



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

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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

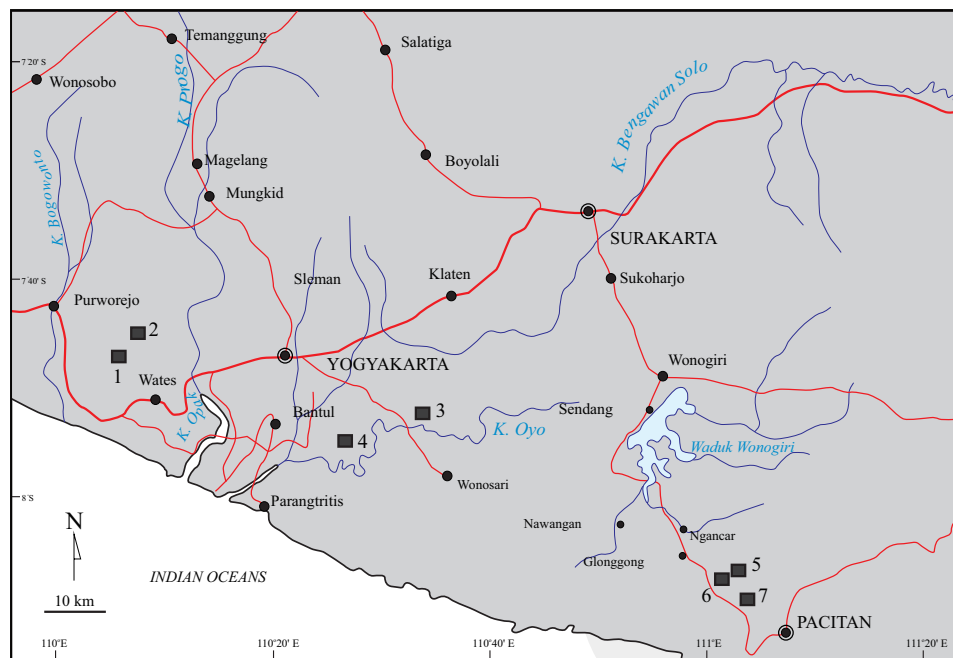


Figure 1. Locality map of the studied area, showing the position of measured section outcrops (black box): 1= Kembang Soka, 2 = Gunung Kucir, 3 = Kali Ngalang, 4 = Kali Urang, 5 = Kali Jaten, 6 = Jalan Desa Jaten, and 7 = Desa Kutukan.

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 GeolLabs 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

