C (Fig. 2). Identification of all the specimens have not been completed as quite a large number are undescribed species, particularly in bivalves. Table 1 lists a total of 63 gastropods and 50 bivalves identified at species or

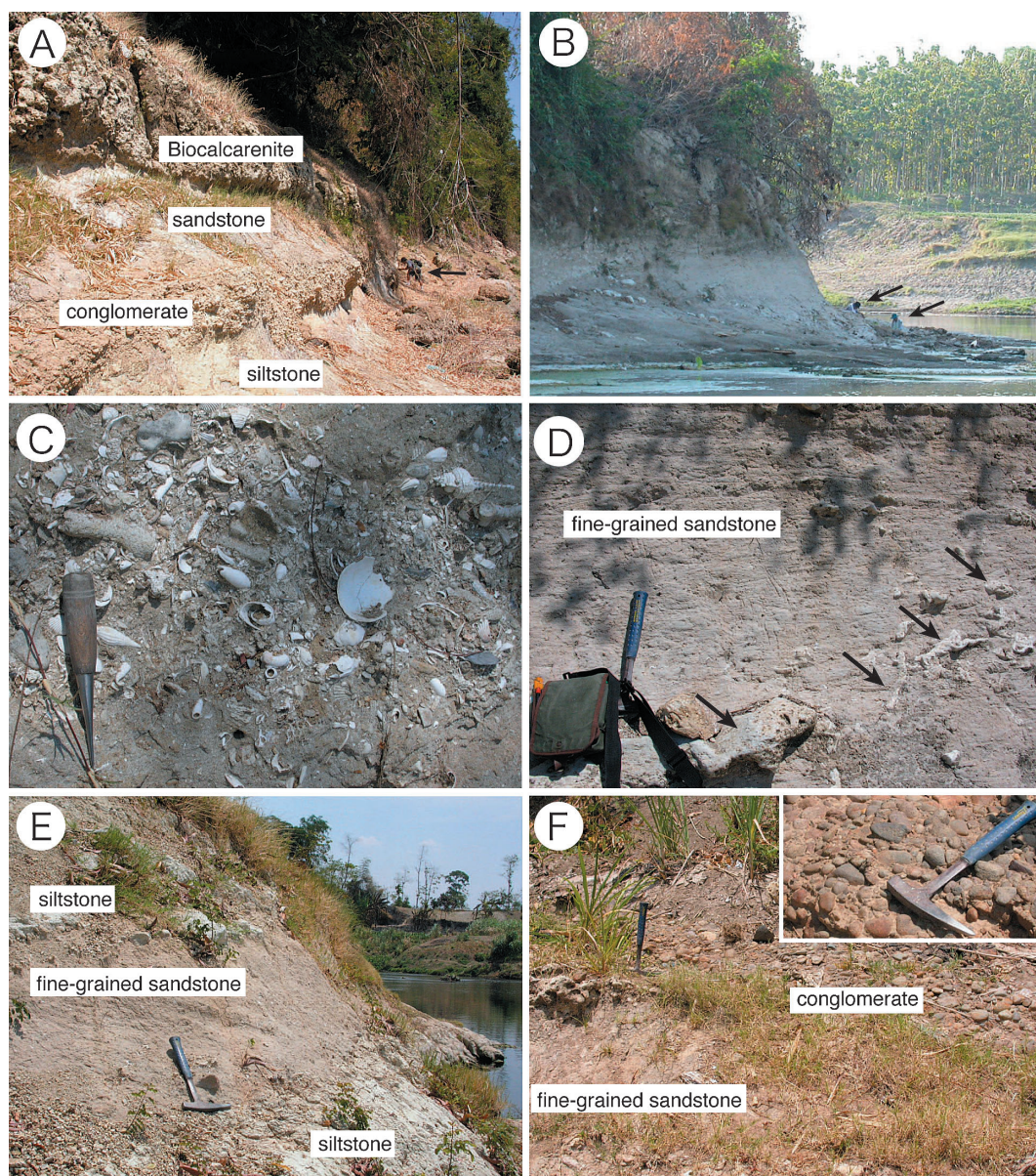


Fig. 3. A. Outcrop photograph showing the stratigraphic succession at S-1. Arrow indicates person for scale. B. Perspective view of S-2. Arrows indicate people for scale. C. Outcrop photograph showing the mode of fossil occurrence at locality SDE-3C. The needle is 12 cm in length. D. Outcrop photograph showing the fine-grained sandstone lithofacies at the middle part of S-2. Arrows indicate calcareous concretions. E. Outcrop photograph showing the stratigraphic succession at S-3. F. Outcrop photograph showing the unconformity between the Klitik Member (fine-grained sandstone) and the Pucangan Formation (conglomerate) at the top of S-4.

generic level, of which 19% identified at species level are extinct. However, this percentage will become higher once all the specimens are identified, because many unidentified species appear to

be extinct.

The species composition differs considerably between the three beds in spite of the close position stratigraphically. The assemblage in SDE-3A

Table 1. List of molluscan species from the Bangun locality in the Sonde area, East Java. Extinct species are indicated by asterisks.

Species	Fossil beds			Habitats of modern counterparts
	3A	3B	3C	
Gastropoda				
<i>Yayoiacmaea oyamai</i> (Habe)		38		low intertidal to subtidal
<i>Diodora quadriradiata</i> (Reeve)		3		intertidal to 30 m
<i>Diodora</i> sp.		5		
<i>Turbo</i> (<i>Marmarostoma</i>) <i>sondeianus</i> Martin*	1		4	
<i>Turbo</i> (<i>Marmarostoma</i>) <i>gemmatus</i> Reeve			2	
<i>Turbo</i> (<i>Turbo</i>) <i>petholatus</i> Linnaeus		2		
<i>Angaria</i> cf. <i>neglecta</i> Poppe & Goto			1	intertidal to 20 m
<i>Trochus</i> cf. <i>maculatus</i> Linnaeus		2		intertidal to upper subtidal
<i>Trochus sondeianus</i> Martin			3	
<i>Rossiteria pseudonucleus</i> Poppe, Tagaro & Dekker		14		intertidal to 842 m
<i>Ethalia</i> sp.		17	8	
<i>Minolia belcheri</i> (Philippi)		17	2	subtidal to 150 m
<i>Calliostoma</i> sp. 1		6		
<i>Calliostoma</i> sp. 2		1		
<i>Calliostoma</i> sp. 3			1	
