Journal of Tropical Biodiversity and Biotechnology
Volume 08, Issue 02 (2023): jtbb81769
DOI: 10.22146/jtbb.81769

Research Article

Biostratigraphy and Climate Change in the Late Miocene Age Based on Foraminifera in the Oyo Formation, Oyo River Section, Gunung Kidul, Yogyakarta

Adesti Audina Ulfah[1], Akmaluddin[1]*, Didit Hadi Barianto[1]
1)Department of Geological Engineering, Faculty of Engineering, Universitas Gadjah Mada, Jl. Grafika Bulaksumur No.2, Sleman, Yogyakarta 55284
* Corresponding author, email: akmaluddin@ugm.ac.id

Keywords:
Paleoclimate
Foraminifera
Biostratigraphy
Oyo Formation
Late Miocene
Submitted:
26 January 2022
Accepted:
08 March 2023
Published:
28 June 2023
Editor:
Miftahul Ilmi

ABSTRACT
The date of the paleoclimate event was ascertained using a biostratigraphic analysis. The thickness of the Oyo Formation was measured using measurements with a Jacob stick method, yielding a thickness of 80.8 meters and 23 rock samples. In the Southern Mountains Zone, new result of the age of the upper part of the Oyo Formation by biostratigraphy investigation of the hill Late Miocene (9.79 Ma to 5.78 Ma). Biostratigraphic investigation in the Oyo River revealed 28 species and 9 genera, with two datums. The study area was classified into three biozonations based on the datum found *Globorotalia acostaensis*/M13a/N16 zone, the lower *Globorotalia plesiotumida*/M13b/N17 zone, and the upper *Globigerinoides conglobatus*/M14/N17 zone. The results of a paleoclimate analysis on the Oyo River Section show a general cooling tendency in the study area. Seven paleoclimate zones can be determined from these trends consisting of four warm and three cold zones. Zone I (warm), zone II (cold), zone III (warm), and zone IV (cold) have the coldest peak in the study region in 8.3 Ma, zone V (warm), and zone VI (cold), followed by zone VII (warm). Based on the correlation with other studies (South China Sea, Pacific Ocean, Oyo River, Ngalang River, and Ngioro Section), paleoclimate events in the study area occur globally.

INTRODUCTION
The Late Miocene age period, when the global climate experience a cooling trend, has many fascinating phenomena to investigate (Zachos et al. 2001). The stable oxygen isotope value increased to a maximum of 6.9 million during the Late Miocene, according to Billups (2002). At first, this pattern was thought to increase global ice volume due to a two-step increased benthic foraminiferal $\delta^{18}O$ values site located on the Atlantic coast of Morocco. Still, after studying the trends associated with cooling the air masses in the Southern Ocean, it was found that after the Middle Pliocene, both the north and south poles were covered in ice. Other changes included the cooling of the ocean, expansion of the Antarctic ice sheet, chunks of ice in the north (predominantly in the North Atlantic), and other changes (Billups 2002). The ratio of oxygen isotopes at 6.8 Ma - 4.8Ma, was used in the study of Rousselle et al. (2013) in the IODP U1338 well in the Pacific Ocean. It is also experiencing a decrease in

temperature. The Middle China paleosol layer between 7.1 Ma - 5.5 Ma shows the dominant winter monsoon. Evidence of hydraulic changes in the South China Sea, changes in vegetation, the average grain size of sediments, and the dominance of s mollusk groups that live in dry-cold conditions in China; all support the theory that drying and freezing occurred on the Asian continent at the age of 7 Ma (Holbourn et al. 2018). Significant biological, climatic, and tectonic changes have happened elsewhere, particularly in Asia, Concurrent with advances at both poles. It is, therefore, fascinating to do paleoclimate studies in the Late Miocene.

In Indonesia, the Late Miocene age range also shows a cooling trend by several researchers using foraminifera, nannofossil and isotopes. Van Gorsel & Troelstra (1981) in the Late Miocene to Pliocene age range and Rachmadhan (2019) in the Middle Miocene to Pliocene age range provide evidence of paleoclimate examples utilising foraminifera and Choiriah & Prasetyadi (2020) in the Late Miocene to Early Pliocene age range using nannofossil to determine paleoclimate. The three researchers performed their investigation in the Kendeng Zone. In terms of isotope studies for paleoclimate, one was carried out by Akmaluddin et al. (2010) in the Southern Mountain Zone.

Paleoclimate studies planktonic foraminifera conducted in the Solo River by Van Gorsel & Troelstra (1981) revealed that cooling occurred in the Late Miocene. Rachmadhan (2019), in the Late Miocene age range of the Ngioro Section, there were three paleoclimate climate changes, with a tendency to warm in 8.68 to 6.2 Ma, cooling in 6.2 to 5.72 Ma and cooling in 5.72 to 5.48 Ma. Choiriah & Prasetyadi (2020) in the Kedung Sumber River in the Late Miocene age range also shows a cooling trend.

Akmaluddin et al. (2010) used stable oxygen and carbon isotopes in the Ngalang River in the Oyo Formation in the Late Miocene age range 11 Ma - 9.2. There was a decrease in the stable carbon value and an increase in the stable oxygen value; this is indicated as a cooling trend and coincides with the decline in the Indonesian sea, resulting in a decrease in sea level. However, paleoclimate studies in the Southern Mountains Zone at a younger age range have yet to be carried out, so paleoclimate studies in the upper Oyo Formation have been attempted. One of the locations exposed by Late Miocene sedimentary rocks in the Oyo Formation is in the Oyo River Section, Playen District, Gunung Kidul Regency, Yogyakarta (Figure 1).

Changes in the form of ocean circulation have an impact on basin topography, climate change, and tectonic movements. The flow is affected by a restricted route caused by plate displacement. The walkway is known as a seaway. The Indonesian seaway influences the research area, which results in the closure of the equatorial ocean current system between the Pacific Ocean and the Indian Ocean. The closure of the equatorial ocean current affected temperature changes in Indonesia during the Miocene-Pliocene. Wilson (2008) revealed the closure of the Indonesia seaway, which shows the tectonic movement of the distribution of carbonate rocks in Indonesia, indicating a process of movement of the Australian plate to Eurasia resulted in the closure of the Indonesia seaway (Figure 2).

Biostratigraphic evidence is required to determine when the paleoclimate event occurred. Biostratigraphic studies on planktonic foraminifera were conducted by observing the presence of foraminifera species from foraminifera shells in the form of micro-sized sediment grains discovered after preparation. In contrast, studies on nannofossil were conducted by observing the presence of morphology of nano-sized nannofossil species after smear slides from images. Biostratigraphic research in the Southern Mountain Zone has been carried out by Surono (2009), Akma-

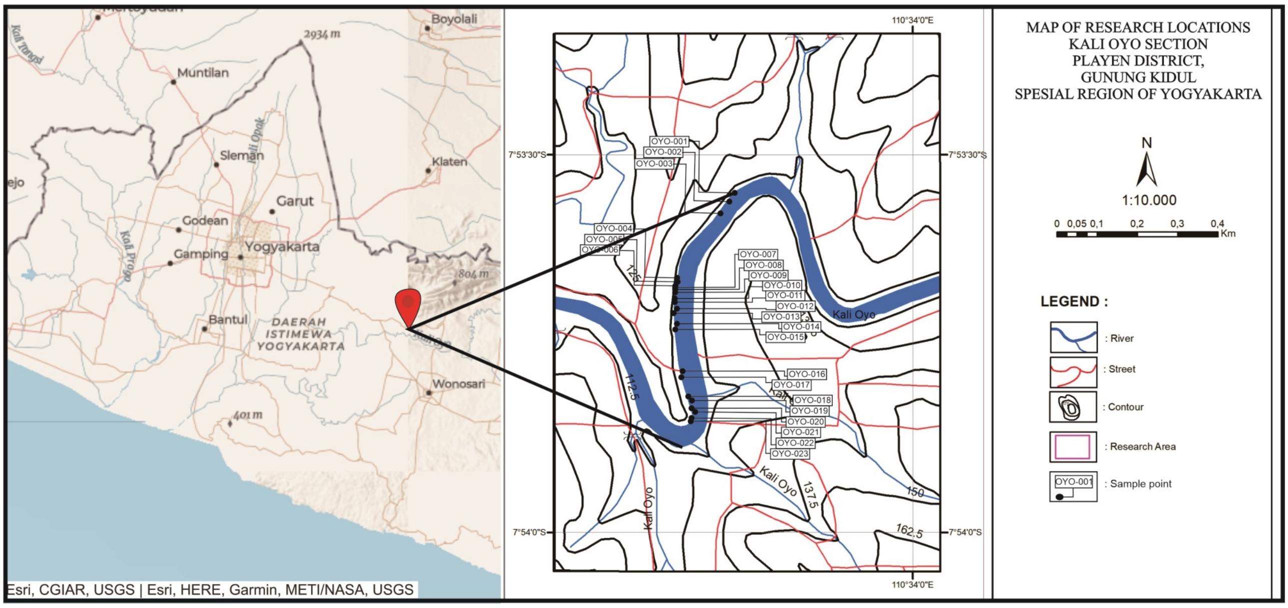

Figure 1. Location of the Research Route in the Oyo River Section, Playen District, Gunung Kidul Regency, Yogyakarta (Badan Informasi Geospasial 2017)

