The Mid Miocene Climatic Optimum (MMCO) Indication at Low Latitude Sediment

Case Study: The Miocene Cibulakan Formation, Bogor Basin

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Abstract

Global climatic event on Middle Miocene triggered by geology activity is called by Mid- Miocene Climatic Optimum (MMCO). This event was widely distributed and associated with increasing temperature and CO_2 content in the atmosphere. The effect of MMCO was widely known the mid-latitude region, but still limited information in low latitude sediments. This study try to perform the effect of MMCO at Cibulakan Formation in which deposited in the low latitude basin, Bogor Basin.

Fifty eights samples from Cileungsi River were taken at Cibulakan Formation and quantitative nannoplankton analysis was carried out for this study. Nannoplankton shows the sensitive response with sea surface temperature changes. Increasing of total population nannoplankton indicates the rising of temperature and dropping temperature is marked by decreasing population. The effect of sea surface temperature changes relates with salinity changes as the effect of evaporation. *Helicosphaera carteri* and *Umbilicosphaera jafari* were counted to know the salinity trend at Cibulakan Formation.

Sea surfaces temperature changes was observed on Early Miocene which was influenced by small scale Early Miocene glaciation and active tectonic during this period. Warming temperature taken place on Middle Miocene as the effect of warm and open sea during Mid Miocene Climatic Optimum. Afterwards, hot temperature continued on Late Miocene triggered by global increasing temperature at Pacific Ocean and widely distribution of clean water at North West Java Basin.

Key words: Mid Miocene Climatic Optimum (MMCO), nannoplankton, temperature changes. Cibulakan Formation

Introduction

Global climatic event during Middle Miocene showed increasing of global temperature called by Mid-Miocene Climatic Optimum (MMCO) [1]; [2]. Increasing of temperature in MMCO period related with geology activity which followed by increasing of CO_2 content in the atmosphere. The impact of Mid Miocene Climatic Optimum was widely distributed and associated by 6^0C temperature warming in the mid-latitude region [3]. Moreover, Antarctic vegetation in the MMCO reported that average temperature during summer period showed 11^0C warmer than today and annual sea surface temperature ranging between 11.5^0C.

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The increasing of temperature during MMCO performs the relationship with the changing of nannoplankton population. Nannoplankton shows the sensitivity response with the increasing of temperature. It can be performed by the number of species diversity and population of nannoplankton significantly increased in MMCO period, when the surface temperature rose from 5^0C to 8^0C [4]. Not only increasing of nannoplankton population, but also MMCO evidence made the coccolithophores evolved rapidly and several species showed high diversification [4].

Limited information of MMCO evidence in the tropic evidence is a major challenge to solve. Limitation of geochemical data and quantitative microfossil microfossil analysis in continue section of Middle Miocene Sediments caused the impact of MMCO in equator area, especially in Indonesia is not solving. This study aim to know the impact of MMCO with in Early - Middle Miocene Cibulakan Formation by nannoplankton population changes.

Geology Setting

The research area is situated in Cileungsi River, Bogor,West Java as a part of North West Java Basin [5] (Figure 1 A.). The research area is situated in Cileungsi River, Bogor, as a part of North West Java Basin [5] (Figure 1A.). This basin was formed by the collision of the Eurasian Plate with the Indian Australian Plate during Late Cretaceous to Early Eocene [5];[6]; [7];[8]. On Early – Late Miocene, Cibulakan Formation was deposited in Bogor Basin in back arc setting [5] (Figure 1B). The back arc setting is a place with stable environment and the high sediment supplies from continental crust that triggers the domination of siliciclastic sediment. Depositional environment changes in the back arc setting is controlled by sea level changes both regional and eustasy. Drowning phase during this age resulted deepening upward sequence and revealed the transition – shallow marine environment.

On Early – Late Miocene, Cibulakan Formation was deposited infill of Bogor Basin in a back arc setting [5](Figure 1B). Generally, Cibulakan Formation is represented by interbedded of claystone and sandstone, and minor limestone as intercalation [9]; [10]. This formation has conformity contact with Parigi Formation in the upper part, and unconformity contact with Jatibarang Formation in the lower part [5]. Moreover, Cibulakan Formation has interfingering contact with deep water Jatiluhur Formation [11].

Transgressive phase was taken place during Cibulakan Formation deposition. Sea level rise during Early Miocene drowned the Jatibarang Formation and changed the environment from terrestrial and volcanic deposit to transition deposit [9]. At the bottom part, The Cibulakan Formation was deposited in paralic environment and near with active delta progradation [12]. Trangressive phase continued into middle part of Cibulakan Formation and showed gradually changes of paralic environment to shallow clean water

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environment. At the upper part, offshore bar sediments occupied which was characterized by claystone to bioturbated silty claystone and closed by calcarenite limestone [11].

