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Biostratigraphy and Depositional Environment of Early to Middle Miocene Sediments at Kulon Progo, Wonosari, and Punung Areas Based on Their Foraminiferal and Palynological Assemblages

Rakhmat Fakhruddin

Centre for Geological Survey, Geological Agency, Ministry of Energy and Mineral Resources
Jln. Diponegoro No.57 Bandung, Jawa Barat, Indonesia

Corresponding author: rakhmatfakh@gmail.com
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Abstract - Epiclastic sediments at Kulon Progo, Wonosari, and Punung areas were deposited in marine and terrestrial environments. The aim of this study is to reconstruct biostratigraphy, depositional environments, and sequence stratigraphy of several sections of these epiclastic sediments. Combined foraminiferal and palynological analysis needs to be done to better understand the age correlation of epiclastic sediments of those three studied areas. Epiclastic sediments at Wonosari area (Sambipitu Formation) were deposited at N7-N8 zones, late Early Miocene, while at Kulon Progo area (lower part of Jonggrangan Formation) and Punung area (Jaten, Wuni, and Nampol Formations) were deposited at Middle Miocene. Sediments of the lower part of Jonggrangan Formation were deposited in various environments: mangrove and inner to middle shelf. Depositional environments at the lower part of Sambipitu Formation at Kali Ngalang section are peat swamp and mangrove environments which are more landward compared to the upper part of sediments of Sambipitu Formation which were deposited in marine environments: inner shelf, middle shelf, and outer shelf. At Punung area, the depositional environments are riparian forest, alluvial swamp, backmangrove, mangrove, and inner shelf. MFS-A and MFS-B at Wonosari area found in N8 zone, late Early Miocene, were made as a regional datum correlation for this area, because they are the good age control as they show low diachronous. MFS-1 and MFS-2 at Kulon Progo and Punung areas are found in *Florschuetzia meridionalis* zone, Middle Miocene.

Keywords: biostratigraphy, depositional environment, sequence stratigraphy, foraminifera, palynology

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Introduction

Background

Early to Middle Miocene sediments at Kulon Progo, Wonosari, and Punung areas, were deposited between marine and terrestrial environments, and composed of epiclastic sediments (Rahardjo *et al*., 1995; Surono *et al.,* 1992; Samodra *et al.,* 1992).

At Kulon Progo area, epiclastic sediments are represented by Jonggrangan Formation that were deposited during the Early Burdigalian (Early Miocene, Tf1 zone), based on the larger foraminiferal analysis and were dated 18.9 Ma based on the Sr isotope analysis (Reich *et al*., 2014). They assumed that these sediments were deposited in a paleodepth of ~5 - 20 m. Limestone of the Jonggrangan Formation is dated Early Miocene by Maryanto (2013), while it is dated Middle to Late Miocene by Pambudi and Budiadi (1999, in Satyana, 2005).

Epiclastic sediments at Wonosari area are represented by Sambipitu Formation, which is dated Early Miocene, N4-N8 zones (Kadar, 1986). On the other hand, Suyoto and Santoso (1986) stated that the age of this unit was younger, N7-N9 zones (Early to Middle Miocene). Slightly different opinions are provided by Akmaluddin *et al*. (2012), who concluded that Sambipitu Formation was deposited at NN2-NN6 zones (Early to Middle Miocene) from the nannofossil analysis and N6-N8a zones (Early Miocene) from the foraminiferal analysis. Sediments of Sambipitu Formation were deposited in a deep marine turbidite environment (Rahardjo *et al*., 1995; Akmaluddin *et al.*, 2012). Another depositional environment interpretation of this formation is also offered by Surono and Permana (2011) who stated that this unit was deposited between N7 and N8 zones, and the lower member was deposited in a tidal influenced environment consisting of a volcanic material debris flow. While sediments of the upper member were deposited in a deeper inner shelf environment.

Stratigraphic position, from old to young of epiclastic sediments at Punung area, is Jaten, Wuni, and Nampol Formations, which were deposited in shallow marine environments and dated Early Miocene (Sartono, 1964). A different opinion is offered by Rahardjo and Yulianto (1998) that sediments of Jaten Formation are younger, Middle Miocene. The sediments of Wuni and Nampol Formations are also dated younger to Middle Miocene (Samodra *et al.,* 1992; Surono *et al.,* 1992).

Combined foraminiferal and palynological analyses need to be done to better understand the age correlation of epiclastic sediments of the three studied areas. This study aims to provide biostratigraphy, depositional environments, and sequence stratigraphy interpretations using foraminifera and palynomorph fossils at Kulon Progo (Jonggrangan Formation), Wonosari (Sambipitu Formation), and Punung (Jaten, Wuni, and Nampol Formations) areas.

Epiclastic sediments at the studied areas are a potential source rock, but their subsurface distribution and volumetric are not yet clear (Sunjaya *et al*., 2006). Results of this study are expected to provide some preliminary information on the exploration of new hydrocarbon resources in the Southern Mountain Java Basin.

Methods and Materials

Sediment samples were taken from the stratigraphic measured sections at two locations in Kulon Progo area and three locations in Punung area (Figure 1). Foraminifera and palynomorph data assemblages of Kali Ngalang and Kali Urang (Wonosari area) were taken from Fakhruddin (2010). The sample collection were emphasized on limestone, calcareous sandstone, and mudstone for foraminiferal analysis and carbonaceous mudstone and lignite for palynological analysis with representative spacing for each formation. The rock units of each location and the sampling summary are presented in Table 1.

At Kulon Progo section, volcanic rocks as the base of the section represented by Old Andesit Formation (OAF) consist of volcanic breccia and lava. The OAF, at these sections, underlies the Jonggrangan Formation, comprising tuffaceous, medium- to coarse- grained sandstone, and carbonaceous mudstone with intercalation of lignite and sandy limestone. The limestone contains mollusk and coral. The Jonggrangan Formation found in this area is considered to be equivalent to the lower part of Jonggrangan Formation as described by Maryanto (2013). The upper part of Jonggrangan Formation consists of reef limestone, *Globigerina* limestone, and marl (Maryanto, 2013).

The base of the section at Wonosari area is Nglanggran Formation, which is composed of andesitic lava and volcanic breccia. This formation is overlain by Sambipitu Formation comprising tuffaceous fine- to coarse-grained sandstone interbedded with tuffaceous mudstone and intercalation of breccia and lignite, containing trace fossils. Breccia fragments are lithics, corals, and

Figure 1. Locality map of the studied area, showing the position of measured section outcrops (black box): 1= Kembang Soka, 2 = Gunung Kucir, 3 = Kali Ngalang, 4 = Kali Urang, 5 = Kali Jaten, 6 = Jalan Desa Jaten, and 7 = Desa Kutukan.

Table 1. Sampling Summary

No.	Studied Area	Rock Unit	Sample Number	
			Foraminifera	Palynology
1	Kembang Soka, Kulon Progo	Lower part of Jonggrangan Formation	12	7
2	Gunung Kucir, Kulon Progo		2	4
3	Kali Ngalang, Wonosari	Sambipitu and Oyo Formation	32	12
4	Kali Urang, Wonosari		24	12
5	Kali Jaten, Punung	Jaten, Wuni, Nampol, and Punung Formations	4	8
6	Jalan Desa Jaten, Punung		2	4
7	Desa Kutukan, Punung		2	7

carbon clast. Above Sambipitu Formation there is Oyo Formation which consists of calcareous fine- to medium- grained sandstone, tuffaceous, interbedded with limestone, calcareous mudstone, tuffaceous with intercalation of andesite breccia, containing trace fossils.

At the base of the section of Punung area, there is Besole Formation comprising lapilli tuff mostly altered into clay minerals and chlorite. On top of the Besole Formation, there is Jaten Formation comprising fine- to very coarse- grained quartz sandstone, tuffaceous, locally crossbedded, interbedded with carbonaceous mudstone, sandy limestone, conglomeratic sandstone with andesite and mollusc clasts, and lignite seams, containing limestone nodules. Wuni Formation above the Jaten Formation consist of andesite breccia interbedded with medium- to coarse-grained sandstone. Wuni Formation is overlain by Nampol Formation comprising conglomerate interbedded with fine- to coarse- grained sandstone and carbonaceous mudstone, intercalated with lignite seam. At the top of the section, there is Punung Formation composed of bedded limestone containing limestone nodules and mollusk.

Foraminiferal and palynological analyses were carried out in GeoI*Labs* of The Centre for Geological Survey. All the original sample size to analyze is 100 gram. Samples for foraminiferal analysis were treated with H_2O_2. After the fossil grains were extracted, they were washed with water, heated in the oven, and separated from residue using sieves of 63 and 125 μm mesh. Observations of foraminifera were done using 100X magnification binocular microscope. Palynomorph analysis involved extraction from 100 gram samples which was carried out using HF and HCl. Palynomorphs were separated from the substrate using zinc chloride solution. The residue was then sieved with a 5 μm mesh and mounted on slides with glycerin jelly. Palynomorph observation was done using 1000X magnification polarization microscope.

Biostratigraphy

Identifications of foraminifera were done based on Barker (1960), Blow (1969), and Bolli *et al*. (1985). Palynomorph identification was based on Morley (1990, 2000), biozonation of foraminifera was referred to Blow (1969), and palynological zonation was referred to Rahardjo *et al*. (1994).

Sequence Stratigraphy

Identifications of sequence stratigraphic surface were conducted based on foraminiferal and palynomorph assemblages. This analysis was done based on the comparison of planktonic, benthic, and total foraminiferal diversity, planktonic, benthic, and total foraminifera abundance, total palynomorph diversity, total palynomorph abundance, total marine palynomorph diversity, and total mangrove-back mangrove palynomorph diversity on every samples. Identified sequence stratigraphic surfaces at this study are sequence boundary (SB) and maximum flooding surface (MFS). SB is marked by abrupt basinward shifts of facies (Catuneanu, 2006), of which in this study is identified by the sudden changes from deeper marine biofacies to shallower biofacies in vertical sequence. MFS was characterized by marine microfossil abundance acmes (Morley *et al*., 2011). MFS is generally conformable and low diachroneity (correlable), because they were formed at relatively the same geological time (Catuneanu, 2006).

Depositional environments

The depositional environment interpretation was done using foraminiferal analysis (Rauwerda *et al*., 1984; Murray, 2006) and palynological analysis (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). The depositional environments, from land to marine, were divided into: alluvial swamp, peat swamp, riparian forest, beach forest, backmangrove forest, mangrove forest, inner shelf, middle shelf, and outer shelf.

Results and Discussions

Kembang Soka, Kulon Progo

Biostratigraphy

The first occurrence of *Florschuetzia meridionalis* in sample A02 and the last occurrence of *Florschuetzia trilobata* in sample A16 suggest a *Florschuetzia meridionalis* zone of Rahardjo *et al*. (1994) for interval between sample A02 to A16 (Table 2 and Figure 2). This zone is assigned to Middle Miocene, age equivalent to N9-N15 zones (Blow, 1969).

Volcanic activities at Kulon Progo area are represented by OAF, which is stratigraphically deposited below the lower part of Jonggrangan Formation (Figure 2). The absolute age of the OAF based on K-Ar analysis at Kulon Progo area is 29.6 to 25.4 Ma (Soeria-Atmaja *et al.,* 1994). The upper part of Jonggrangan Formation deposited above this section dated as Middle to Late Miocene (Pambudi and Budiadi, 1999 in Satyana, 2005).

Sequence Stratigraphy

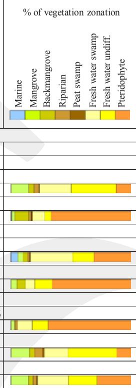
SB-1 is located at the boundary between OAF and the lower part of Jonggrangan Formation. This SB marked the unconformity between these two units (Figure 2). Two MFSs are identified based on their foraminiferal and palynological characteristics of Kembang Soka section (Table 2 and Figure 2). MFS-1 is located at the lower part of Jonggrangan Formation based on the peak of the total foraminiferal diversity and abundance at sample A07. MFS-2 is located at sample A15

Table 2. Foraminifera and Palynomorph Distributions of Kembang Soka Section

Sample	Formation	Biozonation	Depositional environment	Sequence stratigraphy	Analysis	Planktonic: *Globigerina praebulloides*	*Globigerina venezuelana*	*Globigerinoides immaturus*	*Globigerinoides sacculifer*	*Globigerinoides subquadratus*	*Globigerinoides trilobus*	*Globoquadrina dehiscens*	*Globorotalia siakensis*	*Hastigerina praesiphonifera*	Total Planktonic
A 19	Jonggrangan Fm.		IS		F										
A 18	Lower part of Jonggrangan Formation		IS		F										
A 17			IS		F										
A 16		*Florschuetzia meridionalis* zone	MF		P										
A 15			MS	MFS-2	F+ P	2	3	9	9	12	22	3	18	4	82
A 14			IS		P										
A 13			MF		F										
A 12			IS		F										
A 11			IS		P										
A 10			IS		F										
A 09			MF		P										
A 08			-		F	Foraminifera barren									
A 07			IS	MFS-1	F	5									5
A 06			MF		P										
A 05			MF		F										
A 04			MF		P										
A 03			-		F	Foraminifera barren									
A 02			MF		P										
A 01				SB-1	F	Foraminifera barren									

Sample	Benthic: *Amphistigena* sp.	*Bolivina* sp.	*Bolivinella* sp.	*Cassidulina* sp.	*Chrysalidinella* sp.	*Cibicides* sp.	*Clavulina* sp.	*Discorbis* sp.	*Elphidium* sp.	*Eponides* sp.	*Myogypsina* sp.	*Nodosaria* sp.	*Nonion* sp.	*Pyrgo* sp.	*Quinqueloculina* sp.	*Reussela* sp.	*Rotalia* sp.	*Siphonina* sp.	*Triloculina* sp.	*Uvigerina* sp.	ostracods	Total Benthic	Total Foraminifera
A 19	2					6		5	2				6	10	7	2	3					43	43
A 18									11			1	10	2	17						3	41	41
A 17	4								2	3	2		9	11	3	4						38	38
A 16																							
A 15	3	1		2					2	2		1	5					1		1		18	100
A 14																							
A 13									2	1			10		14				5			32	32
A 12			2				15		9	1			13									40	40
A 11																							
A 10									7				11	1	8		4				3	31	31
A 09																							
A 08																							
A 07		1	1		8	5			12	2			7	3	10		2					51	56
A 06																							
A 05	15								10				11		17							53	53
A 04																							
A 03																							
A 02																							
A 01																							

% of vegetation zonation



Sample	Marine: Dinoflagellata cysts	Foram test linings	Mangrove: *Avicennia*-type	*Camptostemon*-type	*Exoecaria*-type	***Florschuetzia meridionalis***	***Florschuetzia trilobata***	*Zonocostites ramonae*	Backmangrove: *Acrostichum aureum*	*Chenopodipollis* sp.	*Discoidites* sp.	*Florschuetzia levipoli*	*Spinizonocolpites baculatus*	*Spinizonocolpites echinatus*	Riparian: *Ilexpollenites* sp.	*Pandaniidites* sp.	*Pometia*-type	*Retistephanocolpites williamsii*	*Sapotaceoidaepollenites* sp.
A 19																			
A 18																			
A 17																			
A 16			5		15	4	**26**	27	3		1	8	1	2	7		7		2
A 15																			
A 14		1	3			1		1	5					17	4				2
A 13																			
A 12																			
A 11	18	1	9				3	5	2	1	1		1	7	5			1	2
A 10																			
A 09			1		1		1	6	8		1	1		2					
A 08																			
A 07																			
A 06					2	3	5	1	1						2	2			
A 05																			
A 04			6	4	5	10	23	18	3			7		2	15	2	2		4
A 03																			
A 02			22		5	**2**	24	2	5		1			2	6			2	
A 01																			

