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Nutrient Level Change Based on Calcareous Nannofossil Assemblages During Late Miocene in Banyumas Subbasin

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Abstract - Hydrographic situation on surface waters is more challenging to be understood, related to global and regional climate change in tropical regions. In addition, records from these tropical areas are limited compared to other areas of subtropical and polar regions. The aim of this study is to reconstruct Cenozoic paleoceanography, in particular nutrient level, using outcrop samples from Kali Pasir, Banyumas, Indonesia. This study is focused on the relationships of the relative abundance of *Discoaster,* coccolith size of *Reticulofenestra,* and lithofacies characteristics. Nutrient level is reconstructed using quantitative analysis of calcareous nannofossil by counting calcareous nannofossils on 400 fields of View (FOV) for each sample. The abundance of *Discoaster* and the large *Reticulofenestra* represent a deep thermocline and nutricline, which is a typical of oligotrophic condition. This condition also associated with the muddy facies in the early stages of Late Miocene (NN8-NN10a). Conversely, decreasing *Discoaster* abundance and the abundance of small *Reticulofenestra* indicate a shallow thermocline and nutricline, resulting strong eutrophication of surface waters in the later stage of Late Miocene (NN10b-NN11). A high nutrient content in this stage is related to classical turbidite deposits. A change in a sea surface resulted in strong eutrophication, which is in this section similar to the eastern Indian Ocean micropaleontology records during the Late Miocene (NN10). This finding shows that strong eutrophication in Kali Pasir section is probably driven by nutrient-rich terrestrial material related to the onset of Indian monsoon during the Late Miocene.

Keywords: nutrient level, nannofossil, Late Miocene, classical turbidite

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Introduction

Vertical distribution of calcareous nannoplankton as a major component of oceanic phytoplankton is mainly influenced by surface water properties such as light, temperature, salinity, turbidity, and nutrient content (McIntyre and Bé, 1967). Modern distribution of *Florisphaera profunda* is considered as lower photic zone species (Okada and Honjo, 1973). This species lives below 100 m water depth and is found abundantly in low-latitude areas in the equatorial Pacific and the Indian Ocean (Okada and Honjo 1973; Hagino *et al*., 2000; Takashi and Okada, 2000). Quaternary paleoceanography is often reconstructed using a living calcareous nannoplankton (Di Stefano and Incarbona, 2004; Chiyonobu *et al*., 2006; and Bolliet *et al*., 2011). However, reconstruction of pre-Quaternary, especially Miocene period, using nannofossil is more challenging as mentioned by

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a previous study (Imai *et al*., 2015), because the majority of species are now extinct. In this study, nutrient level change is reconstructed based on previous method (Imai *et al*., 2015) using the relative abundance of *Discoaster* and the coccolith size of *Reticulofenestra. Discoaster* abundance and *Reticulofenestra* size are correlated with lithological characteristics of Halang Formation in Central Java, Indonesia (Figure 1).

Previous researchers (*i.e*. Sato and Chiyonobu, 2009; Hermann and Thierstein, 2012; Imai *et al*., 2013; Imai *et al*., 2015) have observed assemblages of calcareous nannofossil throughout various geological timescale to understand paleoenvironmental condition from various land sections and oceans. Small *Reticulofenestra* specimens are commonly used for eutrophic condition in the upwelling areas (Imai *et al*., 2015; Takahashi and Okada, 2000; Kameo, 2002; Chiyonobu *et al*., 2006; Balleeger *et al*., 2012). Nutrient levels are regarded as a primary factor in coccolith sizes. However, another proxy based on the abundance of *Dictyococcites* (Beltran *et al.*, 2014) supposes the light intensity is the most important in formation of acme of small *Dictyococcites* (a junior synonym of *Reticulofenestra*). Therefore, regarding subsequent nutrient observations, Takahashi and Okada (2000), Kameo (2002), Chiyonobu *et al.* (2006), Balleeger *et al*. (2012), and Beltran *et al*. (2014) stated thatprimary control of nutrient levels is challenging to be revealed based on calcareous nannofossil assemblages during pre-Quaternary. Such characteristics must be investigated in more regions to elucidate accurate reconstruction of Cenozoic paleoceanography. The objectives of this study are (1) to find out relationships between the relative abundance of *Discoaster*, the coccolith size of *Reticulofenestra*, and the lithological characteristics; (2) to reconstruct changes of the thermocline and nutricline in Kali Pasir section based on those parameters; (3) to understand the influence of turbidite current with nutrient levels in Banyumas, Central Java.