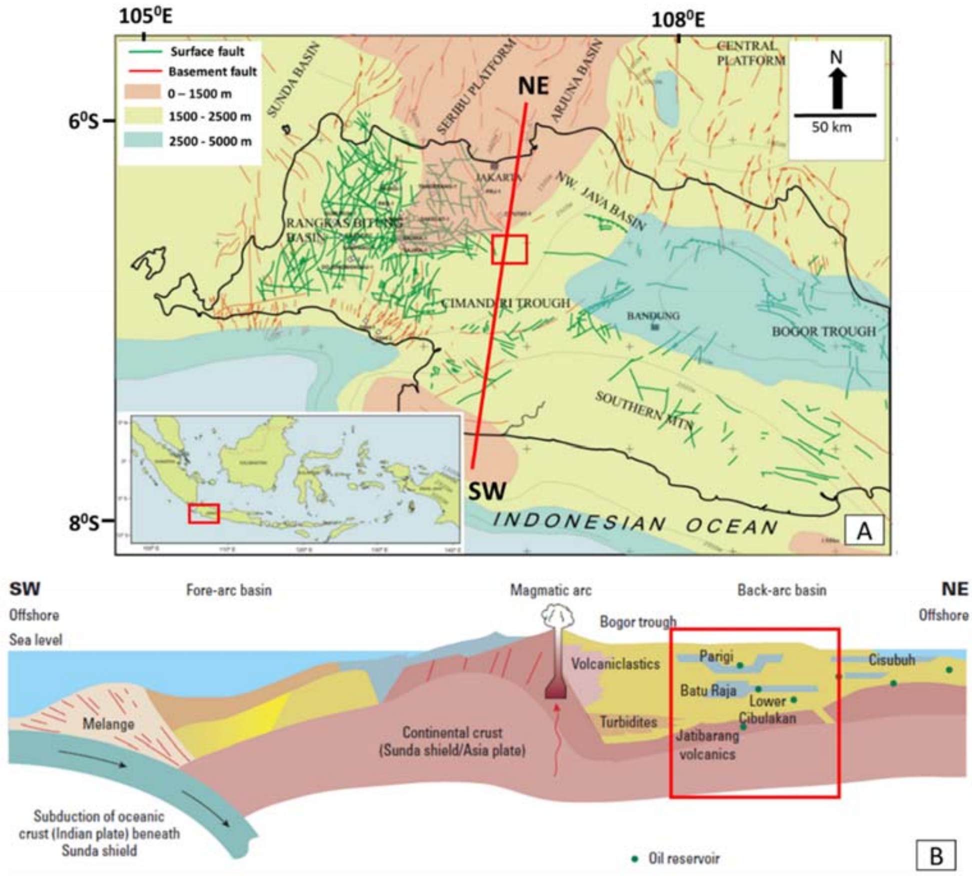

Figure 1. (A). Structure map of West Java (Modified from [5]). The research area (red box) occupy Bogor Through. (B) Schematic cross section of West Java SW – NE (Modified from [7]). Cibulakan Formation infill back-arc basin setting in Bogor Through (red box)

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Method

Measuring section and samples collecting were performed during fieldwork in the Cileungsi River, Bogor, West Java. The outcrop condition is continue, represent the sedimentology dynamic, and cover the short term of nannoplankton ecological changes. Five kilometers traverse was described to know the vertical succession of sediment profile (Figure 2). Sampling was focused on the claystone and limestone of Cibulakan Formation and total samples were fifty eight samples.

Preparation was employed by quick smear slides method [13]. Samples were crushed and the powder smeared in the cover glass. After that, the powders were draped by canada balsam and covered by cover glass. To keep the original composition of sediment, no material was added during preparation. For the observation, quantitative methods were examined which has been accomplished by the commonly-used Field of View (FOV) method [13]. Nannoplankton observation was performed in Micropaleontology Laboratory, Department of Geology, Institut Teknologi Bandung using polarization microscope Nikon Alphashot YS2-H.