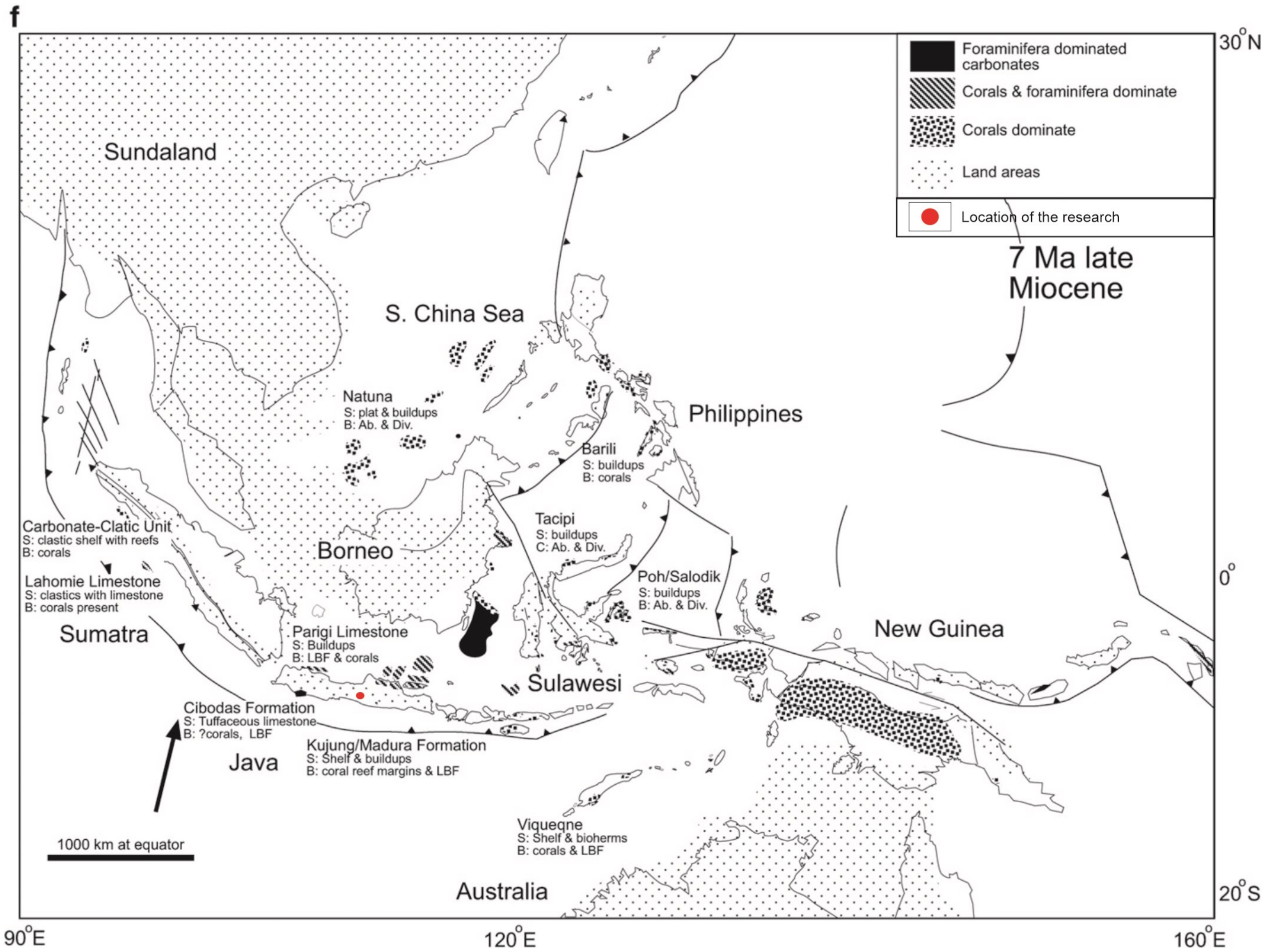

Figure 2. Plate movements during the Late Miocene were based on carbonate development (Wilson 2008).

luddin (2012), and Purbantoro et al. (2020). Surono (2009) using planktonic foraminifera was carried out in the Ngalang River in the Upper Sambipitu Formation during the Early Miocene age (N8), and the Oyo Formation was Early – Middle Miocene (N8-N11). Akmaluddin (2012) in the Ngalang River based on nannofossils from 39 samples, the Early – Middle Miocene Sambipitu Formation (NN2-NN6) and the Late Miocene Oyo Formation (NN8-NN10). In addition, further research on the boundaries of the Sambipitu Formation and Oyo Formation on Jalan Ngalang - Gading by Purbantoro et al. (2020) revealed that the Sambipitu Formation is N13-N15 in age, while the Oyo Formation is N14-N16. Despite of several investigations, the upper Oyo Formation has never been the subject of biostratigraphic investigation. Therefore, a thorough biostratigraphic study of the upper Oyo Formation, which represents the Late Miocene age range, is required. This information will then be used to determine when these paleoclimate changes had a place.

Regional Geology

Stratigraphy of the Southern Mountains Zone (Surono 2009), where Pre-tertiary metamorphic rocks underlie the Southern Mountains Zone. Then on top, they were unconformably deposited sedimentary rocks of the Eocene age, namely the Wungkal Formation and the Gamping Formation. Unconformably deposited in the Kebo Formation and Butak Formation, which are of Late Oligocene – Early Miocene age. The Semilir Formation harmoniously overlays the Kebo-Butak Cluster. Then the Semilir Formation is overlapped in harmony with the Nglanggeran Formation. On top of the Nglanggeran Formation was deposited the Early Miocene Sambipitu Formation, then successively superimposed by the Oyo Formation and the Wonosari Formation on top of Sambipitu Formation. The Oyo Formation is Early Miocene - Middle Miocene, while the Wonosari Formation is Middle Miocene - Late Miocene. Above, the Wonosari Formation is punctuated by the Early Pliocene Kepek Formation.

Based on Figure 3 of the regional geological map (Surono et al. 1992), the study area is included in the Wonosari Formation. However, this study refers to a research by Akmaluddin (2012), the Oyo Formation includes the research area which its composition is dominated by tuffaceous limestone, tuffaceous marl and well-layered andesitic tuff, with depository and biogenic structures.

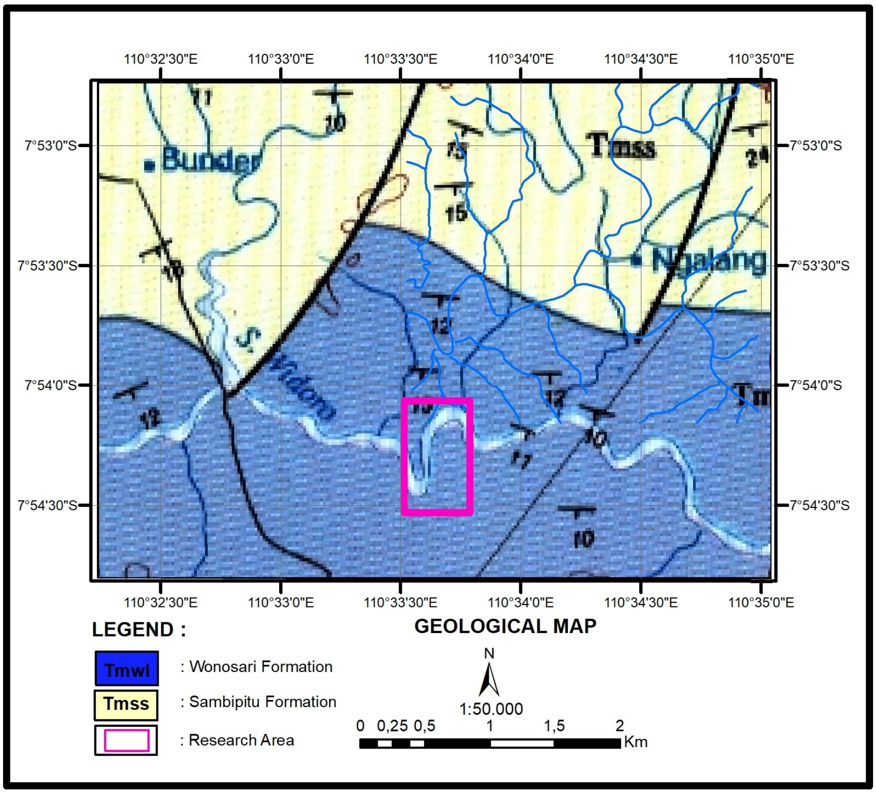

Figure 3. Geological Map of the Study Area, Salatiga Sheet (Surono et al. 1992 in modification).

