

Foraminiferal Analysis Related to Paleoceanographic Changes of Arafura Sea and Surrounding During Holocene

Analisis Foraminifera Berkaitan dengan Perubahan Oseanografi Purba di Laut Arafura dan Sekitarnya selama Holosen

Luli Gustiantini¹, Swasty Aninda Piranti¹, Rina Zuraida¹, Sangmin Hyun², Duddy A.S. Ranawijaya¹, F.X. Harkin¹

¹ Marine Geological Institute of Indonesia, Jl. Junjuran No. 236 Bandung, 40174 Indonesia, Energy and Mineral Resources Research and Development Agency

² Marine Geology & Geophysics Division, Korea Institute of Ocean Science & Technology (KIOST), 385, Haeyang-ro, Yeongdo-gu, Busan Metropolitan City, 49111 KOREA

Corresponding author : lgustiantini@yahoo.com

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ABSTRACT: Arafura Sea is located between Papua and Australia as a part of Sahul Shelf. It is strongly influenced by ITCZ, ITCZ replacement, monsoon, and ENSO circulation that interplay with local mechanism. To understand the paleoceanographic parameter changes during Holocene, we conducted foraminiferal quantitative analysis from a 152 cm length sediment core (Aru-07), in every 10 cm interval. This sediment core was retrieved from 134°00'33.6" E, 5°55'51.59" S, by RV Geomarin 3 belongs to Marine Geological Institute. Geochronology of the sediment was reconstructed based on 2 AMS ¹⁴C age dates, analyzed on organic samples. We identified 129 species of benthic and 24 species of planktonic foraminifera that is dominated by planktonic specimens with average of 53.14%. Predominant species are *Globigerina bulloides* (16.16%), *Globigerinoides ruber* (11.18%), and *Neogloboquadrina dutertrei* (5.65%). Benthic type is dominated by genera *Bolivina*, *Bulimina*, and *Uvigerina* by 25.86% (average). This might suggest eutrophic condition associated with carbon-rich or low oxygen level (dysoxic) condition. Single linkage cluster analysis revealed 3 paleoenvironmental zones, are: Zone I: older than 3.9 kyr BP, characterized by depleted oxygen level and nutrient enrichment compared to that of younger zone. Zone II: 3.9 – 2 kyr BP, characterized by oxygen content enrichment and deeper thermocline layer, related to the sea level rise during more neutral or La Niña like condition. Zone III: younger than 2 kyr BP, represent shallower thermocline layer, higher productivity which might be related to upwelling, and dysoxic condition. Sea level might be declined that related to more El Niño like condition.

Keywords: Paleoceanographic changes, upwelling, foraminiferal analysis, Arafura Sea

ABSTRAK: Laut Arafura berlokasi di antara Papua dan Australia sebagai bagian dari Paparan Sahul. Kondisi iklim sangat dipengaruhi oleh ITCZ, perpindahan ITCZ, monsun, dan ENSO yang berinteraksi dengan mekanisme lokal. Untuk memahami perubahan parameter oseanografi selama Holosen, kami melakukan analisis kuantitatif mikrofauna foraminifera, yang dilakukan terhadap sebuah bor sedimen laut sepanjang 152 cm (Aru-07) pada interval setiap 10 cm. Bor sedimen bawah laut ini telah diambil pada posisi 134°00'33.6" BT, 5°55'51.59" LS, menggunakan kapal penelitian Geomarin 3, Pusat Penelitian Geologi Kelautan. Geokronologi sedimen berdasarkan 2 radiocarbon dating, dianalisis dari sampel organik pada sedimen. Teridentifikasi 129 spesies bentik dan 24 spesies planktonik yang didominasi oleh planktonik dengan persentase rata-rata 53.14%. Foraminifera jenis-jenis yang dominan antara lain *Globigerina bulloides* (16.16%), *Globigerinoides ruber* (11.18%), dan *Neogloboquadrina dutertrei* (5.65%). Sedangkan jenis bentik didominasi oleh genus *Bolivina*, *Bulimina*, dan *Uvigerina*, dengan persentase rata-rata 25.86%. Hal tersebut kemungkinan menunjukkan kondisi eutropik yang berasosiasi dengan kondisi kaya karbon dan rendah level oksigen (disoxic). Analisis cluster single linkage menunjukkan tiga zona utama, yaitu: Zona I: lebih tua dari 3.9 kyr BP, dicirikan oleh relatif rendahnya kandungan oksigen dan lebih kaya kandungan nutrisi. Zona II: 3.9 – 2 kyr BP, dicirikan oleh meningkatnya kandungan oksigen, dan mendalamnya lapisan termoklin, berkaitan dengan meningkatnya muka air laut ketika kondisi netral atau kondisi seperti La Niña. Zona III: lebih muda dari 2 kyr BP, merupakan zona dengan kondisi lapisan termoklin yang mendangkal, produktifitas

meningkat yang kemungkinan berkaitan dengan upwelling, dan kondisi disoxic. Muka air laut kemungkinan turun, berasosiasi dengan kondisi seperti El Niño.

Kata kunci: Perubahan paleoseanografi, upwelling, analisis foraminifera, Laut Arafura

INTRODUCTION

Indonesian archipelago is the only low latitude pathways of the global inter-ocean circulation connecting waters from the Pacific Ocean to the Indian Ocean through the Indonesian Throughflow (ITF, e.g. Gordon, 2005; Mayer *et al.*, 2010). Study area is located at the northwestern tip of Arafura Sea (referred as Arafura Shelf), eastern part of Indonesian waters as a part of Sahul Shelf, to the east of the Banda Sea. It is passed through by ITF transport derived both from Banda Sea and from the third pathway of ITF through the Halmahera Sea and Lifamatola which is dominated by South Pacific water (Figure 1). Therefore, the variability of ITF strongly influences the climatic condition in this region which is driven by latitudinal shift of the Intertropical Convergence Zone (ITCZ), coupled with Australian monsoon. During Australian Summer (DJF), northwesterly winds (thus known as northwest/NW monsoon) bring wet and moist air from Indian Ocean and Indonesian Archipelago to the northern Australia, the ITCZ shift southward resulting heavy precipitation over southern Indonesia including Banda Sea, Arafura shelf and northern Australia. During this wet season, nutrient enrichment might be occurred largely derived from fluvial discharge. In

contrast during Australian winter (JJA), strong trade wind brings cool and dry air from the Australian continent, thus termed as southeast (SE) monsoon. The ITCZ migrates northward lead to suppress atmospheric convection in the eastern Banda Sea and surrounding, decrease precipitation and moreover might induce large scale upwelling because of the emptiness of the water column (Moore *et al.*, 2003 and references therein).