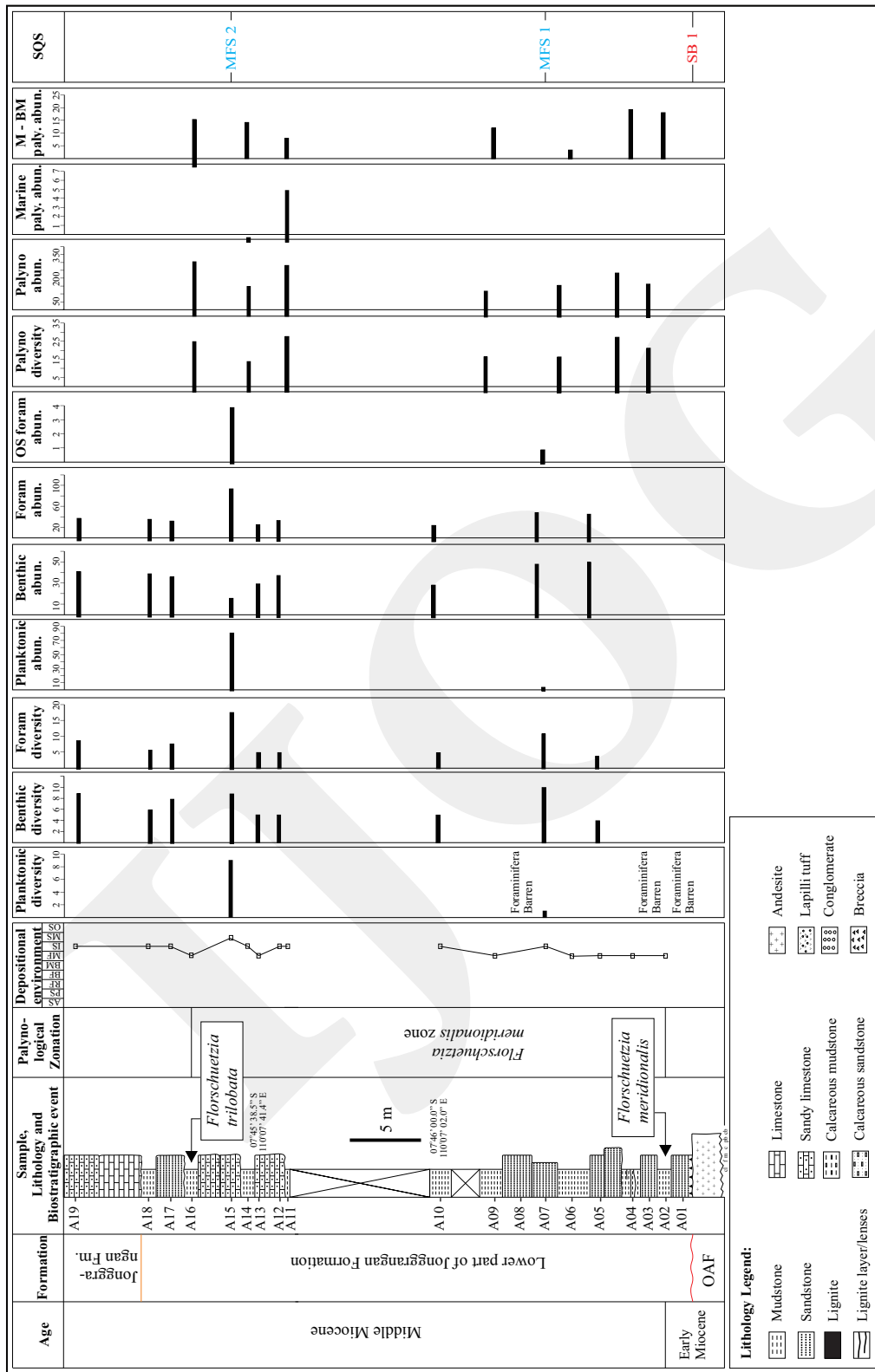


Figure 2. Stratigraphic section, depositional environment interpretation, foraminiferal and palynomorph diversity and abundance, and sequence stratigraphy interpretation of Kembang Soka section. Abbreviation: OAF=Old Andesite Formation, AS=alluvial swamp, PS=peat swamp, RF=riparian forest, BF=beach forest, 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, *Campostemon*-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 en-

vironment 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 palynomorphs 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 a 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-