RESEARCH METHODS

Sampling in the field was carried out by stratigraphic measurements using the Jacob stick method. This study focused on using foraminifera samples due to their abundance and ease of identification also, the depositional environment in shallow oceans made the foraminifera approach more practical. The samples were prepared for planktonic foraminifera weighing 100 grams per sample. Sample preparation was carried out at the Paleontology Laboratory, Gadjah Mada University, starting from mashing the sample, soaking it in a 10% H_2O_2 solution for 1 hour, washing the sampling or sieving it using 3 mesh sizes 16, 30, and 120, then drying the sample using an oven for 4 hours. with a temperature of 70^{o}C. The next stage of determination is identifying the fossils found and counting the number of species obtained. This determination stage refers to Bolli et al. (1989). The determination process was done at the Paleontology Laboratory, Gadjah Mada University, with a 45x magnification binocular microscope. After all, samples had been determined, and biostratigraphic analysis was carried out.

The biostratigraphic analysis uses standard methods by determining the datum based on a species' initial or late appearance. The determination of the datum used refers to Bolli et al. (1989), Blow (1969), and Wade et al. (2011). After the datum was obtained, biostratigraphic zoning was made. The biostratigraphic zone refers to the biozonation of Blow (1969) and Wade et al. (2011).

RESULTS AND DISCUSSION

Research Area Stratigraphy

The Oyo River Section study line's stratigraphic measurements yielded an outcome of 80.8 meters (Figure 4). Sampling was conducted at 1-2meter intervals beside the empty zone. This investigation yielded 23 samples for biostratigraphic ,and paleoclimatic analysis.

The Oyo River Section consists of alternating carbonate sandstones, carbonate tuff sandstones, marl, and limestone, with a laminated top parallel bedding and fine-coarse grain sizes. Tuff nodules are found in several layers (Figure 5). Limestone inserts are found in the middle and bottom of carbonate sandstone lithology at a thickness of 0–5.2 meters. Then, at a thickness of 16.7–20 meters, limestone layers predominate. Two marl strata are 24.9–25.5 meters thick and 30.4–31.3 meters thick. There are alternations of carbonate sandstone limestone layers and carbonate tuff sandstones, with thicknesses ranging from 32.4 to 25.7 meters. There are tuff nodules in several layers, and some have also undergone oxidation. Limestone layers were found between 61.4- 63 meters thick. Carbonate sandstone and limestone alternate with a thickness of 67.5-80.8 meters.

Biostratigraphy

Biostratigraphic analysis of planktonic foraminifera was carried out using a binocular microscope with a magnification of 45x in the study area, which is in the Oyo River Section, Playen District, Gunung Kidul Regency, Yogyakarta. Biostratigraphic analysis of planktonic foraminifera in the study area found rare to moderate foraminifera. From 23 samples, 9 genera and 28 species of planktonic foraminifera were obtained (Figure 6). Two datums were obtained in this study, the first appearance of *Globorotalia plesiotumida* and the first appearance of *Globigerinoides conglobatus.* The Oyo River Section is separated into three zones based on these two datums. The zoning arrangement from old to young (Table 1) includes:

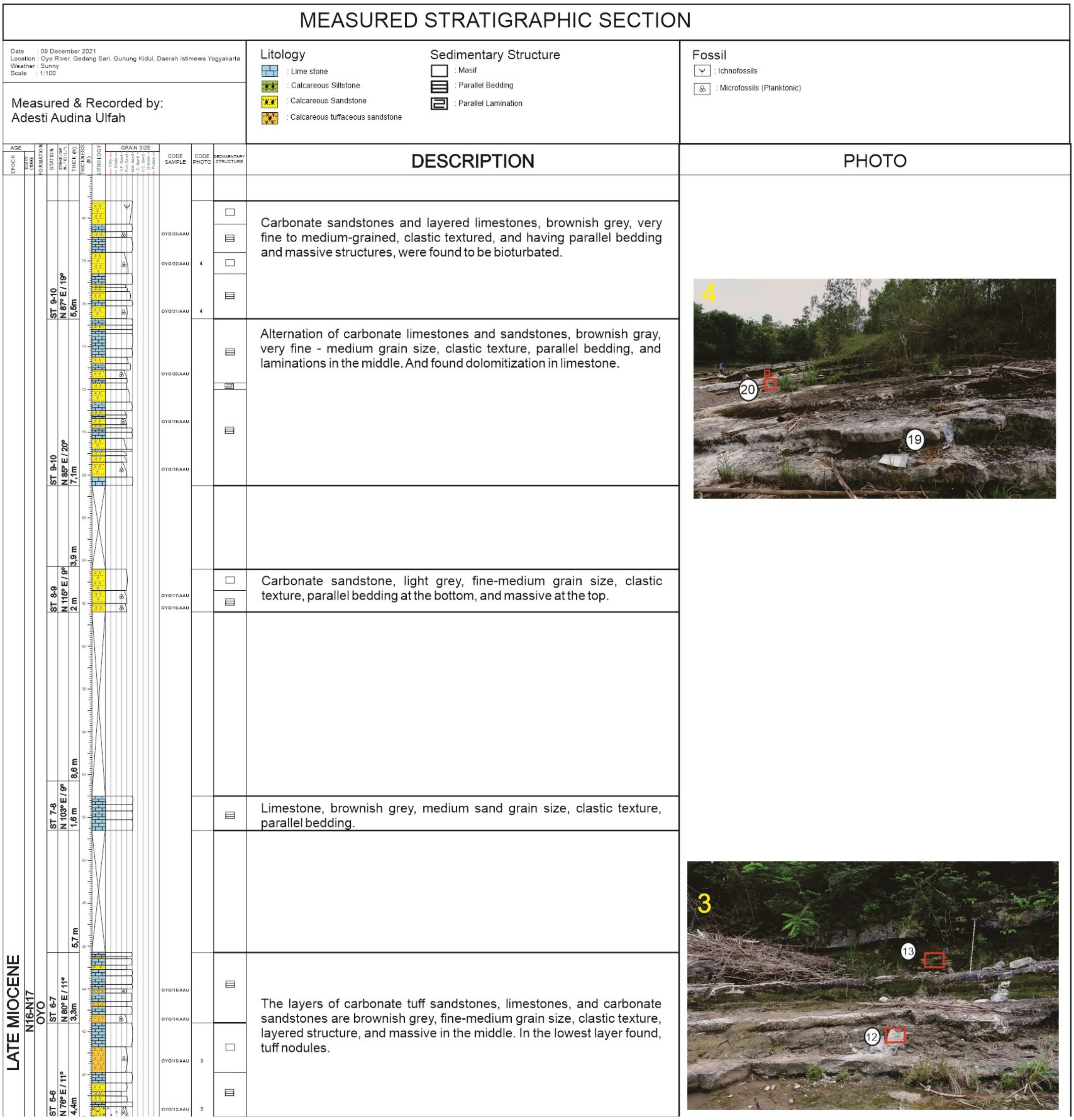

Figure 4. The results of measured stratigraphic measurements on the Oyo River Section with a thickness of 80.8 meters.