Sample	Freshwater swamp: *Calophyllum* sp.	*Crassoretitriletes* sp.	*Dicolpopollis* sp.	*Magnastriatites howardi*	*Marginipollis concinnus*	*Palmae* sp. (echinate)	*Palmae* sp. (psilate)	*Palmae* sp. (reticulate)	*Polygonum*-type	Freshwater undifferentiated: *Casuarina* -type	*Dacrycarpites* sp.	Gramineae	*Ixonanthes*-type	*Lakiapollis* sp.	*Lanagiopollis* sp.	*Margocolporites* sp.	*Perfotricolpites digitatus*	*Polyadopollenites* sp.	*Pteris*-type	*Podocarpidites* sp.	*Retitricolporites* sp.	*Retitriporites* sp.	*Stephanocolporites* sp.	Pteridophyte: Monolete spore	Psilate trilete	Reticulate trilete	*Verrucatosporites* sp.	Total Palinomorph
A 19																												
A 18																												
A 17																												
A 16			7			7	17	35		1			5		9		4		3		78	29	2	20	2		22	349
A 15																												
A 14						2	17	1						1							9			56	18	8	45	191
A 13																												
A 12																												
A 11	4		6		2	26	16	56	2			6	3	2	5		3				35	4		58	9	7	27	327
A 10																												
A 09			1		2		5	4		1		1									20		2	67	11	6	25	166
A 08																												
A 07																												
A 06		3	3			1	10	3								6	1			4	16			64	26	11	40	204
A 05																												
A 04	10		6	1		3	12	1		8	1				2	1		1	1		90	9	2	13	8		14	284
A 03																												
A 02	4		7		4	2	11	1	2	1											39	6	5	29	4	1	27	214
A 01																												

Note: Abbreviation: F = Foraminifera, P = Palinological, IS = inner shelf, MF = mangrove forest

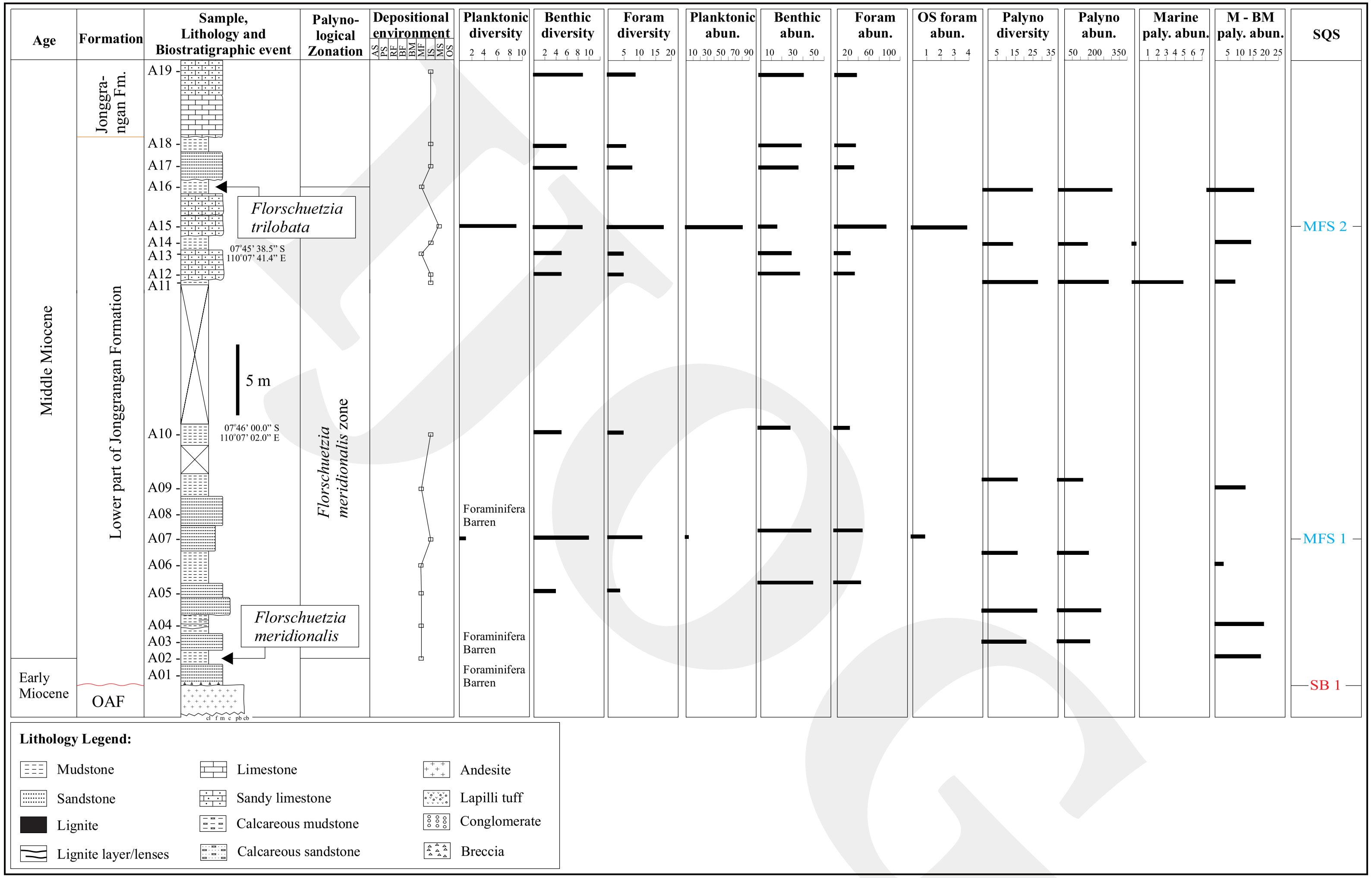


Figure 2. Stratigraphic section, depositional environment interpretation, foraminiferal and palynomorph diversity and abundance, and sequence stratigraphy interpretation of Kembang Soka section. Abbreviation: OAF=Old Andesite Formation, AS=alluvial swamp, PS=peat swamp, RF=riparian forest, BF=beach forest, BM=backmangrove forest, MF=mangrove forest, IS=inner shelf, MS=middle shelf, OS=outer shelf, planktonic diversity=total planktonic diversity, benthic diversity=total benthic diversity, foram diversity=total foraminifera diversity, planktonic abun.=total planktonic abundance, benthic abun.=total benthic abundance, foram abun.=total foraminifera abundance, OS foram abun.=total outer shelf foraminifera abundance, palyno diversity=total palynomorphs diversity, palyno abun.=total palynomorphs abundance, marine paly. abun.=total marine palynomorphs abundance, m- bm palyno abun.=total mangrove−back mangrove palynomorph abundance, sqs=sequence stratigraphic surface.

which is based on the peak of foraminiferal diversity and abundance.

Depositional environment

Sediments of Kembang Soka section were deposited in various depositional environments: mangrove, inner shelf, and middle shelf (Table 2 and Figure 2). Sediments below MFS-1 (samples A01-A06) were deposited in a mangrove environment based on the findings of *Zonocostites ramonae, Exoecaria*-type*, Avicennia*-type*, Camptostemon*-type*, Florschuetzia meridionalis,* and *Florschuetzia trilobata* (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). The occurrence of benthic foraminifera *Elphidium* sp., *Quinqueloculina* sp., and *Nonion* sp. supports this interpretation (Rauwerda *et al*., 1984; Murray, 2006). The depositional environment then changed into inner shelf at MFS-1 (sample A07), based on the occurrences of *Cibicides* sp., *Elphidium* sp., *Nonion* sp., *Amphistegina* sp., and *Rotalia* sp. (Rauwerda *et al*., 1984; Murray, 2006).

Between MFS-1 and MFS-2 (sample A08-A14), the depositional environment varies between mangrove and the inner shelf. Mangrove environment is interpreted based on the occurrence of *Zonocostites ramonae, Exoecaria*-type*, Avicennia*-type, and *Florschuetzia trilobata* (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). The presence of marine palynomorph, such as dinoflagellata cysts and foram test linings, and the occurrence of benthic foraminifera *Elphidium* sp., *Nonion* sp., and *Rotalia* sp. show an inner shelf environment (Rauwerda *et al*., 1984; Murray, 2006). Subsequently, a middle shelf environment developed at MFS-2 (sample A15), which is marked by the presence of *Uvigerina* sp., *Bolivina* sp., *Eponides* sp., *Cassidulina* sp., and *Siphonina* sp. (Rauwerda *et al*., 1984; Murray, 2006).

Sediments that were deposited after the MFS-2 event (sample A16-A19) were accumulated in a mangrove environment. This is indicated by the presence of *Zonocostites ramonae, Exoecaria*-type*, Avicennia*-type, *Florschuetzia meridionalis,* and *Florschuetzia trilobata* (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). Then, the environment changed into inner shelf indicated by the occurrence of *Nonion* sp., *Amphistegina* sp., *Myogipsina* sp., *Rotalia* sp., and *Quinqueloculina* sp. (Rauwerda *et al*., 1984; Murray, 2006).

Gunung Kucir, Kulon Progo

Biostratigraphy

Identified foraminifera and palinomorphs of Gunung Kucir section are presented in Table 3. *Florschuetzia meridionalis* zone (Rahardjo *et al*., 1994) is recognized at this section based on the first occurrence of *Florschuetzia meridionalis* in sample B02 and the last occurrence of *Florschuetzia trilobata* in sample B05.

Sequence Stratigraphy

Similar to Kembang Soka section, SB-1 at this section is also located at the unconformity boundary between OAF and the lower part of Jonggrangan Formation (Figure 3). MFS-1 (sample B03) is interpreted based on the peak of the total foraminiferal diversity and abundance (Table 3 and Figure 3).

Depositional environment

Sediments of the Gunung Kucir section were deposited in mangrove and inner shelf environments (Table 3 and Figure 3). Before the MFS-1 (samples B01 and B02), sediments were deposited in an mangrove environment. This interpretation is indicated by the occurrence of *Zonocostites ramonae, Florschuetzia meridionalis,* dinoflagellata cysts, and foram test linings in these sediments (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). This interpretation is also supported by the presence of benthic foraminifera *Elphidium* sp. and *Quinqueloculina* sp. (Rauwerda *et al*., 1984; Murray, 2006). The depositional environment then changed into an inner shelf environment (sample B03), which is indicated by the presence of *Cibicides* sp., *Amphistegina* sp., *Textularia* sp., *Nonion* sp., *Elphidium* sp., and ostracods at the MFS-1 event (Rauwerda *et al*., 1984; Murray, 2006). After the MFS-1 (samples B04 and B05), the depositional environment of this section changed into a mangrove environ-

Table 3. Foraminifera and Palynomorph Distributions of Gunung Kucir Section.

Sample	Formation	Biozonation	Depositional environment	Sequence stratigraphy	Analysis	Planktonic: *Globigerinoides subquadratus*	Benthic: *Amphistigena* sp.	*Bolivina* sp.	*Cibicides* sp.	*Elphidium* sp.	*Eponides* sp.	*Nonion* sp.	*Quinqueloculina* sp.	*Reussela* sp.	*Spirulina* sp.	*Textularia* sp.	Ostracods	Total Benthic	Total Foraminifera	Palinomorph: % of vegetation zonation (Marine, Mangrove, Backmangrove, Riparian, Peat swamp, Fresh water, Fresh water, Pteridophyte)
B 05	Lower part of Jonggrangan Formation	*Florschuetzia meridionalis* zone	MF		P															
B 04			MF		P															
B 03			IS	MFS-1	F	11	3	1	16	16	4	3		16	1	1	5	66	77	
B 02			MF		F + P				2	9			7					18	18	
B 01			MF	SB-1	P															

Sample	Marine: Dinoflagellata cysts	Foram test linings	Mangrove: *Avicennia*-type	*Exoecaria*-type	***Florschuetzia meridionalis***	***Florschuetzia trilobata***	*Zonocostites ramonae*	Backmangrove: *Acrostichum aureum*	*Discoidites* sp.	*Florschuetzia levipoli*	*Spinizonocolpites baculatus*	*Spinizonocolpites echinatus*	Riparian: *Ilexpollenites* sp.	*Pandaniidites* sp.	*Pometia*-type	*Striatricolpites* sp.	Freshwater swamp: *Crassotriletes* sp.	*Marginipollis concinnus*	*Palmae* sp. (echinate)	*Palmae* sp. (psilate)	*Palmae* sp. (reticulate)	*Polygonum*-type
B 05	1		7	1		**8**			1		6		3	26	4	12	1	2	14	17		
B 04			9		18			30		13			1	11						7	1	2
B 03																						
B 02	4				**1**					3	2								2	12	2	
B 01	6	2					1				5	1	1				3		2	14	3	

Sample	Freshwater undifferentiated: *Gardenia* sp.	Gramineae	*Lanagiopollis* sp.	*Margocolporites* sp.	*Perfotricolpites digitatus*	*Pinuspollenites* sp.	*Podocarpidites* sp.	*Polyadopollenites* sp.	*Pteris*-type	*Retitricolporites* sp.	*Retitriporites* sp.	*Stephanocolporites* sp.	Pteridophyte: Monolete spore	Psilate trilete	Reticulate trilete	*Verrucatosporites* sp.	Total Palinomorph
B 05	5		1	4	2	2	1	1	1	40	3	2	44	6		26	241
B 04	2	1	1						1	13		1	68		1	22	202
B 03																	
B 02		1	1	3	1				1	10			51	10	3	45	152
B 01			1	4	3					3			46	8	3	51	157

Abbreviation: see Table 2 and Figure 2

ment, which is interpreted based on the presence of *Exoecaria*-type, *Avicennia*-type, *Florschuetzia meridionalis*, *Florschuetzia trilobata,* and dinoflagellata cysts (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000).

Kali Ngalang, Wonosari

Biostratigraphy

Reinterpretation of the foraminiferal stratigraphic distribution of Kali Ngalang section (Fakhruddin, 2010) permits the recognition of three biozones within the section (Table 4 and Figure 4). They are, from the base to the top: *Globorotalia birnageae - Praeorbulina transitoria* zone, *Praeorbulina transitoria - Orbulina universa* zone, and *Orbulina universa* zone. *Globorotalia birnageae - Praeorbulina transitoria* zone is characterized by the first occurrence of *Globorotalia birnageae* at the base and the first occurence of *Praeorbulina transitoria* at the top. This zone is correlated with N7 zone of Blow (1969). The age of sediments below the first occurrence of *Globorotalia birnageae* is undetermined, because the sediments of the section do not contain any foraminifera. *Praeorbulina transitoria - Orbulina universa* zone is marked by the first occurrence of *Praeorbulina transitoria* at the base and the fisrt occurence of *Orbulina universa* at the top. This zone is equated with N8 zone of Blow (1969). The first occurrence of *Orbulina universa* defines the base of *Orbulina universa* zone. This zone is correlated with N9 zone (Blow, 1969).

The Nglanggeran Formation below the Sambipitu Formation was dated 20 to 19 Ma using U-Pb method (Smyth, 2005 in Bronto, 2010). Carbonate sediment above the Sambipitu Formation is Oyo Formation, which is based on the foraminiferal analysis by Surono (2009) which was deposited up to N11 zone (Blow, 1969).