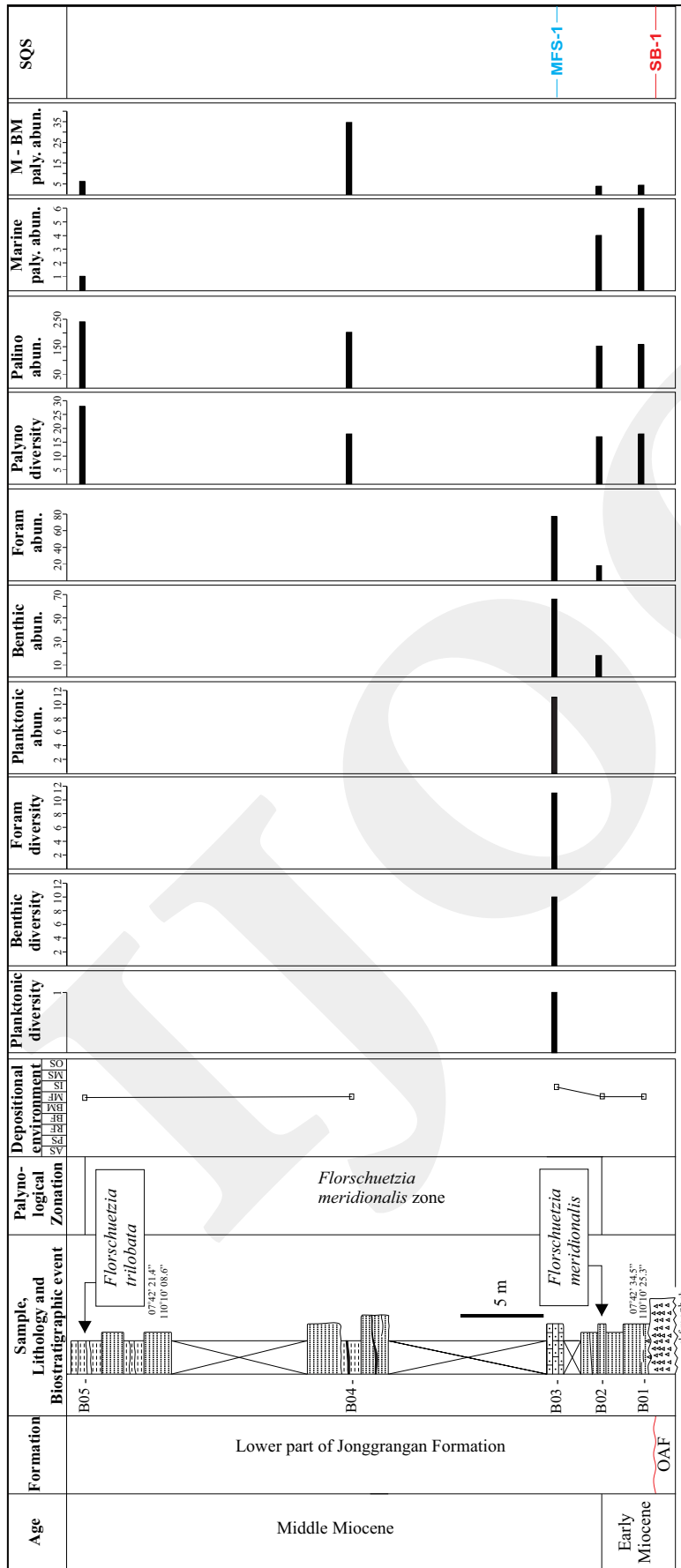


Figure 3. Stratigraphic section, depositional environment interpretation, foraminiferal and palynomorph diversity and abundance, and sequence stratigraphy interpretation of Gunung Kucir section. Legend and abbreviation: see Figure 2.

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

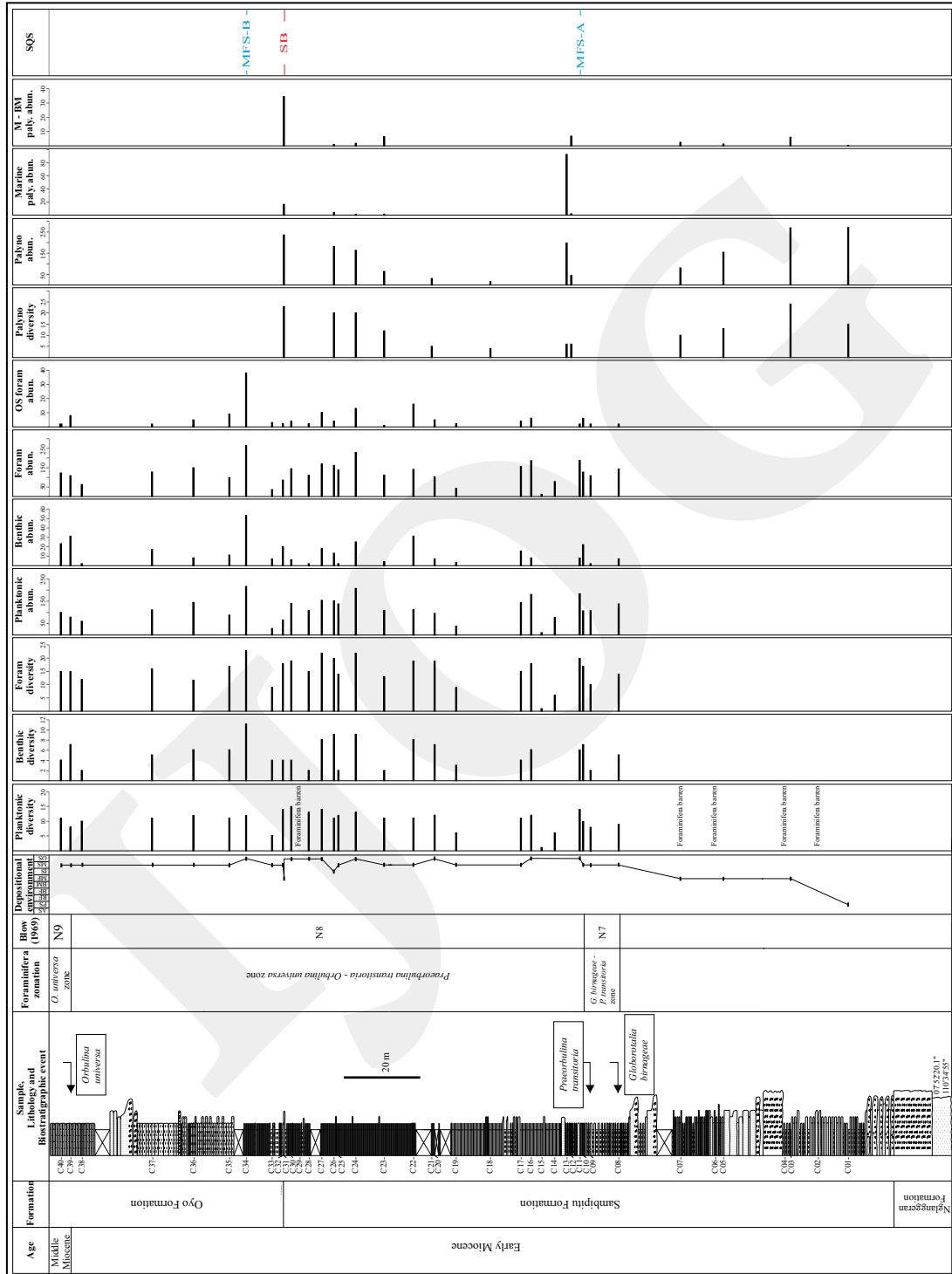


Figure 4. Stratigraphic section, depositional environment interpretation, foraminiferal and palynomorph diversity and abundance, and sequence stratigraphy interpretation of Kali Ngalang section (modified from Fakhruddin, 2010). Abbreviation: see Figure 2.