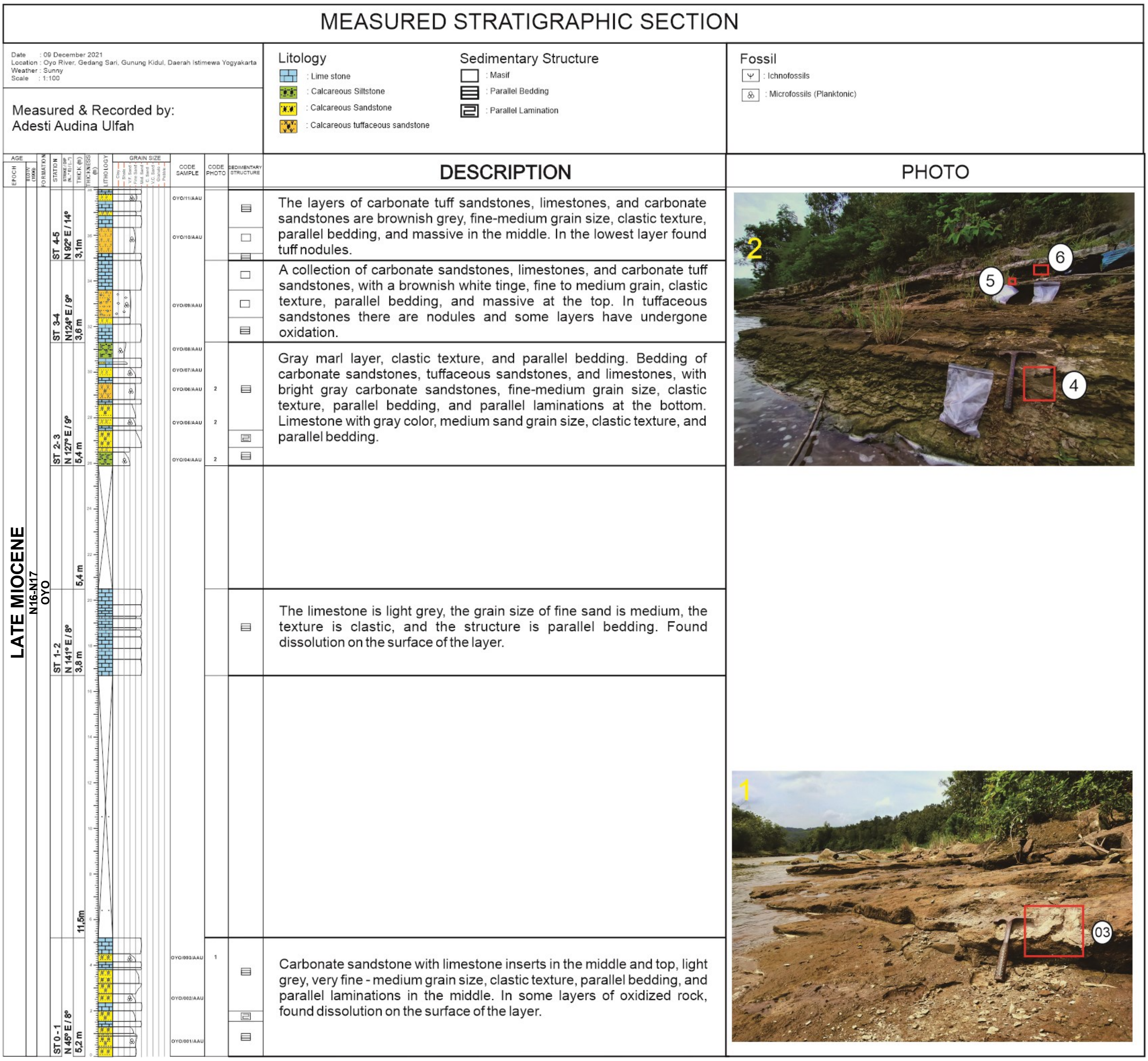

Figure 4. Continued

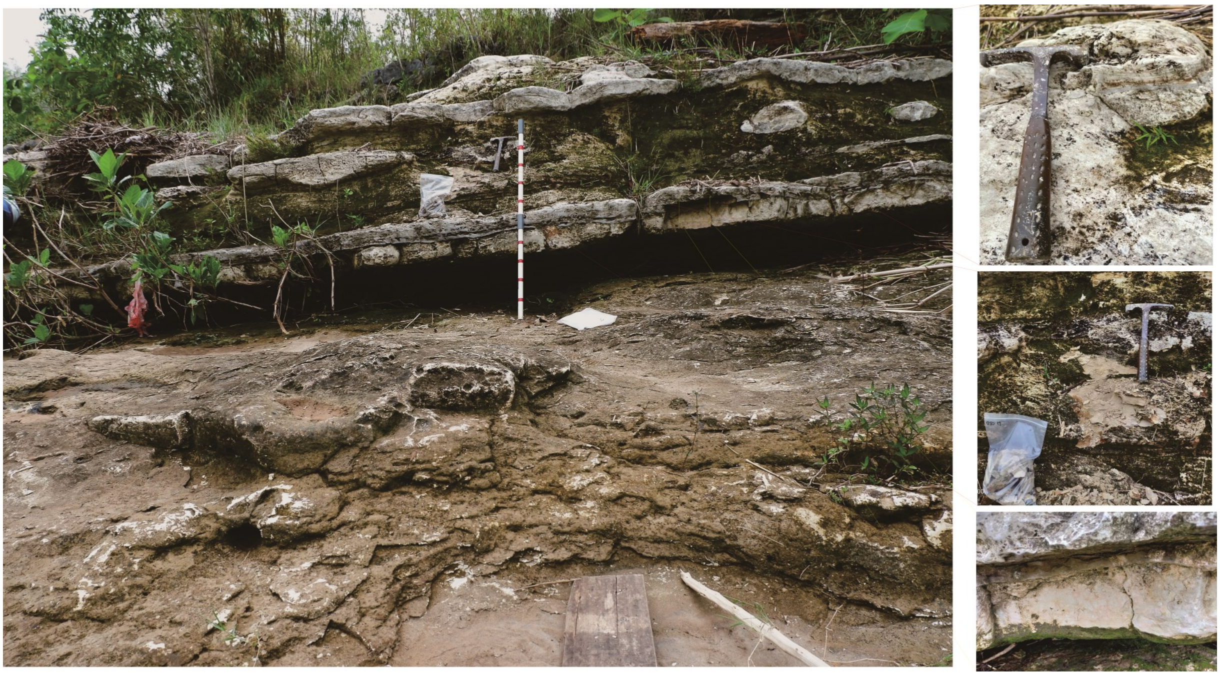

Figure 5. Outcrop photo of carbonate sandstone and limestone on the Oyo River Section with a thickness of 69.2-72 meters with sample code OYO/017/AAU at STA 9-10.

Globorotalia acostaensis / M13a / N16 Zone

The *Globorotalia acostaensis* zone was found in samples OYO/001/AAU – OYO/010/AAU. This zone is characterized by the upper limit of the early appearance of the species *Globorotalia plesiotumida,* while the lower limit is unknown.

Reworked species in this zone are *Globorotalia mayeri* and *Globorotalia fohsi fohsi.* The *Globorotalia acostaensis* zone is by the presence of the *Globigerina venezuelana*, *Globigerinoides bulloideus*, *Globigerinoides quadrilobatus*, *Globorotalia acostaensis*, *Globorotalia humerosa*, *Globorotalia menardii*, *Hastigerina siphonifera*, and *Sphaerodinellopsis seminulina*.

The *Globorotalia acostaensis* zone is equated with the Blow zone (1969) aged N16 (Late Miocene) or in the age range of 9.79 Ma to 8.52 Ma. (Wade et al. 2011). This zone can be compared to the *Globorotalia acostaensis* zone (Blow 1969) or the *Neogloboquadrina acostaensis* zone (M13a) (Wade et al. 2011)

Globorotalia plesiotumida / M13b / N17 Lower Zone

The *Globorotalia plesiotumida* zone was found in sample OYO/011/AAU – OYO/019/AAU. This zone has a lower limit for the early appearance of the species *Globorotalia plesiotumida* and an upper limit for the initial appearance of the species *Globigerinoides conglobatus.*

Reworked species in this zone are *catapsydrax dissimilis* and *Globorotalia fohsi fohsi.* The *Globorotalia plesiotumida* zone is characterized by the presence of the species *Globigerina venezuelana*, *Globigerinoides bulloideus*, *Globigerinoides quadrilobatus*, *Globorotalia acostaensis*, *Globorotalia humerosa*, *Globorotalia menardii*, *Globorotalia plesiotumida*, *Hastigerina siphonifera*, *and Sphaerodinellopsis seminulina.*

The *Globorotalia plesiotumida* zone is equated with the Blow zone (1969) aged N17 Lower (Late Miocene) or in the age range of 8,52 Ma to 6,08 Ma (Wade et al. 2011). This zone can be compared to the *Globorotalia humerosa* zone (Blow 1969), or the *Globorotalia plesiotumida* zone and *Globorotalia lenguensis* zone (M13b) (Wade et al. 2011).

Table 1. Distribution and abundance of foraminifera species and foraminifera zoning in the Oyo River Section.

No.	Formation	Species / Sample	1 *Catapsydrax dissimilis*	2 *Globigerina venezuelana*	3 *Globigerinoides bulloideus*	4 *Globigerinoides conglobatus*	5 *Globigerinoides quadrilobatus*	6 *Globigerinoides ruber*	7 *Globigerinoides sacculifer*	8 *Globigerinoides trilobus*	9 *Globoquadrina altispira*	10 *Globoquadrina dehiscens*	11 *Globorotalia acostaensis*	12 *Globorotalia crassaformis*	13 *Globorotalia fohsi fohsi*	14 *Globorotalia humerosa*	15 *Globorotalia limbata*	16 *Globorotalia mayeri*	17 *Globorotalia menardi*	18 *Globorotalia plesiotumida*	19 *Globorotalia pertenuis*	20 *Globorotalia pseudopima*	21 *Globorotalia sticula*	22 *Hastigerina siphonifera*	23 *Orbulina bilobata*	24 *Orbulina suturalis*	25 *Orbulina universa*	26 *Pulleniatina obliquiloculata*	27 *Sphaeroidinellopsis disjuncta*	28 *Sphaeroidinellopsis seminulina*	Biodatum	This Study	Blow (1969)	Wade, et al (2011)		EPOCH
1	OYO	OYO/023/AAU			R	**R**		F	R	F			F			C	R		R	**R**						F	C					Globigerinoides conglobatus zone	N17	M14		LATE MIOCENE
2		OYO/022/AAU			R			F								C	F		F	**F**	R			C		F	C				FO *Globigerinoides conglobatus* (6,08 Ma)					
3		OYO/021/AAU						C		F		R	F			A											R									
4		OYO/020/AAU		R	R	**R**		F	F	F	R		F			C	R		F	**R**							F		R						6,08 Ma	
5		OYO/019/AAU		R				F		C	R	R	F			C			R					F			F	R				Globorotalia plesiotumida zone		M13b		
6		OYO/018/AAU					R	C	R	F		F	R			C			R	**R**							F			F						
7		OYO/017/AAU						C	R	F	R		F			C	R							C	R	R	R									
8		OYO/016/AAU		R	F			C	R	F		F	F			C	R		F	**R**							C	R		R						
9		OYO/015/AAU			F			F		F	R	F	F			A			F	**F**				R			F									
10		OYO/014/AAU			R			C	R	C	R	R	F			C			F	**F**				F			C									
11		OYO/013/AAU			F			F	R	F	R	F	F	F	F	C			F	**F**				R		R	F									
12		OYO/012/AAU	R	R	R		R	F		C		F	R			C			R	**R**				R		R	F				FO *Globorotalia plesiotumida* (8.52 Ma)					
13		OYO/011/AAU		R	F			F	R	F	F	F	F			C				**R**							F			R					8,52 Ma	
14		OYO/010/AAU		R	F			R	R	F	R	C	R	R	F	C								R		R	F			F		*Globorotalia acostaensis zone*	N16	M13a		
15		OYO/009/AAU			R			F		F	F	C	F	R		A		F	R					R			R									
16		OYO/008/AAU			F			F	R	F	F	F	R	R	R	C								F			F			R						
17		OYO/007/AAU			F			F	F	C	F	F	R			C								F			C	R		F						
18		OYO/006/AAU		R	F			R	R	C	F	F	R	F		C									R		C			F						
19		OYO/005/AAU		F				R		F	R	F	R			C								C			C									
20		OYO/004/AAU		R	F		R	F		C	R	C	R			C		R									C			F						
21		OYO/003/AAU			F		R			R			R			C		F						C			C									
22		OYO/002/AAU			F					F		R	R			C		F				R	F	F	R		F									
23		OYO/001/AAU		F	F					C	F	C	R		R			C						F			F		R							