The climate in this area is also modified by the mechanism in Timor and Papua islands that is related to high topographic relief and mountains (Alongi *et al.*, 2011). It is also situated within Indo Pacific Warm Pool (IPWP), therefore inter annual climatic variability i.e. ENSO circulation interferes the climatic condition in the study area. Moore *et al.* (2003) and Beaufort *et al.* (2010) observed that productivity in Banda Sea indicates not only seasonal variability but also inter-annually, which related to the ENSO circulation. It is observed that during El Niño years the primary productivity tends to last longer and more intensive (Moore *et al.*, 2003). Furthermore, Linsley *et al.* (2010) have compiled data within Indonesian waters and surrounds as a part of IPWP (Sulu Sea, Banda Sea, Makassar Strait, Bali Basin, Timor Sea, South China Sea) and described that elevated SST during Early

Holocene in those area was more correlated to the westward shift or the expansion of the West Pacific Warm Pool boundaries. This finding led to the question: how about Arafura Sea? Is this area also more affected by West Pacific dynamic particularly during Holocene?

Arafura Sea is a part of Coral Triangle that is occupied by high diversity of the world marine organism. It is also an area nearby the large oil and gas field, including Abadi and Tangguh gas field (Roberts *et al.*, 2011). In addition to that this area shares a border between 4 nations are Indonesia, New Guinea, Timor-Leste and Australia, therefore studying the environmental condition of this area will give positive feedback for every aspect including oceanography, climatology, biodiversity, economic, and geo-politic.

The purpose of this study is to understand the paleoceanographic condition during Holocene derived from foraminiferal assemblages, which may provide a clue in determining air-sea interaction in the Arafura Sea. Foraminifera is marine organism that has been used widely as paleoceanography and

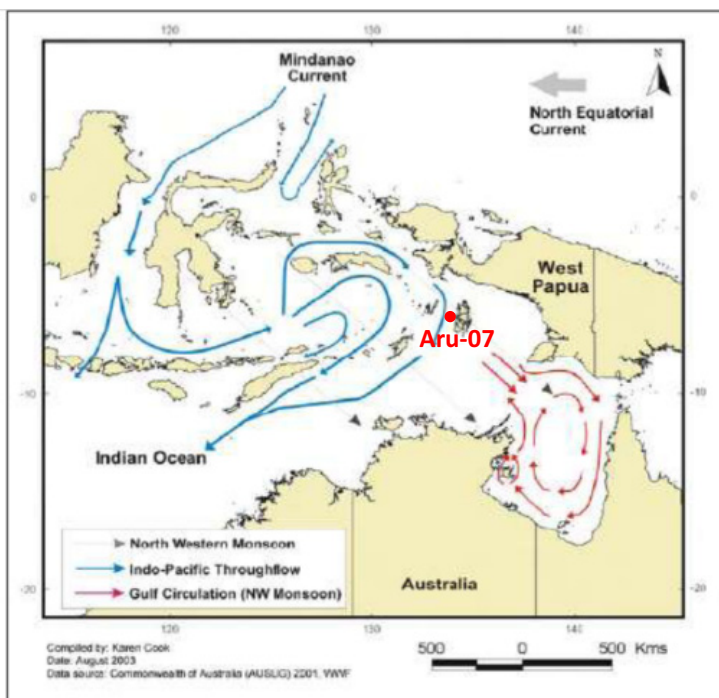


Figure 1. The Indonesian through flow pathways and their transport volume estimation (figure from Alongi *et al.*, 2011). Red dot is the position of sediment core for this study (Aru-07).

paleoclimatology proxy both from its shell geochemistry and from its assemblages. The abundance of typical genera or species might interpret certain environmental condition. For example group of *Bulimina*, *Bolivina*, and *Uvigerina* commonly abundant in dysoxic condition, *Neogloboquadrina dutertrei*, *Globigerina bulloides*, and *Pulleniatina obliqueloculata* are abundant in thermocline layer and prefer to live in eutrophic condition, which might be related to upwelling process, in contrast *Globigerinoides ruber* and *Globigerinoides sacculifer* will be dominant in mixed layer and thrived in warm and oligotrophic condition (e.g. Baohua *et al.*, 1997; Barmawidjaja *et al.*, 1993; Ding *et al.*, 2006; Drinia *et al.*, 2003). Its large population in marine sediment and its relatively simple and cheap preparation are the superiority of this method.

Previous study of foraminiferal assemblages has been done in Banda Sea during Cruise G5 of the Indonesian – Dutch Snellius-II Expedition, which was conducted during northeast monsoon (April/May 1985). The finding indicates that during this season planktonic foraminifera is dominated by *Globigerinoides ruber* and *Globigerinoides trilobus*, typical for low nutrient condition (Troelstra and Kroon, 1989). From this cruise, bathymetric distribution of foraminifera in Banda Sea has been also studied which related to the oceanographic condition of this area (van Marle, 1988). Furthermore, Ganssen *et al.* (1989) studied paleo-climatology and paleoceanography during Late Quaternary in Banda Sea and Seram Trough based on multi proxy analyses including foraminiferal assemblages and its shells isotope. Their finding indicates 2 steps deglaciation in 14.2 ka and 9.2 ka which led to increase humidity rather than to the SST variation. They observed that since ca. 10.5 the climate was wetter, and from ca. 9.2 ka upwelling intensity increase due to stronger monsoon. Monsoonal intensity then decreased in about 2.7 ka.

