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Miocene Warm Tropical Climate: Evidence Based on Oxygen Isotope in Central Java, Indonesia

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Abstract—Oxygen and carbon isotopes records of multi-species planktonic, benthic foraminifera and bulk carbonate sample from Central Java Indonesia demonstrate that warm sea surface temperature occurred during the Miocene. Planktonic $\delta^{18}O$ values from this study consistently lighter (-4 to -3 ‰PDB) than previous studies that indicate sea surface temperature during Miocene in this area was warm than tropical/equatorial localities. A surprising decrease of oxygen isotopic composition was recorded at ±14 Ma where the maximum of $\delta^{18}O$ values is -4.87 ‰PDB for Orbulina universa, -5.02 ‰PDB for Globigerinoides sacculifer and -4.30 ‰PDB for Globoquadrina dehiscens, this event we predict as Middle Miocene Optimum. Warming of sea surface temperature we interpret as related to the development of Western Pacific Warm Pool where warm water from Pacific Ocean through the Indonesian seaway appears to remain during Miocene. Our result also show increasing suddenly of oxygen isotope values of planktic, benthic and bulk carbonate sample from ± 12 Ma, the increasing cooled surface water relatively high degree with Late Miocene global cooling climate or we predict that due to closing of Indonesian Gateway.

Keywords**—**Oxygen isotope, Foraminifera, Miocene, Paleoclimate, Indonesian.

I. INTRODUCTION

NUMEROUS studies have been carried out in Indian and Pacific Ocean to understand Miocene climate history. Data from previous workers indicate that the Middle Miocene was clearly warmer than today [1], [2]. However, study about closing Indonesian Seaway between the Indian Ocean and the Pacific is related to plate-tectonic developments [3]-[7] and evolutionary history of the western Pacific warm pool [8], [9] was still interesting and not clear.

Study on paleoclimate in Indonesia especially in Java Island is still rare. Reconstruction of paleoclimate in Solo River, Central Java was started by [10] using conventional method, abundance of fossil foraminifera. Meanwhile, stable isotope data such as oxygen and carbon isotopes for interpretation of paleoclimate is still not available in Southern Mountains area, Central Java.

The primary purpose of this study is to evaluate the climate change during Miocene at Central Java Indonesia. Multi-species planktic foraminifera and benthic foraminifera were used to understand the climate history in equatorial/tropical environment related to closure Indonesian seaway and heat transfer of the western Pacific warm pool.

II. GEOLOGICAL SETTING

The study area located at the Southern Mountains is a stratigraphic region located in the southern part of Java Island [11]. This region consists of interbedded Tertiary carbonate rocks in Sambipitu Formation, Oyo Formation and Kepek Formation. Tertiary volcanic rocks also dominate in Southern Mountains as Semilir and Nglanggran Formations [12], see Figure 1.

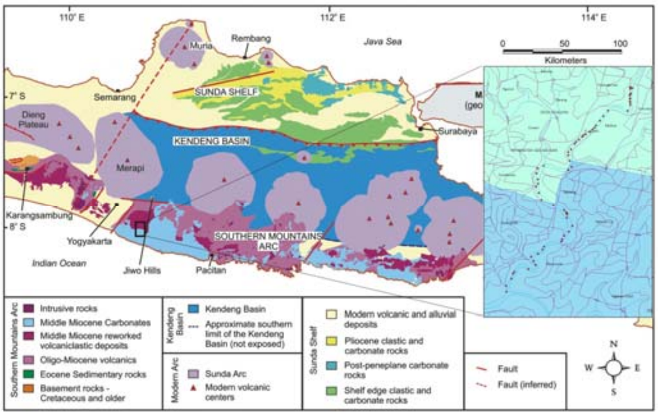

Fig. 1 Simplified geologic map of Central Java Indonesia [12], and location of study area.

Our study focuses on Sambipitu and Oyo Formation along the Ngalang River section. These formations consist of interbedded siltstones, claystones and calcareous sandstone (Fig. 2). Based on biostratigraphy data these formations deposited during the Early Miocene until the Late Miocene or 18 – 9 Ma [13]-[15].