R = 1 F = 2 - 5 C = 6 - 20 A = >20

Figure 6. Assemblages of planktonic foraminifera species in the Oyo River Section (1) *Globigerina venezuelana*, sample OYO/001/AUU; (2) *Pulleniatina obliquiloculata*, sample OYO/007/AA; (3) *Orbulina universa*, sample OYO/004/AUU; (4) *Orbulina bilobata*, sample OYO/002/AAU; (5) *Globoquadrina altispira*, sample OYO/007/AAU; (6) *Globoquadrina dehiscens* sample OYO/006/ AAU; (7) *Hastigerina siphonifera*, sample OYO/001/AAU; (8) *Sphaeroidinellopsis disjuncta*, sample OYO/001/AAU; (9) *Sphaeroidinellopsis seminulina*, sample OYO/004/AAU; (10) *Globigerinoides sacculifer*, sample OYO/006/AAU; (11) *Globigerinoides bulloideus*, sample OYO/006/AAU; (12) *Globigerinoides conglobatus*, sample OYO/020/AAU; (13) *Globigerinoides quadrilobatus*, sampel OYO/003/AAU; (14) *Globigerinoides ruber*, sample OYO/006/AAU; (15) *Globigerinoides trilobus* sample OYO/006/AAU; (16) *Globorotalia acostaensis*, sample OYO/007/AAU; (17) *Globorotalia crassaformis*, sample OYO/006/AAU; (18) *Globorotalia fohsi fohsi*, sample OYO/009/AAU; (19) *Globorotalia humerosa*, sample OYO/004/AAU; (20) *Globorotalia mayeri*, sample OYO/004/AAU; (21) *Globorotalia limbata*, sample OYO/016/AAU; (22) *Globorotalia plesiotumida*, sample OYO/011/AAU; (23) *Globorotalia pseudopima*, sample OYO/002/AAU; (24) *Globorotalia sticula*, sampel OYO/002/AAU; (25) *Catapsydrax dissimilis*, sample OYO/012/AAU. Note: (a) ventral view, (b) dorsal view.

Globigerinoides conglobatus / M14 / N17 Upper Zone

The *Globigerinoides conglobatus* zone was found in sample OYO/020/AAU – OYO/023/AAU. This zone is scharacterised by the lower boundary of the early emergence of the species *Globigerinoides conglobatus*, while the upper boundary is unknown. No reworked species were found in this zone.

No reworked species were found in this zone. The *Globigerinoides conglobatus* zone is scharacterised by the presence of the *Globigerina venezuelana*, *Globigerinoides bulloideus*, *Globigerinoides conglobatus*, *Globorotalia acostaensis*, *Globorotalia humerosa*, *Globorotalia menardii*, *Globorotalia plesiotumida*, *Hastigerina siphonifera*.

The *Globigerinoides congloabatus* zone is equated with the Blow zone (1969) aged N17 Upper (Late Miocene) or in the age range of 6,08 Ma to 5,78 Ma (Wade et al. 2011). This zone can be compared to the *Globorotalia humerosa* zone (Blow 1969) or the *Globigerinoides extremus* zone (M14) (Wade et al. 2011).

Paleoclimate

Determination of the paleoclimate in the study area used the method of chamber rotation of *Globorotalia humerosa* and the diameter of the shell *Orbulina universa* and the species *Globigerinoides bulloideus* as warm climate characteristics, with 50 species in each method. Paleoclimate changes in the Oyo River Section, Playen District, Gunung Kidul Regency, Yogyakarta show a cooling trend occurring in the Late Miocene (N16-N17) or the age range 9.79 Ma to 5.78 Ma (Figure 7). The age range obtained is a cross plot of the absolute age of the datum obtained vs. the rock layer thickness measured in the field. From the cooling trend it can be divided into 7 paleoclimate zones (Figure 8) consisting of:

Zone I (Warm)

Zone I includes OYO/001/AAU samples through OYO/003/AAU. This zone is implied as a warmer climate or transition zone towards cold. In this zone, the average diameter of *Orbulina universa* is between 370 µm – 530 µm. In addition, the chamber rotation of *Globorotalia humerosa* has increased in the dextral direction, and the abundance of the warm- characterising species *Globigerinoides bulloideus* has increased. This zone lasts from 9,79 Ma to 9,5 Ma.

Zone II (Cool)

Zone II includes the sample OYO/004/AAU through OYO/006/AAU. This zone is implied as a cold climate. In this zone, the average diameter of *Orbulina universa* is between 424 µm – 499 µm. The chamber rotation of *Globorotalia humerosa* is predominantly sinistral, and the presence of the warm characterising species *Globigerinoides bulloideus* has been reduced in number. This zone extends from 9,5 Ma to 8,75 Ma.

Zone III (Warm/Transition)

Zone III includes the sample OYO/007/AAU through OYO/012/AAU. This zone is implied as a warmer climate or transition zone. In this zone, the average diameter of *Orbulina universa* is between 389 µm – 461 µm. The chamber rotation of *Globorotalia humerosa* has increased in the dextral, and the abundance of the warm-scharacterising species *Globigerinoides bulloideus* has increased. This zone lasts from 8,75 Ma to 8,45 Ma.