Geological Setting

Arafura Shelf is an extension of the stable northern Australian shield area, a submerged of Australian continental crust, bounded by an extinct accreting plate margin (Jongsma, 1974). Tertiary orogenic belts of Banda Arc and Timor are the border in the west and northwest, Tertiary collision zone between the Australian Craton and the Northern Papua Island Arc in the north, Australian Craton is the border in the south, and graben of Gulf Carpentaria in the east (Harahap, 2012; Jongsma, 1974). Deep Aru Basin and Timor Trough as part of the Outer Banda Arc separated Arafura and Sahul Shelves from the Tertiary geosyncline of Timor and East Celebes (Jongsma, 1974).

Basement of Arafura Sea and southern region of Papua is interpreted as pre-Cambrian rock and Cambrian to Devonian, which then unconformably overlain by the Permian Aiduna Formation of the Aifam Group (compiled by Harahap, 2012). Unconformity regional revealed at the base of the Mesozoic, overlies the pre-Cambrian. Recent terrigenous sediments are restricted in the inner part, with coarse shelly quartz sand grading into silty clay seaward, while the outer part composed of Pleistocene relict sediment which are extensively glauconitized, some of the surface sediment particularly in the northeast are originated from eroded calcareous quartz-rich Tertiary sediment (Jongsma, 1974). Beach rock and shallow water corals are found at 200 m water depths as evidence of extremely low sea level stand during glacial period older than 170.000 years BP and during 14.000 years BP (Jongsma, 1974).

Million years ago, the position of Papua, New Guinea and Australia were further south than their present position. Reorganization of the SE Asia including subduction of oceanic crust beneath the SE Asia led to the northward movement of Australia and New Guinea, and westward displacement of Halmahera, hence narrowing Indonesian seaway between the Philippine and Papua, and hampered the throughflow (Cane and Molnar, 2001; Hall, 1996; Kuhnt *et al.*, 2004). Convergent of Bird's Head and Sulawesi, and between Bird's Head and Seram have resulted in shallowing of Molucca Sea and seafloor between New Guinea Papua and Sulawesi (Cane and Molnar, 2001). As a result, the inflow from relatively warm South Pacific was switched into relatively cold North Pacific, led to decrease the SST in the Indian Ocean and increase aridity in Africa. It is also presumed that the restriction of Australia – Asia gap initiated the existence of WPWP (Cane and Molnar, 2001; Kuhnt *et al.*, 2004).

Oceanography

Water Depths of Sahul Shelf are mostly less than 200 m, it increases from Australia toward Timor Trough and the Banda Sea, marked by steep slope along its western edge which deeper than 600 m (Harahap, 2012; Jongsma, 1974; Williams *et al.*, 1974). Mixed layer is between 20 to 50 m in the end of upwelling season (October) and up to 100 m in the early March (Williams *et al.*, 1974; Wyrski, 1961). Temperature and salinity measurement were carried out during the Cruise of R.V. "Samudera", indicated between 25.6° and 27.0° C of surface temperature in August 1984, and between 28.4° and 29.6° C in February 1985, while mean surface salinity during August is 33.00, lower than that during February (33.45) (Ilahude *et al.*, 1990). Higher surface salinity during August is related to the upward movement of cool and more saline deeper water

induced by upwelling which also bring more nutrient to the surface. Wyrki (1961) also noted that upwelling during SE monsoon is considerably observed in this water. Upwelling particularly takes place along the shelf and slope in the western part with relatively high inorganic phosphate and low oxygen level in the surface (Jongsma, 1974). Being a part of the Coral Triangle, Arafura Sea is known as one of the extremely high productivity and recognized with the most pristine but most endangered tropical coastal and marine ecosystems in the world (Alongi *et al.*, 2011 and reference therein).

Major oceanic feature in Indonesian waters including Arafura Sea is the Indonesian Throughflow (ITF), branch of global thermohaline circulation which connecting water from Pacific Ocean to the Indian Ocean (Gordon, 2005; Mayer *et al.*, 2010). The ITF is coupled with large scale climatic phenomena including ENSO circulation driven by the gradient density between West Pacific and East Pacific, Australian monsoon and Indian Ocean Dipole (Alongi *et al.*, 2010; Gordon, 2005; Newton *et al.*, 2011).

METHODS

This study is a part of a collaborative project between Indonesia (Marine Geological Institute) with the Korea Institute of Ocean Science & Technology (KIOST). For this study, we conduct quantitative analysis of microfauna foraminifera from marine sediment core Aru-07, a 152 cm length sediment core, retrieved from west of Aru Islands, Arafura Sea (134°00'33.6" E, 5°55'51.59" S, figure 2). The core was collected from 276 m water depth, on board

Geomarin 3, Marine Geological Institute of Indonesia. Foraminiferal assemblage was analyzed in every 10 cm interval, in total, 15 samples were analyzed. Approximately 300 individu of foraminifera were picked from > 150 µm size fraction, in order to eliminate the juvenile form (Spooner *et al.*, 2005). In relatively large volume of samples, sample was firstly splitted to contain at least 300 individu of foraminiferal shells. Shells were handy picked and multiplied by splitter, then foraminiferal taxon were identified refer to Bolli *et al.* (1985), Holbourn *et al.* (2013), Loeblich and Tappan (1994), Postuma (1971), and van Marle (1988). Determination was also referred to foraminiferal websites including <http://www.foraminifera.eu>, <http://www.marinespecies.org> (World Register of Marine Species, WoRMS), and <http://species-identification.org>.

