Pliocene-Pleistocene Calcareous Nannoplankton Biostratigraphy, Section Banyuurip, Rembang Zone, East Java Basin, Indonesia

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***Abstract*—The present study was carried out at the Banyuurip area in the East Java Basin, Indonesia, a site contains nannofossil assemblages of Pliocene to Pleistocene, with lithology is suitable for nannoplankton research. Methods used in this research include making a Stratigraphical section Measurement, collecting 41 samples and preparing the samples with the smear slides method to be observed using a polarizing microscope with 1000x magnification, and preparing several rock samples using SEM analysis. Analysis of nannofossil resulted in identifying 19 genus and 51 species. Biostratigraphic zone of this study can be arranged into 9 biostratigraphic zones. The zone order from older to younger are: a) *Sphenolithus neoabies* Zone /NN12/Late Miocene to Early Pliocene, b) *Ceratolithus rugosus* Zone /NN13/Early Pliocene, c) *Discoaster asymmetricus–Reticulofenestra pseudoumbulicus* Range Zone/NN14-NN15/Early Pliocene to Middle Pliocene, d) *Discoaster surculus* Zone/NN16/Middle Pliocene, e) *Discoaster pentaradiatus* Zone/NN17/Late Pliocene, f) *Discoaster brouweri* Zone/NN18/Late Pliocene, g) *Gephyrocapsa caribbeanica* Zone/NN19 Zone/Early Pleistocene, h) *Gephyrocapsa oceanica* Zone/NN20 Zone/Middle Pleistocene, and i) *Emiliania huxleyi* Zone/NN21 Zone/Late Pleistocene.**

***Index Terms*—nannofossil, biostratigraphy, Rembang zone**

I. Introduction

The research area is located in the Banyuurip area of Rembang Zone, East Java Basin Indonesia. North East (NE) Java Basin is composed of the Kendeng and Rembang Zones. These two zones are separated by Randublatung High. The Kendeng zone is an anticlinorium with a general east-west direction. The northern part of Kendeng Zone is bounded by the Randublatung Depression while to the south it is bordered by the Quaternary volcano range (Solo Zone). Kendeng Zone extends from Salatiga in the west to Mojokerto area in the East and drops below the alluvial of the Brantas River, and its continuation can still be followed up below the Madura Strait [1] "Fig. 1".

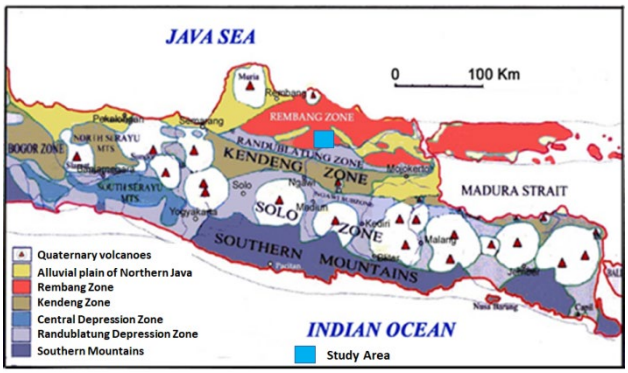

Figure 1. Physiography of East Java Basin [1].

The North East Java Basin was divided into seven tectonic units - physiographical exchanges from north to south as follows: 1) Alluvial Plain of North Java 2) Anticlinorium Rembang-Madura-Cepu 3) Randublatung Zone and Dander Hills, Pegat and Ngimbang, 4) Kendeng Zone, 5) Central Java Plain, 6) Volcanic Belt, 7) Southern Mountain Zone [1].

A. Pliocene to Pleistocene

The Pliocene-Plistocene was the most important moment in the geological history of Java. At this time, an orogenic process occurs causing the formation of mountains, folds, and faults in a relatively short time and covers a narrow area in the form of fold-thrust belt of Kendeng Mountain and the Rembang Anticlinorium, etc.

Pliocene: At this time the North East Java Basin experienced a transgression where the the limestone of

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Paciran Formation was deposited that was not aligned above the Tuban Formation. This formation is quite widespread and is dominated by limestone with shallow marine environment [2].

Pleistocene: A regression phase occurs with the deposition of Kabuh Formation (terrestrial environment) and unconformable with the above Paciran Formation [2]. In some places the Kabuh Formation was deposited in a transitional environment. At this time there was also an extreme climate change (glaciation), a drastic fall in the temperature of the earth which hit most of the world, including Indonesia and resulted in the formation of the configuration of the Indonesian archipelago as it is today [3].