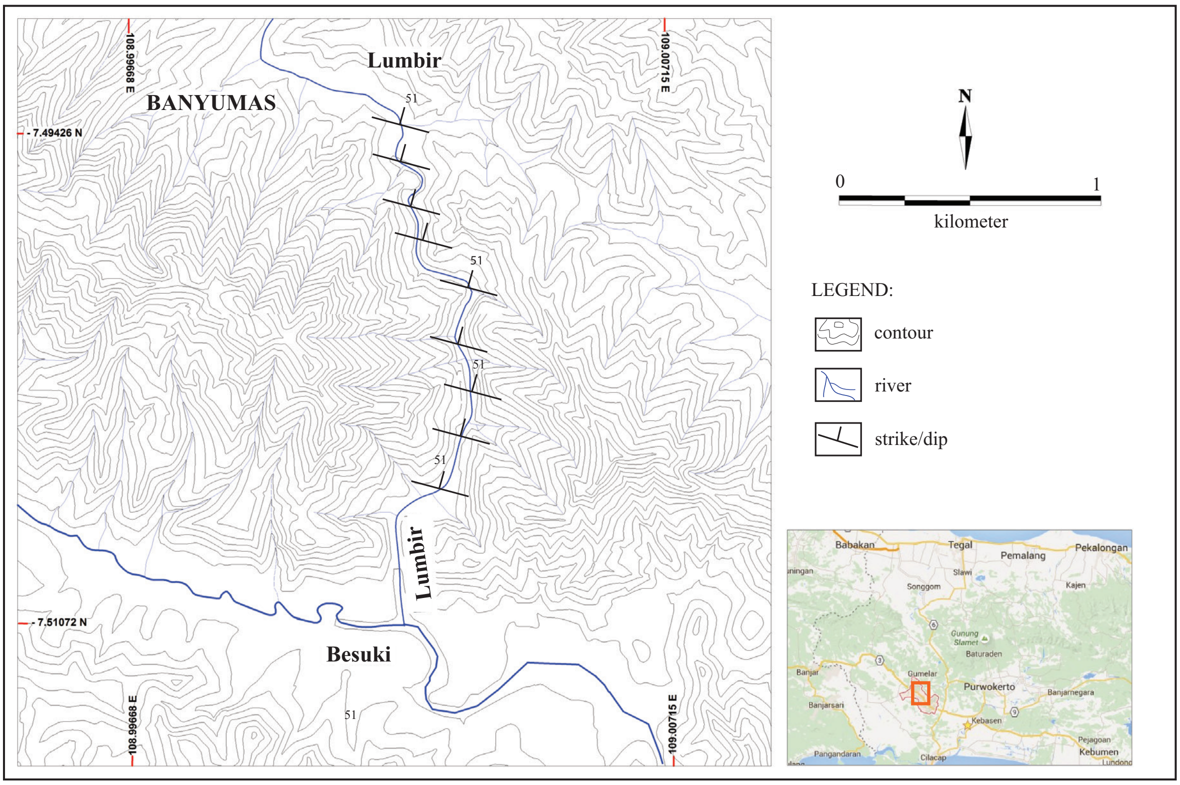

Figure 1. Locality and sampling map in Kali Pasir, Banyumas. The red box shown in the figure indicates site section in Banyumas, Central Java.

Kali Pasir section (108°59'37" E, 7°29'37" S) is located in the Banyumas Subbasin, Central Java, and this subbasin belongs to South Central Java Basin. This subbasin is in the Sumatra-Java magmatic arc region, which is bordered in the north by the Northwest Java Basin, and in the south by the Sumatra-Java Fore-arc Basins (Hendrizan *et al.*, 2014). This section represents Halang Formation, which is dominated by mixed sandy and muddy facies with relatively minor mudstone and sandstone facies. Moreover Mulhadiyono (1973), Sujanto and Roskamil (1975), Kadar (1986), Lunt *et al.* (2009), and Hendrizan *et al.* (2014) have observed stratigraphy of this region in the details. The formations deposited in this section include Gabon, Kalipucang, Halang, Pemali, Bantardawa, and Talanggundang.

MATERIAL AND METHODS

The total number of 121 samples was obtained from the detailed measured section in Kali Pasir, Banyumas (Figure 1). Each sample of ±0.5 mg was prepared by smear slide method; by scratching rock sample using a cutter to be a residue. Then, the residue on the objective glass was scattered, added with distilled water, flattened, and dried on a hot plate. The dry sample was covered by a glass with Canada balsam adhesive, and labelled. Calcareous nannofossil on the objective glass was counted manually on the 400 field of view (FOV) and identified using 1000x magnification of a polarized microscope. A number between 0 and 28491 specimen can be identified for each sample.

Data analysis from assemblage counting was reconstructed to reveal the sea surface condition in Kali Pasir section. Some important specimens were analyzed from genus *Discoaster, Reticulofenestra,* and other abundant specimens. In addition, the turbidite characteristic also would be observed to uncover relationship between the sea surface condition and the possibility of the sediment source from Java. Additionally, Imai *et al.* (2015) has mentioned about thermocline and nutricline deepening based on the abundance of lower photic zone (*e.g. Discoaster*) and deepening situation yielded a decrease of coccolith production and the relative abundance of small *Reticulofenestra*. This situation is known as oligotrophic. In contrast, a decrease of *Discoaster* and an increase of small *Reticuofenestra* yield a shoaling of thermocline and nutricline. Waters above the thermocline and nutricline are shown as eutrophic (Imai *et al.*, 2015). Therefore, to reconstruct the mechanism of nutrient level change from the Banyumas region, analysis of sea surface condition in this section follows preceding study carried of by Imai *et al.* (2015).