Geochronology of the sediment was reconstructed based on radiocarbon AMS ¹⁴C dating, analyzed on organic samples collected from 2 sample horizons, by the Korean counterpart. The resulted radiocarbon age was then converted into calibrated calendar age by calculating the distribution probability of the samples true ages by CALIB 7.0.4, an online software first developed by Stuiver *et al.* in 1986, and the latest version in 2018, by using the Intcal13 calibration data set (Reimer *et al.*, 2013, in conjunction with Stuiver and Reimer, 1993). Intcal13 is commonly used for no-marine sample (Reimer *et al.*, 2013). Derived calendar age is presented in term Before Present (BP), where “present time” is defined as AD 1950 (Currie, 2004). The calibrated age was then interpolated and extrapolated in Kaleidagraph 4.5 a software from Synergy.

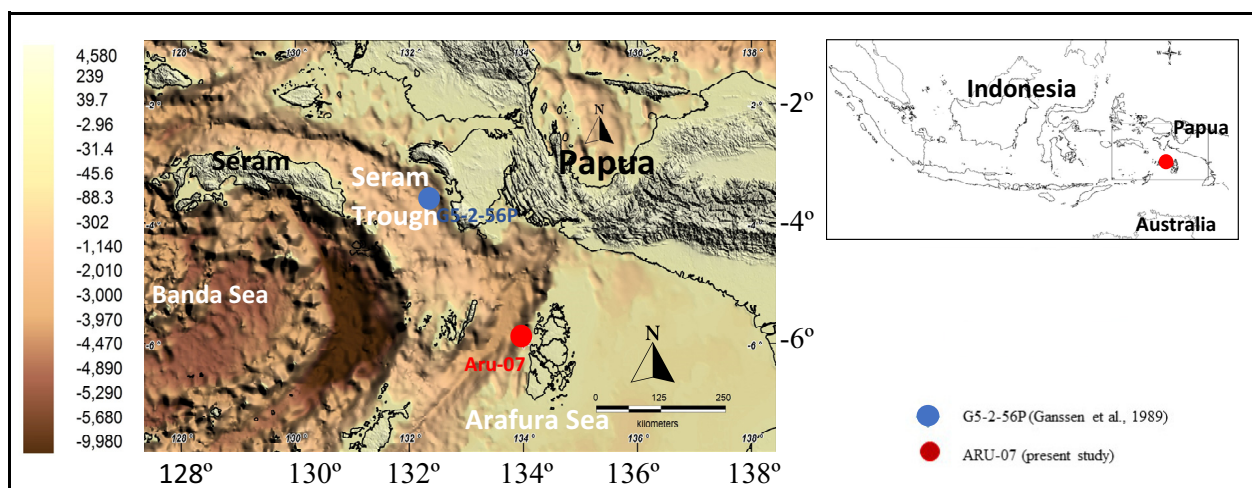


Figure 2. Map of the study area in Arafura Sea, red circle is the position of the marine sediment core Aru-07. Colour indicates elevation.

RESULTS

Geochronology

For geochronology, 5 horizons were chosen, however, only two samples (horizon 22-24 cm and 122-124 cm) that are considered revealing true age. Sample at horizons 15-17 cm indicates older age (3000 older),

and the other two horizons (66-68 cm, and 146-148 cm) display younger age (2000 and 3000 yr younger respectively) than the one derived from the age model (Table 1, Figure 3). The average sedimentation rate is 6.56 cm/kyr BP during 3 kyr, and 25.2 cm/kyr BP during 7.5 kyr (Figure 4).

Table 1. Data of sample for radiocarbon dating, resulted and calibrated age

No	sample	PT_Material	c13_DAT	Conventional Age	Calender age (BP) 2 sigma Cal	sed. rate (cm/kyr)
1	ARU-07(15-17cm)	(organic sediment): acid washes	-20.7 o/oo	6490 +/- 40 BP		
2	ARU-07(22-24)	(organic sediment): acid washes	-21.2 o/oo	3270 +/- 30 BP	3508 ± 63	6.56
3	ARU-07(66-68cm)	(organic sediment): acid washes	-21.2 o/oo	3110 +/- 30 BP		
4	ARU-07(122-124)	(organic sediment): acid washes	-21.4 o/oo	6590 +/- 30 BP	7474.5 ± 43.5	25.21
5	ARU-07(146-148cm)	(organic sediment): acid washes	-20.1 o/oo	5420 +/- 30 BP		