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III. MATERIAL AND METHODS

Sediment samples were disaggregated in water with 10~15% hydrogen peroxide, then washed over 63 µm opening sieving, and the remaining residues were oven-dried at 50°C. In order to remove the secondary calcite cement, the samples were soaked and washed in ultra sonic bath repeatedly. Well-preserved foraminifera from the coarse-fraction samples were handpicked. For each sample, multiple foraminifera (planktic and benthic) were separated and crushed. All of these procedures were done at Laboratory of Economic Geology Dept of Earth Resources Engineering Kyushu University. Scanning Electron Microscope (SEM) observations were analyzed for recognized of secondary cement on the surface of foraminifera (Fig. 3). Bulk sediment samples from carbonate sequences (upper part in this section) were also analyzed for oxygen isotopic composition to evaluate effects of diagenesis of foraminifera shell.

Fig. 2 Field observations. (A) Interbedded siltstones, claystones and calcareous sandstone at Lower part of Sambipitu Formation. (B) Intebedded marl and limestone at Upper part of Oyo Formation.

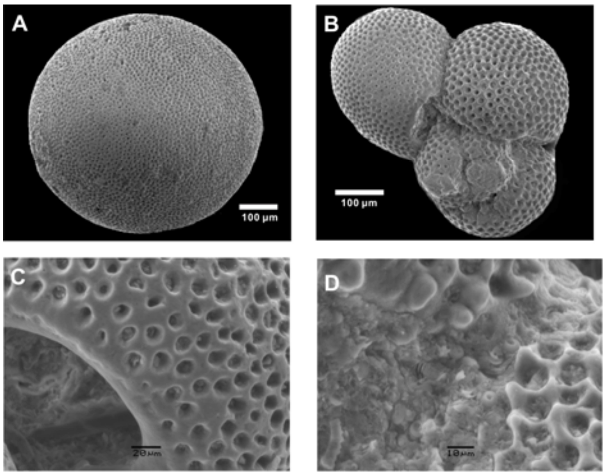

Fig. 3 Scanning electron micrographs of a cleaned test of foraminifera (A) *Orbulina universa*; B) *G. sacculifer*; (C) contrasting well preserved of foraminifera test; (D) inside of test show abundance of nannofossils

Five to ten of individual clean test foraminifera were lightly crushed. We analyzed δ^{18}O using a Thermo Finnagan MAT Delta-plus mass spectrometer at The Department of Environmental Changes, Faculty of Social and Cultural Studies, Kyushu University Japan.

All isotopic data are calibrated to the PeeDee Belemnite (PDB) standard, calcaluted following the formula [16].

$$\delta^{18}\mathrm{O} = \frac{\left(\frac{\delta^{18}\mathrm{O}}{\delta^{18}\mathrm{O}}\right)\text{ sample } - \left(\frac{\delta^{18}\mathrm{O}}{\delta^{18}\mathrm{O}}\right)\text{standard}}{\left(\frac{\delta^{18}\mathrm{O}}{\delta^{18}\mathrm{O}}\right)\text{standard}}\; x\,1000$$

Each specimen was reacted at 60°C with an excess of 100% H_3PO_4, and CO^2 gas was purified in a glass-line connected with the mass-spectrometer [17]-[18].

The results were regularly checked with International standard NBS19, only < 0.2‰ of standard deviation were selected for analyses.

IV. RESULTS

Stable isotope results obtained from planktonic foraminifera, benthic foraminifera and bulk carbonate samples are shown in Table 1 and cross plot with measured section are shown in Figure 4.

The δ^{18}O values of planktic foraminifera between -5.74 to -0.60 *‰PDB*, benthic foraminifera between -3.66 to 1.50 *‰*.

V. DISCUSSION

A. Warm Tropical Climate

The oxygen isotope values is relatively homogeneous lighter/warmer (-3 *‰PDB*) for planktic foraminifera and 0 to 1‰ for benthic foraminifera. We also compare δ^{18}O records from ODP site the tropical western Indian Ocean, northern South China Sea [19].

The planktonic foraminifera (*G. sacculifer and G. dehiscens*) of the Sambipitu Formation (taken from the samples no SBT02 - A6) shows that the oxygen isotope composition is relatively homogeneous, values ranging from -3.2 to -3.6 *‰PDB* (Fig. 3).

Rapid decrease of values of stable isotopes started in early deposition of the Oyo Formation (samples A7-NG16). It suggests the climate became extremely warm at Late Miocene (±12 Ma).

Increasing oxygen isotope values started after extremely warm climate at Late Miocene. Decreasing temperature at Late Miocene equal with Global cooling [1], or we predict that the cooling was due to closing of the Indonesian Seaway.