B. Regional Stratigraphy of Rembang Zone

Based on lithological characteristics, rocks occurring in the study area can be grouped into a number of formal lithostratigraphic units, from older to younger, are: Wonocolo, Ledok, Mundu, and Lidah Formations (Fig. 2). These four formations are from the Late Miocene to Pleistocene [4]. This stratigraphy could be modified [5] regarding global climate change that happened during the glacial-interglacial Ice Age. Therefore this modification of the stratigraphy is possible as the object of the present study on determining the boundary of Tertiary-Quaternary using nanofossil data.

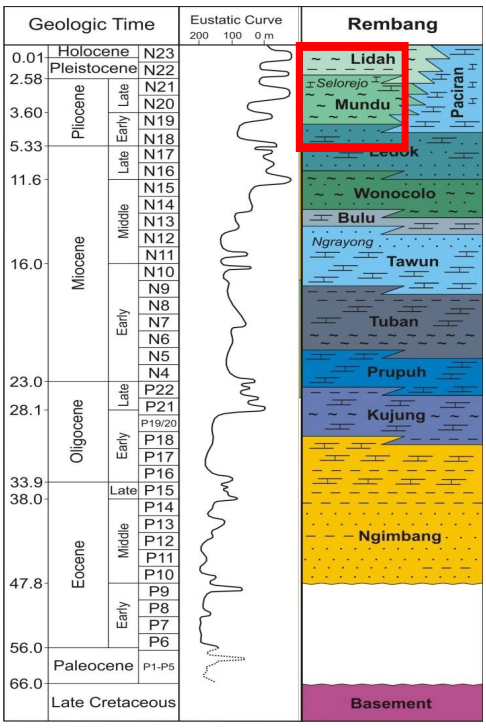


Figure 2. Regional stratigraphy [5].

C. Method and Material

Methods used in this research include making a stratigraphical measurement section at the field, collecting 41 samples and preparing the samples with the smear slides method to be observed using a polarizing microscope with 100x magnification and preparing several rock samples using SEM analysis. Analysis of nannofossil resulted in identification 19 genus and 51 species. Fossil photos were taken using a microscopic camera (*Moticam*) connected to a laptop or computer. Names of genus and species referenced from previous researchers by Martini (1971), Okada and Bukry (1980), Perch and Nielsen (1985), Aubry (1985) and Nannotax3

The appearance of nannofossil species in each rock sample is the main data of this study. The relative abundance of individual species was estimated [6]:

VA = Very Abundant (over 10 specimens per field of view).

A = Abundant (1-10 specimens per field of view).

C = Common (one specimen per 2 to 10 fields of view).

F = Few (one specimen per 11 to 100 fields of view).

R= rare (1 to 2 specimens per slide)

II. Result and Analysis

The lithostratigraphic nomenclature used in this study follows regional stratigraphy [4]. Local Stratigraphy of the Banyuurip section in this study area is composed Calcarenite unit of Ledok Formation, Marl unit of Mundu Formation and Calcareous claystone unit of Lidah Formation "Fig. 3". The age classification used in determining based on Martini (1971) and classification of bathymetry followed Tipsword, *et al.*, 1966 and Wright Barker, 1960).

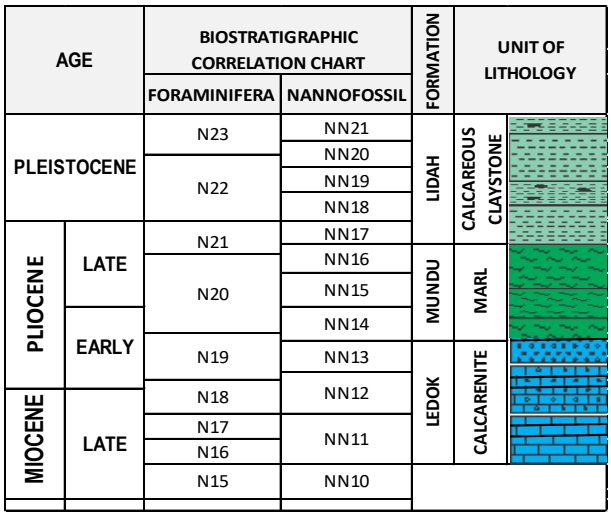


Figure 3. Local stratigraphy of this area.