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., *Bullimina* 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., *Karrerriella* 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 glomerata*, 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., *Bullimina* 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 *Lenticulina* 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 occurrence of *Nodosaria* sp., *Cibicides* sp., *Amphistegina* sp., *Bullimina* sp., *Uvigerina* sp., *Eponides* sp., *Cassidulina* sp., *Nonion* sp., *Dentalina* sp., *Lenticulina* sp., and

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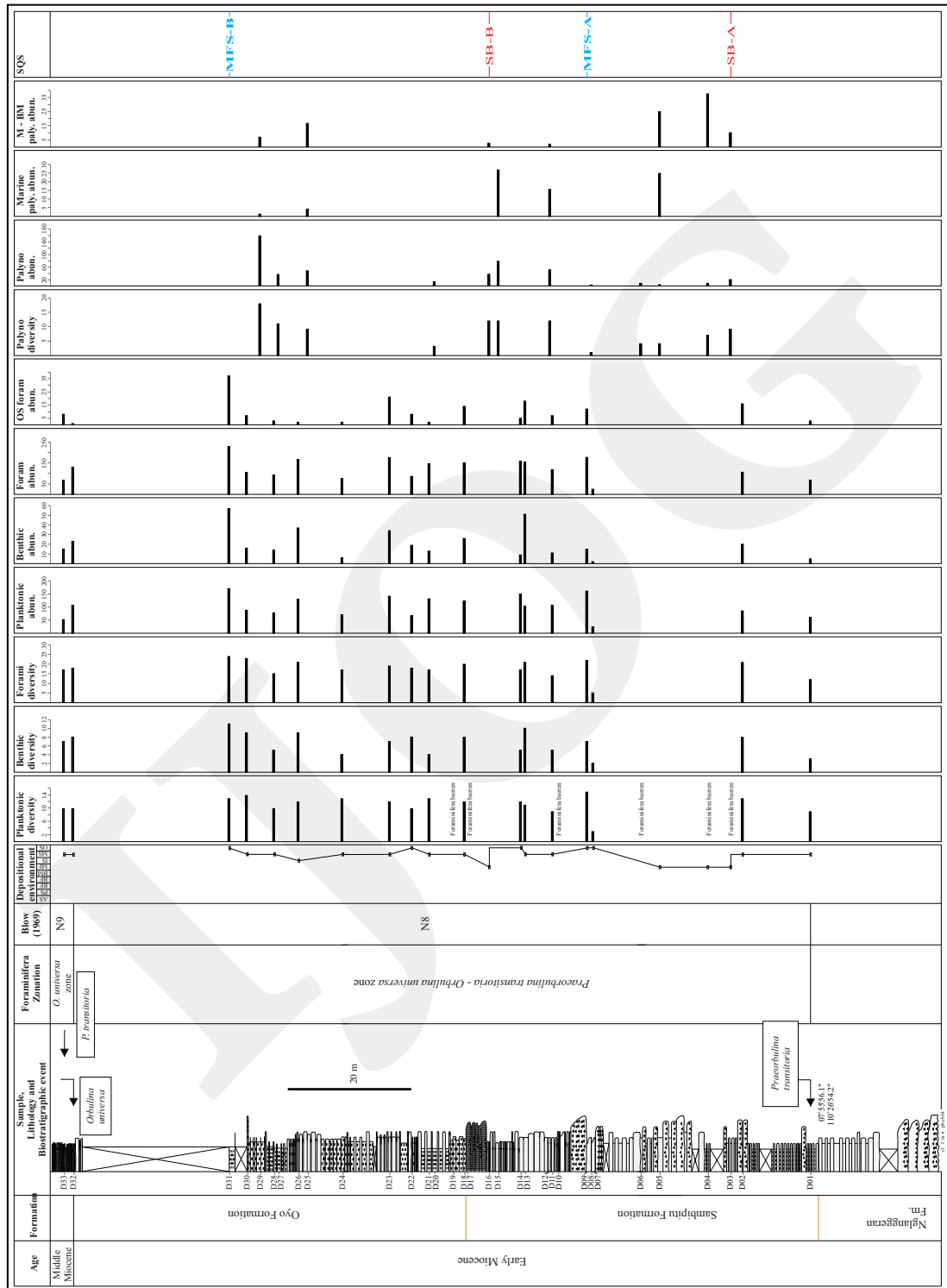


Figure 5. Stratigraphic section, depositional environment interpretation, foraminiferal and palynomorph diversity and abundance, and sequence stratigraphy surface interpretation of Kali Urang section (modified from Fakhruddin, 2010). Abbreviation: see Figure 2.