<i>Nerita</i> sp. 1	1			intertidal
<i>Nerita</i> sp. 2	1			intertidal
<i>Clithon</i> sp. 1			1	estuarine
<i>Clithon</i> sp. 2			1	estuarine
<i>Clithon</i> sp. 3	1			intertidal to upper subtidal
<i>Smaragdia</i> sp.		12		
<i>Plesiotrochus</i> sp.		6		
<i>Cerithium</i> sp. 1	1			
<i>Cerithium</i> sp. 2	1			
<i>Tarebia granifera madiunensis</i> (Martin)	1			estuarine
<i>Tibia powisi</i> (Petit)	1			100–400 m
<i>Strombus</i> (<i>Labiostrombus</i>) <i>fennemai</i> Martin*	9	1	3	
<i>Strombus</i> (<i>Laevistrombus</i>) <i>turturella</i> (Röding)	3			
<i>Strombus</i> (<i>Canarium</i>) <i>labiatus</i> (Röding)			1	lower intertidal to 10 m
<i>Strombus</i> (<i>Canarium</i>) <i>gendinganensis</i> Martin*	1			
<i>Terebellum terebellum</i> (Linnaeus)	1	5		lower intertidal to 20 m
<i>Xenophora chinensis</i> (Philippi)			3	40–140 m
<i>Polinices albumen</i> (Linnaeus)		1		subtidal to 70 m
<i>Polinices powisiana</i> (Recluz)		3		10–50 m
<i>Polinices mammilla</i> (Linnaeus)	14	2	3	intertidal to 20 m
<i>Polinices</i> sp.		8	4	
<i>Glossaulax didyma</i> (Röding)		2		intertidal to 50 m
<i>Natica</i> sp. 1		4	4	
<i>Natica</i> sp. 2		7		
<i>Sinum</i> sp.		2	2	
<i>Erato</i> sp.		9		
<i>Bufonaria ignobilis</i> Beu		1	3	82–390 m
<i>Gyrineum lacunatum</i> (Mighels)		1		intertidal to 210 m
<i>Gyrineum bituberculare</i> (Lamarck)		1		intertidal to 68 m
<i>Gyrineum gyrineum</i> (Linnaeus)	1			intertidal to 68 m
<i>Semicassis bisulcata</i> (Schubert & Wager)		1		50–100 m
<i>Nucella?</i> <i>bantamiensis</i> (Martin)*		1		
<i>Drupella concatenata</i> (Lamarck)	1			intertidal to subtidal
<i>Nassarius</i> (<i>Zeuxis</i>) <i>castus</i> (Gould)	8		17	10–200 m
<i>Nassarius</i> (<i>Niotha</i>) <i>livescence</i> (Philippi)	5		1	intertidal to 104 m
<i>Hindsia gendinganensis</i> Martin*	1			
<i>Phos woodwardianus</i> Martin*		6		
<i>Morum</i> sp.*			1	
<i>Vexillum pricardium</i> (Linnaeus)			2	
<i>Costellaria obeliscus</i> (Reeve)			4	10–100 m
<i>Parametaria bandungensis</i> (Martin)*	9		3	
<i>Conus socialis</i> Martin*	8		16	
<i>Conus ngavianus</i> Martin*				
<i>Conus cinereus</i> Hwass sensu Martin		4		10–50 m
<i>Conus ngavianus</i> Martin*			1	
<i>Conus praecellens</i> Adams			1	20–400 m
<i>Conus sondeianus</i> Martin*	1			
<i>Gemmula gendinganensis</i> (Martin)*			4	