Sequence Stratigraphy

In this section, SB is located about 60 cm below the boundary between Sambipitu Formation and Oyo Formation (Table 4 and Figure 4; Fakhruddin, 2010). It is characterized by a sudden change from marine biofacies (outer shelf, sample

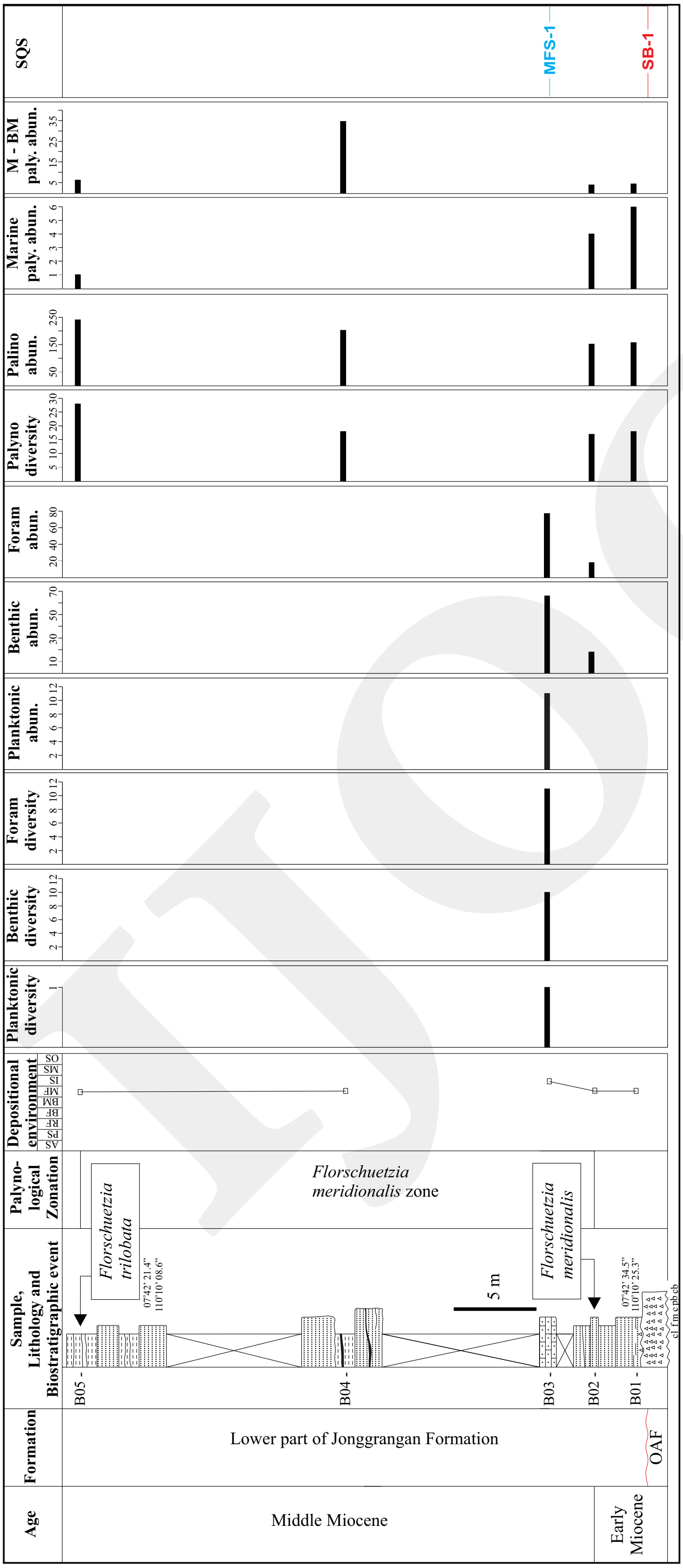


Figure 3. Stratigraphic section, depositional environment interpretation, foraminiferal and palynomorph diversity and abundance, and sequence stratigraphy interpretation of Gunung Kucir section. Legend and abbreviation: see Figure 2.

Table 4. Foraminiferal and Palynomorph Distributions of Kali Ngalang Section (Fakhruddin, 2010)

Planktonic

Sample	Formation	Biozonation	Depositional environment	Sequence stratigraphy	Analysis	*Cassigerinella chipolensis*	*Catapsydrax dissimilis*	*Catapsydrax stainforthi*	*Globigerina praebulloides*	*Globigerina venezuelana*	*Globigerinoides bisphericus*	*Globigerinoides diminutus*	*Globigerinoides immaturus*	*Globigerinoides obliquus*	*Globigerinoides sacculifer*	*Globigerinoides subquadratus*	*Globigerinoides trilobus*	*Globorotalia archeomenardii*	***Globorotalia birnageae***	*Globorotalia continuosa*	*Globorotalia mayeri*	*Globorotalia obesa*	*Globorotalia peripheroronda*	*Globorotalia praescitula*	*Globoquadrina altispira*	*Globoquadrina dehiscens*	*Hastigerina praesiphonifera*	***Orbulina universa***	*Praeorbulina glomerosa*	*Praeorbulina sicana*	***Praeorbulina transitoria***	Total Planktonic
C40	Oyo Formation	*O. universa* zone	MS		F				2	2			11		12		22				14	4	5		12		5	12				101
C39			MS		F				3				12			11			7		17	5	11					**14**				80
C38		*Praeorbulina transitoria - Orbulina universa* zone	MS		F						14				4	4	4	7			10	5			8	3			2			61
C37			MS		F				2		15	10	12			3	5			5	21		11		14				15			113
C36			MS		F			2		3	19	10	10			25			6				3			23			18	20	6	145
C35			MS		F								1			22	3		6		7		1	3	12				21	6	7	89
C34			OS	MFS-B	F					2	4		14		23	60	27		10		24		7	2	36		8					217
C33			MS		F						7					2									5	8				7		29
C32	Sambipitu Formation		MS		F				3		4		5	1	4		10	2			10	6			7	8			2	3	2	67
C31			MF	SB	P																											
C30			OS		F				2	3	1	4	16		11	31			2		18			3	22	1	15			11	1	141
C29			-		F	Foraminifera barren																										
C28			OS		F							2	12		5	4	21		7	5	15		4		14		5			11	5	110
C27			OS		F	12				3	8	3	6		10	26	25		7		21				26		1		4		3	155
C26			IS		F + P				5	5	25			15	13	21	14			1	37					15					1	152
C25			MS		F	17			18	1	12					7	42	2	3	5	19	2			11							139
C24			OS		F + P		5			3			15	1	21	39	21	4	10	14	30	10				35						208
C23			MS		F + P				10	1			7	4	7	19	29		1	1	8					22						109
C22			MS		F					2	29				8	17		1	2	4	19	1			28						2	113
C21			-		P																											
C20			OS		F				4				5		9	19	9		3	4	10	9			17	4	4					97
C19			MS		F								7		5	11					4				4	8						39
C18			-		P																											
C17			MS		F						4		17		13	9	21	1		4	14				29	20					12	144
C16			OS		F			1		25			13		19	21			10	16	19				24	8	10			16		182
C15			-		F																11											11
C14			-		F								7			14	19			5	15				19							79
C13			-		P																											
C12			-		P																											
C11			OS	MFS-A	F	4	2		6	4			19		17	28	23		9	4	41	4			18		4					183
C10			MS		F					7			16		15		25		5		4		3		20		5		7			107
C09			MS		F					5					20	14					20	16			22		9				**2**	108
C08		*G. birnageae - P. transitoria* zone	MS		F				32					12	12	2	22		**2**		12	11				33						138
C07			MF		F + P	Foraminifera barren																										
C06			-		F	Foraminifera barren																										
C05			MF		P																											
C04			-		F	Foraminifera barren																										
C03			MF		P																											
C02			-		F	Foraminifera barren																										
C01			PS		P																											

Benthic

Sample	*Amphistigena* sp.	*Amphicorina* sp.	*Bolivina* sp.	*Bulimina* sp.	*Cassidulina* sp.	*Cibicides* sp.	*Dentalina* sp.	*Eggerella* sp.	*Elphidium* sp.	*Eponides* sp.	*Frondicularia* sp.	*Gyroidina* sp.	*Karreriela* sp.	*Lagena* sp.	*Lenticulina* sp.	*Marginulinopsis* sp.	*Nodosaria* sp.	*Nonion* sp.	*Nonionella* sp.	*Pullenia* sp.	*Pyrgo* sp.	*Siphonina* sp.	*Sphaeroidina* sp.	*Uvigerina* sp.	Total Benthic	Total Foraminifera
C40	14		1			7																		1	23	124
C39	10		3	2	2	11				2														1	31	111
C38										1							1								2	63
C37	5		1			7						1					3								17	130
C36		1		1											3		1	1						1	8	153
C35				2						1				1	3								1	3	11	100
C34			5	9	7	6				2		1		2	8			4				1		8	53	270
C33						1									2		3						1		7	36
C32	13					3									2		2								20	87
C31																										
C30			2	1											1		2								6	147
C29																										
C28			1									1													2	112
C27				4						2		1			2		3	3		1				2	18	173
C26				2	1	3	1	1	1						1		2				1				13	165
C25										2															2	141
C24			2		3	2	1			5			2		7		2							1	25	233
C23						3									1										4	113
C22				3	8	6	2			6					4		1							1	31	144
C21																										
C20		1	1	1	1										1		1						1		7	104
C19	1			1																			1		3	42
C18																										
C17			3	1													6	5							15	159
C16				3		1	1					1			1									1	8	190
C15																										11
C14																										79
C13																										
C12																										
C11										2	1					1	1		1					2	8	191
C10	7			1		5									4		2	2						1	22	129
C09			1	1																					2	110
C08				2			1			2							1	1							7	145
C07																										
C06																										
C05																										
C04																										
C03																										
C02																										
C01																										

Palinomorph (% of vegetation zonation: Marine, Mangrove, Backmangrove, Riparian, Peat swamp, Fresh water swamp, Fresh water undiff., Pteridophyte)

Sample	Marine: Dinoflagellata cysts	Marine: Foram test linings	Mangrove: *Avicennia*-type	Mangrove: *Camptostemon*-type	Mangrove: *Exoecaria*-type	Mangrove: *Florschuetzia meridionalis*	Mangrove: *Florschuetzia trilobata*	Mangrove: *Zonocostites ramonae*	Backmangrove: *Acrostichum aureum*	Backmangrove: *Chenopodipollis* sp.	Backmangrove: *Discoidites* sp.	Backmangrove: *Florschuetzia levipoli*	Backmangrove: *Spinizonocolpites baculatus*	Backmangrove: *Spinizonocolpites echinatus*	Riparian: *Ilexpollenites* sp.	Riparian: *Pandaniidites* sp.	Peatswamp: *Pometia* sp.	Peatswamp: *Retistephanocolpites williamsii*	Peatswamp: *Sapotaceoidaepollenites* sp.	Peatswamp: *Striatricolporites* sp.	Freshwater swamp: *Dicolpopollis* sp.	Freshwater swamp: *Magnastriatites howardi*	Freshwater swamp: *Marginipollis concinnus*	Freshwater swamp: *Palmae* sp. (echinate)	Freshwater swamp: *Palmae* sp. (psilate)	Freshwater swamp: *Palmae* sp. (reticulate)
C40																										
C39																										
C38																										
C37																										
C36																										
C35																										
C34																										
C33																										
C32																										
C31	32	7	3	3		1	3	43	23			2		5	5			3			4			3	15	5
C30																										
C29																										
C28																										
C27																										
C26	6	1	1				2					1												2	7	21
C25																										
C24	1	1				2	2							1								1	2	1	5	7
C23		1				1						3												1	1	8
C22																										
C21																										
C20																										
C19																										
C18																										1
C17																										
C16																										
C15																										
C14																										
C13	2	180																								
C12	1					3	1																			
C11																										
C10																										
C09																										
C08																										
C07						1						1				1										1
C06																										
C05						1	1			1									1						11	2
C04																										
C03	1		3		4	4	2			1			3	1	8		1			1				3	13	6
C02																										
C01							3				1				4	1	130			1					7	45

Sample	Freshwater undifferentiated: *Perfotricolpites digitatus*	*Asplenium* sp.	*Casuarina* -type	*Dacrycarpites* sp.	*Fenestraepollenites* sp.	*Gardenia* sp.	*Gemmapollenites* sp.	Gramineae	*Lakiapollis* sp.	*Lanagiopollis* sp.	*Myricipites* sp.	*Pinuspollenites* sp.	*Pteris* -type	*Retitricolporites* sp.	*Retitriporites* sp.	Pteridophyte: Monolete spore	Psilate trilete	Reticulate trilete	*Verrucatosporites* sp.	Total Palinomorph
C40																				
C39																				
C38																				
C37																				
C36																				
C35																				
C34																				
C33																				
C32																				
C31							1		2	15		2		11		30			17	235
C30																				
C29																				
C28																				
C27																				
C26		2		2	1		1	4					2	7	3	43	48	11	17	182
C25																				
C24			2	9							1		2	17	5	52	28	6	19	164
C23		1												5		17	9	1	16	64
C22																				
C21														8		14	4	1	3	30
C20																				
C19																				
C18														9		3	2			15
C17																				
C16																				
C15																				
C14																				
C13														2		5	2		5	196
C12																21	13		5	44
C11																				
C10																				
C09																				
C08																				
C07			7											15		15	7	2	30	80
C06																				
C05								1	5		1			35		51	13		31	154
C04																				
C03			6			1		4		2				37	7	36	105	3	17	269
C02																				
C01	1		1											14		26	7	7	23	271

Abbreviation: see Table 2 and Figure 2.

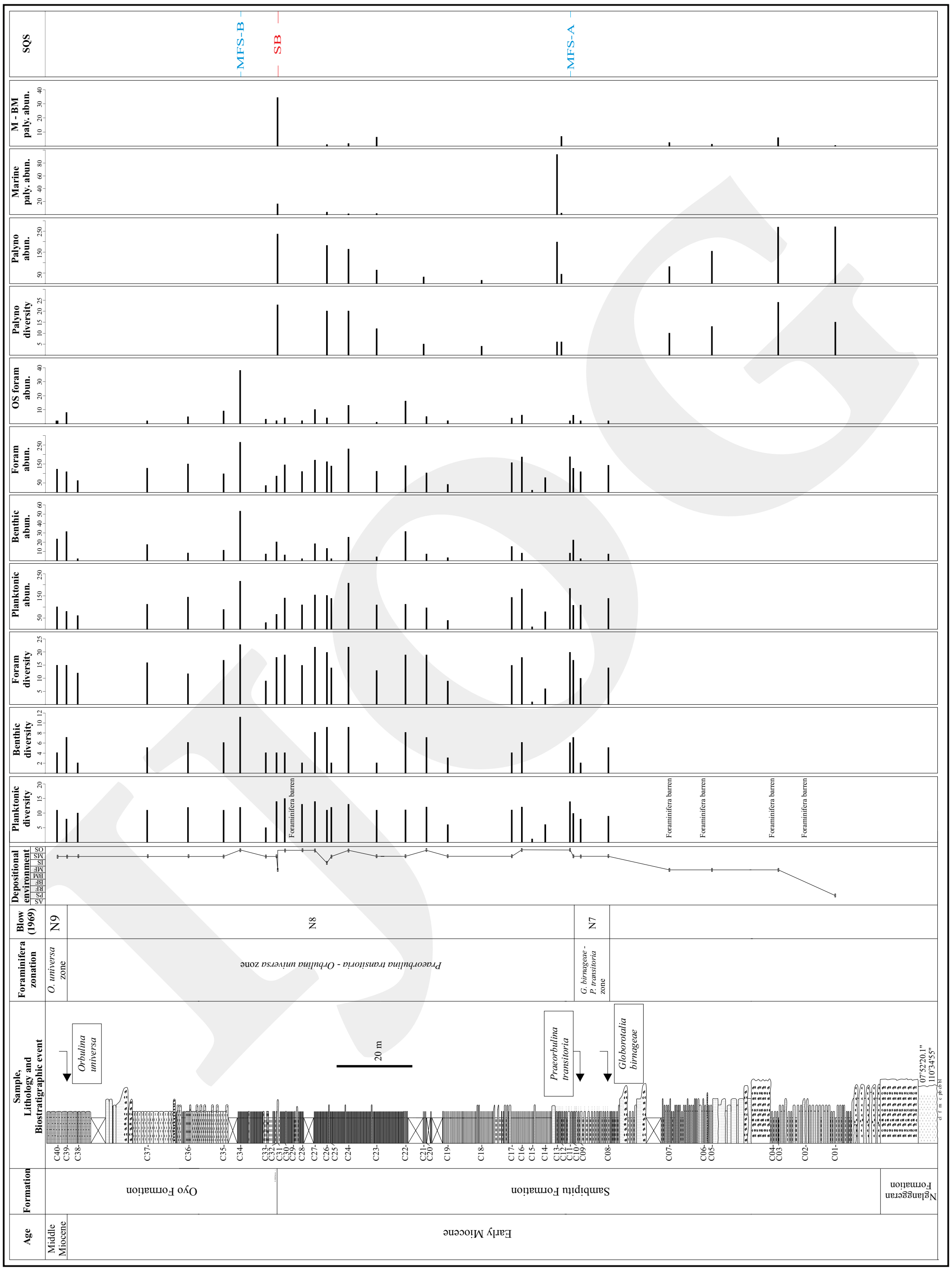


Figure 4. Stratigraphic section, depositional environment interpretation, foraminiferal and palynomorph diversity and abundance, and sequence stratigraphy interpretation of Kali Ngalang section (modified from Fakhruddin, 2010). Abbreviation: see Figure 2.