Siphonina sp. (Rauwerda *et al.*, 1984; Murray, 2006). The outer shelf interpretation is shown by the occurrence 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 occurrence of *Florschuetzia meridionalis* (sample E02) and the last occurrence 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 palynomorph 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

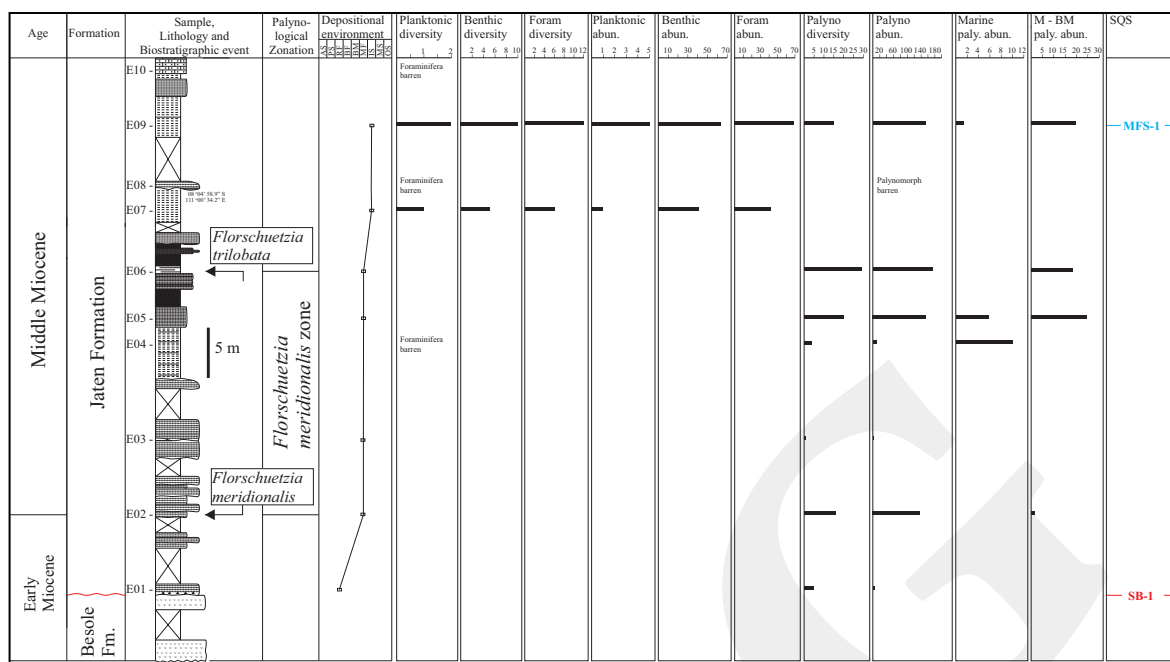


Figure 6. Stratigraphic section, depositional environment interpretation, foraminiferal and palynomorph diversity and abundance, and sequence stratigraphy surface interpretation of Kali Jaten section. Abbreviation: see Figure 2.