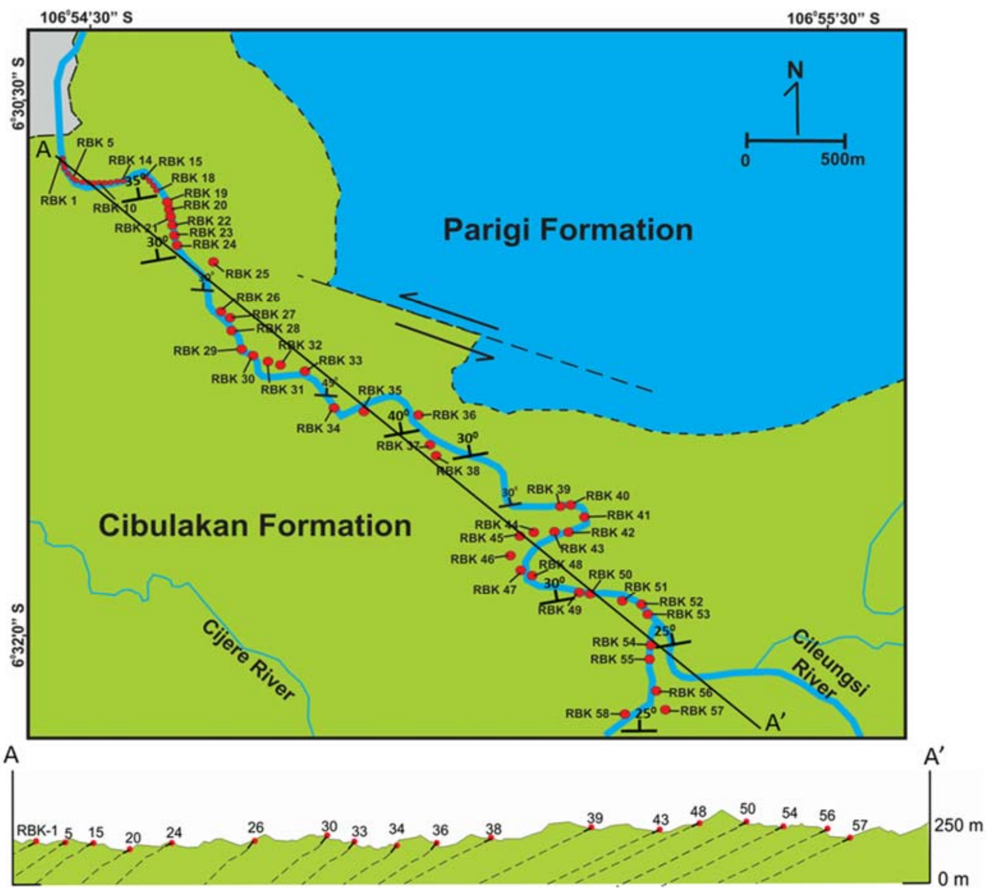

Figure 2. Geology map (top) and geology cross section (bottom) of the Cileungsi River (Modified from [14]). The red dot represents the sample location.

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Result and Discussion

Overall, Cibulakan Formation in the research area was indicated formed in the offshore environment. The indication can be observed by thick offshore shale deposit and capped by bioclastic limestone. The vertical section showed Cibulakan Formation, from bottom to top, can be divided into three sequence which bordered by bioclastic limestone, from bottom to top namely by Sequence I, Sequence II, and Sequence III. Sequence I is characterized by 350 meters thickness of claystone followed by 500 interlamination of thin sandstone and claystone, and wackestone to packestone limestone at the top of sequence (Figure 3). Limestone has many biota fragments, consist coral and foraminifera, which indicates as transgressive carbonates at the offshore.

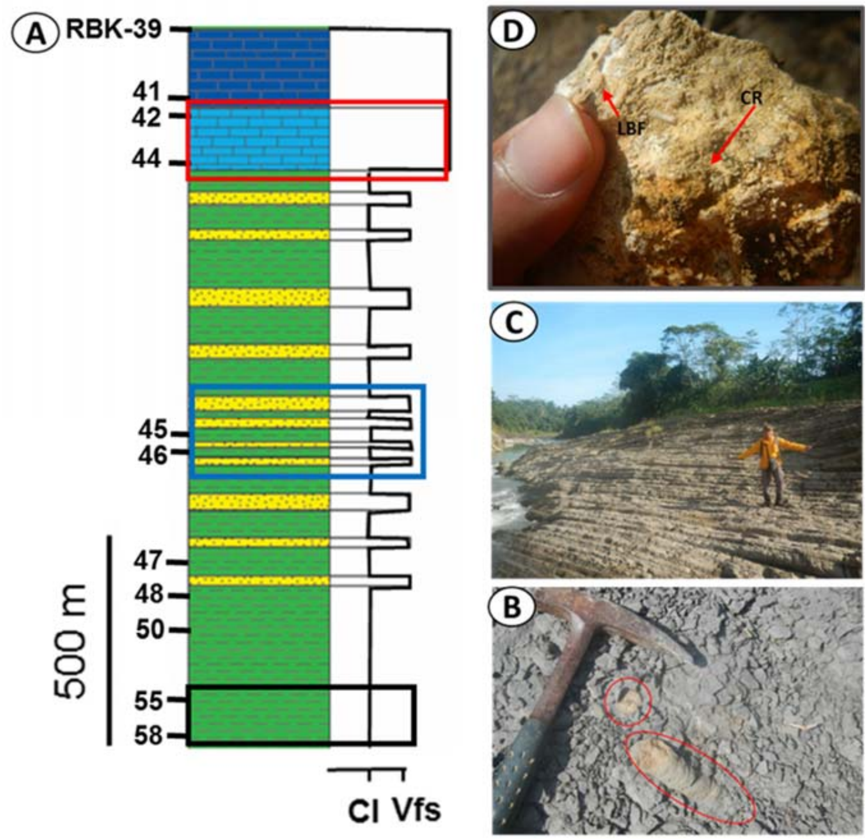

Figure 3. Sequence I at Cibulakan Formation; (A) Section of Sequence I at Cibulakan Formation in the research area. (B) Claystone at the bottom of Sequence I with *Cruziana* sp. ichnofossil (location of photograph is bordered by black box at sedimentation profile). (C) Interbedded sandstone and claystone at the middle of Sequence I (location of photograph is bordered by blue box at sedimentation profile). (D). Limestone at the top of Sequence I with coral (CR) and large benthic foraminifera (LBF) fragments (location of photograph is bordered by red box at sedimentation profile).

Sequence II started by 1250 m interbedded of claystone and sandstone at the bottom, and closed 3000 m by interbedded of thick limestone and claystone. Biota fragment at the limestone in Sequence II is more intensive than limestone in Sequence I (Figure 4). The different character with Sequence I, intensive limestone at Sequence II, is interpreted as the product of sea level rise, which is marked by intensive limestone as the cap of clastic sediment. Sequence III shows interbedded of claystone and sandstone as the representation of regressive sediment (Figure 5).