B. Diagenesis in Foraminifera

The δ^{18}O is easily reset by meteoric and burial diagenesis. Fluids tend to carry lighter isotopes and therefore make the ratios more negative [16], [18] & [20]. SEM observations of foraminifera indicate no effect of diagenesis on surface shell (Fig. 3.).

TABLE I
VALUES OF OXYGEN AND CARBON ISOTOPE FROM SELECTED INDIVIDUAL FORAMINIFERA

		Planktonic Foraminifera						Benthic Foram			
No	Sample	*O. universa*		*G. sacculifer*		*G. dehiscens*		*Cibicides sp.*		Bulk	
		δ^{18}O	δ^{13}C	δ^{18}O	δ^{13}C	δ^{18}O	δ^{13}C	δ^{18}O	δ^{13}C	δ^{18}O	δ^{13}C
1	NG 25	-2.86	-1.75	-1.70	0.50	-1.24	0.76	0.66	-0.20	-	-
2	NG 24	-0.60	1.50	-2.50	1.30	-	-	0.90	0.50	-0.21	0.81
3	NG 23	-1.43	2.15	-2.00	1.60	-	-	0.24	-0.13	-0.85	0.96
4	NG 22	-3.34	-1.06	-3.06	0.70	-2.15	0.53	-0.23	-0.26	-	-
5	NG 21	-1.98	1.96	-1.79	1.63	-1.38	1.92	0.00	-1.17	1.93	0.34
6	NG 20	-2.21	1.76	-0.80	1.80	-2.40	1.70	-0.60	-1.00	-0.20	0.99
7	NG 19	-4.50	1.60	-3.10	1.70	-1.20	1.00	-0.60	-1.30	1.09	0.95
8	NG 18	-3.99	1.64	-	-	-	-	-1.78	1.28	-1.18	1.67
9	NG 17	-4.10	2.00	-4.00	2.10	-2.10	1.60	-1.60	1.80	-1.97	1.63
10	NG 16	-4.99	1.39	-2.10	0.80	-1.30	1.70	0.32	0.75	-	-
11	NG 15	-4.87	1.47	-3.92	1.14	-3.86	1.27	0.72	0.56	-2.28	0.50
12	NG 14	-2.68	1.50	-	-	-	-	-2.54	0.96	-2.00	1.07
13	NG 13	-5.74	-6.42	-4.66	-3.59	-4.20	-3.91	-1.54	-3.14	-3.05	-1.73
14	NG 12	-4.44	1.24	-5.02	-1.39	-4.30	0.29	-1.91	1.03	-	-
15	NG 11	-	-	-	-	-	-	-3.66	0.48	-2.38	1.28
16	NG 10	-3.85	-0.80	-	-	-2.98	1.17	-	-	-2.52	0.78
17	NG 09	-	-	-	-	-	-	-2.05	0.90	-	-
18	NG 08	-	-	-	-	-2.30	2.00	-3.12	1.04	-2.85	1.58
19	NG 07	-	-	-3.75	1.73			-3.30	1.37	-2.03	2.25
20	NG 06	-	-	-	-	-	-			-2.58	1.76
21	A 7	-4.10	1.90	-	-	-3.60	1.02	-0.20	1.70	-	-
22	NG 05	-	-	-	-	-	-			-2.44	0.99