A. Calcarenite Unit of Ledok Formation

The unit is dominated by calcarenite, with intercalation of limestone, calcarenite, marl and and sandy limestone and also contains a lot of the glauconite. The sedimentary structures are massive, lamination, parallel bedding and cross bedding "Fig. 4". Age of this unit is NN11-NN13 (Late Miocene to Middle Pliocene), while based on foraminifera in regional stratigraphy is N16 to N17/Late Miocene [3]. This unit also has benthic foraminifera such as: *Nodosaria catenula, Amphycorina separans, Bulimina pupoides, Nonion asterizans, Dentalina gutifera* which show a bathymetry environment of 100m to 200m or outer neritic and thickness of the unit around 150-200 meters [7], [8].

Figure 4. Calcarenite intercalating with limestone, sandy limestone and marl of the Ledok Formation.

B. Marl Unit of Mundu Formation

This unit is dominated by marl, very thick, massive structure, containing many foraminifera, so it is known as Mundu Marl. Characteristic color of this lithology is bluish-gray and brownish-white "Fig. 5". Stratigraphically it is conformable with calcarenite unit of Ledok Formation. Age of this unit is NN13 to NN16 (Early Pliocene to Middle Pliocene) on the basis of First Occurrence (FO) *Discoaster asymmetricus* and Last Occurrence (LO) *Reticulofenestra pseudoumbilicus* and *Discoaster surculus* [7]-[11]. The bathymetry of the unit is upper bathyal to lower bathyal (200-2000) meters [12], [13] while the thickness is (150-200) meters.

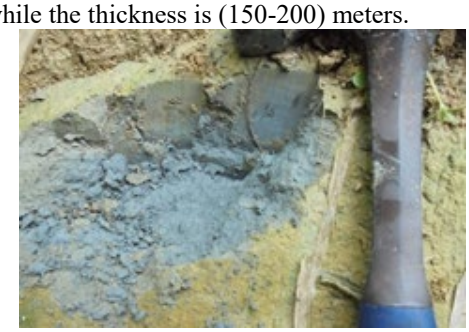


Figure 5. Marl outcrop of Mundu Formation.

C. Calcareous Claystone Unit of Lidah Formation

This unit is dominated by calcareous claystone and claystone, massive structure and there are fragments of mollusc shells "Fig. 6". This unit is NN16 to NN18 (Middle Pliocene-Late Pliocene) based on last occurrence of *Reticulofenestra pseudoumbilicus, Discoaster surculus, Discoaster pentaradiatus, Discoaster brouweri* [7]-[11]. This unit was deposited of the inner bathyal to upper bathyal (200-500) meters [12], [13], and the thickness of 170-200 meters.

Figure 6. Calcareous claystone Unit of Lidah Formation.

D. Biostratigraphy

Nannofossil biostratigraphy in this study has been compiling based on Measure section data consisting of 41 samples outcrop. The results of the analysis showed that there were 19 genus, 51 species and 9 zone of biostratigraphy (Table I). The abundant of nannofossils are found in marl lithology and calcareous claystone. The classification of genus and species refers to Perch-Nielsen (1985) and Bown, *et al.*, (1998) [14].

Nannofossils biostratigraphy is arranged based on the First Occurrence (FO) or First Appearance Datum (FAD) and Last Occurrence (LO) or Last Appearance Datum (LAD) of the species index of nannofossil. Based on the data of nannofossil analysis, there are 9 Zone (8 Interval Zone and 1 of Range Zone). The Zone are listed in (Table II) and the explanation is as follows:

1) Interval Zone of *Sphenolithus neoabies* Zone (NN12)
2) Interval Zone of *Ceratolithus rugosus* Zone (NN13)
3) Range Zone of *Discoaster asymmetricus* to *Reticulofenestra pseudoumbilicus* Zone (NN14 to NN15)
4) Interval Zone of *Discoaster surculus* Zone (NN16)
5) Interval Zone of *Discoaster pentaradiatus* Zone (NN17)
6) Interval Zone of *Discoaster brouweri* Zone (NN18)
7) Interval Zone of *Gephyrocapsa caribbeanica* Zone or *Pseudoemiliania lacunose* Zone (NN19)
8) Interval Zone of *Gephyrocapsa oceanica* Zone (NN20)
9) Interval Zone of *Emiliania huxleyi* Zone (NN20).