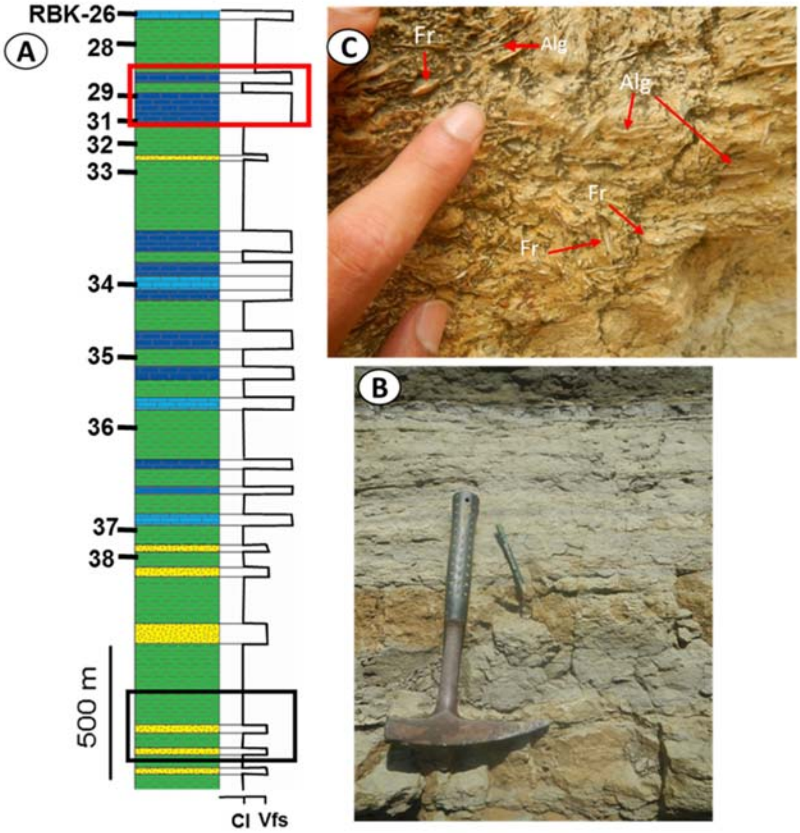

Figure 4. Sequence II at Cibulakan Formation; (A) Section of Sequence II at Cibulakan Formation in the research area. (B) Interbedded sandstone and claystone at the middle of Sequence I (location of photograph is bordered by black box at sedimentation profile). (C). Limestone at the top of Sequence II with intensive encrusting algae (Alg) and large benthic foraminifera (Fr) fragments (location of photograph is bordered by red box at sedimentation profile).

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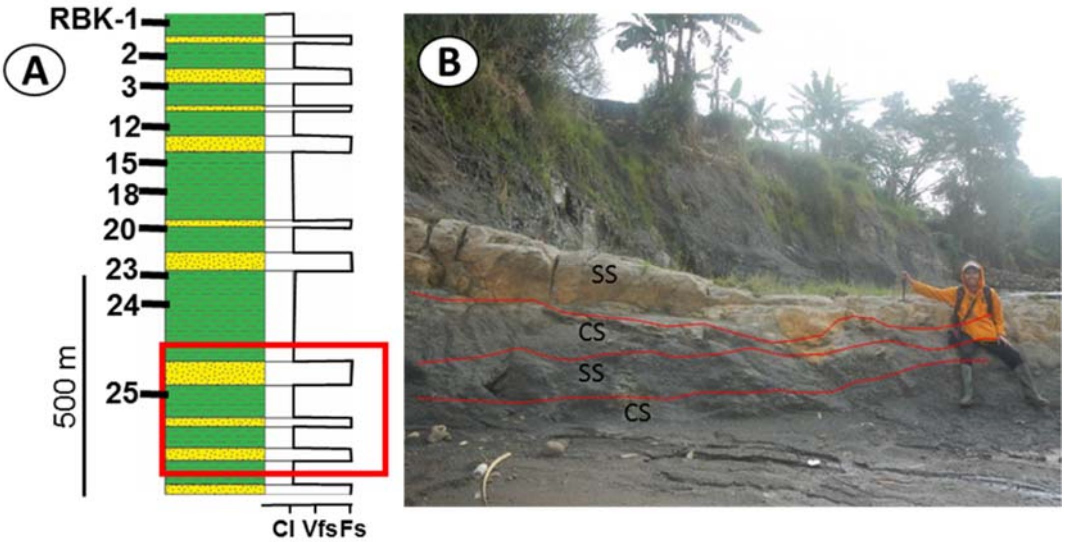

Figure 5. Sequence III at Cibulakan Formation; (A) Section of Sequence III at Cibulakan Formation in the research area. (B) Interbedded sandstone (SS) and claystone (CS) at Sequence III (location of photograph is bordered by red box at sedimentation profile).

Samples RBK 39 to RBK – 58 were taken in Sequence I, with higher resolution sampling was conducted at the top of sequence, bioclastic limestone, with 5 meters spacing. Twelve samples (RBK – 26 to RBK – 38) were collected from Sequence II. The other twenty five samples (RBK 25 – RBK – 1) were conducted in Sequence III, where high resolution sampling was carried out at the top of Sequence III, interbedded calystone and sandstone, with 1.5 meters spacing.