23	NG 03	-	-	-3.91	1.61	-3.94	1.57	-3.65	-1.09	-	-
24	A 6	-	-	-3.37	1.89	-	-	-	-	-	-
25	SB 30	-	-	-3.67	1.00	-3.74	2.06	-	-	-	-
26	SB 29	-	-	-3.46	2.50	-3.43	2.01	-	-	-	-
27	SB 28	-	-	-3.61	1.79	-2.76	1.57	-	-	-	-
28	SB 27	-	-	-	-	-	-	0.27	0.26	-	-
29	SB 25	-	-	-4.43	-0.34	-4.16	-0.18	-	-	-	-
30	SB 24	-	-	-3.15	1.42	-	-	0.37	-0.42	-	-
31	SB 23	-	-	-3.08	0.97	-3.00	0.62	0.59	-0.12	-	-
32	SB 22	-	-	-4.40	-0.54	-3.60	0.00	0.44	-1.04	-	-
33	SB 21	-	-	-3.06	1.13	-2.68	1.15	0.10	-0.01	-	-
34	SB 19	-	-	-3.38	1.73	-2.58	0.87	0.53	-0.61	-	-
35	SB 17	-	-	-4.08	1.93	-6.09	1.70	-	-	-	-
36	SB 16	-	-	-3.02	1.26			1.31	-0.33	-	-
37	SB 15	-	-	-4.40	0.11	-3.09	1.20	1.36	-0.66	-	-
38	SB 14	-	-	-3.44	1.04	-3.62	1.59	0.90	-0.32	-	-
39	SB 13b	-	-	-3.31	1.91	-3.02	0.94	-1.24	-0.99	-	-
40	SB 12	-	-	-3.64	0.19	-3.96	-0.10	-3.19	-0.93	-	-
41	SB 11	-	-	-3.35	0.71	-3.02	0.02	-2.68	-0.75	-	-
42	SB 10	-	-	-3.75	1.00	-2.86	0.41	0.19	-0.30	-	-
43	SB 09	-	-	-3.00	1.25	-2.83	0.89	0.28	-1.09	-	-
44	SB 08	-	-	-2.78	1.02	-3.42	0.81	1.04	-1.27	-	-
45	SB 07	-	-	-3.30	1.60	-	-	1.50	-0.90	-	-
46	SB 06	-	-	-3.27	1.23	-2.29	-0.07	-1.29	-3.64	-	-
47	SB 05	-	-	-3.46	0.06	-3.40	-0.60	-	-	-	-
48	SB 04	-	-	-3.40	0.87	-	-	-2.83	-1.86	-	-
49	SBTU 12	-	-	-3.03	1.20	-2.93	0.61	1.03	-1.33	-	-
50	SBTU 11	-	-	-3.89	0.29	-3.21	0.02	0.04	-2.43	-	-
51	SBTU 10	-	-	-3.97	0.54	-3.42	0.06	0.19	-1.60	-	-
52	SBTU 9	-	-	-3.34	1.10	-2.45	-1.19	-1.71	-4.04	-	-
53	SBTU 8	-	-	-2.66	0.85	-2.87	0.81	-0.36	-0.76	-	-
54	SBTU 7	-	-	-3.29	-0.70	-2.45	-1.19	-0.26	-3.06	-	-
55	SBTU 6	-	-	-3.21	1.76	-0.79	0.55	1.15	-1.75	-	-
56	SBTU 5	-	-	-3.52	1.76	2.82	1.13	0.91	-2.28	-	-
57	SBTU 4	-	-	-4.45	1.40	-2.88	0.91	1.16	-1.65	-	-
58	SBTU 3	-	-	-3.80	1.46	-2.67	0.65	1.00	-1.27	-	-
59	SBTU 2	-	-	-3.40	-1.66	-1.28	0.55	0.81	-1.87	-	-