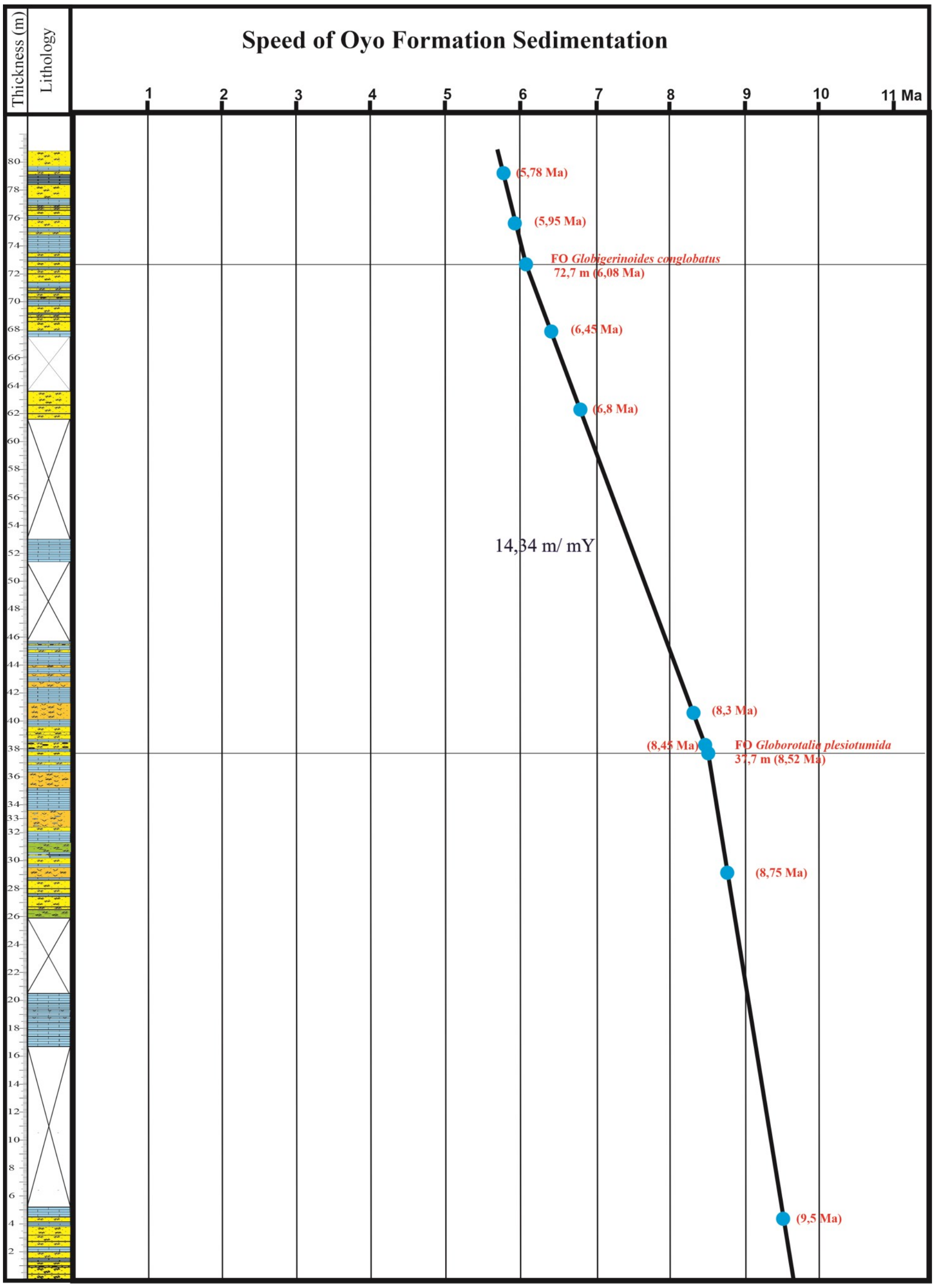

Figure 7. The absolute age of obtained datum vs. rock layer thickness measured in the field in the Oyo River Section. Ventral indicates layer thickness, and horizontal indicates absolute age.

Zone IV (Cool)

Zone IV includes the OYO/013/AAU sample. This zone is implied as a cold climate. In this zone, the average diameter of *Orbulina universa* is 402 µm. The chamber rotation of *Globorotalia humerosa* is predominantly sinistral, and the presence of the warm scharacterising species *Globigerinoides bulloideus* has been reduced in number. This zone extends from 8,45 Ma to 8,3 Ma.

Zone V (Warm)

Zone V includes OYO/014/AAU samples through OYO/017/AAU. This zone is implied as a warmer climate. In this zone, the average diameter of *Orbulina universa* is between 364 µm – 435 µm. In addition, the chamber rotation of *Globorotalia humerosa* has increased in the dextral direction, and the abundance of the warm-scharacterising species *Globigerinoides bulloideus* has increased. This zone lasts from 8,3 Ma to 6,8 Ma.

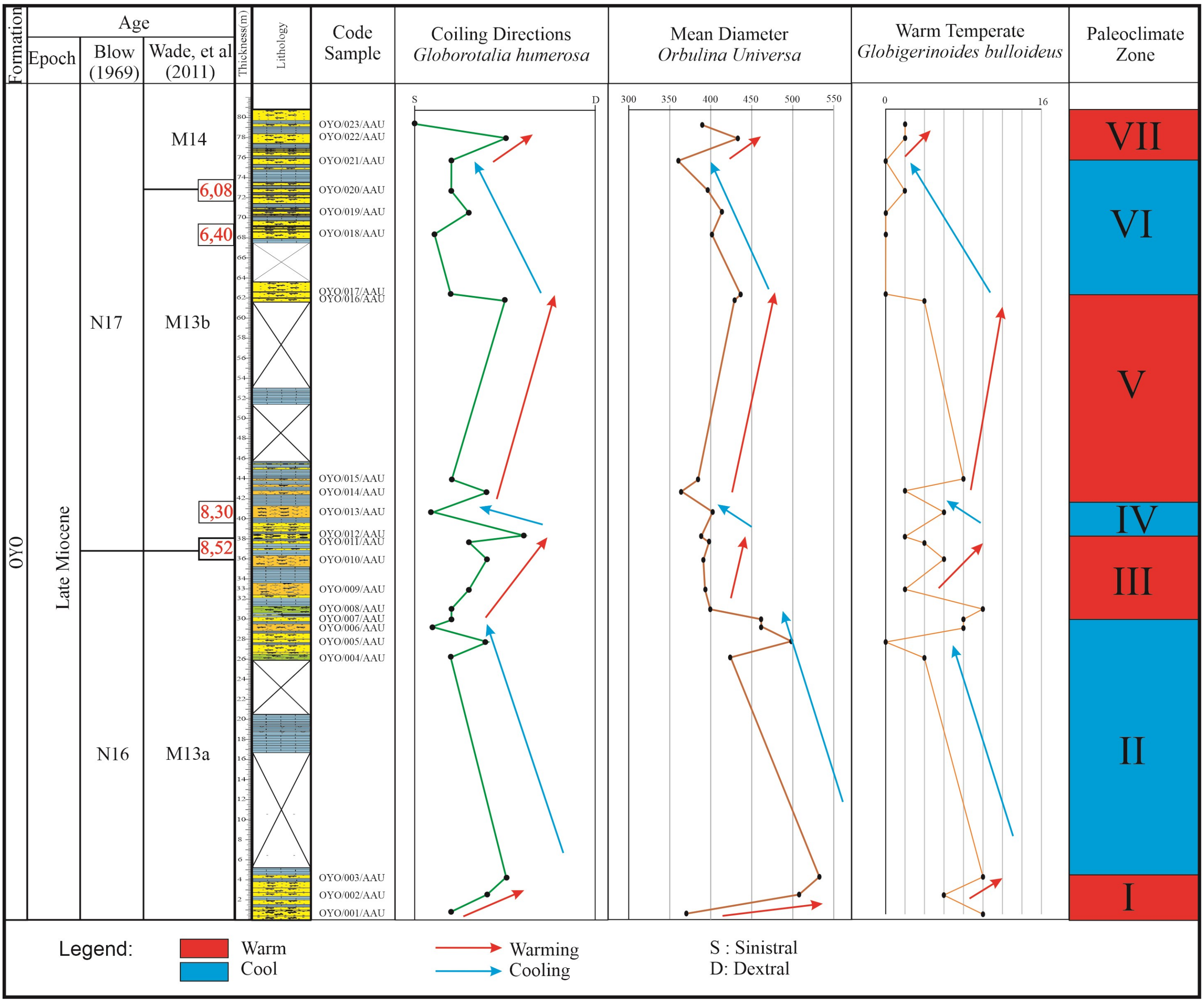

Figure 8. Paleoclimate reconstruction in the study area analysis based on *Globorotalia humerosa* chamber rotation, *Orbulina universa* diameter, and the distinctive species of *Globigerinoides bulloideus.*

Zone VI (Cool)

Zone VI includes the sample OYO/018/AAU through OYO/021/AAU. This zone is implied as a cold climate. In this zone, the average diameter of *Orbulina universa* is between 360 µm - 402 µm. The chamber rotation of *Globorotalia humerosa* is predominantly sinistral, and the presence of the warm scharacterising species *Globigerinoides bulloideus* has been reduced in number. This zone extends from 6,8 Ma to 5,95 Ma.

Zone VII (Warm)

Zone VII includes the samples OYO/022/ through OYO/023AAU. This zone is implied as a warmer climate or transition zone towards cold. In this zone, the average diameter of *Orbulina universa* is between 389 µm – 433 µm. In addition, the chamber rotation of *Globorotalia humerosa* has increased in the dextral direction, and the abundance of the warm-scharacterising species *Globigerinoides bulloideus* has increased. This zone lasts from 5,95 Ma to 5,78 Ma.

Discussion

The paleoclimate reconstruction includes the rotation chamber of *Glo-*

borotalia humerosa, the average diameter of *Orbulina universa*, and the warm climate species *Globigerinoides bulloideus*. If the species *Globorotalia humerosa* is found in the left spatial rotation direction, the species lives in a cold climate. Conversely, if it is located in the dextral rotation direction, it indicates that the species lives in an environment with a warm climate. (Jenkins 1967).

Method using the average diameter of *Orbulina universa* species. The larger the diameter of the species indicates that the species lives in an environment with a warm climate, but if the diameter is smaller, the species lives in a cold climate. According to Van Gorsel & Troelstra (1981), *Orbulina universa* species will have a maximum diameter in areas with tropical and subtropical climates.

Then the last method is the species that scharacterise the warm-cold climate, seen from the abundance of the species that scharacterise the warm-cold climate. In this research, the scharacterising species used is *Globigerinoides bulloideus*, which is scharacterised by a scharacterising warm climate (Bicchi et al. 2003). The age of paleoclimate events using the method by (Akmaluddin et al. 2019)

Based on the results of paleoclimate reconstruction using the direction of chamber rotation of *Globorotalia humerosa*, the diameter of *Orbulina universa*, and the characteristic warm species *Globigerinoides bulloideus*, the research area experienced several changes in paleoclimate events. However, if we look at the research area, the overall trend changes are cooling. This change can be seen from the direction of rotation of the chamber *Globrotalia humerosa* to the sinistral direction. In the Range of 8.52 Ma to 6.08 Ma in the study area, there were 3 paleoclimate events: cold, transition, and cold again. There was a change in trend from 8.52 Ma to 8.3 Ma, where there was a cooling trend, then in the age range of 8.3 Ma to 6.8 Ma, which was warmer than the previous trend. It is estimated that this age range is a transition zone. Later paleoclimate trends revealed colder temperatures between 6.8 Ma and 6.08 Ma. Comparisons were made in the study area with existing studies (Figure 9).