Table 1. Continued.

Species	Fossil beds			Habitats of modern counterparts
	3A	3B	3C	
Bivalvia				
<i>Arca navicularis</i> Burguiere		1	5	intertidal to 20 m
<i>Arca plicata</i> (Dillwyn)		19		intertidal to 20 m
<i>Anadara antiquata</i> (Linnaeus)	1		2	lower intertidal to 5 m
<i>Anadara (Anadara) biformis</i> (Martin)*	5	7	2	
<i>Anadara pangkaensis</i> Martin*	1		36	
<i>Anadara (Tosarca) pseudoantiquata</i> (Martin)*		2		
<i>Limopsis</i> sp.	2	11	65	
<i>Glycimeris reevei</i> (Mayer)		4	3	3–50 m
<i>Glycimeris junghuhni</i> (Martin)*		15		
<i>Glycimeris</i> sp.*		2		
<i>Tucetona</i> sp.*		4		
<i>Lithophaga (Diberus) malaccana</i> (Reeve)	ca. 10	2		intertidal to 20 m
<i>Lima vulgaris</i> Link		1		intertidal to 20 m
<i>Mimachlamys</i> sp. 1		1	8	
<i>Mimachlamys</i> sp. 2	3	1	3	
<i>Mimachlamys</i> sp. 3			1	
<i>Coralichalmys?</i> sp.			1	
<i>Chlamys (Azumapecten) squamata</i> (Gmelin)			3	5–40 m
<i>Cryptopecten nux</i> (Reeve)		2	1	20–100 m
<i>Juxtamusium coudeini</i> (Bavay)		3	1	
<i>Amusiopecten gendinganensis</i> (Martin)*		1	3	
<i>Annachlamys striatula</i> (Linnaeus)		1	9	
<i>Serratovola gardineri</i> (Smith)*	5	2	14	10–30 m
<i>Decatopecten plica</i> (Linnaeus)		1	8	intertidal to 10 m
<i>Lamellolucina</i> sp.*	19			
<i>Lucinoma</i> sp.			1	
<i>Cardita variegata</i> Bruguiere		12		intertidal to 15 m
<i>Cardita decipiens</i> Martin*		2		
<i>Cardita</i> sp. 1		14	10	
<i>Cardita</i> sp. 2			1	
<i>Glans cf. granulatus</i> Noda*		1		
<i>Fragum alfurieum</i> (Fischer)		16		
<i>Nipponocrassatella</i> sp.*		12	2	
<i>Vasticardium cf. transcendens</i> (Melvill & Standen)		1		20–80 m
<i>Vasticardium</i> sp.		2		
<i>Laevicardium attenuatum</i> (Sowerby)		3		subtidal to 20 m
<i>Lunulicardia subretusa</i> (Sowerby)		1		
<i>Corbula fortisulcata</i> Smith		30		20–50 m
<i>Corbula</i> sp. 1		312		
<i>Corbula</i> sp. 2		11		
<i>Cyprimeria sawitrae</i> Beets*		2		
<i>Venus (Ventricolaria) toreuma</i> (Gould)		1		intertidal to 20 m
<i>Dosinia boettgeri</i> Martin*			9	
<i>Circe (Circe) aff. scripta</i> (Linnaeus)		2		
<i>Callista phasianella</i> Deshayes	9			subtidal to 20 m
<i>Callista</i> sp. 1		5	3	
<i>Callista</i> sp. 2*			3	
<i>Meretrix</i> sp.		7		
<i>Placamen chloroticum</i> (Philippi)			6	
<i>Timoclea</i> sp.*		27		

