Bulletin of the Geological Society of Malaysia, Volume 72, November 2021, pp. 137 - 149
DOI: https://doi.org/10.7186/bgsm72202111

A preliminary study in vertical distribution of planktonic foraminifera and marine ecological conditions of Simeulue sub-basin, Aceh, Indonesia

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Abstract: A marine sediment core EW17-09 (03˚ 28'358" latitude and 96˚ 18'788" longitude, 870 m water depth, 390 cm core length) was retrieved from the western Sumatra, Simeulue sub-basin, Indonesia. Simeulue sub-basin are situated in eastern Indian Ocean, western part of Aceh Province, which is one of the outer islands in Indonesia. This sub-basin is influenced by adjacent lands in response to tectonic and climate dynamics. The dynamics of marine ecological conditions in the past is an urgent need for providing an analogy to the changes in the future conditions. In this study, the ecological conditions were examined by identifying the vertical distribution of planktonic foraminifera assemblages. This preliminary study demonstrated the presence of *Globigerinoides ruber, Neogloboquadrina dutertrei, Pulleniatina obliquiloculata, Globigerina calida calida, Globigerinoides elongates, Globigerinoides cyclostomus* and *Globigerinoides sacculiferus* in the samples. The assemblages indicate warm water conditions prevailed in the Simeulue sub-basin during the deposition of the samples. However, subtle ecological changes might have occurred in response to the dynamic of thermocline layer. Cluster analysis of planktonic foraminifera abundance and diversity resulted in three groups showing different ecological conditions. Warm water conditions, high salinity, deeper thermocline with moderate sedimentation disturbance prevailed during the deposition of lower part of the core. Oligotropic water conditions with higher temperature, lower salinity, shallower thermocline layer, and moderate sedimentation disturbance predominated during the deposition of the middle part of the core. The paleooceanography conditions of the upper part of the core are comparable to the lower part. Nevertheless, there are a shoaling of the thermocline in the end of the period. These conditions may indicate an increase in upwelling fluctuations and may represent a change in the IOD-like mean state of the Indian Ocean.

Keywords: Planktonic foraminifera, abundance, diversity, marine ecology, Simeulue sub-basin

INTRODUCTION

Planktonic foraminifera are a group of pelagic organisms. This group inhabits around 500 m of water column depths across the open ocean (Fairbanks *et al*., 1982; Kuroyanagi & Kawahata, 2004; Pados & Spielhagen, 2014; Iwasaki *et al*., 2017; Rebotim *et al*., 2017). Planktonic foraminifera life cycle, growth and distribution are influenced by several ecological factors, such as salinity, temperature, depth, tides, current, oxygen levels, nutrients, sediment, turbidity, stratification, light intensity, food availability, and other ecological factors (Boltovskoy & Wright, 1976; Fairbanks *et al*., 1982; Kuroyanagi & Kawahata, 2004; Armstrong & Brasier, 2005; Zaric *et al*., 2005; Salmon *et al*., 2015; Rebotim *et al*., 2017). Foraminifera can be used to estimate ancient marine conditions because of their growing productivity and sensitivity to changes in marine ecological conditions. Their calcareous shell deposited in marine sediments are widely used to reconstruct past climatic conditions. Vertically, changes in the abundance and diversity of planktonic foraminifera may reflect changes in depth and time (Schiebel & Hemleben, 2017). Therefore, information about the marine ecological conditions by identifying planktonic foraminifera vertically is very important (Ardi *et al*., 2019).

The detailed compilation of spatial data on planktonic foraminifera assemblages are available from sea surface sediments around the Indonesian Archipelago, including in the Simeulue sub-basin (Ding *et al*., 2006; Mohtadi *et al*., 2007, 2009; Natsir & Wibowo, 2019; Saputro *et al*., 2019; Putra & Nugroho, 2019). A study by Ding *et al* (2006) showed that the characteristics of planktonic foraminifera groups in the western waters of Sumatra

0126-6187; 2637-109X / Published by the Geological Society of Malaysia.

illustrate an oligotrophic environment with low salinity, a low gap in seasonal temperature, shallow thermocline, and high dissolution. Furthermore, reports by Mohtadi *et al*. (2007) and Mohtadi *et al*. (2009) in the south and southwest of Indonesia revealed that planktonic foraminifera assemblages in the surface sediment reflect a clear response to current oceanographic conditions, ocean productivity, and upwelling. Interestingly, a down-core study off the coast of southwest Sumatra showed the upwelling conditions could not been obviously identified since the last 35 ka, except for the interval between 14 and 9 ka (Murgese *et al*., 2008). A down-core study to determine temporal changes in upwelling conditions of western Sumatra waters should be proven in detail. It will provide an analogy to changes the future marine ecological conditions.