III. Discussion

A. The Pliocene Biostratigraphy: 6 Zone

1) Sphenolithus neoabies Zone (NN12 Zone)

This Zone is determined based on FO *Sphenolitus neoabies* [7] the presence of this species indicates Middle Miocene to Early Pliocene (NN7–NN15) dan FO *Sphenolitus neoabies* characterizing of the bottom NN12 Zone, so this zone as a NN12.

2) Ceratolithus rugosus Zone (NN13 Zone)

The datum plane of *Ceratolithus rugosus* to indicated by FO *Ceratolithus rugosus* (Early Pliocene to Pleistocene or NN13 to NN19). The first occerunce of this species characterizes the base of NN13 so that the age of this biodatum is the base of NN13 [7].

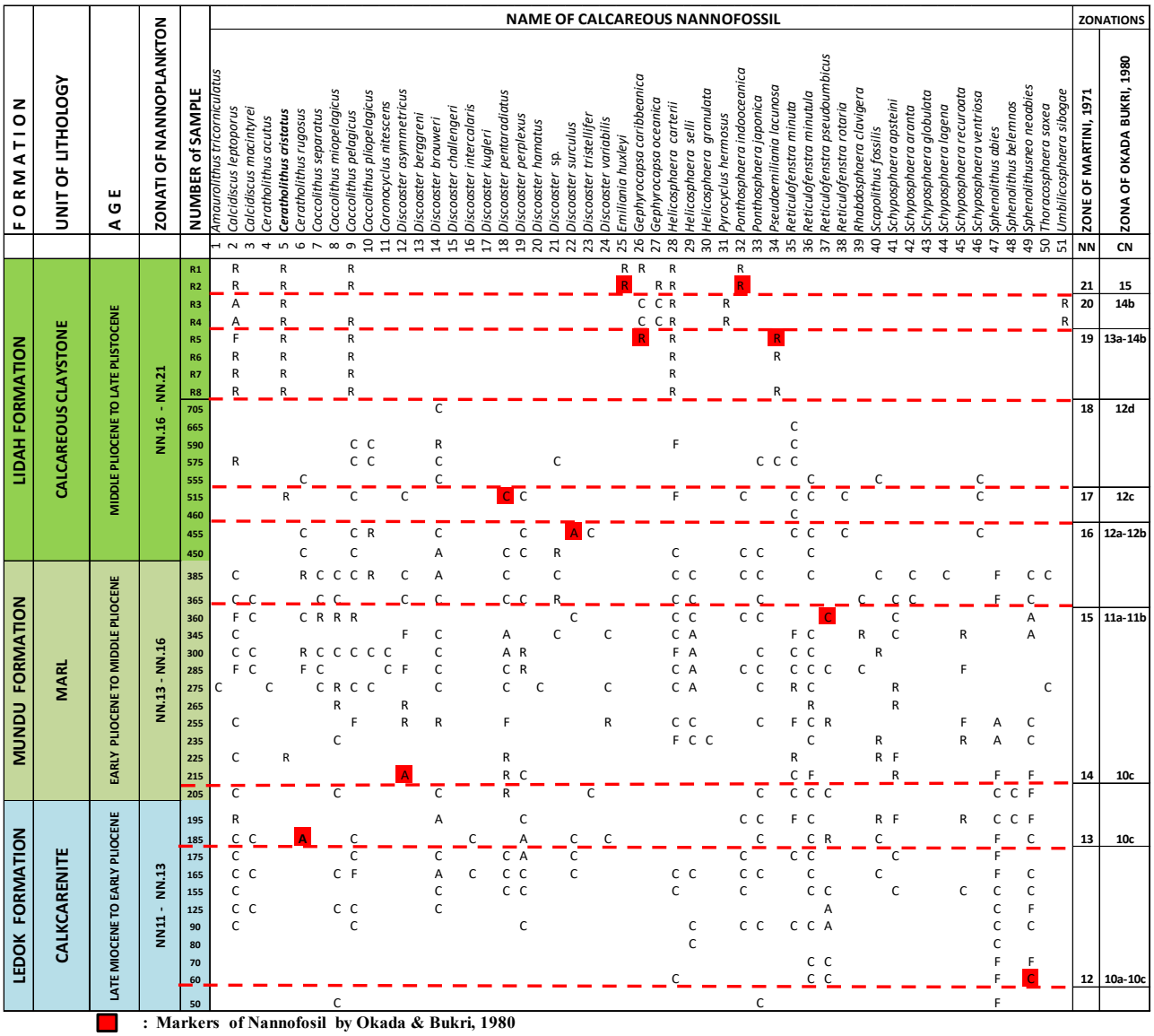
3) Discoaster asymmetricus - Reticulofenestra pseudoumbilicus Zone (NN14 to NN15 Zone)