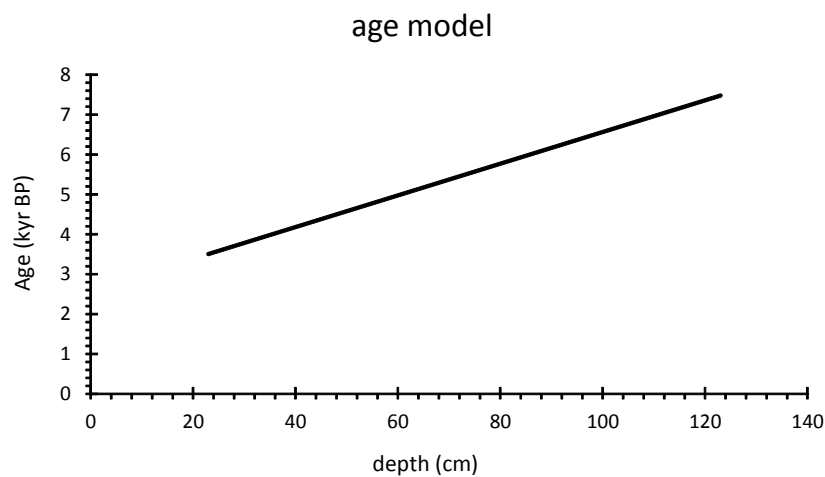


Figure 3. Age model reconstruction of marine sediment core Aru-07

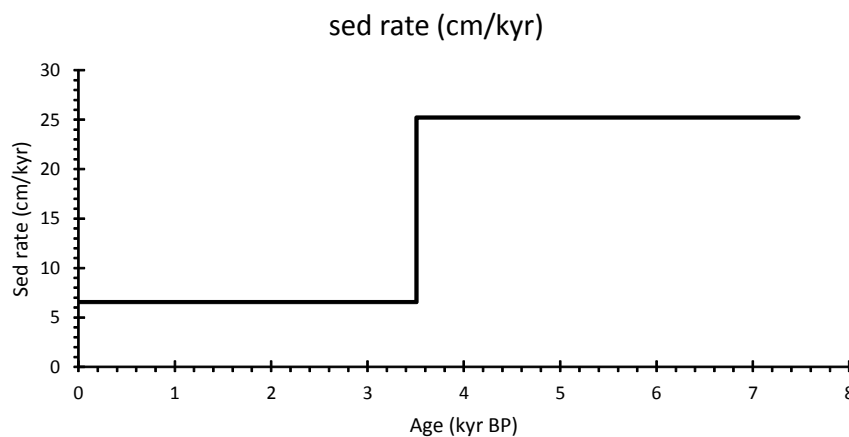


Figure 4. Sedimentation rate of marine sediment core Aru-07

Foraminifera

There are 153 species of foraminifera found vertically in the study area that consists of 129 benthic and 24 planktonic. One unidentified benthic and unidentified juvenile planktonic is also found (Appendix 1). Planktonic foraminifera is slightly more dominant with average percentage 53.14%. The highest percentage is in the top part of the core (10-12 cm, 82.66%), the lowest planktonic percentage is in 110-112 cm interval (29.89%). The dominant planktonic foraminifera are *Globigerina bulloides* with average percentage 16.16%, *Globigerinoides ruber* (11.18%), *Neogloboquadrina dutertrei* (5.65%), and *Globorotalia*

menardii (4.09%). Moreover, *Pulleniatina obliqueloculata*, *Hastigerina pelagica* and *Globigerinoides sacculifer* are also commonly found with percentage average 3.41%, 2.93%, and 2.49% respectively (Figure 5).

Dominant benthic foraminifera particularly are *Bolivina compacta* (14.26%) found in every level, *Bulimina* spp. (particularly *B. marginata* and *B. pagoda* type) with total average percentage 5.23%, *Uvigerina peregrina* (2.67%), *Paracassidulina neocarinata* (1.66%), and *Lenticulina* cf. *L. iota* (1.29%). In general, total of genera *Bolivina*, *Bulimina*, and *Uvigerina* are dominant, with percentage average 25.86%.