RESULTS AND ANALYSIS

Calcareous Nannofossil Assemblages and Lithology

Calcareous nannofossil biostratigraphy of Kali Pasir section was divided into five zonations (Hendrizan *et al.*, 2014) based on the first occurrences and the last occurrences of specimens following Martini (1971). Nannofossil assemblages were dominated by nine species (Figure 2) and their photomicrographs are shown on Figure 3. During Late Miocene (NN8-NN10a), *Sphenolithus compactus* dominated with the average number of 29.32 %, followed by another species with the average between 1.33 and 19.82% (Table 1). The following period (NN10b-NN11) was dominated by *Reticulofenestra minuta* with the average of 48.65 %. Another species in this period contained the average number between 0.28 - 16.39 % (Table 1). To differ the period during Late Miocene in this section, the nomenclature of early stage of Late Miocene (NN8-NN10a) and later stage of Late Miocene (NN10b-NN11) would be applied in this study.

A contrast lithology difference between the early stages of Late Miocene and the later stage of Late Miocene exists. The early stage of Late Miocene (NN8-NN10a) deposit consists of muddy and sandstone lithofacies. This lithofacies occurs at the thickness between 880 and 1,350 m (Figures 4a, b). This stage deposit has less sedi-

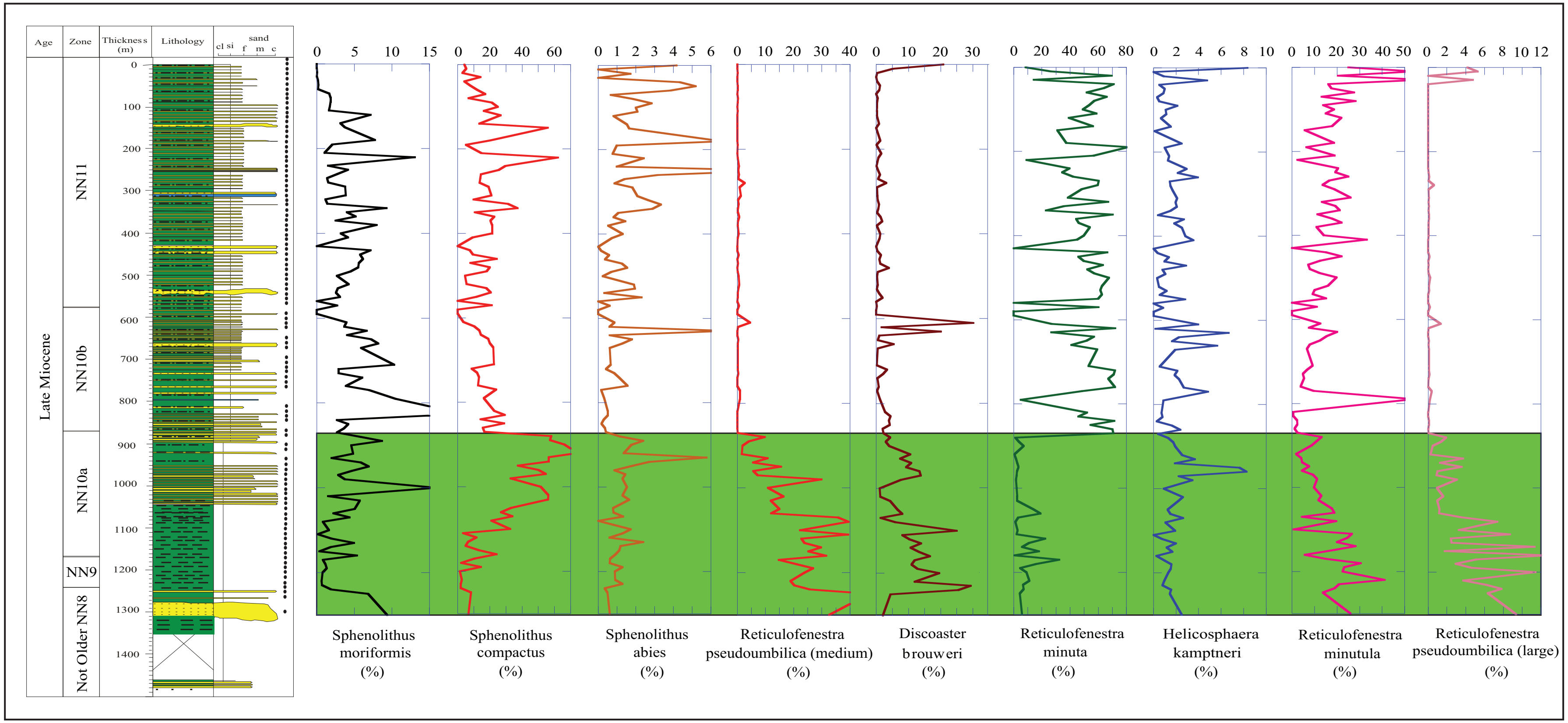

Figure 2. Graphs of calcareous nannofossil assemblages domination in Kali Pasir section on the right, lithofacies of Kali Pasir section is shown on the left. The green shading reflects the total number of calcareous nannofossil distributed in the muddy facies and the white shading reflects the total number of calcareous nannofossil distributed in the classical turbidite in this section.