C30) to mangrove biofacies (sample C31). SB found at this section is interpreted as a subaerial unconformity type with nondeposition surface that marks the sudden changes from outer shelf to mangrove depositional environments.

There are two MFS at Kali Ngalang section (Table 4 and Figure 4; Fakhruddin, 2010). MFS-A occurs in the Sambipitu Formation, that is interpreted based on the peak of the total foraminiferal diversity and the abundance of sample C11. MFS-B is found in the Oyo Formation. This event is indicated by the peak of the total foraminiferal diversity and the abundance and the peak of outer shelf benthic foraminiferal abundance (sample C34).

Depositional environment

Depositional environment interpretation of Sambipitu Formation varies mostly in a shelf environment, with peat swamp to mangrove environment found before the first appearance of *Globorotalia birnageae* and mangrove environment at SB event (Table 4 and Figure 4; Fakhruddin, 2010). Sediments of the Sambipitu Formation were deposited in a peat swamp environment (sample C01) based on the abundance of *Pometia* sp. and the presence of *Striatricolporites* sp. (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). Above it (samples C03, C05, and C07), the depositional environment of this formation changes into a mangrove one as shown by the presence of *Exoecaria*-type, *Avicennia*-type, *Florschuetzia meridionalis,* and *Florschuetzia trilobata* (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). The first appearance of *Globorotalia birnageae* marks the shift of the depositional environment into the middle shelf (samples C08, C09, and C10) indicated by the presence of benthic foraminifera: *Uvigerina* sp., *Cibicides* sp., *Bulimina* sp., *Amphistegina* sp., *Bolivina* sp., *Nodosaria* sp., *Lenticulina* sp., *Nonion* sp., *Eponides* sp., and *Dentalina* sp (Rauwerda *et al*., 1984; Murray, 2006). The depositional environment becomes outer shelf at MFS-A event (sample C11), characterized by the presence of *Uvigerina* sp., *Nodosaria* sp., and *Eponides* sp. (Rauwerda *et al*., 1984; Murray, 2006).

In interval from MFS-A to SB event (sample C12 to C30), sediments of the Sambipitu Formation were variably deposited in inner, middle, and outer shelf environments. The inner shelf environment interpretation is indicated by the presence of *Elphidium* sp., *Cibicides* sp. and *Eggerella* sp. (Rauwerda *et al*., 1984; Murray, 2006). The middle shelf environment is characterized by the occurrence of *Amphistegina* sp., *Bolivina* sp., *Cassidulina* sp., *Cibicides* sp., *Dentalina* sp., *Eponides* sp., *Lenticulina* sp., *Nodosaria* sp., *Nonion* sp., and *Uvigerina* sp. (Rauwerda *et al*., 1984; Murray, 2006). The outer shelf environment is shown by the presence of *Bolivina* sp., *Bullimina* sp., *Cassidulina* sp., *Dentalina* sp., *Eponides* sp., *Gyroidina* sp., *Karreriella* sp., *Lenticulina* sp., *Nodosaria* sp., *Pullenia* sp., *Sphaerodina* sp., and *Uvigerina* sp. (Rauwerda *et al*., 1984; Murray, 2006).

SB event at the Sambipitu Formation (sample C31) marks the shift of depositional environment into a mangrove environment, characterized by the occurrence of *Zonocostites ramonae*, *Avicennia*-type, *Camptostemon*-type, *Florschuetzia meridionalis,* and *Florschuetzia trilobata* (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000).

Above SB event (samples C32 and C33), sediments of the Oyo Formation were deposited in the middle shelf setting indicated by the presence of *Nodosaria* sp., *Cibicides* sp., *Amphistegina* sp., and *Lenticulina* sp. (Rauwerda *et al*., 1984; Murray, 2006). The depositional environment changes into an outer shelf at MFS-B (sample C34) which is shown by the presence of *Bullimina* sp., *Uvigerina* sp., *Gyroidina* sp., *Bolivina* sp., *Eponides* sp., *Cassidulina* sp., *Lenticulina* sp., and *Siphonina* sp. (Rauwerda *et al*., 1984; Murray, 2006).

From MFS-B to the end of the section (samples C35-C40), the sediments of Oyo Formation were deposited in the middle shelf characterized by the occurrence of *Nodosaria* sp., *Cibicides* sp., *Amphistegina* sp., *Nonion* sp., *Uvigerina* sp., *Bolivina* sp., and *Lenticulina* sp. (Rauwerda *et al*., 1984; Murray, 2006).

Kali Urang, Wonosari

Biostratigraphy

Foraminiferal distribution chart from Fakhruddin (2010) is reinterpreted into two biozonations: *Praeorbulina transitoria - Orbulina universa* zone and *Orbulina universa* zone (Table 5 and Figure 5). The bottom boundary of *Praeorbulina transitoria - Orbulina universa* zone is defined by the first occurrence of *Praeorbulina transitoria* and its top boundary is marked by the first occurrence of *Orbulina universa.* This zone is correlated with N8 zone of Blow (1969). *Orbulina universa* zone is defined by the first occurrence of *Orbulina universa* at its base and the co-occurrence of *Praeorbulina transitoria* and *Praeorbulina glomerosa*, suggesting that this zone is correlated with N9 zone of Blow (1969).

Sequence Stratigraphy

There are two SBs found in Kali Urang section (Table 5 and Figure 5; Fakhruddin, 2010). SB-A is interpreted from the sudden depositional environment changes from the middle shelf (sample D02) to mangrove environment (sample D03). SB-B is found near the boundary between Sambipitu and Oyo Formation, similar to the SB found in Kali Ngalang. It is interpreted from the sudden changes in depositional environment, from outer shelf, at samples D14 and D15, to mangrove environment at sample D16.

There are two MFSs in Kali Urang section (Table 5 and Figure 5; Fakhruddin, 2010). MFS-A is found in the Sambipitu Formation, interpreted on the basis of the peak of the total foraminiferal diversity and the abundance at sample D09. MFS-B is found in Oyo Formation, which is interpreted on the basis of the peak of the total foraminiferal diversity and the abundance and the peak of the outer shelf benthic foraminiferal abundance (Table 5 and Figure 5; Fakhruddin, 2010) in sample D31.

Depositional environment

Sediments of the Sambipitu Formation (sample D01 and D02) were deposited in the middle shelf setting characterized by the presence of *Uvigerina* sp., *Cibicides* sp., *Bulimina* sp., *Amphistegina* sp., *Bolivina* sp., *Nodosaria* sp., *Lenticulina* sp., *Nonion* sp., *Eponides* sp., *Rotalia* sp., and *Dentalina* sp. (Table 5 and Figure 5; Rauwerda *et al*., 1984; Murray, 2006). The depositional environment shifting into mangrove setting at samples D03 (SB-A event), D04, and D05 was interpreted from the presence of *Florschuetzia meridionalis, Florschuetzia trilobata,* and *Avicennia*-type. (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). At sample D07 and during the MFS-A event (sample D09), the depositional environment changes into the outer shelf indicated by the presence of *Bullimina* sp., *Bolivina* sp., *Eponides* sp., *Cassidulina* sp., *Sphaerodina* sp., and *Lenticuna* sp. (Rauwerda *et al*., 1984; Murray, 2006).

After MFS-A (samples D11 and D13), the sediments of Sambipitu Formation were deposited in the middle shelf, as shown by the presence of benthic foraminifera: *Amphistegina* sp., *Cibicides* sp., *Bullimina* sp., *Uvigerina* sp., *Bolivina* sp., *Eponides* sp., *Cassidulina* sp., *Dentalina* sp., *Lenticulina* sp., and *Loxostomum* sp. (Rauwerda *et al*., 1984; Murray, 2006). The depositional environment subsequently changes into the outer shelf (sample D14) shown by the presence of *Uvigerina* sp., *Bolivina* sp., *Eponides* sp., and *Sphaerodina* sp. (Rauwerda *et al*., 1984; Murray, 2006). The shifting of depositional environment into mangrove setting occurs at the SB-B event (sample D16), interpreted from the presence of *Avicennia*-type (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000).

Sediments of the Oyo Formation (sample D18 to D33) above the Sambipitu Formation were variably deposited in the inner shelf, middle shelf, and outer shelf setting. The inner shelf interpretation is shown by the presence of *Amphistegina* sp. and *Elphidium* sp. (Rauwerda *et al*., 1984; Murray, 2006). The middle shelf interpretation is characterized by the occurence of *Nodosaria* sp., *Cibicides* sp., *Amphistegina* sp., *Bullimina* sp., *Uvigerina* sp., *Eponides* sp., *Cassidulina* sp., *Nonion* sp., *Dentalina* sp., *Lenticulina* sp., and

Table 5. Foraminiferal and Palynomorph Distributions of Kali Urang Section (Fakhruddin, 2010)

Sample	Formation	Biozonation	Depositional environment	Sequence stratigraphy	Analysis
D 33	Oyo Formation	***O. universa* zone**	MS		F
D 32			MS		F
D 31		***Praeorbulina transitoria - Orbulina universa* zone**	OS	MFS-B	**F**
D 30			MS		F
D 29			-		P
D 28			MS		F
D 27			-		P
D 26			IS		F
D 25			-		P
D 24			MS		F
D 23			MS		F
D 22			OS		F
D 21			MS		F
D 20			-		P
D 19			-		F
D 18			MS		F
D 17	Sambipitu Formation		-		F
D 16			MF	SB-B	P
D 15			-		P
D 14			OS		**F**
D 13			MS		F
D 12			-		P
D 11			MS		F
D 10			-		F
D 09			OS	MFS-A	F
D 08			-		P
D 07			OS		F
D 06			-		F + P
D 05			MF		P
D 04			MF		F + P
D 03			MF	SB-A	F + P
D 02			MS		F
D 01			MS		F

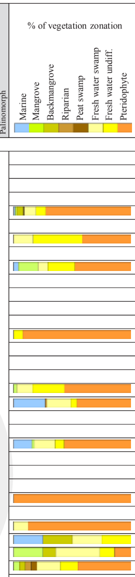
Planktonic

Sample	*Catapsydrax dissimilis*	*Globigerina praebulloides*	*Globigerina venezuelana*	*Globigerinoides bisphericus*	*Globigerinoides diminutus*	*Globigerinoides immaturus*	*Globigerinoides obliquus*	*Globigerinoides sacculifer*	*Globigerinoides subquadratus*	*Globigerinoides trilobus*	*Globorotalia archeomenardii*	*Globorotalia birnageae*	*Globorotalia continuosa*	*Globorotalia mayeri*	*Globorotalia obesa*	*Globorotalia peripheroronda*	*Globorotalia praescitula*	*Globoquadrina altispira*	*Globoquadrina dehiscens*	*Hastigerina praesiphonifera*	*Orbulina suturalis*	***Orbulina universa***	*Praeorbulina glomerosa*	*Praeorbulina sicana*	***Praeorbulina transitoria***	*Sphaeroidinellopsis seminulina*	Total Planktonic
D 33						7	2							8		1		2	11		4	10	4		3		52
D 32			2			9		4	5		14			13		18		23				**16**				3	107
D 31				10				7	25	9				29	4	4	4	21		4			27	15	12		171
D 30		3				4		6	8			2		15	4	2	5	10	5				12	2	10		88
D 29																											
D 28						8		1	12							5	8	12		1			10	11	10		78
D 27																											
D 26					14	8		7	16	21						17	2	15		3			18	8		1	130
D 25																											
D 24				4	2			3	10	6	1			15		2	4	2	5				9		8		71
D 23		3		17	23	26		1	15						3	19	13		20				1		1		142
D 22		2		11				2	22							4		4	11				2	8	1		67
D 21		23		14	2		9	5	21	22	1				2			15	5				3		10		132
D 20																											
D 19	Foraminifera barren																										
D 18				10	9	1		5	25							15	3	9		2			13	20	11		123
D 17	Foraminifera barren																										
D 16																											
D 15																											
D 14		3			8				7	4		4		9				27	3	9			41	27	8		150
D 13		4	7	5	10			12	14	6				19				19	2						5		103
D 12																											
D 11				16			9	10	1	16				23	2				14						16		107
D 10	Foraminifera barren																										
D 09	1					18		15	9	2		2	1	27	4	3	3	17		5			22	33			162
D 08																											
D 07				2		4				17																	23
D 06	Foraminifera barren																										
D 05																											
D 04	Foraminifera barren																										
D 03	Foraminifera barren																										
D 02		2		4			3	6	6	7		3		22	5		11	9	5						3		86
D 01				4		9		3	8					13	3			5	8						**8**		61

Benthic

Sample	*Amphistigena* sp.	*Bolivina* sp.	*Bulimina* sp.	*Cassidulina* sp.	*Cibicides* sp.	*Dentalina* sp.	*Elphidium* sp.	*Eponides* sp.	*Gyroidina* sp.	*Lagena* sp.	*Lenticulina* sp.	*Loxostomum* sp.	*Nodosaria* sp.	*Nonion* sp.	*Reusela* sp.	*Rotalia* sp.	*Saracenaria* sp.	*Siphonina* sp.	*Sphaeroidina* sp.	*Textularia* sp.	*Uvigerina* sp.	Total Benthic	Total Foraminifera
D 33	2		1	3	1	3					1							4				15	67
D 32	13	1		1	1			2					2	2				1				23	130
D 31	8	11	4		1			2	3		10		4	2				3			9	57	228
D 30	2	2	2		1			2		1	3		2					1				16	104
D 29																							
D 28	1	2			7								3						1			14	92
D 27																							
D 26	9			1	2		2	12					6		2		2		1			37	167
D 25																							
D 24		1		1	2								2									6	77
D 23		10	4	3	12						3	1									1	34	176
D 22		2			1			4	3				5					1	1		2	19	86
D 21				2	7								3							1		13	145
D 20																							
D 19																							
D 18		5		3				5			5		1				1	5			1	26	149
D 17																							
D 16																							
D 15																							
D 14		1			1			3											3		1	9	159
D 13	13	2	3	8	13			2			4	4				1					1	51	154
D 12																							
D 11			1	5	1	1		3														11	118
D 10																							
D 09		1	2	3	1			2			5								1			15	177
D 08																							
D 07								1		1												2	25
D 06																							
D 05																							
D 04																							
D 03																							
D 02		8	2		1	1		2			4		1						1			20	106
D 01	2			1							2											5	66