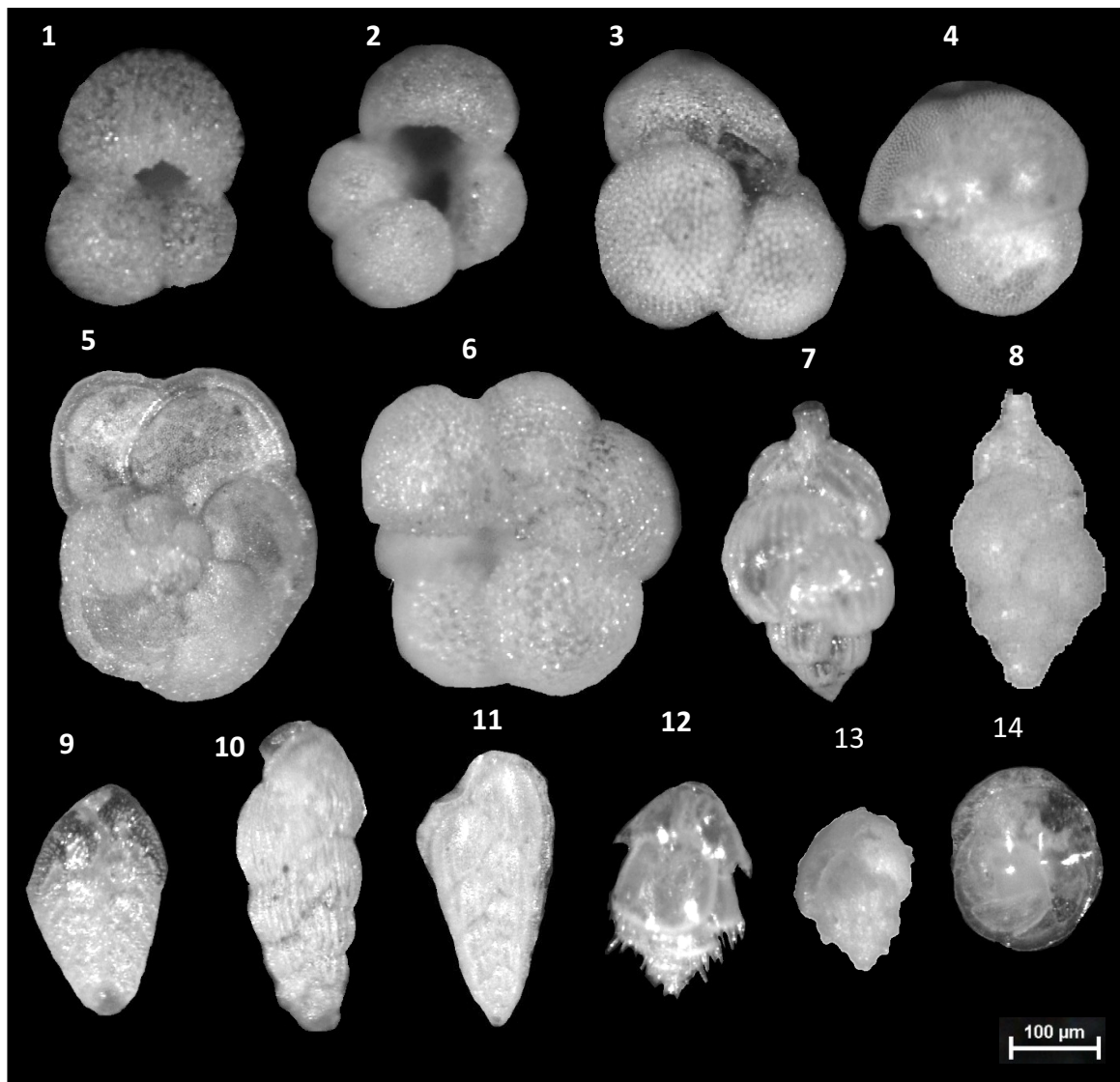


Figure 5. Dominant foraminifera: planktonic foraminifera: 1). *Globigerinoides ruber* (d'Orbigny), 2). *Globigerina bulloides* d'Orbigny, 3). *Globigerinoides sacculifer* (Brady), 4). *Pulleniatina obliqueloculata* Parker and Jones, 5). *Globorotalia menardii* (d'Orbigny), 6). *Neogloboquadrina dutertrei* d'Orbigny, benthic foraminifera: 7). *Uvigerina peregrina* Cushman, 8). *Uvigerina proboscidea* Schwager 9). *Bolivina compacta* Sidebottom, 10). *Saidovina karreriana* (Millet) 11). *Bolivina hantkeniana* Brady, 12). *Bulimina pagoda* Cushman, 13). *Bulimina marginata* d'Orbigny, 14). *Paracassidulina neocarinata* (Thalman).

Single linkage cluster analysis applied to the assemblage of foraminifera (Figure 6), dividing cluster by distance 25, reveals 3 main group, are:

Zone I: older than 3.9 kyr BP, characterized by relatively high percentage of dysoxic type of benthic ($\pm 41\%$ in average) and lower planktonic percentage compared to that of younger zone (Figure 7). Planktonic is dominated by thermocline layer dweller including *Globigerina bulloides*, *Neogloboquadrina dutertrei*, and *Pulleniatina obliqueloculata*. While dysoxic type of benthic exhibit higher percentage compared to that of younger zone. This might reflect higher nutrient content condition and lower oxygen level. This situation is also confirmed by relatively lower *Globigerinoides ruber* and *Globigerinoides sacculifer*.

Zone II: 3.9 – 2 kyr BP, characterized by increase of planktonic type, particularly abrupt increase of *Globigerinoides ruber* and *Globigerinoides sacculifer*, and the increase of mixed layer dweller type. In contrast, thermocline layer dweller type slightly decreased, as well as *Neogloboquadrina dutertrei* and benthic dysoxic type. Sea level might be increased,

lead to increase oxygen content, deeper thermocline layer and thicker mixed layer. Slightly increase of *Pulleniatina obliqueloculata* while *Neogloboquadrina dutertrei* decrease might exhibit changes in nutrient source. Detrital derived nutrient might be more dominant due to increase precipitation.

Zone III: younger than 2 kyr BP, characterized by decrease of planktonic percentage, *Globigerinoides ruber*, *Globigerinoides sacculifer*, and mixed layer dweller type, in contrast thermocline layer dweller, dysoxic genera, *Pulleniatina obliqueloculata*, and *Neogloboquadrina dutertrei* are increased. Sea level might be drop during this time, lead to shallower thermocline layer, and thinning the mixed layer, productivity increase hence oxygen content decline.

DISCUSSION

In general, total of genera *Bolivina*, *Bulimina*, and *Uvigerina* are dominant, with percentage average 25.86%. This might suggest eutrophic condition associated with carbon-rich or low oxygen level (dysoxic) condition (i.e. Boltovskoy and Wright, 1976; Jorissen, 1987; Martins *et al.* 2015; etc.). The nutrient enrichment at this site during the last 9 ky BP is also

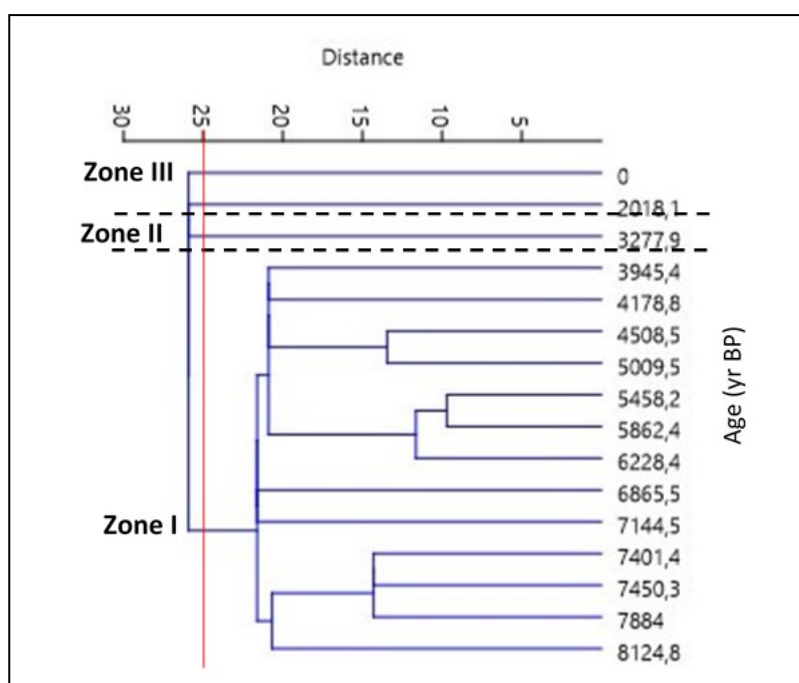


Figure 6. Cluster analysis of microfaunal percentage indicate 3 different biozone in marine sediment Aru-07.