includes species that are 8.9% and 18.8% in common with SDE-3B and SDE-3C, respectively, and 23.7% of species in common between SDE-3B and SDE-3C. This fact strongly suggests that the marine environment changed abruptly during the deposition of the Klitik

Member.

Bed SDE-3A consists of muddy sandstone and contains well-preserved molluscs distributed rather sporadically. Most of the molluscs do not show any indication of shell abrasion nor strong current transportation; the most common bivalve

is *LamelloLucina* sp. that occurs mostly with conjoined valves, suggesting *in situ* occurrence. This species appears to be an undescribed new species, and seven modern congeners restricted in the Indo-Pacific are known in depths from 10 m down to over 300 m (Taylor & Glover, 2002). This bed contains two specimens of two undetermined *Nerita* and one specimen of *Tarebia granulifera madiuensis*, but the former two and the latter one are considered to have been transported from an upper intertidal rocky shore and a freshwater stream on land, respectively. The modern species so identified in this assemblage inhabit a zone between intertidal to 200 m. The bed also includes some platy boulder-sized calcareous concretions frequently bored by *Lithophaga (Diberus) malaccana* (Reeve) in the upper part. This species today is known from intertidal zones down to 20 m, and it is improbable that such large boulders were transported down to any depth. Therefore, the most plausible interpretation for the depositional environment of this bed is upper sublittoral bottom. Contrasted with this is the occurrence of *Tibia powisi* (Petit), because modern individuals are recorded from 100 m to 200 m (Okutani, 2000). However, this species commonly occurs in the intertidal to subtidal sediment of the middle Pliocene Tartaro Formation at Angat in Luzon, northern Philippines (Kase & Aguilar, 2007). We suggest that this species inhabited shallower habitats in the past than do modern representatives.

Bed SDE-3B consists of coarse-grained biocalcarene and contains abundant and diverse molluscs that exhibit an allochthonous occurrence. The bed also contains many pebble- to boulder-sized brain corals and thin beds of concretions frequently bored by *Lithophaga (Diberus) malaccana* (Reeve). A majority of the molluscs identified to modern species are dwellers of intertidal to 20 m depth. Therefore, the most reasonable interpretation of the depositional environment for this bed is upper sublittoral bottom, but probably shallower than bed SDE-3A. An exception to this is the occurrence of *Bufonaria ignobilis* Beu, because this species

is recorded from depths ranging from 82 m to 390 m (Beu, 1987, 1998). We suggest that this is another example of species that changed the habitat since the middle Pliocene.

Bed SDE-3C consists of fine-grained sandstone with a lenticular geometry indicating a high-energy environment of deposition. The species composition suggests that the bed was deposited in an upper sublittoral bottom the same as bed SED-3A.

To sum up these facts, the molluscan assemblages at the Bangun locality are intertidal to upper sublittoral dwellers.