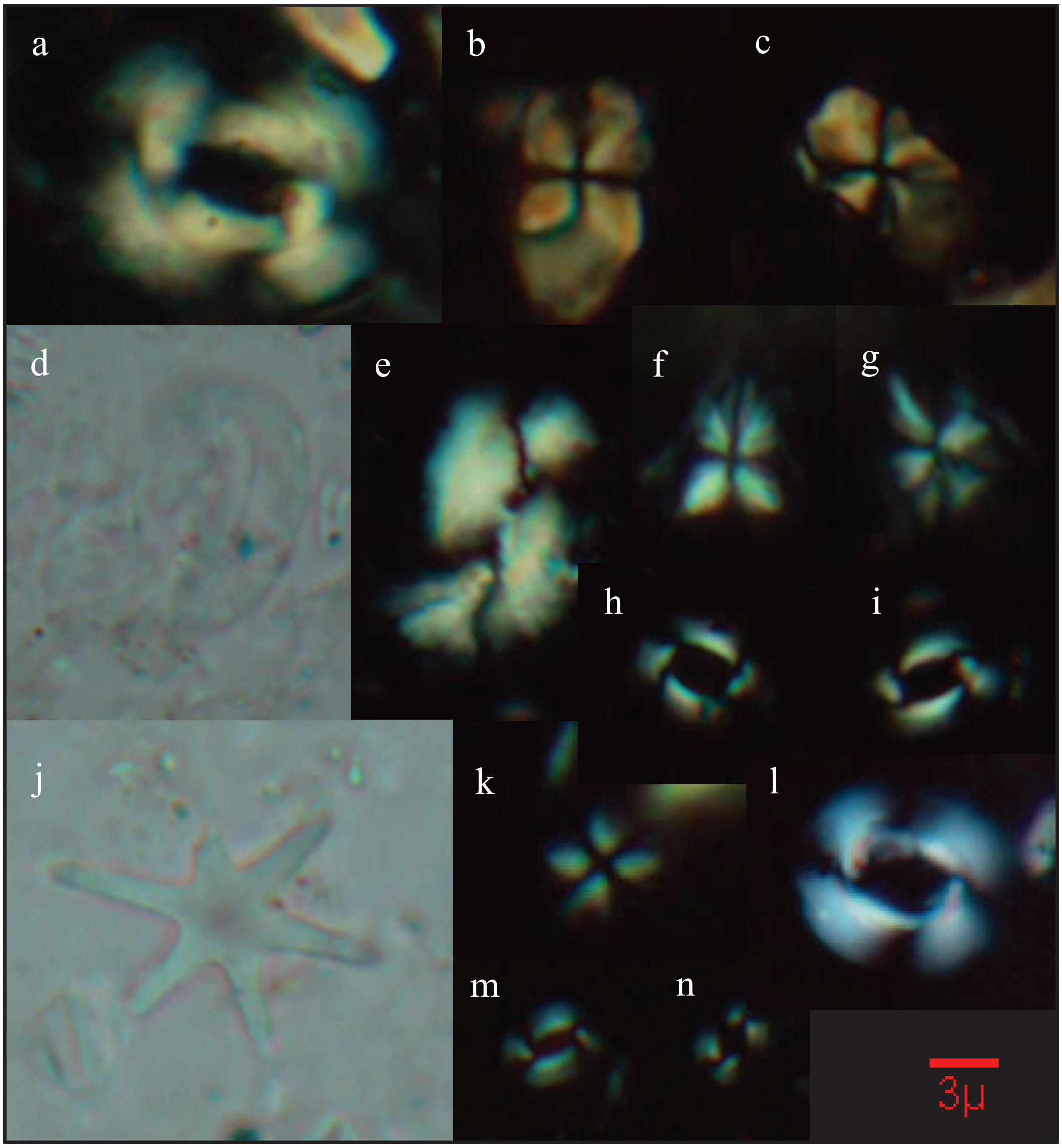

Figure 3. Photomicrographs of dominated nannofossil assemblages in Kali Pasir section. a. *Reticulofenestra pseudoumbilica* (large); b and c. *Sphenolithus moriformis*; d and e. *Helicosphaera kamptneri*; f and g. *Sphenolithus abies*; h and i. *Reticulofenestra minutula*; j. *Discoaster brouweri*; k. *Sphenolithus compactus*; l. *Reticulofenestra pseudoumbilica* (medium); m and n. *Reticulofenestra minuta*.