indicated by relatively high percentage of *Globigerinoides bulloides*, *Neogloboquadrina dutertrei*, *Globorotalia menardii*, and *Pulleniatina obliqueloculata*, which are known to be species prefer to live in high nutrient level (e.g. Barmawidjaja *et al.*, 1989; 1993; Baohua, 1997; Ding *et al.*, 2006; Drinia *et al.*, 2003; Mohtadi *et al.*, 2009; Sijinkumar *et al.*, 2011; Spooner *et al.*, 2005; Tedesco *et al.*, 2007). High nutrient might be resulted from enhance upwelling that fluently occurred nearby Arafura Sea. As has been described above upwelling intensification is one of the Banda Sea and surrounding's responds particularly to the SE monsoon event (Moore *et al.*, 2003). According to Ganssen *et al.* (1989), upwelling enhanced nearby Banda Sea and seram Trough from 9 ka related to stronger monsoon regime. Ilahude *et al.* (1990) observed that during August (SE monsoon) nutrient level in surface and bottom water in Arafura Sea is very rich due to stronger upwelling. Meanwhile, during NW monsoon (February), upwelling weakened hence productivity decline. However, nutrient is still higher compared with that of Banda Sea during this time derived from terrestrial input, mostly from Papua, and

decreased, particularly *Neogloboquadrina dutertrei* is absent during this time. Sea level might increase, which initiated the warmer Late Holocene time. The increase of mixed layer dweller indicates thickening of mixed layer hence deepening the thermocline layer depth. Increase of *Globigerinoides ruber* might suggest nutrient declined, similar with the result of Troelstra and Kroon (1989) who studied foraminiferal assemblages from surface water of Banda Sea during North western monsoon, they observed that during this season frequency of *Globigerinoides ruber* and *Globigerinoides trilobus* are the highest suggest oligotrophic condition. Afterwards sea level abruptly decreased again from ca. 2 kyr BP, indicated by decrease of total planktonic percentage and decrease of mixed layer dweller species *Globigerinoides ruber* and *Globigerinoides sacculifer* (Figure 7). Mixed layer is thinner during this time, as a result shoaling thermocline layer. Nutrient content is higher indicated by increase of *Neogloboquadrina dutertrei* and *Pulleniatina obliqueloculata* might be resulted from enhance upwelling. It has been reported that during ca. 2000 to 800 yr El Niño was stronger or more often,

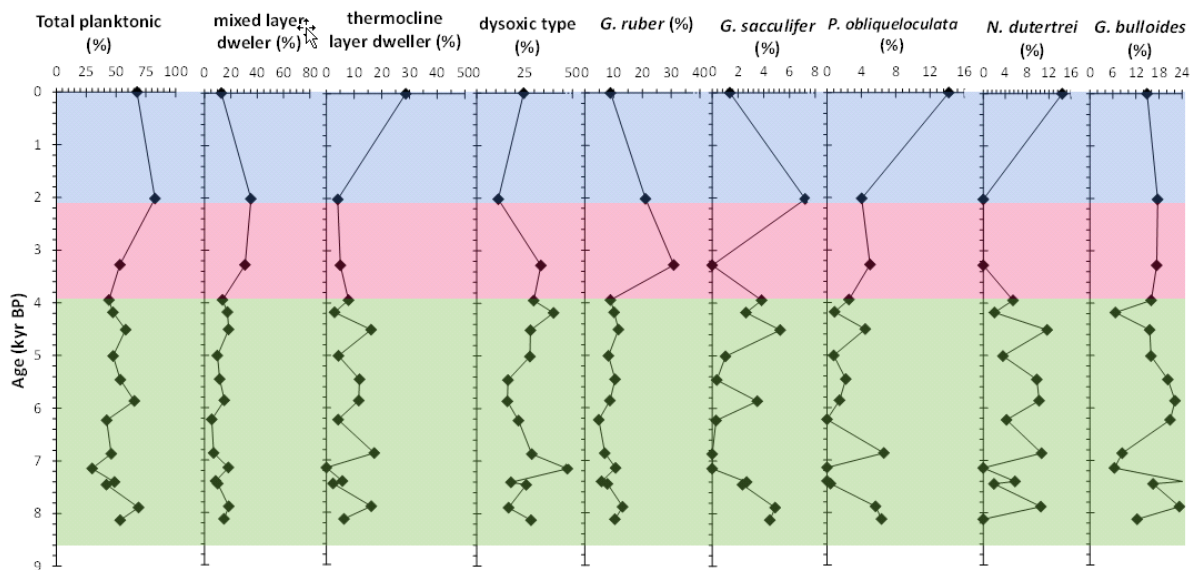


Figure 7. Predominant species percentages including group of dysoxic type, mixed layer dweller, and thermocline layer dweller.

partly from Aru, Yamdena and Kei Islands (Alongi *et al.*, 2011).

Distinctive environmental changes occur from approximately 3.9 kyr BP, indicated by clear increase of total planktonic percentage, abrupt increase of mixed layer dweller species including *Globigerinoides ruber* and *Globigerinoides sacculifer*, in contrast thermocline layer dweller species and dysoxic type genera are

trade wind was weakened hence reduce heat flux transport from Pacific to Indian Ocean (Newton *et al.*, 2011). Meanwhile, Langton *et al.* (2008) found more neutral or La Niña – like condition during 3500 – 1700 yr BP in Kau Bay, Halmahera, Indonesia, that associated with sea level rise and increase terrigenous input during this time. After 1700 yr BP, thermocline

shoaling occurred in WPWP related to intensification of more El-Niño-like condition thus improve ventilation.

CONCLUSION

In general, during Holocene, according to the foraminiferal assemblages, the water condition in the Arafura Sea particularly in the western of Aru Islands is relatively dysoxic and high nutrient. Distinctive environmental changes particularly occurred in 3.9 kyr BP indicated by clearly increase of total planktonic and mixed layer dweller percentage. It might be related either due to the sea level rise and thickening of mixed layer, or the nutrient decline. More neutral or La Niña like condition might be occurred during this time. Sea level might be drop after 2 kyr BP that might be related to the more El Niño like condition, lead to increase upwelling and nutrient content, and improve ventilation. However, more analysis is needed in order to get more robust finding.