Palinomorph



	Marine		Mangrove				Backmangrove					Riparian	Peatswamp	Freshwater swamp				Freshwater undifferentiated											Pteridophyte				
Sample	Dinoflagellata cysts	Foram test linings	*Avicennia*- type	*Exoecaria*- type	*Florschuetzia meridionalis*	*Florschuetzia trilobata*	*Acrostichum aureum*	*Chenopodipollis* sp.	*Florschuetzia levipoli*	*Spinizonocolpites baculatus*	*Spinizonocolpites echinatus*	*Ilexpollenites* sp.	*Sapotaceoidaepollenites* sp.	*Calophyllum* -type	*Palmae* sp. (echinate)	*Palmae* sp. (psilate)	*Palmae* sp. (reticulate)	*Fenestraepollenites* sp.	*Gemmapollenites* sp.	Gramineae	*Lakiapollis* sp.	*Lanagiopollis* sp.	*Pinuspollenites* sp.	*Podocarpidites* sp.	*Psilatetricolporites* sp.	*Pteris* -type	*Retitricolporites* sp.	*Retitriporites* sp.	Monolete spore	Psilate trilete	Reticulate trilete	*Verrucatosporites* sp.	Total Palinomorph
D 33																																	
D 32																																	
D 31																																	
D 30																																	
D 29		2			2		3			3	3	1				11	5	1		1	1				5	4		1	58	12	4	41	158
D 28																																	
D 27						1										3	2			2		2				1	5	5	10	1		4	36
D 26																																	
D 25	2			8												4										1	10		20	1	1	1	48
D 24																																	
D 23																																	
D 22																																	
D 21																																	
D 20																											1		11			1	13
D 19																																	
D 18																																	
D 17																																	
D 16			1													3	2		1	1	2			1		3	2		12	3		6	37
D 15	21											1			1	12	3			1			2			1			24	3	2	7	78
D 14																																	
D 13																																	
D 12	8		1												2	3	4							1			2	1	16	2	5	6	51
D 11																																	
D 10																																	
D 09																																	
D 08																													3				3
D 07																																	
D 06																1													4	2	1		8
D 05	1					1		1												1													4
D 04			2			1			1							1	1										1				1		8
D 03					1				1			1	1	3			1										3		8			1	20
D 02																																	
D 01																																	

Note: Abbreviation: see Table 2 and Figure 2

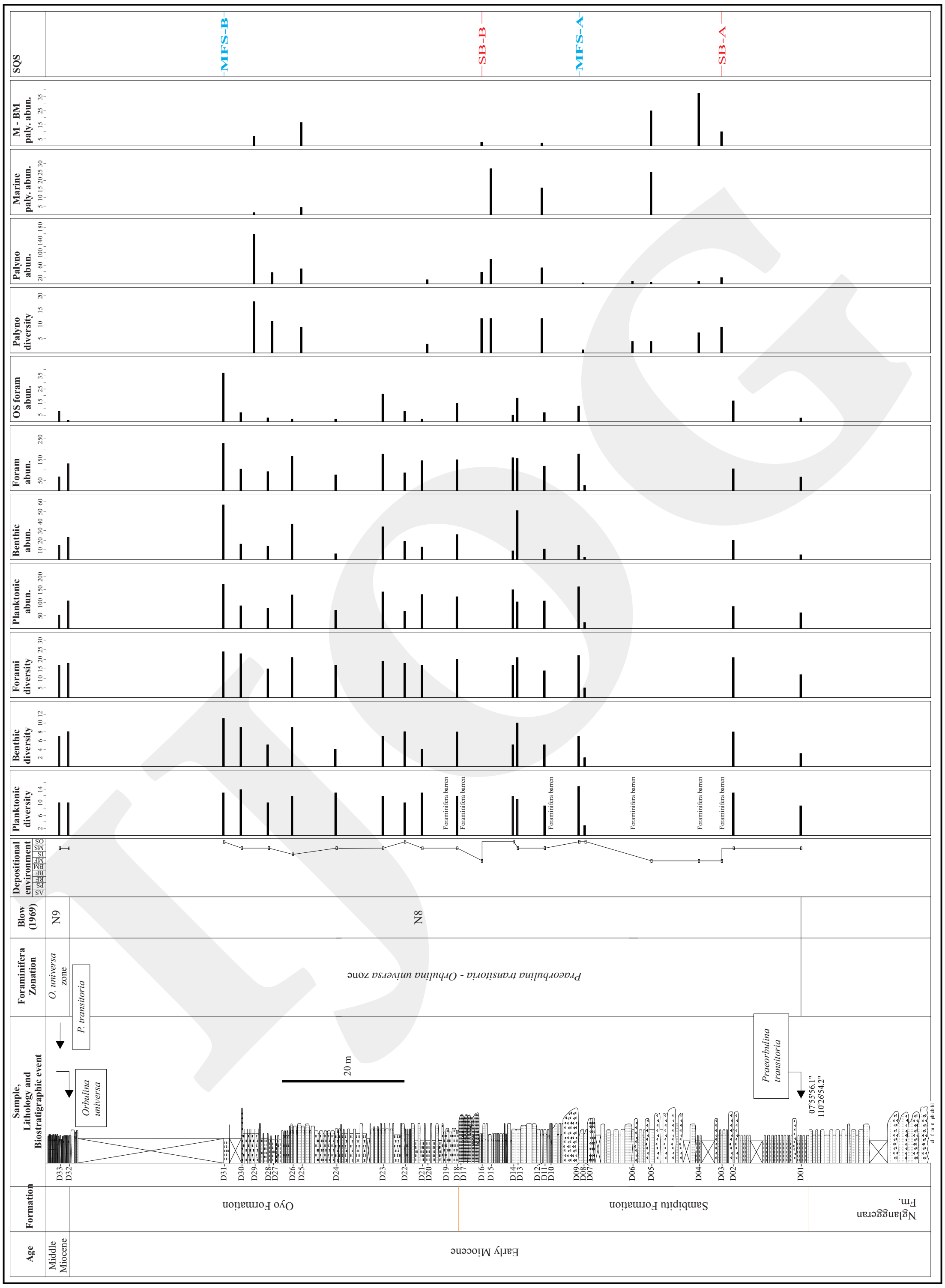


Figure 5. Stratigraphic section, depositional environment interpretation, foraminiferal and palynomorph diversity and abundance, and sequence stratigraphy surface interpretation of Kali Urang section (modified from Fakhruddin, 2010). Abbreviation: see Figure 2.

Siphonina sp. (Rauwerda *et al*., 1984; Murray, 2006). The outer shelf interpretation is shown by the occurence of *Nodosaria* sp., *Bullimina* sp., *Uvigerina* sp., *Gyroidina* sp., *Bolivina* sp., *Eponides* sp., *Lenticulina* sp., and *Sphaerodina* sp. (Rauwerda *et al*., 1984; Murray, 2006).

Kali Jaten, Punung

Biostratigraphy

Palynological analyses of Kali Jaten section show the first occurence of *Florschuetzia meridionalis* (sample E02) and the last occurence of *Florschuetzia trilobata* (sample E06), indicating *Florschuetzia meridionalis* zone (Rahardjo *et al.,* 1994) for sample E02-E06 interval (Table 6 and Figure 6).

The absolute age for the Besole Formation using K-Ar method is 42.7 to 18.99 Ma (Soeria-atmaja *et al.,* 1994) and 19.2 ± 0.37 Ma (Bellon *et al.,* 1983 in Soeria-atmaja *et al.,* 1994). Arjosari Formation which is the lateral equivalent of Besole Formation is dated N3-N5 zones (Soeria-atmaja *et al.,* 1994).

Sequence Stratigraphy

SB-1 is interpreted at the boundary between the Besole Formation and the Jaten Formation (Table 6 and Figure 6). Similar to the SB found in the Kulon Progo section, SB-1 also marks an subaerial unconformity between the volcanic rock (Besole Formation) and epiclastic sediments (Jaten Formation). MFS-1 is found at sample E09 as shown by the peak of the total foraminifera diversity and abundance (Table 6 and Figure 6).

Depositional environment

Sediments of Jaten Formation were deposited in a riparian forest environment (sample E01), characterized by the presence of pollen fossil *Pandaniidites* sp., Palmae, and Gramineae (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). Subsequently, the depositional environment becomes mangrove environment (samples E02, E05, and E06) indicated by the presence of foram test linings, dinoflagellata cysts, *Zonocostites ramonae, Exoecaria*-type*, Avicennia*-type*, Camptostemon*-type*, Florschuetzia meridionalis,* and *Florschuetzia trilobata* (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000).

Depositional environment turned into the inner shelf at samples E07 and E09 (MFS-1 event) as shown by the presence of *Cibicides* sp., *Bolivina* sp., *Elphidium* sp., *Nonion* sp., *Operculina* sp., *Rotalia* sp., *Textularia* sp., *Uvigerina* sp., and ostracods (Rauwerda *et al*., 1984; Murray, 2006).

Jalan Desa Jaten, Punung

Biostratigraphy

A stratigraphic succession of this section shows rock sequences from older to younger: Jaten Formation, Wuni Formation, and Nampol Formation (Figure 7). The presence of *Florschuetzia trilobata* (sample F02) in Jaten Formation indicates that the age of this sample is not younger than Middle Miocene (Morley, 1991; Rahardjo *et al.,* 1994) (Table 7). No biostratigraphically useful palynolomorph recovered from the Wuni Formation (sample F04) and foraminifera is absent. Co-occurrence of *Florschuetzia meridionalis* and *Florschuetzia trilobata* at sample F05 suggest that the age of this sample is Middle Miocene (Rahardjo *et al.,* 1994).

Depositional environment

Sediments of the Jaten Formation were deposited in a backmangrove environment indicated by the presence of *Spinizonocolpites echinatus* in sample F01 (Table 7 and Figure 7; Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). Depositional environment changes into mangrove (sample F02) characterized by the presence of *Florschuetzia trilobata* (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). The depositional environment then turned into the inner shelf (sample F03) as shown by the presence of benthic foraminifera *Nonion* sp., *Elphidium* sp., *Ammonia* sp., and ostracods (Rauwerda *et al*., 1984; Murray, 2006).

Sediments of the Wuni Formation were deposited in fluvial to neritic environments (Sartono, 1964). Whilst, sediments of the Nampol

Table 6. Foraminifera and Palynomorph Distributions of Kali Jaten Section

Sample	Formation	Biozonation	Depositional environment	Sequence stratigraphy	Analysis	Planktonic: *Globigerina praebulloides*	*Globigerinoides subquadratus*	Total Planktonic	Benthic: *Bolivina* sp.	*Cibicides* sp.	*Elphidium* sp.	*Nonion* sp.	*Operculina* sp.	*Reusela* sp.	*Rotalia* sp.	*Textularia* sp.	*Uvigerina* sp.	ostracods	Total Benthic	Total Foraminifera
E 10	Jaten Formation		-		F	Foraminifera barren														
E 09			IS	MFS-1	F+P	4	1	5	7	10	20	5	3	1	15	2	1	10	64	69
E 08			-		F															
E 07			IS		F		1	1	4	4	12	21						3	41	42
E 06		***F. meridionalis* zone**	MF		P															
E 05			MF		P															
E 04			-		P	Foraminifera barren														
E 03			-		P															
E 02			MF		P															
E 01			RF	SB-1	P															

Sample	Marine: Dinoflagellata cysts	Foram test linings	Mangrove: *Avicennia*-type	*Camptostemon*-type	*Exoecaria*-type	***Florschuetzia meridionalis***	***Florschuetzia trilobata***	*Zonocostites ramonae*	Backmangrove: *Acrostichum aureum*	*Discoidites* sp.	*Florschuetzia levipoli*	*Spinizonocolpites echinatus*	Riparian: *Ilexpollenites* sp.	*Pandaniidites* sp.	Peatswamp: *Cephalomappa* sp.	Freshwater swamp: *Calophyllum*-type	*Crassotriletes* sp.	*Dicolpopollis* sp.	*Marginipollis concinnus*	*Palmae* sp. (echinate)	*Palmae* sp. (psilate)	*Palmae* sp. (reticulate)	*Polygonum*-type
E 10																							
E 09	1	1			1			19	3			7	2			6		9			18	2	
E 08	Palynomorph barren																						
E 07																							
E 06			6	4	3	1	1	9	7		2		1		2	16		3	1		7	1	
E 05		9	1		6	3	9	26		2			1			27		1		1	1	3	
E 04	1																				4		
E 03																							
E 02	1					**1**	4				1		4			6	4			13	2		2
E 01														1								1	

Sample	Freshwater undifferentiated: *Casuarina*-type	*Ericipites* sp.	*Fenestraepollenites* sp.	*Gemmapollenites* sp.	*Gemmatricolporites* sp.	Gramineae	*Lakiapollis* sp.	*Lanagiopollis* sp.	*Margocolporites*	*Myricipites* sp.	*Perfotricolpites digitatus*	*Podocarpidites* sp.	*Polyadopollenites* sp.	*Retitricolporites* sp.	*Retitriporites* sp.	Pteridophyte: Monolete spore	Psilate trilete	Reticulate trilete	*Verrucatosporites* sp.	Total Palinomorph
E 10																				
E 09											1					56		5	22	153
E 08																				
E 07																				
E 06	2	4	1		4		1	7	1	2				15	1	53	1	2	15	173
E 05	3			1				1						34	4	19			3	155
E 04												2				3				10
E 03																3				3
E 02			1			8							1	7		64	3		16	138
E 01						1								1	1					5

Note: Abbreviation: see Table 2 and Figure 2

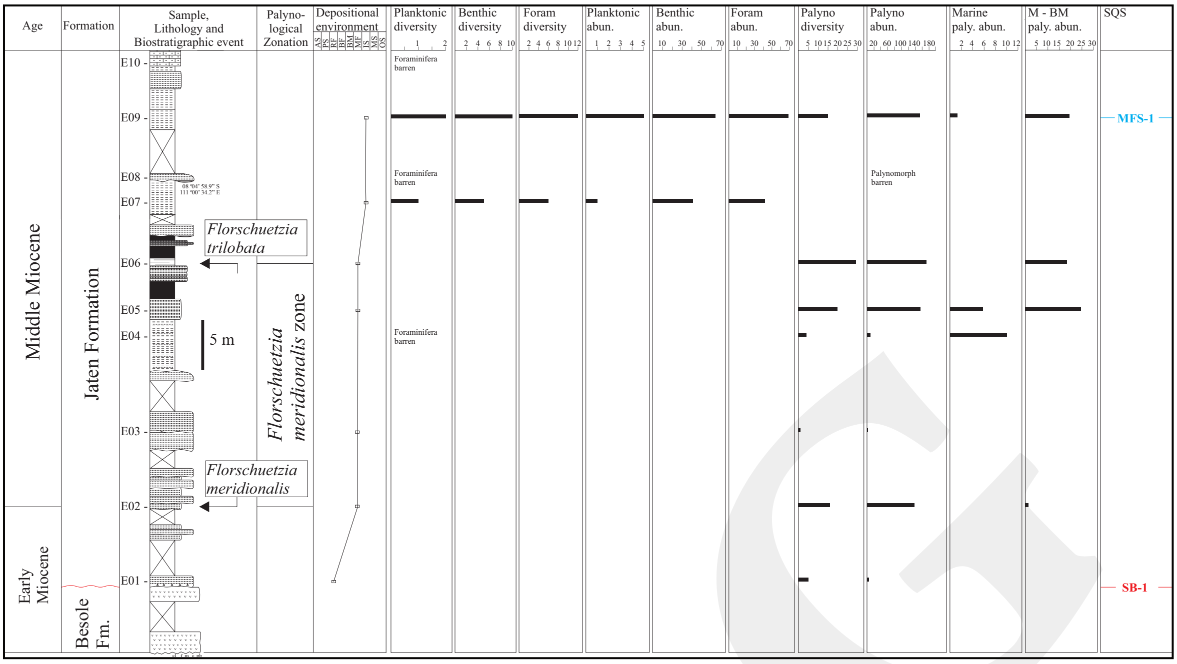


Figure 6. Stratigraphic section, depositional environment interpretation, foraminiferal and palynomorph diversity and abundance, and sequence stratigraphy surface interpretation of Kali Jaten section. Abbreviation: see Figure 2.