This zone is determined based on the FO *Discoaster asymmetricus (*Early Pliocene to Late Pliocene / NN14-NN17), no boundaries were found so species were used LO *Reticulofenestra pseudoumbilicus* is Middle Miocene to Late Pliocene (NN5 to NN15), and the LO of this species is used as NN15

4) Discoaster surculus Zone (NN16 Zone)

This zone is determined based on LO *Discoaster surculus,* Late Miocene to Early Piocene, (N10 to NN16) and used for base of NN16 Zone.

TABLE I. DATA OF THE CALCAREOUS NANNOPLANKTON OF THIS STUDY AREA



VA = Very Abundant (over 10 specimens per field of view).
A = Abundant (1-10 specimens per field of view).
C = Common (one specimen per 2 to 10 fields of view).
F = Few (one specimen per 11 to 100 fields of view).
R= rare (1 to 2 specimens per slide)

5) Discoaster pentaradistus Zone (NN17 Zone)

This zone is determined based on LO *Discoaster pentaradiatus*. This species appears in Late Miocene to Late Pliocene (NN9 to NN17) and the LO *Discoaster pentaradiatus* characterizes the top of NN17. Age of this zone is the top of NN17 equivalent to the absolute age of 2.2 Ma [7]. This zone is determined based on the LO of *Discoaster pentaradiatus*. This species appeared in Late Miocene to Late Pliocene (NN9 to NN17) and the LO of *Discoaster pentaradiatus* characterizes the top of NN17 [4]. Age of this zone is the top of NN17 equivalent to the absolute age of 2.2 Ma [7].

6) Discoaster brouweri Zone/NN18 (Late Pliocene), to indicated by LO *Discoaster pentaradiatus* and upper part based on LO *Discoaster brouweri.* This zone genus of *Gephyrocapsa* has not yet appeared.

B. The Pleistocene Biostratigraphy: 3 Zone

1) Gephyrocapsa caribbeanica Zone or Pseudoemiliania lacunose Zone (NN19 Zone)

This zone is determined based on four species indexes. The absence of *Discoaster brouweri,* FO *Ceratolithus cristatus,* FO *Gephyrocapsa caribbeanica,* LO *Pseudoemiliania lacunose* indicates age of Early Pleistocene (NN19). In this zone *Gephyrocapsa oceanica* have not yet been found

2) Gephyrocapsa oceanica Zone (NN20 Zone)

This zone indicated by the absence of *Pseudoemiliania lacunose,* and FO *Gephyrocapsa oceanica,* so this data concluded of Middle Pleistocene (NN20). In this zone *Emiliania huxleyi* have not found,

3) Emiliania huxleyi Zone (NN21 Zone)

This zone is determined based on FO *Emiliania huxleyi,* so concluded of Late Pleistocene (NN21).

TABLE II. NANNOFOSSIL ZONATION SCHEME MODIFIED WITH MARTINI (1971) AND OKADA BUKRY (1980)