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4.9	interpolated age	
2018	Benthic	
3278	<i>Ammonia</i> spp. (3 species)	
3945	<i>Angulogerina angulosa</i> (Williamson)	
4179	<i>Bolivina compacta</i> Sidebottom	
4509	<i>Bolivina</i> spp. (6 species)	
5010	<i>Bulimina</i> spp. (7 species)	
5458	<i>Caribbeanella</i> spp. (2 species)	
5862	<i>Chilostomella oolina</i> Schwager	
6228	<i>Cibicides</i> spp. (3 species)	
6866	<i>Discorbinella</i> spp. (2 species)	
7145	<i>Elphidium</i> spp. (2 species)	
7401	<i>Eponides</i> spp. (3 species)	
7450	<i>Evolvocassidelina</i> spp. (2 species)	
7884	<i>Globocassidulina subglobosa</i> (Brady)	
8125	<i>Gyroidina</i> sp.	
Average	<i>Hansenisca soldanii</i> (d'Orbigny)	
1.31	<i>Hanzawaia mantaensis</i> (Galloway & Morrey)	
0.24	<i>Heterolepa</i> spp. (2 species)	
14.26	<i>Hoeglundina elegans</i> (d'Orbigny)	
2.37	<i>Hyalinea baltica</i> (Schroeter)	
5.23	<i>Lenticulina</i> cf. <i>L. iota</i>	
0.28	Other <i>Lenticulina</i> spp. (4 species)	
0.47	<i>Melonis barleeianum</i> (Williamson)	
0.67	<i>Neoeponides auberii</i> (d'Orbigny)	
0.62	<i>Nonionoides</i> spp. (3 species)	
0.31	<i>Paracassidulina neocarinata</i> (Thalmann)	
0.73		
0.44		
0.64		
0.20		
0.92		
0.29		
0.20		
0.38		
0.97		
1.29		
0.94		
1.27		
0.61		
0.84		
1.66		

interpolated age	Benthic	Planulina sp.1	Quinqueloculina spp. (5 species)	<i>Uvigerina peregrina</i> Cushman	Other <i>Uvigerina</i> spp. (2 species)	Other Textularina (5 species)	Other rare taxa (< 0.2%, 63 species)	unidentified (broken)	Planktonic	<i>Globigerina bullides</i> d'Orbigny	<i>Globigerinoides immaturus</i> LeRoy	<i>Globigerinoides ruber</i> (d'Orbigny)	<i>Globigerinoides sacculifer</i> (Brady)	<i>Globorotalia menardii</i> (d'Orbigny)	Other <i>Globorotalia</i> (4 species)	<i>Hastigerina aequilateralis</i> (Brady)	<i>Hastigerina pelagica</i>	<i>Neoglobobquadrina dutertrei</i> d'Orbigny	<i>Pulleniatina obliqueloculata</i> Parker & Jones	<i>Tenuitella anfracta</i> (F.L. Parker)	Other rare taxa (< 0.5%, 10 species)	planktonic juvenile	Total bentic (%)	Total planktonic (%)	Dysoxic type (%)				
4.9			0.69	2.97	1.60	0.92	14.87			8.92	1.37	5.26	0.69	2.52	5.03	14.42	14.19	0.23	32.49	67.51	24.49								
2018				1.73		2.31	17.63			21.10	7.23	9.83	6.94	14.74		1.16	17.34	82.66	11.27	17.34	82.66	11.27							
3278				6.07		4.22	17.41			30.87										5.01		46.70	53.30	33.51					
3945			0.64	3.19	1.28	3.19	15.97	0.96		8.95	3.83	4.15	0.96			2.24	55.91	44.09	29.71	55.91	44.09	29.71							
4179			1.16	2.91	0.87	2.33	6.69			10.17	2.62	5.52	4.65	9.30		0.29	52.62	47.38	40.12	52.62	47.38	40.12							
4509			0.56	2.78	1.39	5.00	15.56			11.67	5.28	2.78	1.39			0.83	41.94	58.06	28.06	41.94	58.06	28.06							
5010		0.77	1.03	1.80	0.26	4.11	15.94			8.23	1.03	0.77	2.31	0.51		3.86	52.44	47.56	27.76	52.44	47.56	27.76							
5458		2.17		0.72		5.43	20.29			10.51	0.36	3.99	0.72	0.72		1.45	46.38	53.62	16.30	46.38	53.62	16.30							
5862				1.17	0.87	3.21	22.16			8.75	3.50	7.58	0.87	2.92		1.52	34.69	65.31	16.03	34.69	65.31	16.03							
6228			1.21	0.61	2.12	7.27	20.91			4.85	0.30	5.45	1.21	0.30		1.75	57.88	42.12	21.82	57.88	42.12	21.82							
6866				1.84	1.10	4.04	8.46			6.99		2.94					54.04	45.96	28.68	54.04	45.96	28.68							
7145			1.42	10.32	1.07	2.14	6.41			10.68		2.49		7.47			70.11	29.89	47.33	70.11	29.89	47.33							
7401		0.89	0.89	1.34	4.91	5.36	24.11			5.80	2.68	2.23	2.23			3.13	51.34	48.66	17.86	51.34	48.66	17.86							
7450		1.18	1.57	0.78	3.53	5.49	16.47			7.84	2.35	1.18				8.24	58.04	41.96	25.88	58.04	41.96	25.88							
7884				1.88	2.26	1.88	23.31	1.50		13.16	4.89	5.26	0.38			4.14	31.20	68.80	16.54	31.20	68.80	16.54							
8125			1.12	2.61		2.99	12.31	1.87		10.45	4.48	5.97				6.34	46.64	53.36	28.36	46.64	53.36	28.36							
Average	0.31	0.64	2.67	1.33	0.76	3.74	16.16	1.10		11.18	2.49	4.09	0.54	1.80	2.93	5.65	3.41	0.95	2.24	46.86	53.14	25.86							