Formation (sample F05) were deposited in a mangrove environment characterized by the presence of *Zonocostites ramonae*, *Avicennia*-type, *Florschuetzia meridionalis,* and *Florschuetzia trilobata* (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000).

Desa Kutukan, Punung

Biostratigraphy

Florschuetzia meridionalis zone (Rahardjo *et al*., 1994) is identified at this section in sediments of the Nampol Formation (Table 8 and Figure 8). It is characterized by the first occurrence of *Florschuetzia meridionalis* in sample G06 and the last occurrence of *Florschuetzia trilobata* in sample G08. The zone present suggests that the age of this interval (sample G06-G08) is Middle Miocene (Rahardjo *et al.,* 1994). Planktonic foraminifera for biostratigraphic identification is absent in sample G09 (Punung Formation).

Sequence Stratigraphic Surface

MFS is found in Nampol Formation (sample G06), indicated by the peak of total mangrove-back mangrove taxa and the presence of foram test linings.

Depositional environment

The sediments of Nampol Formation in this section were deposited in a riparian forest (sample G02), suggested by the presence of *Ilexpollenites* sp., Palmae, and *Retitricolporites* sp. (Table 8 and Figure 8; Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). Depositional environment changes into alluvial swamp (sample G03 and G04), shown by the presence of *Dicolpopollis* sp. and Palmae (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). Sample G05 marks the shifting of the environment into a backmangrove, as shown by the presence of *Florschuetzia trilobata*, *Chenopodipollis* sp., Palmae*, Polygonum*-type, and Gramineae (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). The depositional environment then becomes a mangrove environment (sample G06 and G07), identified by the presence of *Zonocostites ramonae, Exoecaria* type, *Avicennia*-type, *Florschuetzia meridionalis*, *Florschuetzia trilobata,* and foram test linings (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). Subsequently, in sample G08, the environment changes into a backmangrove indicated by the presence of *Spinizonocolpites echinatus*, *Acrostichum aureum*, *Florschuetzia levipoli,* and

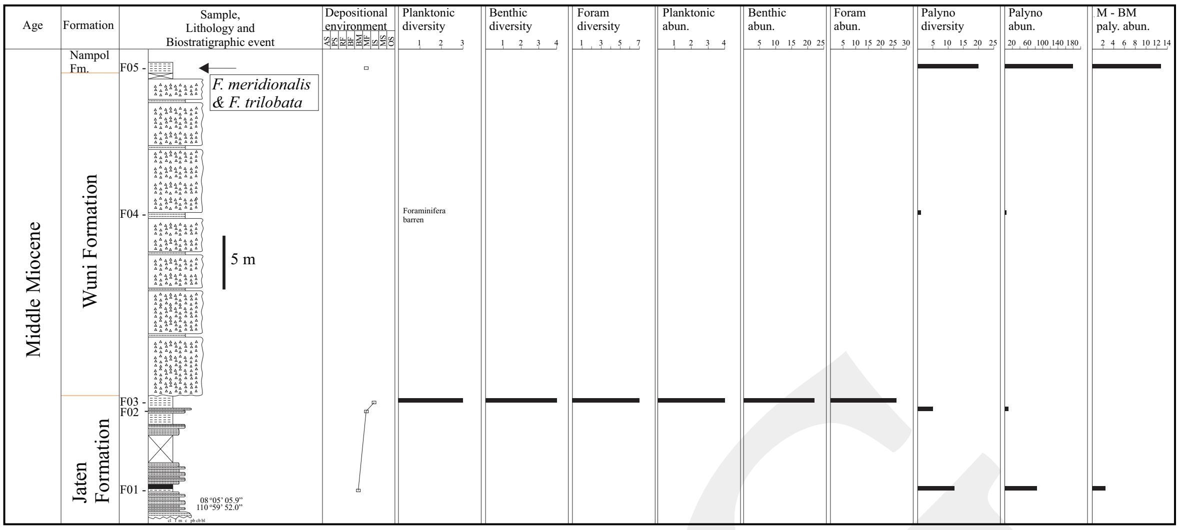


Figure 7. Stratigraphic section, depositional environment interpretation, and foraminiferal and palynomorph diversity and abundance of Jalan Desa Jaten section. Abbreviation: see Figure 2.

Discoidites sp. (Hasseldonx, 1974; Hillen, 1986; Morley, 1990, 2000). Sediments of the Punung Formation (sample G09) were deposited in the inner shelf, marked by the presence of *Eponides* sp., *Elphidium* sp., and *Planorbulina* sp. (Rauwerda *et al*., 1984; Murray, 2006).

Florschuetzia meridionalis

One of significant fossil indexes which can be used in the determination and correlation of the stratigraphic framework of the studied areas is *Florschuetzia meridionalis*. Botanical affinity of this fossil is *Sonneratia alba* (Graham, 2013; Mao and Foong, 2013), which is a typical mangrove vegetation.

The First Appeareance Datum (FAD) of *Florschuetzia meridionalis* according to Rahardjo *et al*. (1994) coincides with the FAD of *Orbulina universa*, at the base of the N9 zone (Blow, 1969). Morley (1991) mentioned that the FAD of *Florschuetzia meridionalis* in Southeast Asia was located close to the boundary between the Early and the Middle Miocene (NN5/NN4; nannoplankton zonation; Martini, 1971).

Rare amounts of *Florschuetzia meridionalis* in Kali Ngalang section started to occur before N7 zone (Sambipitu Formation; samples no C03, C05, and C07; Table 4). At N8 zone of Kali Ngalang section, *Florschuetzia meridionalis* also occurs in rare amounts within Sambipitu Formation (samples C12, C23, C24, and C31; Table 4). In Kali Urang section (Table 5), *Florschuetzia meridionalis* occurs in samples D03 (Sambipitu Formation), D29 (Oyo Formation), and in N8 zones before the first occurrence of *Orbulina universa*. The rare appearance of *Florschuetzia meridionalis* before the Middle Miocene was also reported by Yaksan *et al*. (1996), based on the study at Malay Basin. The author states that this fossil has already occurred at 17.1-16.5 Ma, during the Burdigalian (Ogg *et al*., 2016).

The first appearance of *Florschuetzia meridionalis* in western Indonesia is at N9 zone, as reported by Rahardjo *et al*. (1994) in West Java, Lelono *et al.* (2014) in Sumatra, and by Germeraad *et al*. (1968), Muller (1984), and Morley (1991) in Kalimantan. In Sulawesi, *Florschuetzia meridionalis* first occurred at N11 (Lelono, 2007), while in Papua New Guinea, *Florschuetzia meridionalis* first occurred at Late Miocene (Khan, 1974 in Mao and Foong, 2013). Lei (1998, in Mao and Foong, 2013) stated that deposition of *Florschuetzia meridionalis* in southern China is later compared to southeastern Asia. This indicates that the ancestor of *Sonneratia* is probably migrated northwards from southeastern Asia (Mao and Foong, 2013).

Table 7. Foraminifera and Palynomorph Distributions of Jalan Desa Jaten Section

Sample	**Formation**	**Depositional environment**	Analysis	Planktonic	*Globigerinoides immaturus*	*Globigerinoides obliquus*	*Globigerinoides trilobus*	Total Planktonic	Benthic	*Ammonia* sp.	*Elphidium* sp.	*Nonion* sp.	ostracods	Total Benthic	Total Foraminifera	Palinomorph	% of vegetation zonation (Marine, Mangrove, Backmangrove, Riparian, Peat swamp, Fresh water swamp, Fresh water undiff., Pteridophyte)	Mangrove: *Avicennia*-type	Mangrove: ***Florschuetzia meridionalis***	Mangrove: ***Florschuetzia trilobata***	Mangrove: *Zonocostites ramonae*	Backmangrove: *Acrostichum aureum*	Backmangrove: *Discoidites* sp.	Backmangrove: *Florschuetzia levipoli*	Backmangrove: *Spinizonocolpites baculatus*	Backmangrove: *Spinizonocolpites echinatus*	Riparian: *Ilexpollenites* sp.	Riparian: *Pometia*-type	Riparian: *Sapotaceoidaepollenites* sp.	Freshwater swamp: *Palmae* sp. (psilate)	Freshwater swamp: *Palmae* sp. (reticulate)	Freshwater swamp: *Palmae* sp. (echinate)	Freshwater undifferentiated: *Casuarina*-type	Freshwater undifferentiated: *Dacrycarpites* sp.	Freshwater undifferentiated: *Lanagiopollis* sp.	Freshwater undifferentiated: *Retitricolpites* sp.	Freshwater undifferentiated: *Retitricolporites* sp.	Freshwater undifferentiated: *Retitriporites* sp.	Pteridophyte: Monolete spore	Pteridophyte: Psilate trilete	Pteridophyte: Reticulate trilete	Pteridophyte: *Verrucatosporites* sp.	Total Palinomorph
F 05	Nampol Fm.	MF	P															2	**3**	**15**	3	2	2	6	1	4	4	2		9	8	3	1		2	57			45		4	7	180
F 04	Wuni Fm.	-	F	Foraminifera barren																																			4				4
F 03	Jaten Fm.	IS	F		1	1	2	4		6	5	11	7	22	26																												
F 02	Jaten Fm.	MF	P																	1							2			1						4		1					9
F 01	Jaten Fm.	BM	P																							2	1		1	1	4			1	4		7		44	1	5	13	84

Table 8. Foraminifera and Palynomorph Distributions of Desa Kutukan Section

Sample	Formation	Biozonation	Depositional environment	Sequence stratigraphy	Analysis	Benthic	*Elphidium* sp.	*Eponides* sp.	*Planorbulinella* sp.	Total Benthic	Total Foraminifera	Palinomorph	% of vegetation zonation (Marine, Mangrove, Backmangrove, Riparian, Peat swamp, Fresh water swamp, Fresh water undiff., Pteridophyte)
G 09	Punung Fm.		IS		F		16	2	1	3	3		
G 08	Nampol Fm.	***F. meridionalis* zone**	BM		P								
G 07			MF		P								
G 06			MF	MFS	P								
G 05			BM		P								
G 04			AS		P								
G 03			AS		P								
G 02			RF		P								
G 01			-		F	Foraminifera barren							

	Marine	Mangrove						Backmangrove					Riparian			Freshwater swamp					Freshwater undifferentiated													Pteridophyte				
Sample	Foram test linings	*Avicennia*-type	*Camptostemon*-type	*Exoecaria*-type	***Florschuetzia meridionalis***	***Florschuetzia trilobata***	*Zonocostites ramonae*	*Acrostichum aureum*	*Chenopodipollis* sp.	*Discoidites* sp.	*Florschuetzia levipoli*	*Spinizonocolpites echinatus*	*Ilexpollenites* sp.	*Pometia*-type	*Sapotaceoidaepollenites* sp.	*Calophyllum*-type	*Dicolpopollis* sp.	*Palmae* sp. (echinate)	*Palmae* sp. (psilate)	*Palmae* sp. (reticulate)	*Polygonum*-type	*Casuarina*-type	*Fenestraepollenites* sp.	Gramineae	*Lakiapollis* sp.	*Lanagiopollis* sp.	*Myricipites* sp.	*Perfotricolpites digitatus*	*Periporites* sp.	*Pteris*-type	*Retitricolpites* sp.	*Retitricolporites* sp.	*Retitriporites* sp.	*Stephanocolporites* sp.	Monolete spore	Psilate trilete	Reticulate trilete	*Verrucatosporites* sp.	Total Palinomorph
G 09																																							
G 08		3	17		1	**1**		15		2	4	5		8			5		20	4		1			2			2	1	2		18	6		41	8	6	21	193
G 07		2		1	4	4	1	1			1		23	3	5		8	1	5	6		3	1		2	2		7	1		10	56		3	32	1		61	244
G 06	1	5			**43**	37		1		1	43	1	14	2	2	3	4	4	10	3		18			1		1			1		66	4	1	13			8	287
G 05						1			1										1		2			2						3		1			1				12
G 04																																			3				3
G 03																	1			1												2			1				5
G 02													1						1													17			62	1			82
G 01																																							

Note: Abbreviation: see Table 2 and Figure 2

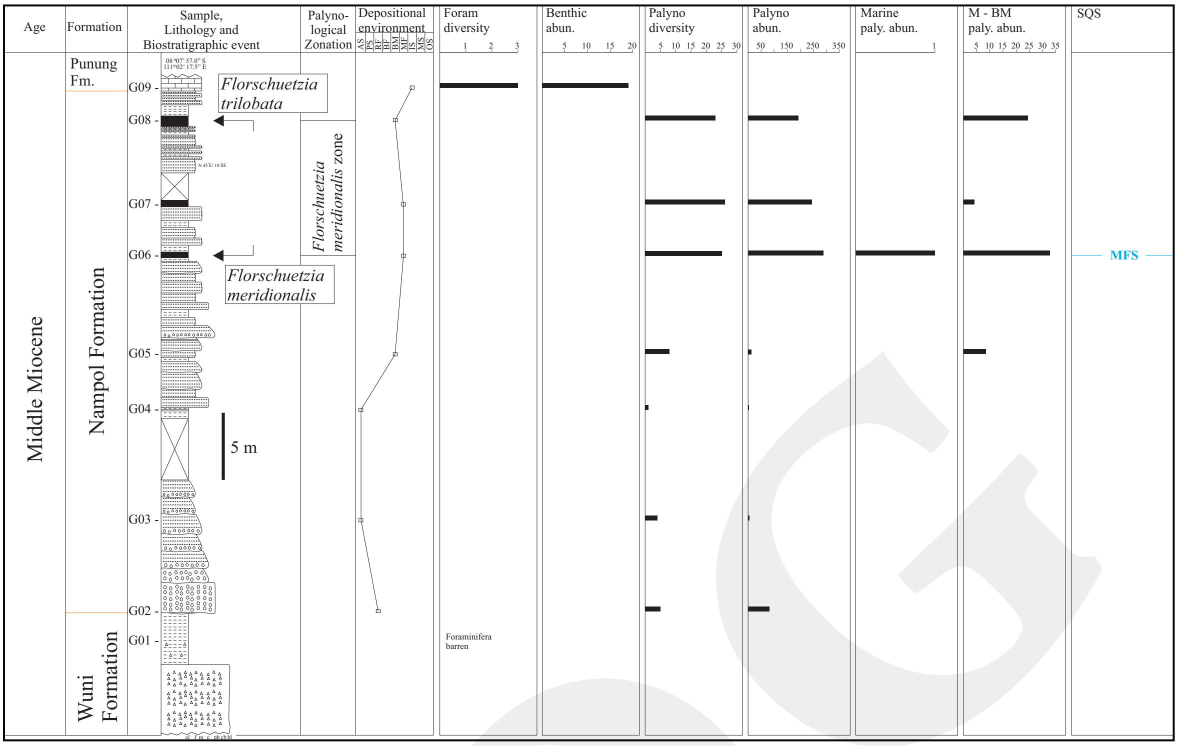


Figure 8. Stratigraphic section, depositional environment interpretation, foraminiferal and palynomorph diversity and abundance, and sequence stratigraphy surface interpretation of Desa Kutukan section. Abbreviation: see Figure 2.