Table 1. Average Number of dominated Nannofossil in Kali Pasir Section during Late Miocene Period

Dominated nannofossil	**Age**	
	Late Miocene (NN8-NN10a)	**Late Miocene (NN10b-NN11)**
S. moriformis	4.04%	3.83%
S. compactus	29.32%	16.39%
S. abies	1.33%	1.53%
R. pseudoumbilica (med)	19.82%	0.32%
D. brouweri	10.26%	2.09%
R. minuta	7.00%	48.65%
H. kamptneri	2.06%	1.73%
R. pseudoumbilica (large)	4.10%	0.28%
R. minutula	15.5%	14.7%

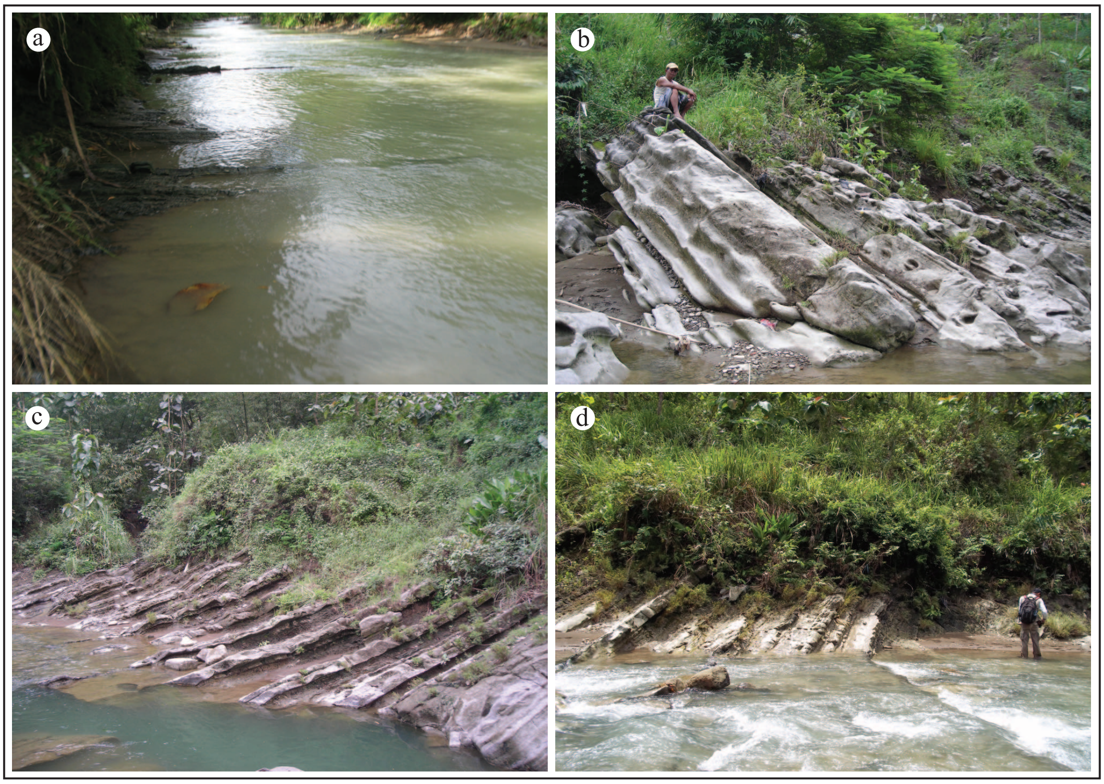

Figure 4. a. The underwater muddy facies, b. The sandstone facies in the lower part; c and d. The mixed muddy and sandy as a classical turbidite in the upper part.

mentary structure than the upper part, because contains only laminar bedding. In the later stages of Late Miocene, sediments between 0 and 880 m are typical of classical turbidites. They contain mixed muddy and sandy lithofacies (Figures 4c, d) associated with several sedimentary structures, such as parallel lamination (Figures 5a, c); ripple mark (Figure 5b); convolute (Figures 5a, d) occurring in this section (Figure 5).

The difference between lower and upper facies in this section shows the dissimilarity of current energy in Kali Pasir section. The lower facies during the early stage of Late Miocene with muddy dominated system could be maintained by a low/minimum density current. A low/minimum density current is suitable to control a dominant assemblage of nannofossil such as *Sphenolithus compactus,* both *Reticulofenestra pseudoumbilica* with medium and large size, and *Discoaster brouweri* (Figures 2). The upper facies containing mixed muddy and sandy sediment as a classical turbidite on the later stage of Late Miocene could be driven by a higher density current rather than the lower part in this section. The total amount of sediment discharge from Java Island would be transported by a high intensity of current which is caused by that large precipitation intensity. Small *Reticulofenestra,* especially *Reticulofenestra minuta* (Figure 2), has dominated this classical turbidite. The local factor of sediment discharge in this section, especially large precipitation intensity during Late Miocene, probably has maintained high distribution of mud and sand ratio in the upper classical turbidite. That sediment discharge from mainland Java due to precipitation intensity is supposed to have been going to distribute nutrient content from the land, which is associated with intensification of classical turbidite. The evidence of high abundance small *Reticulofenestra,* especially *Reticulofenestra minuta,* in Kali Pasir section during the later stage of Late Miocene maintains eutrophic condition as mentioned by previous study (Imai *et al.,* 2015). Intensified sandy transport of classical turbidite would transport high nutrient and trigger high abuncance of small *Reticulofenestra* (Fig-