Cibulakan Formation in the research area was deposited during Early – Late Miocene, based on nannoplankton biozones by Martini [15]. Nannoplankton biozones of Cibulakan Formation yielded many calcareous nannoplankton event, which were clearly observed. First Appearance Datum (FAD) and Last Appearance Datum (LAD) from nannoplankton fossil can be used to divide biostratigraphy event which correlates with age and stratigraphy succession. Several nannoplankton species which act as index fossils consist of *Sphenolithus belemnos, Helicosphaera vederii, Sphenolithus heteromorphus, Discoaster challengeri, Catinaster coalithus,* and *Discoaster neohamatus* (Figure 6).

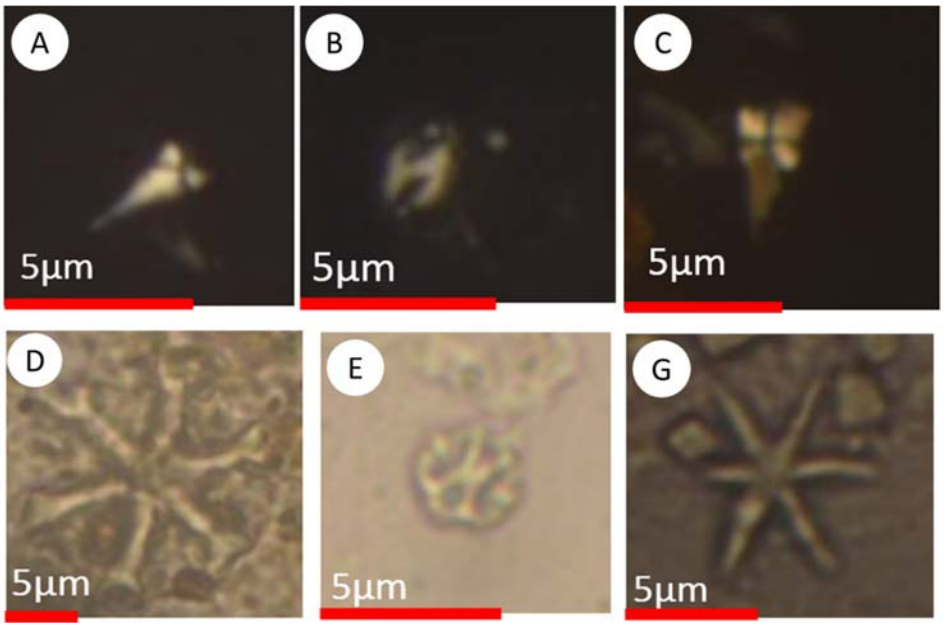

Figure 6. Index fossils of biostratigraphy zone; (A) *Spenolithus belemnos*, (B*) Helicosphaera vederii*, (C) *Spenolithus heteromorphus*, (D) *Discoaster challengeri,* (E) *Catinaster coalithus,* (F) *Discoaster neohamatus*.

There are the biostratigraphy zone in Cibulakan Formation (Figure 7):

Sphenolithus belemnos zone

This zone is bordered by LAD (Last Appearance Datum) of *Sphenolithus belemnos*, in which the samples were taken in the RBK – 58 to RBK – 45 at claystone lithology. *Sphenolithus belemnos* zone equal with NN-3 [15] and relates with Early Miocene, around 17.95 mya or older [16].

Sphenolithus belemnos – Helicosphaera vederii zone

Partial zone is marked by interval from extinction of *Sphenolithus belemnos* and FAD (First Appearance Datum) of *Helicosphaera vederii*. This zone can be observed from RBK – 44 to RBK 42 and equal with NN – 4 [15], border of Early Miocene and Middle Miocene, around 14.91 mya [16] .

Helicosphaera vederii - *Sphenolithus heteromorphus* zone

Concurrent zone is bordered by FAD (First Appearance Datum) of *Helicosphaera vederii* and extinction of *Sphenolithus heteromorphus.* This zone occupy from RBK – 41 to RBK - 39 which is equal with NN – 5 [15], Middle Miocene around 13.53 mya [16].

Sphenolithus heteromorphus - *Discoaster challengeri* zone

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Partial zone is bordered by extinction of *Sphenolithus heteromorphus* and FAD (First Appearance Datum) of *Discoaster challengeri.* This zone can be observed from RBK – 38 to RBK - 23, equal with NN -6 [15], Middle Miocene around 13.27 mya [16]. Moreover, LAD (Last Appearance Datum) of *Sphenolithus heteromorphus*, *Discoaster brouweri* has the first appearance in this zone.

Discoaster challengeri - *Catinaster coalithus* zone

This zone is marked by interval from e FAD (First Appearance Datum) of *Discoaster challengeri* and FAD (First Appearance Datum) of *Catinaster coalithus.* This zone occupy from RBK – 23 to RBK - 16 which is equal with NN – 7 [15], Middle Miocene around 10.89 mya [16]

Catinaster coalithus - *Discoaster neohamatus* zone

This zone is bordered by FAD (First Appearance Datum) of *Catinaster coalithus* and FAD (First Appearance Datum) of *Discoaster neohamatus.* This zone can be observed from RBK – 15 to RBK - 13, equal with NN -8 [15] which is border of Middle Miocene and Late Miocene around 10.55 mya [16].

Discoaster neohamatus zone

This zone is marked by FAD (First Appearance Datum) of *Discoaster neohamatus* and the extinction of *Spenolithus moriformis*. This zone can be observed from RBK – 12 to RBK – 1, which is equal with NN - 9 [15], Late Miocene age, younger than 10.55 mya [16].