Planktonic Foraminiferal Biostratigraphy

We analyzed planktonic foraminifers from sediment samples from three beds SDE-2.1 (uppermost part of the Kalibeng Formation), SDE-3.1 (middle part of the Klitik Member) and SDE-3.2 (upper part of the Klitik Member). All the samples contain abundant well-preserved planktonic foraminifers, of which the sample from SDE-3.1 yielded individuals ubiquitously. Table 2 lists the species found in the three samples and Fig. 4 illustrates some important species for age determination in this study.

All the three samples are dominated by species of *Globigerinoides* and also associated with species of *Globorotalia* and *Pulleniatina*, an assemblage typical of tropical and subtropical waters. All the samples contain *Dentoglobigerina altispira altispira* (Cushman & Jarvis) (Fig. 4A, B), whose last occurrence has been set at 3.09 Ma (Berggren *et al.*, 1995). Also, all the samples are dominated by the dextrally coiled forms of *Pulleniatina obliquiloculata* (Parker & Hones). Domination of the dextrally coiled forms of *P. obliquiloculata* started at 3.95 Ma, so that all the samples are restricted to date within a time interval from 3.95 to 3.09 Ma. The sediment sample from SDE-3.2 yielded *Globorotalia margaritae* Bolli & Bermudez (Fig. 4C, D) whose last occurrence is at 3.58 Ma (Berggren *et al.*, 1995). Furthermore, *Sphaeroidinellopsis seminulina* (Schwager) occurred in SDE-3.2 (Fig. 4G, H),

Table 2. Occurrence list of fossil planktonic foraminifera from the Kalibeng Formation in the Bangun area, East Java, Indonesia. Bed numbers see Figure 2. Abbreviations: M: Moderate; VG: Very Good; A: Abundant (>16%); C: Common (8–16%); R: Rare (4–8%); +: Trace (<4%).

Species	Beds		
	SDE-2.1	SDE-3.1	SDE-3.2
<i>Dentoglobigerina altispira altispira</i> (Cushman and Jarvis)	+	+	+
<i>Globigerina bulloides</i> d'Orbigny	C	+	+
<i>Globigerina umbilicata</i> Orr and Zaitzeff	R		
<i>Globigerina falconensis</i> Blow	+	+	
<i>Globigerinella siphonifera</i> (d'Orbigny)	+	R	R
<i>Globigerinita glutinata</i> (Egger)	+	+	
<i>Globigerinoides obliquus</i> Bolli	R	+	C
<i>Globigerinoides ruber</i> (d'Orbigny)	R	A	+
<i>Globigerinoides sacculifer</i> (Brady)	C	A	A
<i>Globoconella puncticulata</i> (Deshayes)	R	+	
<i>Globorotalia</i> cf. <i>ungulata</i> Bermudez		+	
<i>Globorotalia crassaformis</i> (Galloway and Wissler)	R	+	
<i>Globorotalia margaritae</i> Bolli and Bermudez			+
<i>Globorotalia menardii</i> (Parker, Jones and Brady) s.l.	R	R	R
<i>Globorotalia</i> aff. <i>tosaensis</i> Takayanagi and Saito	+		
<i>Globorotalia tumida</i> (Brady)	C	R	R
<i>Globoturborotalita decoraperta</i> (Takayanagi and Saito)		+	
<i>Globoturborotalita rubescens</i> (Hofker)	R	+	
<i>Globoturborotalita tenella</i> (Parker)	+	+	
<i>Neogloboquadrina conglomerata</i> (Schwager)	R		C
<i>Neogloboquadrina</i> cf. <i>incompta</i> (Cifelli) dextral	R	C	+
<i>Neogloboquadrina dutertrei</i> (d'Orbigny) dextral	+	R	C
<i>Neogloboquadrina dutertrei</i> (d'Orbigny) sinistral	+		
<i>Orbulina universa</i> d'Orbigny	+	+	R
<i>Pulleniatina obliquiloculata</i> (Parker and Jones) dextral	+	C	R
<i>Sphaeroidinella dehiscens</i> (Parker and Jones)		+	
<i>Sphaeroidinellopsis seminulina</i> (Schwager)	+		+
Preservation	M	VG	VG