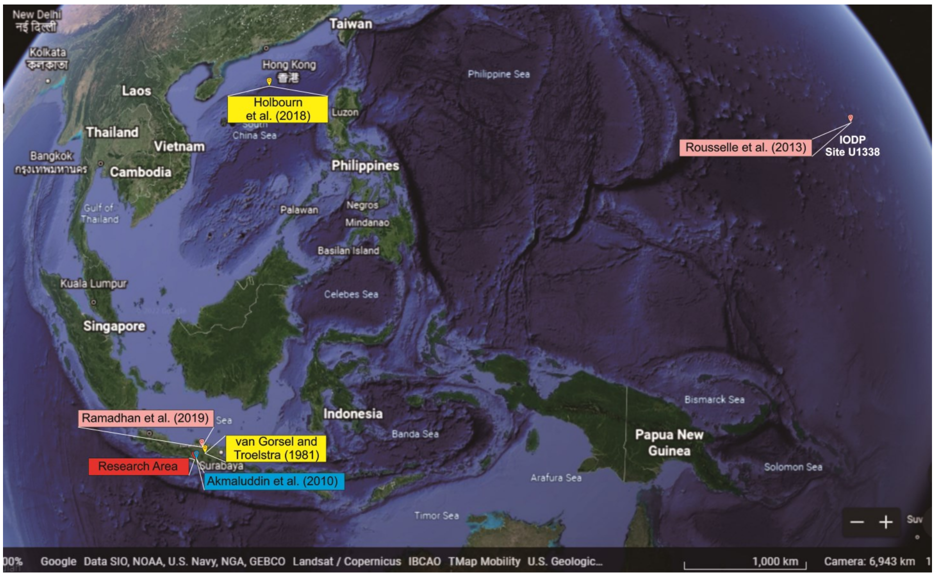

Figure 9. The study area is compared with previous researchers in Java, the South China Sea, and the Pacific Ocean (Source: Google Earth).

Compared with research conducted by Holbourn et al. (2018) in the South China Sea using stable oxygen isotopes and carbon from planktonic and benthic foraminifera in the age range of 8.52 Ma to 6.08 Ma, the same trend occurred in the study area. The trend changes from cold, and then there are a transition or warmer and returns to the cold trend (Figure 10). At 7.7 Ma to 7.2 Ma, based on the existing analysis, the stable oxygen isotope content based on planktonic foraminifera in the South China Sea experiences a warmer or overall trend which can be considered a transition zone before heading to a cooler trend. Although when viewed as a whole in the Range 8.52 Ma to 6.08 Ma in the South China Sea based on data from stable carbon isotopes and stable oxygen isotopes from planktonic and benthic foraminifera, the trend that occurs is dominated by an overall cooling trend.

Rousselle et al. (2013) on the IODP U1338 well in the Pacific Ocean showed a change in trend that occurred in the Late Miocene at 6.8 Ma -5.8 Ma, where there was a decrease in temperature of 1,5°C. The research area in the range of 6.8 Ma – 5.95 Ma is also experiencing a cooling trend, as indicated by the rotation of the *Globorotalia humerosa* shell, which is dominated by sinistral, the average shell diameter of *Orbulina universa* is getting smaller, and the reduced abundance of *Globigerinoides bulloideus* species as a feature of a warm climate.

The study area was compared with the study in Java by Van Gorsel & Troelstra (1981) in the Solo River based on the rotation of the chambers of *Globorotalia menardii* and the diameter of *Orbulina universa*, indicating a change in the cooling trend in the Late Miocene. This trend occurs at the boundaries of N16 and N17 with the species *Globorotalia plesiotumida*. The same thing also happened in the study area. At the boundaries of N16 and N17 or the age range of 8.52 Ma, the study area experienced a change in a cooling trend, indicated by the relatively sinistral rotation of the *Globorotalia humerosa* shell, the smaller the average diameter of the *Orbulina universa*, and reduced species characteristic of *Globigerinoides bulloideus*. Rachmadhan (2019) also conducted a similar study on the Ngioro Section, where at 9.83 Ma – 5.72 Ma, based on planktonic foraminifera, there was a change in trend from cooling, warming, and then cooling. However, in general, the trend was cooling. In a different place, a paleoclimate study conducted by Akmaluddin et al. (2010) in the Ngalang River used stable oxygen and carbon isotopes in the *Globigerinoides sacculifer* shell, showing that there was a temperature change. At

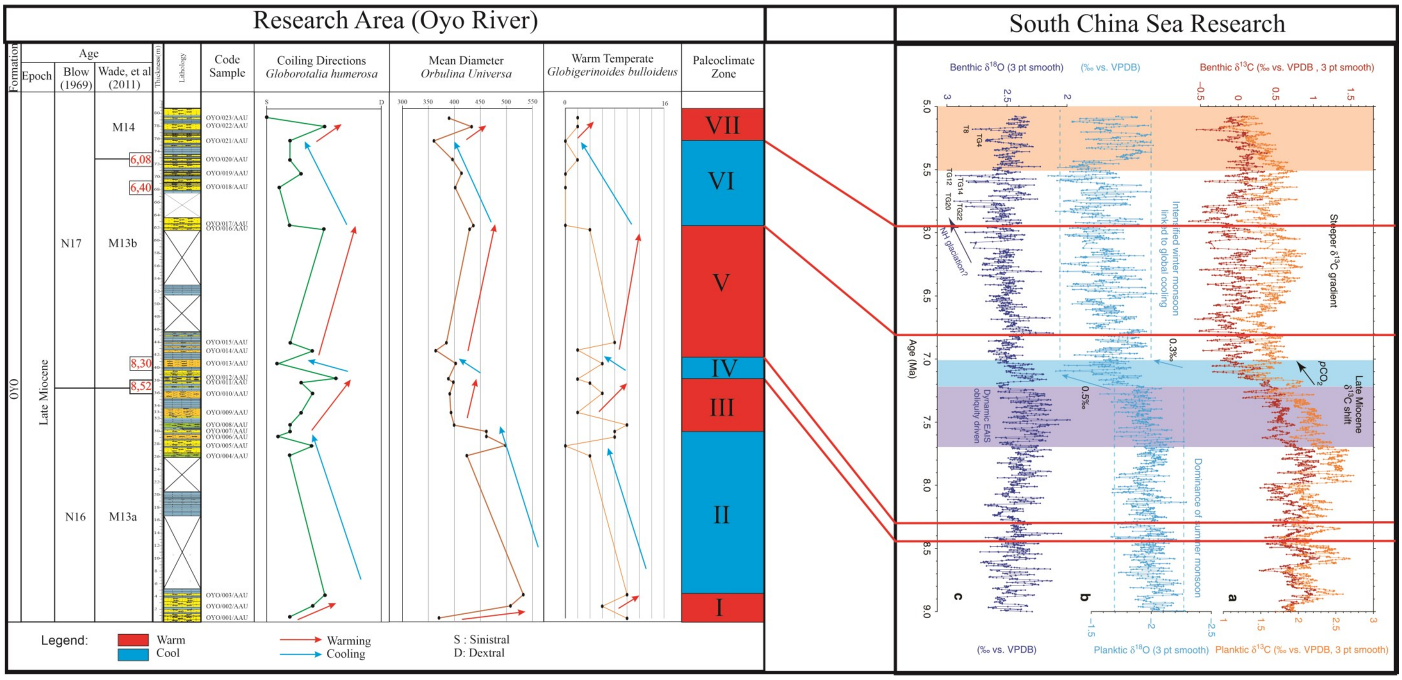

Figure 10. Comparison of the paleoclimate curve of the study area with Holbourn et al. (2018).

9.2 Ma or Late Miocene, this is marked by a decrease in the stable carbon isotope value and an increase in the stable oxygen isotope value, which is indicated as a cooling trend, which coincides with the decline in the Indonesian sea resulting in a decrease in sea level.

Based on a comparison of trends in the study area and other locations (South China Sea, Pacific Ocean, Solo River, Ngalang River, and the Ngioro Section), the paleoclimate in the study area occurs globally. This was initially explained as an increase in global ice volume, but after looking at trends related to the cooling of water masses in the Southern Ocean, cooling in the oceans, expansion of the ice sheet in Antarctica, and ice sheets in the Northern Ocean—hemisphere (predominant in the North Atlantic). The north and south poles were ice-covered after the Middle Pliocene (Billups 2002). Coinciding with the development of ice at both poles, significant ecological, climatic, and tectonic events occurred elsewhere, especially around Asia (Holbourn et al. 2018).

Systematics of Paleontology

Planktonic foraminifera biodiversity was discovered at the Oyo River Section. The samples examined yielded 5 families, 9 genera, and 28 species (Table 2).

CONCLUSION

Based on measured stratigraphic measurements using Jacob's stick method, a thickness of 80.8 meters was obtained. The results of the biostrati-

Table 2. Biodiversity and taxonomy note of foraminifera from Oyo River Section.