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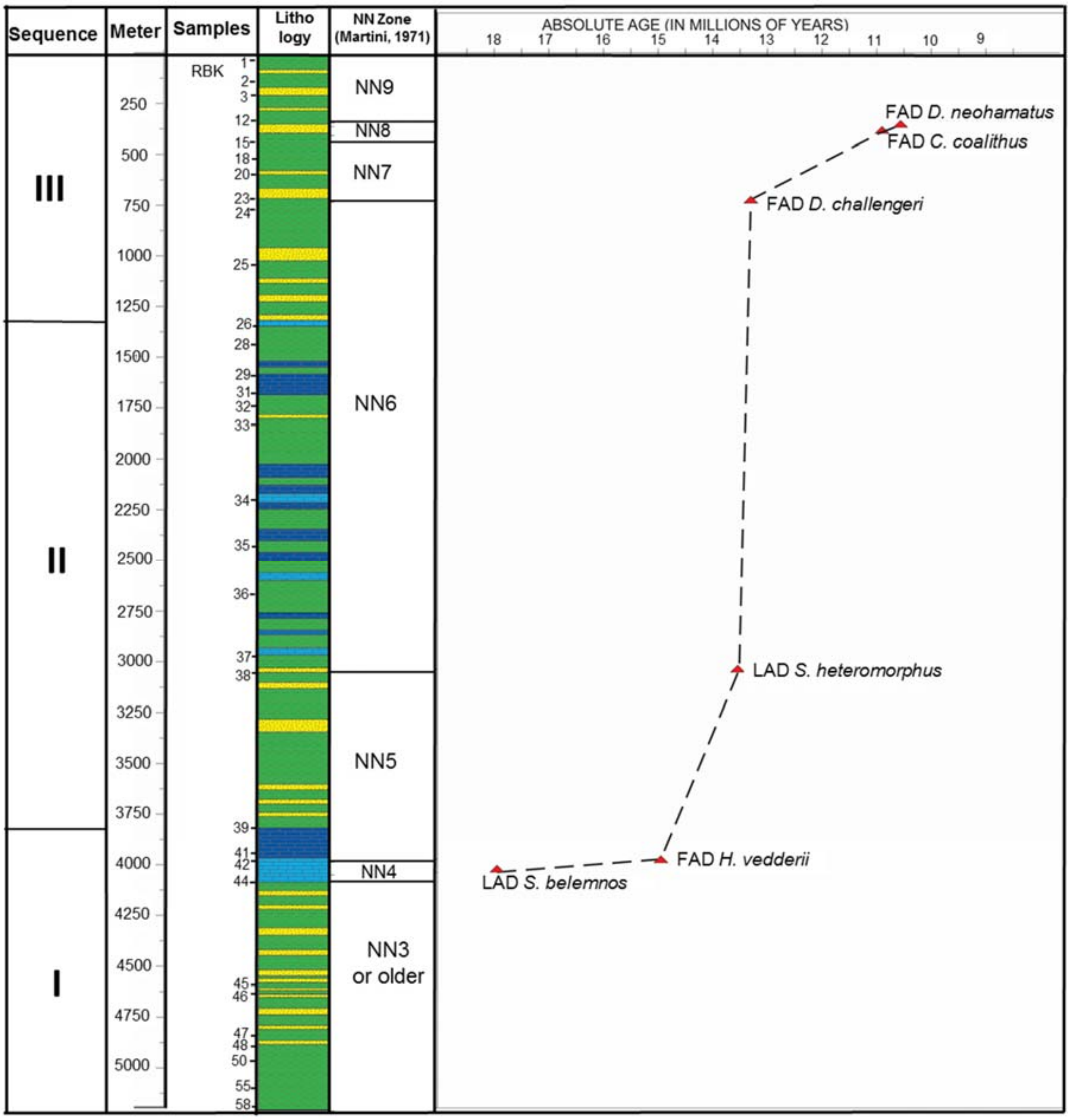

Figure 7. Biostratigraphy zone of Cibulakan Formation in the Cileungsi River.

As sea surface temperatures and paleosalinity indicator, nannoplankton fluctuation was adopted to know the dynamic of environment changes. The total of nannoplankton was carried out as sea surface temperature where rising temperature is followed by blooming nannoplankton and dropping temperature is marked by decreasing population. Another parameter which is revealed besides sea surface temperature is salinity. Temperature has close relationship with salinity condition due to high temperature associated by high salinity or hypersaline condition. On the contrary, low temperature related with low salinity or hyposaline environment. Salinity change is observed by comparison between *Helicosphaera carteri* and

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Umbilicosphaera jafari. *Helicosphaera carteri* has description ellipsoid coccolith, flange end in wings, two narrow pores in central area (Figure 8A and 8B). Increasing population of *Helicoshapera carteri* represents low salinity and brackish environment [17]; [18]. The similar result is revealed by Santoso et al. [19], which analyzed the population of *Helicosphaera carteri* on Late Miocene – Pliocene Sediments in North East Java Basin, Indonesia, and this species increases in low salinity condition. *Umblicosphaera jafari* represents high salinity environment (>35 ppt) [17]. *Umbilicosphaera jafari* is marked by small circular species of coccolith, narrow central-area, and wide distal shield with complex suture (Figure 8C and 8D).