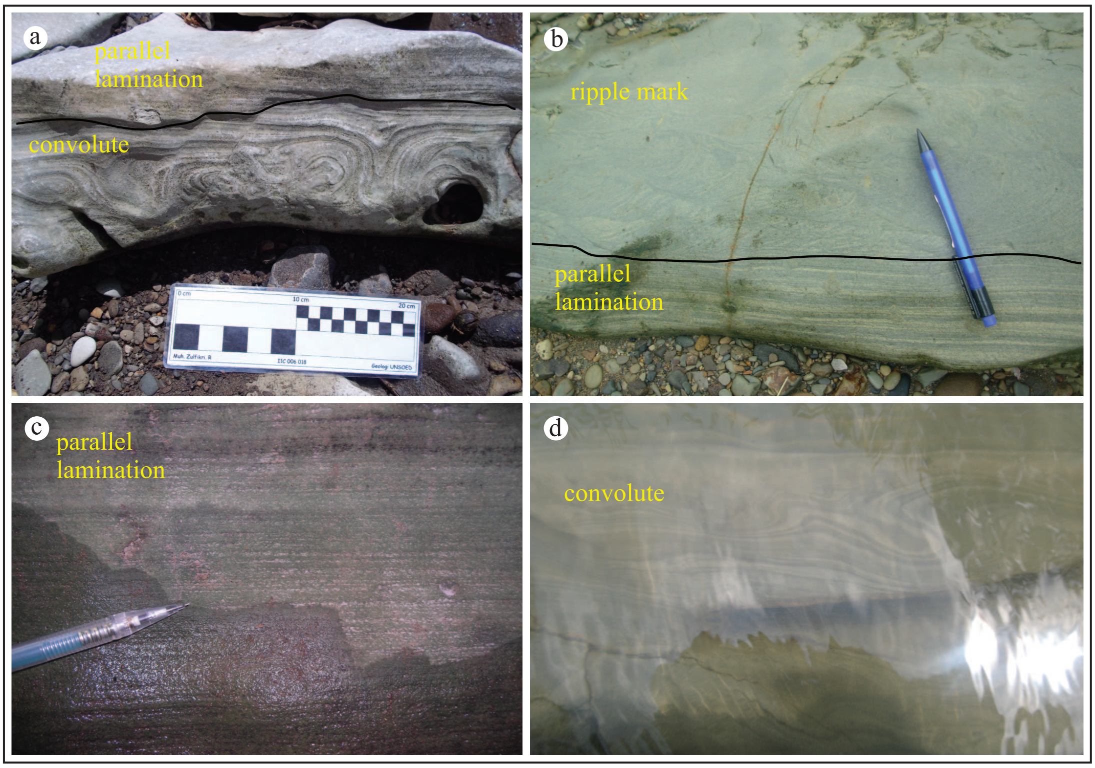

Figure 5. Typical of sedimentary structures occurring in classical turbidite. a. Parallel and convolute lamination; b. Ripple mark and parallel lamination; c. Parallel lamination; d. Convolute.