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

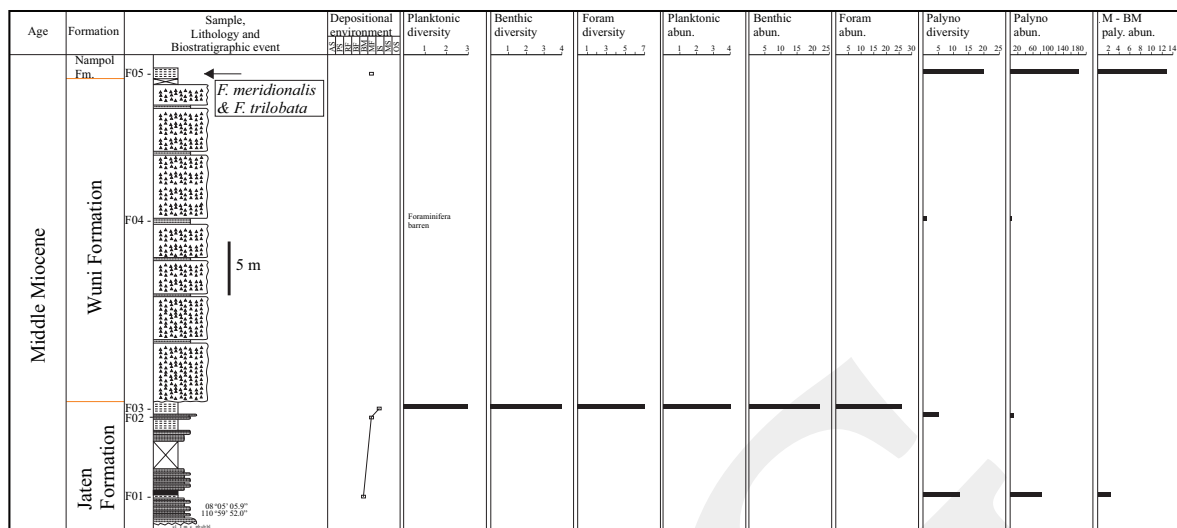


Figure 7. Stratigraphic section, depositional environment interpretation, and foraminiferal and palynomorph diversity and abundance of Jalan Desa Jaten section. Abbreviation: see Figure 2.

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 Appearance 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).

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

Table 8. Foraminifera and Palynomorph Distributions of Desa Kutukan Section

Sample	Formation	Biozonation	Depositional environment	Sequence stratigraphy	Analysis	Benthic	Ephidium sp.	Eponides sp.	Planorbulina sp.	Total Benthic	Total Foraminifera	% 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	17	1	1	15	2	4	5	8	8	20	4	1	2	2	1	2	18	6	41	8	6	21	193
G 08		<i>F. meridionalis</i> zone	BM		P	2	1	4	1	1	1	1	4	1	1	1	23	3	5	5	6	3	1	2	2	7	10	56	3	32	1	61	244
G 07			MF		P	1	5	43	37	1	1	43	1	1	1	14	2	2	3	4	10	3	18	1	1	1	1	66	4	1	13	8	287
G 06			MF		P	1	5	43	37	1	1	43	1	1	1	14	2	2	3	4	10	3	18	1	1	1	1	66	4	1	13	8	287
G 05	Nampol Fm.		BM		P	1	5	43	37	1	1	43	1	1	1	14	2	2	3	4	10	3	18	1	1	1	1	66	4	1	13	8	287
G 04			AS		P	1	5	43	37	1	1	43	1	1	1	14	2	2	3	4	10	3	18	1	1	1	1	66	4	1	13	8	287
G 03			AS		P	1	5	43	37	1	1	43	1	1	1	14	2	2	3	4	10	3	18	1	1	1	1	66	4	1	13	8	287
G 02			RF		P	1	5	43	37	1	1	43	1	1	1	14	2	2	3	4	10	3	18	1	1	1	1	66	4	1	13	8	287
G 01			-		F	16	2	1	3	3	17	1	1	15	2	4	5	8	8	20	4	1	2	2	1	2	18	6	41	8	6	21	193