Figure 8. Salinity indicator.

A and B. *Helicosphaera carteri*. Photograph A in parallel nicol and Photograph B in cross nicol.

C and D. *Umbilicospahera jafari*. Photograph C in parallel nicol and Photograph D in cross nicol.

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As the result, sea surface temperature changes had been occurred from Early to Late Miocene at Cibulakan Formation. Fluctuation of temperature in cooling phase was observed on Early Miocene showed the minimum number of nannoplankton, as result of cooling phase on Early Miocene. Subsequently, sea surface temperatures became warming and followed by rising number of nannoplankton and continued into Middle Miocene. Maximum temperature was founded on Late Miocene which indicated by nannoplankton blooming (Figure 9).

On Early Miocene (NN3 or older zone), fluctuation nannoplankton population was observed as the effect of rapid environment changes. Fluctuation environment had happened due to fluctuation temperature on Early Miocene. The temperature fluctuation correlates with active tectonic related with volcanic sediment in North West Java Basin [20] and global cooling and climatic transition events on Early Miocene [21]. Locally at North West Java Basin, new subduction trend formed at Southern Java, south of North West Java Basin [6]; [20], which deposited volcanic debris Jatiluhur Formation which interfingering with Early Miocene Cibulakan Formation [11]. That volcanic sediment on Early Miocene emerged productivity of nannoplanton and made the fluctuation of nannoplankton fluctuation during Early Miocene. Moreover, temperature decreased $\pm$ 2^0C which observed from drilling project Site 747, Indian Ocean. This event as a result of small scale Early Miocene Glaciation and it was confirmed by increasing of ^{18}O isotope value of foraminifera by Billup and Schrag [21]. Based on global δ^{18}O curve, the value of δ^{18}O showed fluctuation trend which ranging 1.8 – 2 ‰ (Figure 9).

Increasing population of nannoplankton was happened during Middle Miocene period (NN4 – NN7). Global event of Mid Miocene Climate Optimum influenced population and diversification of nannoplankton. Increasing temperature, rising sea level, was suitable environment for nannoplanton growth, which supplied the comfort temperature of nannoplankton's existence [4]. Blooming nannoplankton in this period implies the shallow and open sea environment and warm sea [18]. Moreover, the diminution of volcanic activity on Middle Miocene [20] developed widely distribution of clean water and carbonate build up which provided the stable environment by nannoplankton ecology. Increasing of nannoplankton abundance fit with δ^{18}O trend by Zachos et al. [22] (Figure 10). On NN4 – NN7, the peak of nannoplankton abundance was followed by lowest value of global δ^{18}O curve, which ranging 1.4 – 1.7 ‰. This fact shows that the abundance of nannoplankton on Middle Miocene was controlled by Mid Miocene Climatic Optimum which influences of rising of temperature.

On Late Miocene (NN8 – NN9), blooming nannoplankton continued and reached the peak of population. Increasing temperature around 4^0C at Pacific Ocean [23] triggered the increasing population of nannoplankton. Hence, warm and shallow marine at North West Java Basin [20]; [24] supported suitable

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local influence for nannoplankton growth during this period. This local event can be observed by development of Late Miocene Carbonate of Parigi Formation during this period.

As the effect of sea surface temperature changes, salinity changes have been detected during deposition of Cibulakan Formation (Figure 9). High salinities are affected by hot sea surface temperatures which caused high evaporation. Otherwise, low salinities are performed as the effect of low evaporation and decreasing of sea surface temperature.

On the Early Miocene (NN3 or older zone), salinity changes rapidly fluctuated and showed unstable environment. *Helicosphaera carteri* dominates two starting samples which taken at the base of Early Miocene. It shows that depositional of Cibulakan Formation started with lower salinity environment. However, the environment changed to high salinity environment, where *Umbilicosphaera jafari* population increases at the younger samples on middle of Early Miocene. Salinity became decrease at the intebedded sandstone and claystone on the top of Early Miocene. It was marked by *Helicosphaera carteri* is more dominant than *Umbilicosphaera jafari*. Salinity fluctuation on Early Miocene triggered by fluctuation of temperature on Early Miocene.

On Middle Miocene (NN4 – NN7), stable environment can be observed during deposition of Cibulakan Formation. High salinity marine condition was reflected by the domination *Umbilicosphaera jafari*, and showed higher population than *Helicosphaera carteri*. Warming event as the effect of Mid Miocene Carbonate Optimum (MMCO) related with increasing evaporation on this age and the salinity changes became high salinity condition

The suitable and stable environment continued to Late Miocene (NN8 – NN9). High salinity condition performed and was marked by *Umbilicosphaera jafari* had bloom condition, but *Helicosphaera carteri* drastically decreased. Blooming condition of *Umbilicosphaera jafari* was controlled by high salinity condition, shallow environment, restricted area, and near shore environment during this age [17].