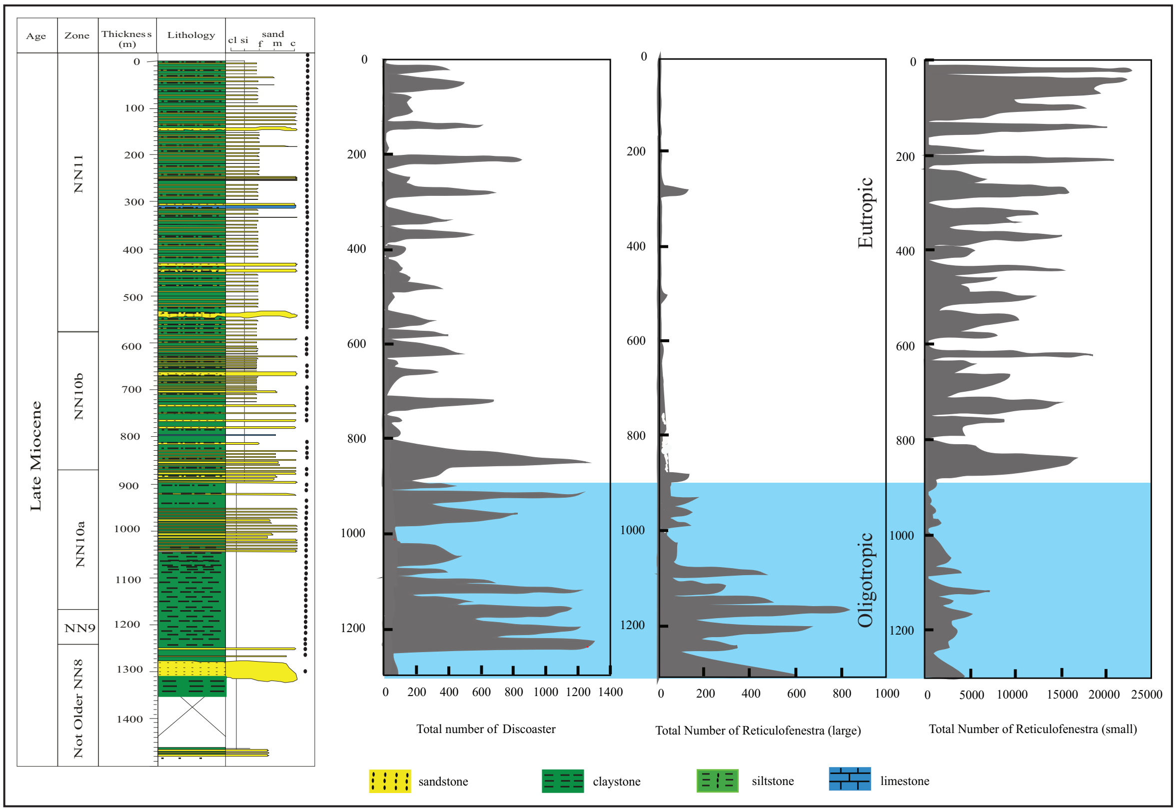

Figure 6. Comparison between relative abundance of *Discoaster* and coccolith size variation of *Reticulofenestra* in Kali Pasir section.

ures 2 and 6) Additional studies (Johnson, 2009; Le Houedec *et al*., 2012), based on pollen and neodymium (Nd) isotope records in the nearest location of this section, interpret a large decrease of rainforest cover in Australia, thus enhanced a continental erosion during the period of Late Miocene. Therefore, the records based on small *Reticulofenestra* (Figures 2 and 6) and other proxies based on pollen and neodymium (Nd) isotope records (Johnson, 2009; Le Houedec *et al.,* 2012) support a local factor of large precipitation that could transport nutrient level from an adjacent island of the Eastern Indian Ocean.

Discussion

Relationship between Relative Abundance of *Discoaster* and Size Variation of *Reticulofenestra*

A high abundance of *Discoaster* and large *Reticulofenestra* is clearly identified (Figure 6) in the early stage of the Late Miocene. This condition supports a previous theory (*i.e.* Flores *et al*., 1995; Sato and Chiyonobu, 2009; Imai *et al*., 2015) that a combination of high abundance of *Discoaster* and large *Reticulofenestra* has a positive correlation in Kali Pasir section (Figure 6), which is both *Discoaster* and the large size of *Reticulofenestra* would increase in the same condition due to thermocline and nutricline deepening, known as oligotrophic condition at the sea surface. These characteristics can be considered as a low nutrient content in this site. The environmental situation started changing from the base of NN10b. This period at the later stage of the Late Miocene is marked by a low abundance of *Discoaster* and high abundance of small *Reticulofenestra,* which indicates the rise of thermocline and nutricline to the sea surface; known as eutrophic condition at the sea surface. This condition is interpreted as indicative of a higher nutrient content during the early stage of Late Miocene (NN8-NN10a) compared to preceding interval during the later stage of Late Miocene (NN10b-NN11) by changing oligotrophic with low nutrient content into eutrophic with high nutrient content in this section.

Changes of *Reticulofenestra* sizes abruptly decrease during the Late Miocene succession (Figure 6), corresponds to a similar decrease of *Reticulofenestra* sizes which was identified in the Indian Ocean (Young, 1990; Imai *et al.,* 2015) *i.e.* especially at NN10 interval. An abrupt decrease of *Reticulofenestra* sizes indicates the sea surface changed suddenly to exhibit a strong eutrophic condition after 8.8 Ma in the eastern Indian Ocean (Imai *et al*., 2015). The sea surface condition in Kali Pasir section confirms the previous study (Young, 1990; Imai *et al*., 2015) on the environmental change controls in the eastern Indian Ocean. Thus, the result convinces that variability in *Reticulofenestra* size during the Late Miocene in the Indian Ocean, especially Banyumas, Central Java, (this study) reflects the effect of environmental change such as nutrient in the eastern Indian Ocean (Young, 1990; Imai *et al*., 2015).