Note: Abbreviation: see Table 2 and Figure 2

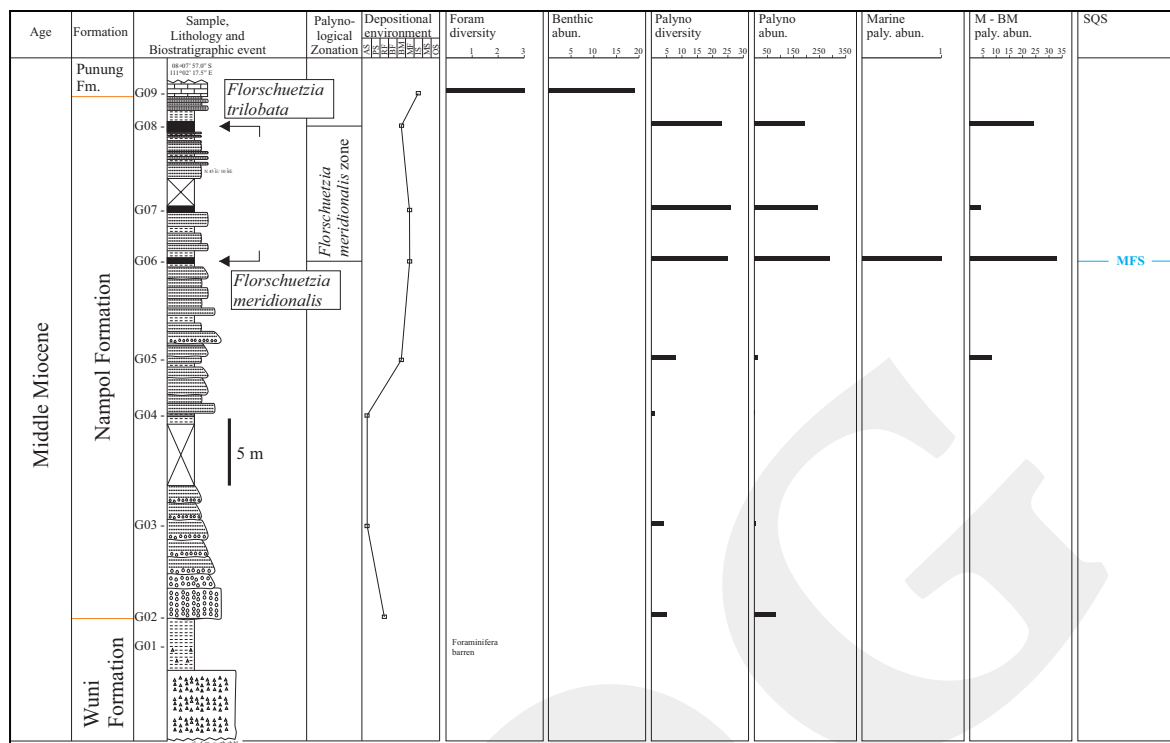


Figure 8. Stratigraphic section, depositional environment interpretation, foraminiferal and palynomorph diversity and abundance, and sequence stratigraphy surface interpretation of Desa Kutukan section. Abbreviation: see Figure 2.

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-

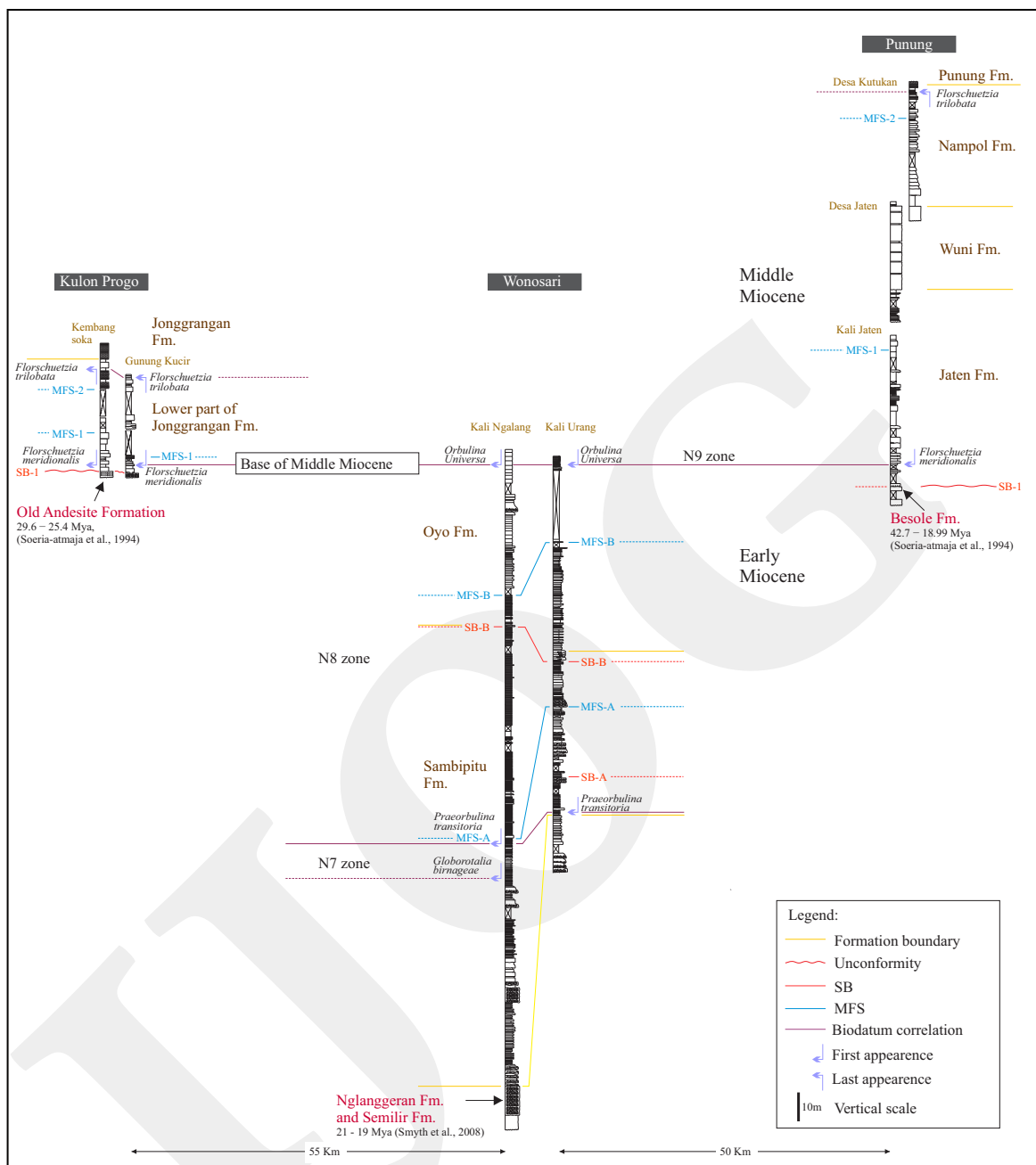


Figure 9. Correlation between the epiclastic sediments of Kulon Progo, Wonosari, and Punung areas. Basic biostratigraphic datum is base of Middle Miocene (Wonosari sections from Fakhruddin, 2010).