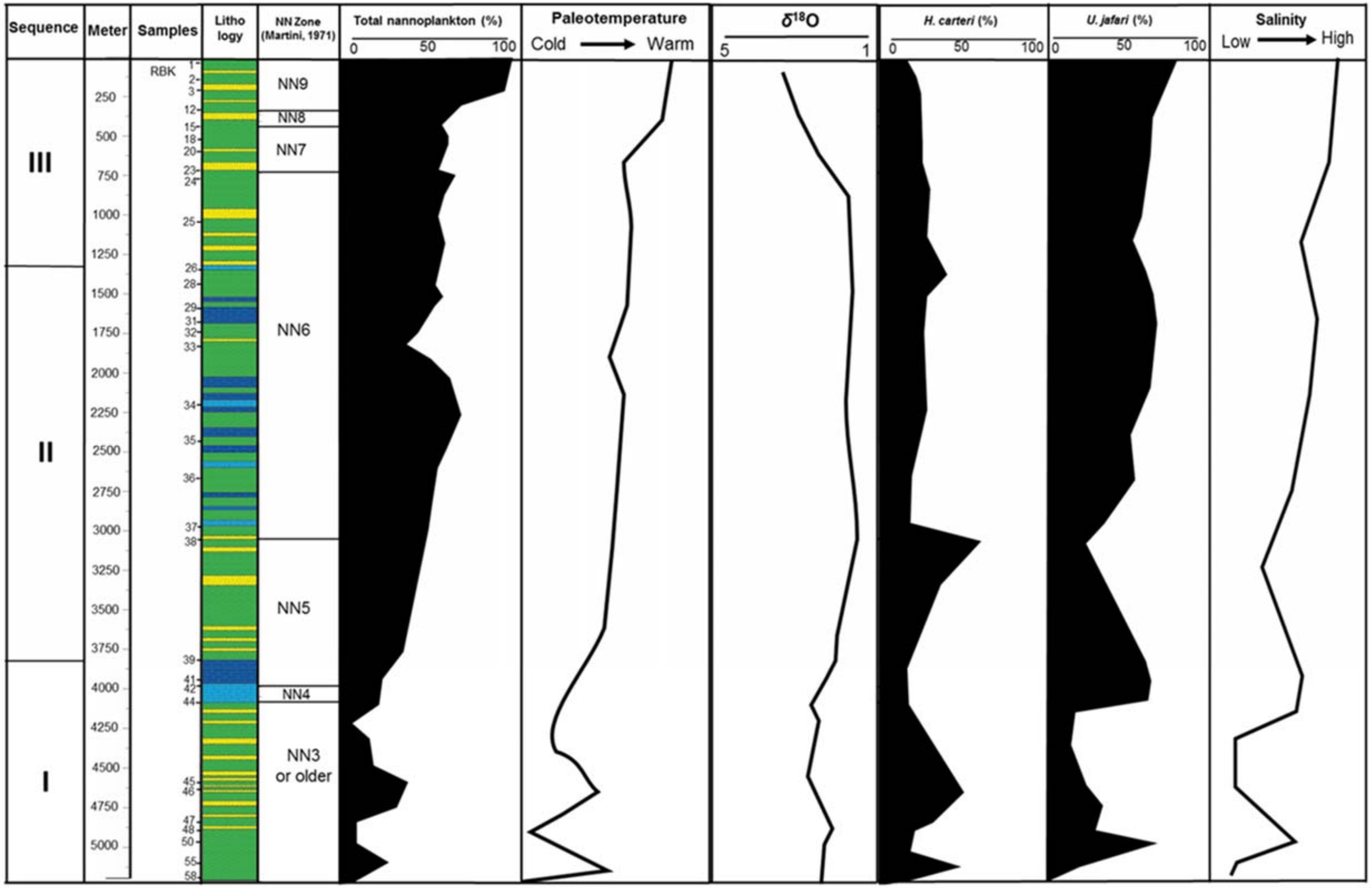

Figure 9. The interpretation of paleotemperaturen and salinity of Cibulakan Formation. The reference of ^{18}O was cited from Zachos et al. (2011) curve.

Conclusion

Nannoplankton population changes can be indicated several paleoecology changes, where blooming nannoplankton in the Cibulakan Formation related with global event of Mid Miocene Climatic Optimum. Mid Miocene Climatic Optimum triggered increasing population of nannoplankton on Middle Miocene and the effect was continue into Late Miocene. Based on all of data and analysis, following conclusion can be drawn:

- Biostratigraphy zone of Cibulakan Formation can be divided into seven zone, namely: *Sphenolithus belemnos* zone, *Sphenolithus belemnos – Helicosphaera vederii* zone, *Helicosphaera vederii* - *Sphenolithus heteromorphus* zone, *Sphenolithus heteromorphus* - *Discoaster challengeri* zone, *Discoaster challengeri* - *Catinaster coalithus* zone, *Catinaster coalithus* - *Discoaster neohamatus* zone, *Discoaster neohamatus* zone.
- Fluctuation of temperatures and environment was observed on Early Miocene which is characterized by fluctuative nannoplankton population. This event was influenced by small scale Early Miocene glaciation and active tectonic during this period. Population of nannoplankton increased on Middle Miocene as the effect of warm and open sea during Mid Miocene Climatic Optimum. Hence, the optimum population on Late Miocene drawn the suitable environment triggered by global increasing temperature at Pacific Ocean and widely distribution of clean water at North West Java Basin.
- Salinity changes can be detected at Cibulakan Formation deposition. On the Early Miocene, salinity changes rapidly fluctuated and showed unstable environment. On Middle Miocene, stable environment can be observed as the effect of increasing temperature which triggered high evaporation on this age. The high salinity condition was continue to Late Miocene and reached the maximum salinity.

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