Phylum	Class	Order	Family	Genus	Species
Foraminifera	Globothalamea	Rotaliida	Globigerinidae	Catapsydrax	*Catapsydrax dissimilis* (Cushman & Bermudez, 1937)
				Globigerina	*Globigerina venezuelana* (Hedberg, 1937)
				Globigerinoides	*Globigerinoides bulloideus* (Crescenti, 1966)
					Globigerinoides conglobatus (Brady, 1879)
					Globigerinoides quadrilobatus (d'Orbigny, 1846)
					Globigerinoides sacculifer (Brady, 1877)
					Globigerinoides ruber (d'Orbigny, 1839)
					Globigerinoides trilobus (Reuss, 1850)
				Orbulina	*Orbulina bilobata* (d'Orbigny, 1846)
					Orbulina suturalis (Bronnimann, 1951)
					Orbulina universa (d'Orbigny, 1839)
				Sphaeroidinellopsis	*Sphaeroidinellopsis disjuncta* (Finlay, 1940)
					Sphaeroidinellopsis seminulina (Schwager, 1866)
			Catapsydracidae	Globoquadrina	*Globoquadrina altispira* (Chusman & Jarvis)
					Globoquadrina dehiscens (Chapman, Parr & Collins, 1934)
			Globorotaliidae	Globorotalia	*Globorotalia acostaensis* (Bolli, 1957)
					Globorotalia crassaformis (Galloway & Wissler, 1927)
					Globorotalia fohsi fohsi (Cushman & Ellisor, 1939)
					Globorotalia humerosa (Takayanagi & Saito, 1962)
					Globorotalia limbata (Fornasini, 1902)
					Globorotalia mayeri (Chusman & Ellisor, 1939)
					Globorotalia menardii (Parker, Jones & Brady, 1865)
					Globorotalia plesiotumida (Banner & Blow 1965)
					Globorotalia pertenuis (Beard, 1969)
					Globorotalia pseudopima (Blow, 1969)
					Globorotalia scitula (Brady, 1882)
			Hastigerinidae	Hastigerina	*Hastigerina siphonifera* (d'Orbigny, 1839)
			Pulleniatinidae	Pulleniatina	*Pulleniatina obliquiloculata* (Parker & Jones, 1865)

graphic analysis in the Oyo River Section from 23 samples obtained 9 genera and 28 species. From the analysis, 2 datums were obtained, the initial appearance of *Globorotalia plesiotumida* and *Globigerinoides conglobatus*. From the datum obtained, the study area was divided into 3 biostratigraphic zones, namely the *Globorotalia acostaensis* / M13a / N16 zone in the age range 9.79 Ma – 8.52 Ma, the *Globorotalia plesiotumida* zone M13b / N17 Lower in the age range, 8.52 Ma – 6, 08 mya and Upper M14 / N17 zona *Globigerinoides conglobatus* in the age range 6.08 Ma – 5.78 Ma.

Determination of the paleoclimate in the study area using the chamber rotation method of *Globorotalia humerosa*, the diameter of *Orbulina universa*, and the warm-cold scharacterising species *Globigerinoides bulloideus*. The research area experienced 7 times the change of paleoclimate events, namely 4 warm and 3 cold zones. However, the paleoclimate change in the study area is experiencing an overall cooling trend when viewed as a whole. Compared to trends in the study area and other locations (South China Sea, Pacific Ocean, Solo River, Ngalang River, and the Ngioro Section), paleoclimate events in the study area occur globally.

AUTHORS CONTRIBUTION

A.A.U. obtained field data, analysed data and created articles for publishing. A. and D.H.B. oversaw all procedures, including data collection, analysis, and paper review.

ACKNOWLEDGMENTS

The researcher wants to express gratitude to everyone who helped carry out this research, from field data gathering to studio and lab analysis. The researcher shows appreciation for the supervising lecturers, the entire Paleontology Laboratory staff, the Department of Geological Engineering, the Faculty of Engineering at Gadjah Mada University, and any other parties who have offered recommendations and guidance on this research. The researcher hopes this research can be expanded in the future and be helpful to many individuals.

CONFLICT OF INTEREST

The authors state that they have no conflicts of interest.

REFERENCES

Akmaluddin et al., 2010. Miocene warm tropical climate: Evidence based on oxygen isotope in central java, Indonesia. *World Academy of Science, Engineering and Technology*., 71(11), pp.66–70. doi: 10.5281/zenodo.1063224

Akmaluddin, 2012. Nannofossils Biostratigraphy Of Miocene Sequences In Southern Mountains, Central Java, Indonesia. *Prosiding Seminar Nasional Kebumian*, (5), p.11.

Akmaluddin, A., Agustin, M.V. & Kurniawan A.M., 2019. Stratigraphy and Foraminiferal Biostratigraphy of Sentolo Formation in Sedayu Area: Local Unconformity Identification in Early Pliocene. *Journal of Applied Geology*., 3(2), pp.32. doi: 10.22146/jag.48596.

Badan Informasi Geospasial, 2017. Ina Geospasial. viewed 20 October 2021, from https://tanahair.indonesia.go.id/portal-web

Bolli, H.M., Saunders, J.B. & Perch-Nielsen, 1989. *Plankton stratigraphy: volume 1, planktonic foraminifera, calcareous nannofossils and calpionellida* (Vol. 1), Cambridge: Cambridge University Press.

Bicchi, E., Ferrero, E. & Malgorzata G., 2003. Palaeoclimatic interpretation based on Middle Miocene planktonic Foraminifera: The Silesia Basin (Paratethys) and Monferrato (Tethys) records. *Palaeogeography, Palaeoclimatology, Palaeoecology.*, 196(3–4), pp.265–303. doi: 10.1016/S0031-0182(03)00368-7.

Billups, K., 2002. Late Miocene through early Pliocene deep water circulation and climate change viewed from the sub-Antarctic South Atlantic. *Palaeogeography, Palaeoclimatology, Palaeoecology.*, 185(3–4), pp.287–307. doi: 10.1016/S0031-0182(02)00340-1.

Blow, W. H., 1969. Late Middle Eocene to Recent Planktonic Foraminiferal Biostratigraphy. *Proceedings of the First International Conference on Planktic Microfossils, Micropaleontology (Geneva, 1967)*, 1(1), pp. 199-422.

Choiriah, S.T. & Prasetyadi, 2020. Paleotemperature Interpretation Based On Calcareous Nannoplankton Of Kedung Sumber River Section, Soko. *Prosiding SEMNAS LPPM.*, 2(1), pp.75–83.

Holbourn et al., 2018. Late Miocene climate cooling and intensification of southeast Asian winter monsoon. *Nature Communications*, 9(1), pp.1-13. doi: 10.1038/s41467-018-03950-1.

Jenkins, D.G., 1967. Recent Distribution, Origin, and Coiling Ratio Changes in Globorotalia pachyderma (Ehrenberg). *Micropaleontology*, 13(2), pp.195. doi: 10.2307/1484670.

Purbantoro, R., Aini, S.N. & Rizqi, A.H.F., 2020. Konfigurasi Stratigrafi Batas Formasi Sambipitu Dan Oyo Di Jalan Ngalang - Gading, Kecamatan Gedangsari - Playen, Gunung Kidul. *GEODA*, 1(2), pp.81–94.

Rachmadhan, H.D., 2019. *Biostratigrafi dan Paleoklimat Menggunakan Foraminifera Kecil, Pada Jalur Ngioro Di Cekungan Rembang.* Universitas Gadjah Mada.

Rousselle et al., 2013. Changes in sea-surface conditions in the Equatorial Pacific during the middle Miocene-Pliocene as inferred from coccolith geochemistry. *Earth and Planetary Science Letters*, 361(41), pp.412 –421. doi: 10.1016/j.epsl.2012.11.003.

Surono, Sudarno, I. & Toha, B., 1992. *Peta geologi lembar Surakarta-Giritontro, Jawa*, Bandung: Pusat Peneliti dan Pengembangan Geologi.

Surono, 2009. Litostratigrafi Pegunungan Selatan Bagian Timur Daerah Istimewa Yogyakarta dan Jawa Tengah. *Jurnal Geologi dan Sumberdaya Mineral*, 19(3), pp.209–221.

Van Gorsel, J.T., & Troelstra, S.R., 1981. Late Neogene planktonic foraminiferal biostratigraphy and climatostratigraphy of the Solo River section (Java, Indonesia). *Marine Micropaleontology*, 6(2), pp.183–209. doi: 10.1016/0377-8398(81)90005-0.

Wade et al., 2011. Review and revision of Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the geomagnetic polarity and astronomical time scale. *Earth-Science Reviews*, 104(1–3), pp.111–142. doi: 10.1016/j.earscirev.2010.09.003.

Wilson, M.E.J., 2008. Global and regional influences on equatorial shallow-marine carbonates during the Cenozoic. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 265(3–4), pp.262–274. doi: 10.1016/j.palaeo.2008.05.012.

Zachos et al., 2001. Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present. *Science*, 292(5517), pp.686-693. doi: 10.1126/science.1059412.