Correlation

Considering the older to younger stratigraphic position of Jaten, Wuni, Nampol, and Punung Formations (Sartono, 1964; Samodra *et al.,* 1992; Surono *et al.,* 1992), a composite log of Punung area was arranged, from bottom to top: Kali Jaten, Desa Jaten to Desa Kutukan section (Figures 9 and 10). From this stratigraphic position, it is interpreted that FAD of *Florschuetzia meridionalis* occurs in Jaten Formation (sample E02, Table 6, Figures 6, 9, and 10), and the last occurrence of *Florschuetzia trilobata* is in sample G08 of Nampol Formation (Table 8; Figures 8, 9, and 10). The interval between sample E02 (Jaten Formation) and sample G08 (Nampol Formation) defines the *Florschuetzia meridionalis* zone of Punung area (Middle Miocene; Rahardjo *et al*., 1994).

The FAD of *Florschuetzia meridionalis* in the lower part of Jonggrangan Formation, Kulon Progo area (samples A02 and B02; Tables 2 and 3; Figures 2, 3, 9, and 10), the FAD of *Orbulina universa* in Oyo Formation, Wonosari area (samples C39 and D32; Tables 4 and 5; Figures 4, 5, 9, and 10), and the FAD of *Florschuetzia meridionalis* in Jaten Formation, Punung area (sample E02; Table 6; Figures 6, 9 and 10) are selected as a boundary between the Early and the Middle Miocene (Morley, 1991; Rahardjo *et al.*, 1994). These three events were made as the basic biostratigraphic datum for the correlation between Kulon Progo, Wonosari, and Punung areas (base of the Middle Miocene; Figures 9 and 10).

The section of Wonosari area that shows the age equivalent to the N7-N8 zones (Blow, 1969) is placed below the base of Middle Miocene line. Based on the previous age interpretations and the biostratigraphic correlation reconstruction (Figures 9 and 10), it can be concluded that the Sambipitu and Oyo Formation (Wonosari) were deposited earlier at N7-N8, late Early Miocene. While the lower part of Jonggrangan Formation (Kulon Progo) and the Jaten, Wuni , and Nampol Formations (Punung) were deposited at Middle Miocene.

MFS-A and MFS-B at Kali Ngalang and Kali Urang sections are made as a regional datum cor-

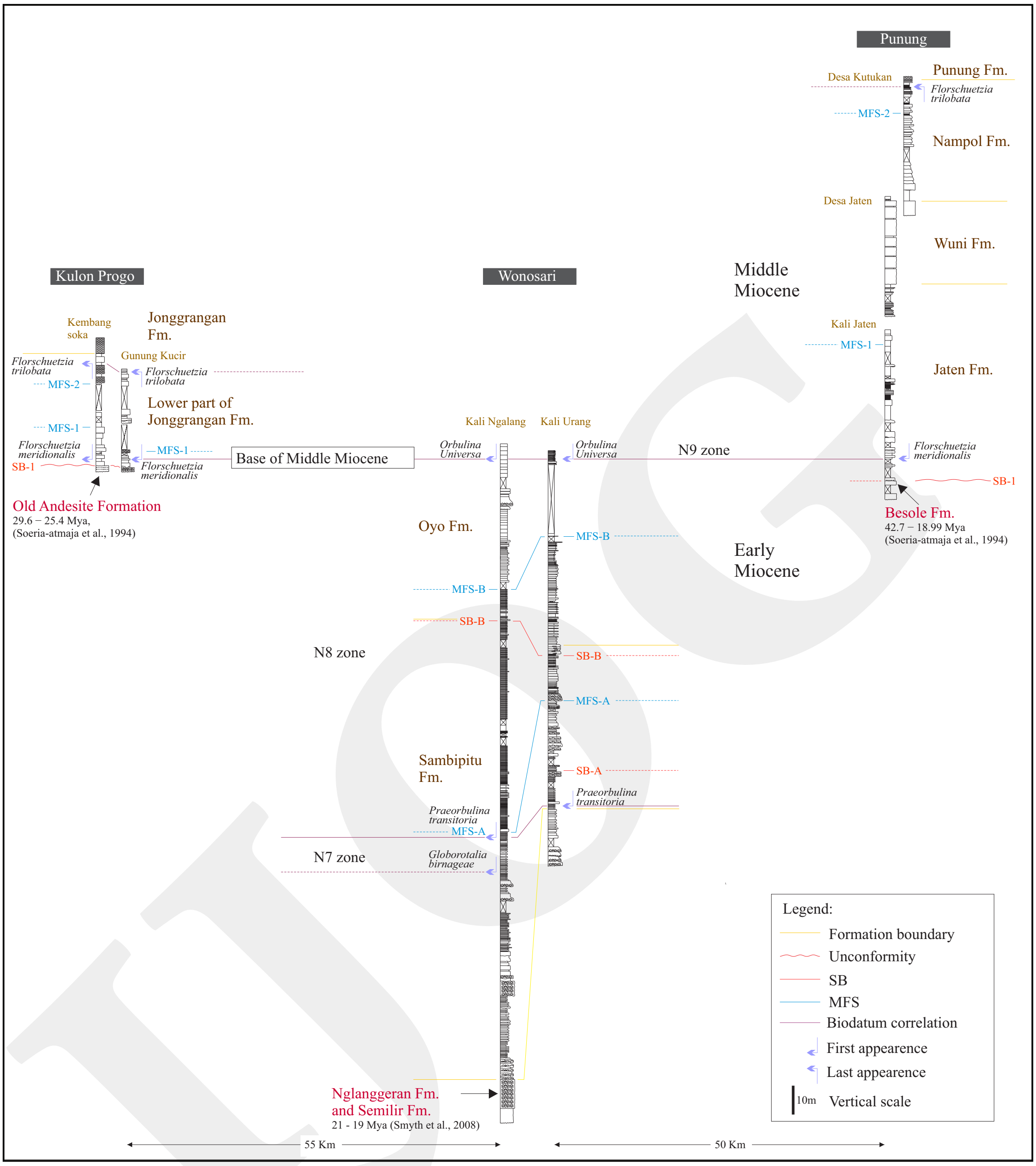


Figure 9. Correlation between the epiclastic sediments of Kulon Progo, Wonosari, and Punung areas. Basic biostratigraphic datum is base of Middle Miocene (Wonosari sections from Fakhruddin, 2010).

relation, because they are the good age controls at Wonosari section (Figure 9) as they show a low diachronous surface. The MFS-A and MFS-B are in N8 zone, in both Kali Ngalang and Kali Urang sections. SB found in Kali Ngalang section is assigned to SB-B, similar to the SB-B found in Kali Urang occurring between the MFS-A and MFS-B events (Figure 9). MFS found in Nampol Formation, Desa Kutukan section, is defined as MFS-2, interpreted from its stratigraphic position above MFS-1 of Jaten Formation (Figure 9). Both MFS-1 and MFS-2 at Kulon Progo and Punung areas are dated as Middle Miocene.

The depositional environment at Wonosari area is shallower in the lower part of Sambipitu Formation, in Kali Ngalang section (Figure 10). In this section (before N7 zone), the depositional environments are peat swamp and mangrove environments. During N7 to N8 zones, sediments of the Sambipitu Formation were deposited in a marine environments: inner shelf, middle shelf, and outer shelf, with mangrove environment only occurred at SB event. The deepest paleobathymetry in Wonosari area is outer shelf (100 - 200 m; Tipsword *et al*., 1966). Middle Miocene sediments at Kulon Progo area were deposited in various environments, from mangrove to inner and middle shelves. The deepest paleobathymetry in this area is middle shelf (MFS-2 event; 20 - 100 m; Tipsword *et al*., 1966). In Punung area, the depositional environment during Middle Miocene varies from riparian forest, alluvial swamp, backmangrove, and mangrove, and the deepest paleobathymetry in this area is in the inner shelf (0-20m; Tipsword *et al*., 1966).

Early to Middle Miocene sediments studied were formed during an Oligo-Miocene compression phase, caused by the Eo-Oligocene subduction, forming a new volcanic arc (Prasetyadi, 2007). The volcanic arc was active from the Middle Eocene (~45 Ma) to the Early Miocene (~20 Ma) (Smyth *et al.,* 2008). The volcanic activities during this period were extensive, explosive, and intermediate to acidic in composition. The centre of these volcanic activities forms a volcanic island arc with east-west direction (Smyth *et al.,* 2008). The products of this volcanic arc activities built up the OAF, Kebo Butak, Semilir, Nglanggeran, and Besole Formations. Deposits from the formations vary from primary volcanic rock to volcaniclastic and epiclastic deposits.

In Wonosari area, sediments of the Kebo Butak Formation were deposited at N2-N5 zones (Soeria-Atmaja *et al.,* 1990). In this area, volcanic activities continued after the deposition of the sediments of the Kebo Butak Formation, which are overlain by the Semilir Formation (Early Miocene; Smyth *et al.,* 2008). On top of the Semilir Formation, the sediments of the Nglanggeran Formation were deposited until about the end of the N6 zone (Surono, 2009). The sediments of the Semilir and Nglanggeran Formations were deposited for approximately two million years ago (21-19 Ma; Smyth *et al.,* 2008). Sediments of the Sambipitu Formation were deposited in the studied area at N7-N8 zones, in subbasins in between volcanic islands (Smyth *et al.,* 2008) due to an establishment of new subbasins at southern Java at that time. In the studied area, sediments of the Oyo Formation overlay the Sambipitu Formation which were deposited at N8 zone and continued to be deposited up to N11 zone (Surono, 2009).

In Kulon Progo area, during the period of the Kebo Butak Formation deposition, volcanic rocks of the OAF were accumulated. The age of the OAF is 29.6 to 25.4 Ma (Soeria-Atmaja *et al.,* 1994). In the studied area, the age of the oldest sediments of lower part of Jonggrangan Formation above the OAF is about equivalent to the base of N9 zone or about 15.1 Ma (Ogg *et al*., 2016). This time gap was caused by the nondepositional phase between 25.4 and 15.1 Ma. Limestone of the Jonggrangan Formation continued to be deposited to Pliocene (Rahardjo *et al*., 1995).

The Middle Eocene to the Early Miocene volcanic phase in Punung area is represented by the Besole Formation. The age of the Besole Formation is 42.7 to 18.99 Ma (Soeria-Atmaja *et al.,* 1994). The oldest sediments of Jaten Formation, overlying the Besole Formation in the studied area, is about equivalent to the base of N9 zone or about 15.1 Ma (Ogg *et al*., 2016). The time gap between 18.99 and 15.1 Ma was caused by the nondepositional phase in the studied area. Limestone of the Punung Formation was deposited in Tf1 zone (Lokier, 2000; Burdigalian-Langhian; Renema, 2007). That limestone continued to be deposited to Tf2 zone (Lokier, 2000; Patriani *et. al*., 2016, Serravalian, Renema, 2007) and Tf3 zone (Sartono *et. al*., 1978, Late Miocene; Renema, 2007).

Epiclastic sediments of the Sambipitu Formation (Wonosari area) rest conformably on its volcanic deposits (Nglanggeran Formation). This is different from the lower part of Jonggrangan Formation and the Jaten Formation which overly unconformably the volcanic rocks below it (OAF

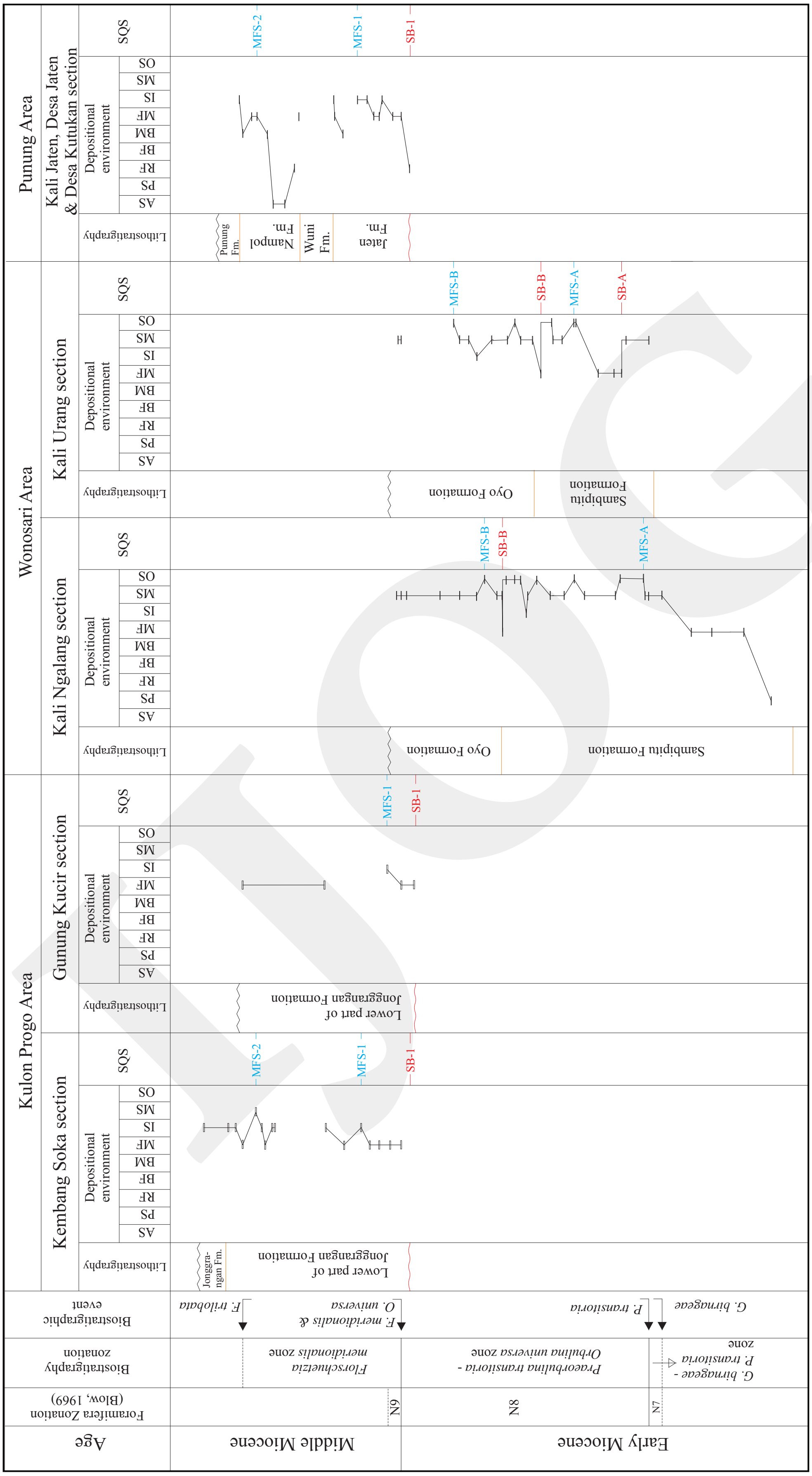


Figure 10. Biostratigraphic framework, depositional environments, and sequence stratigraphy of the epiclastic sediments of Kulon Progo, Wonosari and Punung areas. Abbreviation: see Figure 2.

and Besole Formation). Epiclastic reworking of volcanic arcs occurred earlier at Wonosari area (N7-N8 zones, late Early Miocene) compared to Kulon Progo and Punung area (near base of N9 zone, early Middle Miocene). This is probably related to the former accommodation space between the island arcs available in Wonosari area, because of the position of Wonosari area which is more in the distal facies in the intra-arc basin setting compared with Kulon Progo and Punung areas in the central facies (Bogie and Mackenzie, 1998; Bronto, 2006).