Late Miocene Paleoceanography in the South Java Sea

The abundance of *Discoaster* and the total number of small/large *Reticulofenestra* is used to reconstruct paleoceanographic condition in Banyumas, Central Java, during the Late Miocene. The evidence of oligotrophic condition during the early stages of Late Miocene (Figure 6) and the rest of eutrophic condition at the later stages of Late Miocene in this section supports the result of ODP hole 762B in the northern part of Australia from Imai *et al*. (2015). The onset of the Indian monsoon that was estimated approximately at 9-8 Ma (Zhisheng *et al*., 2001; Zheng *et al*., 2004) may strongly influence eutropication in the eastern Indian Ocean region after nannofossil biohorizon based- NN10b (this study). Thus, the Indian monsoon could maintain runoff in the Indian Ocean which triggers the influx of nutrient-rich terrestrial material. The only reason for intensification of nutrient-rich material is the existence of sand material in classical turbidite at Kali Pasir section. This sand material might be transported by a process of increase of Asian monsoon during 8 Ma (Filippelli, 1997). During Late Miocene, mainland Java was still part of large Sundaland (Hall, 1998; 2002). Climate system of Sundaland should be one system of Asian monsoon in this region. Therefore, the intensification of Asian monsoon during 8 Ma (Filippelli, 1997) induced classical turbidite formation in Kali Pasir section and increased nutrient content at this section.

Previous study (Imai *et al.*, 2015) suggests that a strong eutrophication during the later stage of Late Miocene was affected by coastal upwelling or nutrient-rich terrestrial. This condition has maintained strong Indian monsoon, which triggers Java runoff. However, evidence of classical turbidite related to eutrophic condition in this Kali Pasir section probably demonstrates that mainland Java influx have been transported into the ocean by current transport and deposited as a classical turbidite product. Mechanism of classical turbidite formation is not only caused by slump-initiated turbidity current (Piper and Normark, 2009), but also other mechanisms such as hyperpycnal river flow and suspension of sediment by oceanographic processes (Mulder and Syvitski, 1995; Piper and Normark, 2009) could influence classical turbidite formation. Another mechanism such as hyperpycnal river flow is supposed to have maintained terrestrial runoff in this classical turbidite. However, this hyperpycnal river flow (Piper and Normark, 2009) still needs to be explored any further. This hyperpycnal flow is the only way how nutrient-rich material associate with classical turbidite formation. In this study, it is shown that the influx of nutrient-rich material based on the increase of species from small *Reticulofenestra* and the decrease of *Discoaster* (Figure 6) after NN10a is characterized by the intensification of classical turbidite during this period (Figures 2). This material contains mixed sand and clay which infer to explain how the Indian monsoon has triggers runoff from Java Island. Therefore, the record assumes that runoff-derived the onset of Indian monsoon has triggered eutrophic condition during the later stages of Late Miocene in this section. The evidence of eutrophic condition in this section is shown by the high number of *Reticulonestra minuta* (Figure 2) as small *Reticulofenstra* sizes at the later stages of Late Miocene and decreases other species significantly such as *Sphenolithus compactus, Reticulofenestra pseudoumbilica,* and *Discoaster brouweri* (Figures 2) during this period. Before a high nutrient content in eutrophic condition, oligotrophic situation occurred in the early stage of Late Miocene. It associates with a higher large *Reticulofenestra* abundancy (Figure 6) and high diversity of nannofossil species compared to previous eutrophic condition in Kali Pasir section. A Higher diversity of nannofossil during early stage of Late Miocene due to nannofossil habitat is depending on three sea surface conditions of position of thermocline, nutricline, and sun penetration depth in tropical regions during oligotrophic (Jordan and Chamberlain, 1997). Other study (Bauman *et al.,* 2004) about diversity rate in oligotrophic situation confirms that the high diversity of nannoplankton occurred in the southern South America, and off the western coast of central Africa seems to be well adapted to low nutrient condition during oligotrophic.

CONCLUSION

There is a good relationship between the total numbers of *Discoaster,* variation of *Reticulofenestra* sizes, and lithofacies characteristics during the Late Miocene. The abundance of *Discoaster* and large *Reticulofenestra* suggest a deep thermocline and nutricline, a typical of oligotrophic conditions. These oligotrophic conditions associate with the muddy facies in the early stages of Late Miocene. Conversely, a decrease of *Discoaster* and abundant of small *Reticulofenestra* indicates a shallow thermocline and nutricline, resulting strong eutrophication of surface waters in the later stage of Late Miocene. A high nutrient content in this stage also relates to classical turbidite deposits. A change in sea surface resulted in strong eutrophication in this section similar to records from the eastern Indian Ocean occurred in NN10. Mechanism of strong eutrophication in Kali Pasir section is controlled by the onset of Indian monsoon system, and a high rainfall intensity would drive strong river runoff based on classical turbidite evidence, which transport nutrient content to this Kali Pasir section. Strong eutrophication in this Kali Pasir section is probably driven by nutrient-rich terrestrial material related to climate-induced increases in terrestrial input of nutrients to the oceans.

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