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 en-

vironments. 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 volcanoclastic 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

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

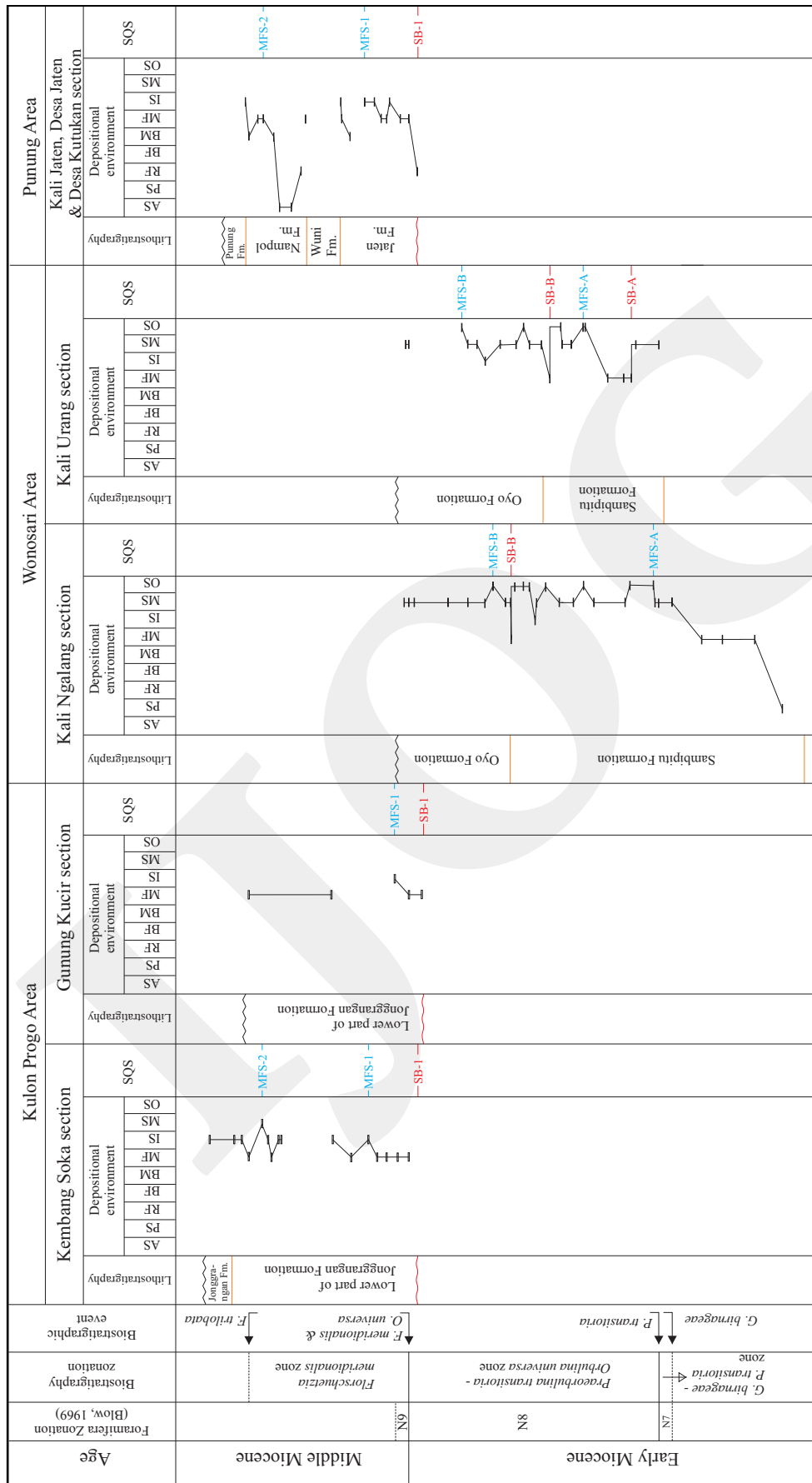


Figure 10. Biostratigraphic framework, depositional environments, and sequence stratigraphy of the epiclastic sediments of Kulon Progo, Wonosari and Punung areas. Abbreviation: see Figure 2.

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 back-mangrove 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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