Conclusions

The FAD of *Florschuetzia meridionalis* at the lower part of Jonggrangan Formation and Jaten Formation is considered to be equivalent with the FAD of *Orbulina universa* of Oyo Formation, at the boundary between N8 and N9 zones and as a basic biostratigraphic datum for a correlation between Kulon Progo, Wonosari, and Punung sections. *Florschuetzia meridionalis* is found in rare and sporadic occurrence in Wonosari area in N7-N8 zones, late Early Miocene.

Epiclastic sediments at Wonosari area (Sambipitu Formation) were deposited at N7-N8 zones, late Early Miocene. While at Kulon Progo area (lower part of the Jonggrangan Formation) and Punung area (Jaten, Wuni, and Nampol Formations) they were deposited at Middle Miocene.

MFS is characterized by the peak of diversity and the abundance of planktonic and benthic forams as well as marine, mangrove, and backmangrove palynomorphs. SB event could be characterized by the sudden changes from the domination of deeper marine biofacies to domination of shallower biofacies or by depositional environment changes from deeper marine depositional to more terrestrial environment. MFS-A and MFS-B at Wonosari area found in N8 zone, late Early Miocene, are made as a regional datum correlation for this area, because they are the good age control as they show a low diachronous. MFS-1 and MFS-2 at Kulon Progo and Punung areas are found in *Florschuetzia meridionalis* zone, Middle Miocene.

Epiclastic sediments in Kulon Progo area were deposited in various environments; these are mangrove and inner-middle shelf. The deepest paleobathymetry of this area is the middle shelf. The depositional environment at Wonosari area, at the lower part of Sambipitu Formation at Kali Ngalang section, is peat swamp and mangrove environments which are more landward compared to the upper part of the sediments of Sambipitu Formation deposited in marine environments; such as inner shelf, middle shelf, and outer shelf. At Punung area, the depositional environments are riparian forest, alluvial swamp, backmangrove, mangrove, and inner shelf. Between the Late Burdigalian and Early Langhian, the sediments in Wonosari area were deposited in a relatively deeper paleobathymetry compared to the sediments in Kulon Progo and Punung areas.

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References

Akmaluddin, Watanabe, K., and Rahardjo, W., 2012. Miocene calcareous nannofossils and foraminifera biostratigraphy, with calibrating the age using 40Ar/39Ar dating in Southern Mountains, Central Java. *Proceedings, 41st Annual Convention Indonesian Association of Geologists*, Yogyakarta.

Barker, R.W., 1960. Taxonomic Notes on the species figured by H.B. Brady in his Report of the foraminifera dredged by HMS Challenger during the years 1873 - 1876. *American Association of Petroleum Geologists Special Publication,* 9, 10238, p.2-240.

Blow, W.H., 1969. Late Middle Eocene to Recent Planktonic Foraminiferal Biostratigraphy. *In:* Bronnimann, P. and Renz, H.H. (eds.), *Proceedings of the 1st International Conference on Planktonic Microfossils,* Geneva, 1, p.199-422.

Bogie, I. and Mackenzie, K.M., 1998. The application of a volcanic facies models to an andesitic stratovolcano hosted geothermal system at Wayang Windu, Java, Indonesia. *Proceedings of 20th NZ Geothermal Workshop*, p.265-276.

Bolli, H.M., Saunders, J.B., and Perch-Nielsen., K., 1985. *Plankton Stratigraphy, Volume 1: Planktic Foraminifera, Calcareous Nannofossils and Calpionellids*. Cambridge Earth Science Series. 608pp.

Bronto, S., 2006. Fasies Gunung Api dan Aplikasinya. *Jurnal Geologi Indonesia*, 1 (2), p.59-71. DOI: 10.17014/ijog.vol1no2.20061.

Bronto, S., 2010. Identifikasi Gunung Api Purba Pendul di Perbukitan Jiwo, Kecamatan Bayat, Kabupaten Klaten - Jawa Tengah. *Jurnal Sumber Daya Geologi,* 20 (1), p.3-13.

Catuneanu, O., 2006. *Principles of Sequence Stratigraphy*. Elsevier Science, 386pp.

Fakhruddin, R., 2010. *Analisis Palinologi dan Foraminifera Kecil di Pegunungan Selatan bagian Timur dan Pengaruhnya Terhadap Korelasi Satuan Batuan*. Master Thesis at Teknik Geologi, Fakultas Ilmu dan Teknologi Kebumian, Institut Teknologi Bandung.

Germeraad, J.H., Hopping, C.A., and Muller, J., 1968. Palynology of Tertiary Sediments from Tropical Areas. *Review of Paleobotany and Palynology*, 6 (3-4), p.189-348. DOI: 10.1016/0034-6667(68)90051-1.

Graham, S.A., 2013. Fossil Records in the Lythraceae. *Botanic Review,* 79, p.48-145. DOI: 10.1007/s12229-012-9116-1

Hasseldonx, P., 1974. A Palynological Interpretation of Palaeo-Environments in S.E. Asia. *Sains Malaysiana*, 3 (2), p.119-127.

Hillen, R., 1986. Palynology as a Tool in Delineating Tropical Lowland Depositional Environments of Late Quaternary Age. *GEOSEA V Proceedings Vol. 1, Geological Society of Malaysia Bulletin,* 19, p.495-504.

Kadar, D., 1986. Neogene planktonic foraminiferal biostratigraphy of the south Central Java area, Indonesia. *Geological Research and Development Centre Special Publication,* Bandung, 5, 83pp.

Lelono, E.B., 2007. Zonasi Polen Tersier Indonesia Timur. *Lembaran Publikasi Lemigas*, 41 (1), p.1-8.

Lelono, E.B., Setyaningsih, C.A., and Nugrahaningsih, L., 2014. Paleogene Palynology of The Central Sumatera Basin. *Scientific Contributions Oil & Gas*, 37 (2), p.105-116.

Lokier, S.W., 2000. *The Miocene Wonosari Formation, Java, Indonesia: Volcaniclastic influences on carbonate platform development.* Doctoral thesis, Department of Geology, Royal Holloway, University of London. 648pp.

Mao, L. and Foong S.Y., 2013. Tracing ancestral biogeography of *Sonneratia* based on fossil pollen and their probable modern analogues. *Palaeoworld*, 22, p.133-143. DOI: 10.1016/j.palwor.2013.09.002.

Martini, M., 1971. Standard Tertiary and Quaternary Calcareous Nannoplankton Zonation. *Proceedings of the 2nd Planktonic Conference*, Roma, 2, p.739-785.

Maryanto, S., 2013. Sedimentologi Batugamping Formasi Jonggrangan di Sepanjang Lintasan Gua Kiskendo, Girimulyo, Kulonprogo. *Jurnal Sumber Daya Geologi,* 23, (2), p.105-120.

Morley, R.J., 1990. Introduction to Palynology, With Emphasis on Southeast Asia. *Short Course, Fakultas Biologi, Universitas Jendral Sudirman,* Purwokerto.

Morley, R.J., 1991. Tertiary stratigraphic palynology in Southeast Asia: current status and new directions. *Bulletin of Geological Society of Malaysia*, 28, p.1-36.

Morley, R.J., 2000. *Origin and Evolution of Tropical Rain Forests*. John Wiley & Sons Ltd, Chichester, 362pp. DOI: 10.1002/jqs.774

Morley, R.J., Swiecicki, T., and Pham, D.T.T., 2011. A Sequence Stratigraphic Framework for The Sunda Region, Based on Integration of Biostratigraphic, Lithological and Seismic Data from Nam Con Son Basin, Vietnam. *Proceedings of Indonesian Petroleum Association, 35th Annual Convention & Exhibition*, Jakarta.

Muller, J., 1984. Significance of fossil pollen for angiosperm history. *Annals of the Missouri Botanical Garden*, 71 (2), p.419-443. DOI: 10.2307/2399033.

Murray, J.W., 2006. *Ecology and applications of benthic foraminifera*. Cambridge, UK, Cambridge University Press, 426pp. DOI: 10.1017/CBO9780511535529.

Ogg, J.G., Ogg, G., and Gradstein, F.M., 2016. *A concise geologic time scale*. Elsevier B.V., Amsterdam, Netherlands, 240pp.

Patriani, E.Y., Rijani, S., and Sundari, D., 2016. Perubahan Biofasies Foraminifera pada Batugamping di Pantai Baron dan Serpeng, Provinsi D.I. Yogyakarta. *Jurnal Geologi dan Sumberdaya Mineral*, 17 (2), p.61-71.

Prasetyadi, C., 2007. *Evolusi Tektonik Paleogen Jawa Bagian Timur*. Doctoral thesis at Teknik Geologi, Institut Teknologi Bandung.

Rahardjo, A.T., Polhaupessy, A.A., Wiyono, S., Nugrahaningsih, L., and Lelono, E.B., 1994. Zonasi Polen Tersier Pulau Jawa. *Makalah Ikatan Ahli Geologi Indonesia*, Pertemuan Ilmiah Tahunan ke-23 Desember 1994, p.77-84.

Rahardjo, W., Sukandarrumidi, and Rosidi, H.M.D., 1995. *Geological Map of the Yogyakarta Quadrangle, Jawa, 1:100.000*. Geological Research and Development Centre, Bandung.

Rahardjo, A.T. and Yulianto, E., 1998. Analisa Palinologi Formasi Jaten Daerah Punung Kabupaten Pacitan, Jawa Timur. *Buletin Geologi*, Jurusan Geologi, Institut Teknologi Bandung, 30 (3), p.13-20.

Rahardjo, A.T., Yulianto, E., and Setijadi, R., 1998. Palinologi Formasi Nampol dan Hubungan Stratigrafinya dengan Formasi Punung di Daerah Punung, Kabupaten Pacitan-Jawa Timur. *Buletin Geologi*, Jurusan Geologi, Institut Teknologi Bandung, 29 (2), p.1-9.

Rauwerda, P.J., Morley, R.J., and Troelstra, S.R., 1984. Assessment of Depositional Environment and Stratigraphy on The Basis of Foraminifera. *Palaeoecology, Internal Report Robertson Research (Singapore) Private Limited.*

Reich, S., Wesselingh, F.P., and Renema, W., 2014. A Highly Diverse Molluscan Seagrass Fauna from The early Burdigalian of Banyunganti (south-central Java, Indonesia). *Annalen des Naturhistorischen Museums in Wien*, Serie A, 116, p.5-129.

Renema, W., 2007. Fauna Development of Larger Benthic Foraminifera in the Cenozoic of Southeast Asia. *In*: Renema, W. (eds.), *Biogeography, Time, and Place: Distributions, Barriers, and Islands*, Springer, p.179-215. DOI: 10.1007/978-1-4020-6374-9_6.

Samodra, H., Gafoer, S., and Tjokrosapoetro, S., 1992. *Geological Map of the Pacitan Quadrangle, Jawa, 1:100.000.* Geological Research and Development Centre, Bandung.

Sartono, S., 1964. *Stratigraphy and Sedimentation of the Easternmost part of Gunung Sewu (East Java).* Publikasi Teknik Seri Geologi Umum No. 1. Republik Indonesia Departemen Perindustrian Dasar/Pertambangan Direktorat Geologi, Bandung. 95pp.

Sartono, S., Hidayat, S., Zaim, J., Nababan, U.P., and Djubiantono, T., 1978. Undak Sungai Baksoko Berdasarkan Analisa Foto Udara. *Berita Penelitian Arkeologi,* 19, (B), p.23-52.

Satyana, A.H., 2005. Oligo-Miocene Carbonates of Java, Indonesia: Tectonic-Volcanic Setting and Petroleum Implications. *Proceedings of Indonesian Petroleum Association, 30th Annual Convention & Exhibition*, Jakarta.

Smyth, H.R., Hall, R., and Nichols, G.J., 2008. Cenozoic volcanic arc history of East Java, Indonesia: The stratigraphic record of eruptions on an active continental margin. *In*: Draut, A.E., Clift, P.D., and Scholl, D.W. (eds), *Formation and Applications of the Sedimentary Record in Arc Collision Zones*, Geological Society of America Special Paper, 436, p.199-222. DOI:10.1130/2008.2436(10).

Soeria-Atmadja, R., Pringgoprawiro, H., and Priadi, B., 1990. Tertiary magmatic activity in Java: a study on geochemical and mineralogical evolution. *Prosiding Persidangan Sains Bumi dan Masyarakat.* Universiti Kebangsaan Malaysia, Kuala Lumpur, p.164-180.

Soeria-Atmadja, R., Maury, R.C., Bellon, H., Pringgoprawiro, H., Polve, M., and Priadi, B., 1994. Tertiary magmatic belts in Java. *Journal of Southeast Asian Earth Sciences,* 9 (1/2), p.13-27.

Sunjaya, E.S., Amir, A., Sudarmawan, D., and Satyana, A.H., 2006. Sedimentology of Wonosari carbonates Southern Yogyakarta: outcrop study and petroleum implications. *Abstract American Association Petroleum Geologists, International Conference and Exhibition*, Perth.

Surono, Toha, B., and Sudarno, I., 1992. *Geological Map of the Surakarta - Giritontro Quadrangle, Jawa. 1:100.000.* Geological Research and Development Centre, Bandung.

Surono, 2009. Litostratigrafi Pegunungan Selatan Bagian Timur Daerah Istimewa Yogyakarta dan Jawa Tengah. *Jurnal Sumber Daya Geologi*, 19, p.209-221.

Surono and Permana, A.K., 2011. Litostratigraphic and Sedimentological Significants of Deepening Marine Sediments of The Sambipitu Formation Gunung Kidul Residence, Yogyakarta. *Bulletin of The Marine Geology*, 26 (1), p.15-30.

Suyoto and Santoso K., 1986. Klasifikasi Stratigrafi Pegunungan Selatan, Daerah Istimewa Yogyakarta dan Jawa Tengah. *Proceedings 15th Annual Convention Indonesian Association of Geologists*, Yogyakarta.

Tipsword, H.L., Setzer, F.M., and Smith, F.L., 1966. Interpretation of depositional environment in Gulf Coast petroleum exploration from paleoecology and related stratigraphy. *Gulf Coast Association of Geological Societies Transactions*, 16, p. 119-130.

Yaksan, A.M., Harun, A., Nasib, B.M., and Morley, R.J., 1996. Integrated biostratigraphic zonation for the Malay Basin. *Bulletin of Geological Society of Malaysia*, 39, p.157-184.