while SDE-3.1 includes only its descendant form *Sphaeroidinella dehiscens* (Parker & Jones) (Fig. 4E, F). Therefore, the evolutionary transition in this lineage appears to occur between SDE-3.1 and SDE-3.2. Morphological evolution in this lineage involves a sudden increase of the percentage of specimens equipped with supplementary aperture and the evolutionary transition (*Sphaeroidinella* event) is marked by the first occurrence of specimens with large supplementary apertures (Kučera, 1998). This event is known to occur diachronously around the world: at about 3.6 Ma in the eastern equatorial Pacific and at 3.5 to 3.6 Ma in the Caribbean, while after 3.5 Ma in the Atlantic and Indian oceans (Kučera, 1998). Therefore, the age of bed SDE-3.2 can be assigned more in detail to around 3.58 Ma, because the bed yields both *G. margaritae* and *S. semi-*

nulina. Additionally, SDE-3.1 is above the *Sphaeroidinella* datum and it is highly probable that the bed is within 3.95 Ma to 3.50 Ma. To sum up, these planktonic foraminifers in the mollusc-bearing beds SDE-3A to SDE-3C are between 3.95 and 3.58 Ma, or latest Early or earliest Late Pliocene in age.

Concluding Remarks

The fossil beds of the Klitik Member of the Kalibeng Formation exposed along the Solo River at Bangun are one of the four classical collecting sites of the Pliocene molluscs in the Sonde area of East Java, Indonesia. Investigations of the molluscan and planktonic foraminiferal assemblages at the Bangun locality reveal that the diverse molluscs dwelt in the in-

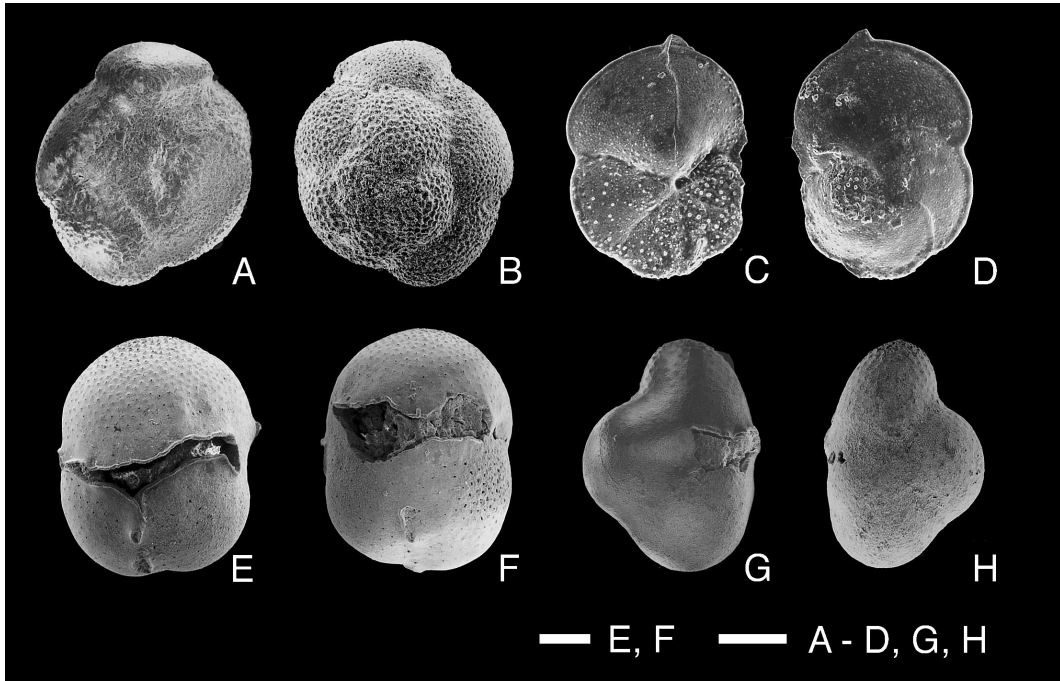


Fig. 4. Pliocene planktonic foraminifers from the Klitik Member of the Kalibeng Formation in the Bangun locality, East Java. A, B: *Dentoglobigerina altispira altispira* (Cushman and Jarvis) from sample SDE-3-1. C, D: *Globorotalia margaritae* Bolli and Bermudez from sample SDE-3-2. E, F: *Sphaeroidinella dehiscens* (Parker and Jones) from sample SDE-3-1. G, H: *Sphaeroidinellopsis seminulina* (Schwager) from sample SDE-3-2. Scale bars=100 μm .