F O+M19+B2:M44+M19+B2+B3	UNIT OF LITHOLOGY	A G E	ZONATI OF NANNOPLANKTON	NUMBER of SAMPLE	FIRST OR LAST OCCURRENCE	NANNOFOSSILS EVENT	ZONE OF BIOSTRATIGRAPHY	ZONATIONS: ZONE OF MARTINI, 1971	ZONATIONS: ZONA OF OKADA BUKRI, 1980	NANNOFOSSILS INDEX
LIDAH FORMATION	CALCAREOUS CLAYSTONE	LATE PLIOCENE	NN.16 - NN.21	R1			Interval Zone	NN21	15	*Emiliani huxleyii*
				R2	↑	*FO Emiliani huxleyii*				
				R3			Interval Zone	NN20	14b	*G. oceanica*
				R4	↑	*FO Gephyrocapsa oceanica*				
				R5			Interval Zone	NN19	13a-14b	*G. caribbeanica / P. lacunosa*
				R6						
				R7						
				R8	↑	*FO Geph.caribbeanica/FO Pseudoemiliania lacunosa*				
		MIDDLE PLIOCENE TO		705	↓	*LO Discoaster brouweri*	Interval Zone	NN18	12d	*Discoaster brouweri*
				665						
				590						
				575						
				555						
				515	↓	*LO Discoaster pentaradiatus*	Interval Zone	NN17	12c	*D.pentaradiatus*
				460						
				455	↓	*LO Discoaster surculus*	Interval Zone	NN16	12a-12b	*D. surculus*
				450						
MUNDU FORMATION	MARL	EARLY PLIOCENE TO MIDDLE PLIOCENE	NN.13 - NN.16	385						
				365						
				360	↓	*LO R.pseudoumbilicus*	Range Zone	NN14 to NN15	11a-11b	*D.asymmetricus - R. pseudoumbilicus*
				345						
				300						
				285						
				275					10c	
				265						
				255						
				235						
				225						
				215	↑	*FO D.asymmetricus*				
				205						
LEDOK FORMATION	CALCARENITE	LATE MIOCENE TO EARLY PLIOCENE	NN12 - NN.13	195			Zona Selang	NN13	10c	*Ceratolithus rugosus*
				185	↑	*FO Ceratolithus rugosus*				
				175						
				165						
				155			Interval Zone	NN12	10a-10c	*Sphenolithus neoabies*
				125						
				90						
				80						
				70						
				60	↑	*FO Sphenolithus neobies*				
				50			Partial Zone	NN11		*Sphenolithus neoabies*

IV. CONCLUSION

A. Stratigraphy

Stratigraphy of this study based on nannofosils is Late Miocene to Late Pleistocene (NN12 to NN21). The stratigraphic sequence from older to younger are Calcarenite Unit of Ledok Formation (Late Miocene to Early Pliocene/NN12 to NN13), was deposited in the outer Neritic (100-200) meters. Marl Unit of Mundu Formation is Early Pliocene-Middle Pliocene (NN13 to NN16) in the upper bathyal to lower bathyal (200-2000) meters. Calcareous claystone Unit of Lidah Formation is Middle Pliocene to Late Pleistocene (NN16 to NN21), was deposited in the Inner Neritic to upper bathyal (200-500) meters.

B. Biostratigraphy

Biostratigraphy of this study can be arranged into 9 biostratigraphic zones. The zones are:

1) *Sphenolithus neoabies* zone /NN12 (Late Miocene to Early Pliocene).
2) *Ceratolithus rugosus* zone */NN13* (Early Pliocene).
3) *Discoaster asymmetricus–Reticulofenestra pseudoumbulicus* Range Zone/NN14-NN15.
4) *Discoaster surculus zone*/NN16 (Middle Pliocene).
5) *Discoaster pentaradiatus* Zone/NN17 (Late Pliocene.
6) *Discoaster brouweri zone/*NN18 (Late Pliocene)
7) *Gephyrocapsa caribbeanica* zone/NN19 Zone (Early Pleistocene).
8) *Gephyrocapsa oceanica* zone/NN20 Zone (Middle Pleistocene),
9) *Emiliania huxleyi* zone/NN21 Zone (Late Pleistocene),

CONFLICT OF INTEREST

The research location is in the oil field of PT. Pertamina. Licensing has been approved and in this study conducted without a conflict of interest.

AUTHOR CONTRIBUTIONS

Ir. Siti U. Choiriah, M.T. contribution to conception, design, acquisition, analysis and interpretation of data preparation of articles. Dr. Ir. C. Prasetyadi, M.Sc. contribution to the Regional Stratigraphic Rembang Zone, critical review and final approval of the submitted version. Dr. Ir. Dwi Fitri Yudiantoro, M.T. Local stratigraphy, critical review and final approval of the submitted version. Dr. Ir. Rubiyanto Kapid, discussion of the result of the nannofossil analysis, final approval of the submitted version. Nanda Ajeng Nurwantari, S.T. contribution to preparation and analysis of Nannofossil, contents of articles, final approval of the submitted version, and presentation of papers.

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