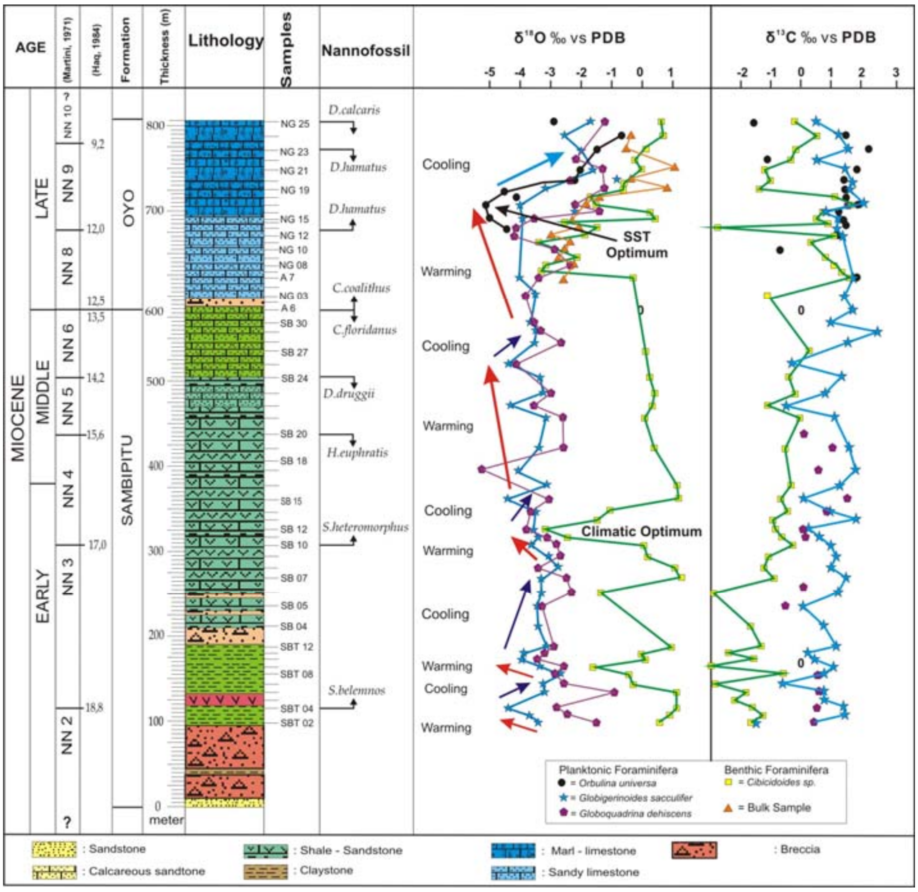

Fig. 4 Measured section of the Sambipitu and Oyo Formation, Oxygen and carbon isotopes values plotted versus stratigraphic section and paleoclimate events.

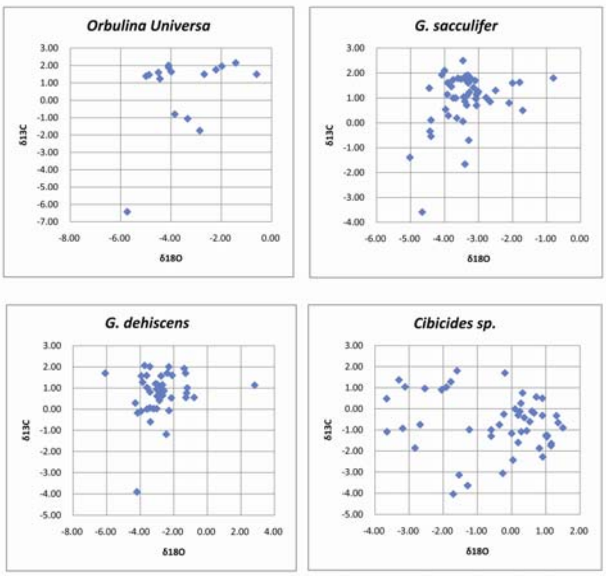

Fig. 5 Cross plots of $\delta^{18}C$ versus $\delta^{18}O$ isotopic composition for planktic foraminifera (*O. universa, G. sacculifer and G. dehiscens*) and benthic foraminifera (*Cibicides sp*)

The $\delta^{18}O$ and $\delta^{13}C$ are a common and convenient way in distinguishing the depositional and/or diagenetic paleo-environments responsible for carbonate formation [21]. The $\delta^{18}O$ - $\delta^{13}C$ cross-plot was prepared by [22]. Our cross-plot result shows no correlation for fresh water diagenesis (Fig. 5).

C. Western Pacific Warm Pool

The Western Pacific Warm Pool (WPWP) occupies much of the tropical-subtropical region of the western Pacific and eastern Indian Ocean and has an average annual sea-surface temperature (SST) of above 28^0C [8], [9]. Several studies have shown that the WPWP was closely related to the closure of the Indonesian and Central American seaways during the Miocene and Pliocene.

Our stable isotope data indicates sea surface warming and a deepened local thermocline that is interpreted to relate to the western Pacific warm pool. Our results conform to [8] who studied WPWP from the South China Sea (ODP site 1143, 1146, 1148).

D. Closing of the Indonesian Seaway

Tectonic reconstruction and biogeographic data indicate that the Indonesia Seaway was effectively closed during early Middle Miocene or 17-15Ma [4], [5], [7]. Reference [23] mentioned that the Indonesian Seaway closed at the Early Pliocene.

Our data indicates that at the sea surface more intensive warm water piled-up than equatorial localities where surface bypass flowed through the Indonesian Seaway remaining until the Middle Miocene (±14 Ma). Increasing planktic foraminifera, benthic foraminifera and bulk carbonate samples we predict as effective closing of the Indonesian Sea or/and global cooling.

VI. CONCLUSION

- Our preliminary study of oxygen isotope analysis in The Southern Mountains Central Java area showed that oxygen can be used and is very powerful for reconstruction of paleo-climate with at least ten climate events were recorded.
- Oxygen isotopic values showed more negative (warmer) than that of equatorial localities.
- Optimum sea surface tempereature as an extreme climate were recorded at The Middle Miocene (±14 Ma).
- Warm sea surface observed during the Miocene which we suggest is related with a western Pacific warm pool.
- Decreasing temperature at the Late Miocene, we predicted as the closing of the Indonesian Sea or/and global cooling.

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