tertidal to upper sublittoral bottoms under the strong influence of oceanic water and can be estimated the age in the range between 3.95 Ma and 3.58 Ma, the latest Early or earliest Late Pliocene. The result suggests that the fossil-bearing beds at the other three classical localities in the Sonde area may have deposited in the environment and age almost the same as the Bangun locality because the beds at those sites are positioned at the same stratigraphic level and not far from the Bangun locality.

A quite diverse but slightly different shallow-marine molluscan assemblage was reported from the Upper Kalibeng Formation in the Sangiran area, about 60 km west-southwest of the Sonde area (Kotaka & Hasibuan, 1983). There are two results with regard to the age of the Upper Kalibeng Formation in the Sangiran area. Siesser *et al.* (1984) investigated the nannofossils from the upper 22 m of the Upper Kalibeng Formation

and assigned the beds to calcareous nannofossil Zone NN16 (3.23–2.3 Ma). Reanalysis of the stratigraphic distribution of nannofossils listed by Siesser *et al.* (1984) based on the modern scheme of biostratigraphy revise the age of the fossil-bearing beds in the Sangiran area. Important for the age control of the section is the common occurrence of *Sphenolithus* spp. throughout the section and the few or rare occurrences of *Reticulofenestra pseudoumbilica* (Gartner) from most of horizons they examined. The last occurrences of *Sphenolithus* spp. and *R. pseudoumbilica* are 3.65 Ma and 3.85 Ma, respectively (Raffi & Flores, 1995). Because *R. pseudoumbilica* is so uncommon, it is suggested that this species was derived from older strata and therefore a possible age is 3.85–3.65 Ma for the Upper Kalibeng Formation in the Sangiran area. On the other hand, Kadar (1985) reported the occurrence of *Globorotalia tosanensis* (Takayanagi & Saito)

in the lower part of the studied section and the absence of *Globorotalia truncatulinoides* (d'Orbigny) throughout the section, and assigned the beds to Blow's (1969) N21 that spans from 3.35 Ma to 2.20 Ma (Berggren *et al.*, 1995). The discrepancy of ages resulted from the planktonic foraminifer and nannofossil analyses can be interpreted in that the nannofossils were all derived from older rocks and the real age is Blow's (1969) N21 indicated by the planktonic foraminifers. If this were the case, the fossil-bearing beds in the Sangiran area would be younger than those in the Sonde area.

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インドネシア・東部ジャワ島のソンド貝化石群の地質年代

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インドネシア東部ジャワ島ソンド地域のソロ川に露出するカリベン層のクリティク部層は貝化石を豊富に産出し、インドネシアの新第三紀貝化石層序の一つであるソンド階の準模式地で、その時代は漠然と鮮新世後期とされている。本研究では、ソンド地域の古典的な4ヶ所の貝化石産地の一つであるソンド西方2 kmに位置するバングンのクリティク部層の地質調査を行い、貝化石と浮遊性有孔虫を解析し、ソンド貝化石群の生息環境とその時代の詳細を検討した。その結果、バングンのクリティク部層の貝化石群は総計150種を超え、現生種に同定される種の現在の深度分布から、外海水の影響を強く受ける潮間帯下部から上部浅海帯の群集であることが明らかとなった。また、同部層からは豊富な浮遊性有孔虫が産出し、その解析から、クリティク部層の貝化石群は3.95 Maから3.58 Maの間の時代、すなわち前期鮮新世最末期あるいは後期鮮新世最初期のものであることが明らかとなった。本研究の結果は、熱帯西太平洋の新生代貝化石群の進化を明らかにするための重要な新知見である。