Several downcore studies have been carried out in the Indonesian waters (Figure 1), which is that, MD98-2162 (Visser *et al*., 2003), MD98-2170 (Stott *et al*., 2004), MD98-2165 (Levi *et al*., 2007), MD01-2378 (Xu *et al*., 2008), MD01-2390 (Steinke *et al*., 2008), SO139-74 KL (Lückge *et al*., 2009), GeoB 10038-4, GeoB 10029-4 (Mohtadi *et al*., 2010), 13GGC (Linsley *et al*., 2010), SHI9034 (Ding *et al*., 2013), MD10-3339 (Gustiantini *et al*., 2015), GEOB10043-3 (Setiawan *et al*., 2015), SO184-10043 (Li *et al*., 2016), BS-36 (Zuraida *et al*., 2017), BS-24 (Li *et al*., 2018), ST-13 (Damanik *et al*., 2019), STA3 (Hendrizan *et al*., 2019), OS-07 (Damanik *et al*., 2020a, b), and ST-08 (Ardi *et al*., 2019, 2020). However, only a few studies have identified the abundance and diversity of vertical planktonic foraminifera distribution to determine the marine ecological conditions (i.e. Gustiantini *et al*., 2015; Ardi *et al*., 2019; Hendrizan *et al*., 2019; Damanik *et al*., 2019; Damanik *et al*., 2020b; Ardi *et al*., 2020). A downcore study have also been conducted in Simeulue sub-basin, such as Li *et al*. (2018) who reconstructed the spatiotemporal pattern of sea surface temperature (SST)

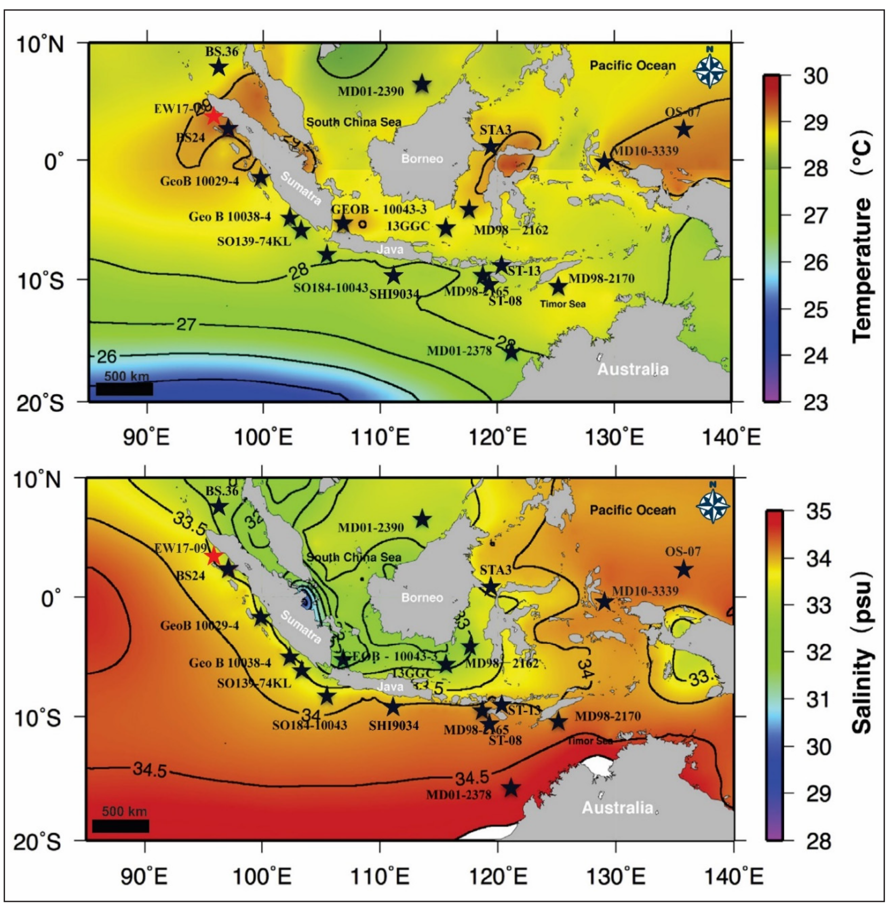

Figure 1: Location of sediment cores discussed in this study (black star): MD98-2162 (Visser *et al*., 2003), MD98-2170 (Stott *et al*., 2004), MD98-2165 (Levi *et al*., 2007)), MD01-2378 (Xu *et al*., 2008), MD01-2390 (Steinke *et al*., 2008), SO139-74 KL (Lückge *et al*., 2009), GeoB 10038-4, GeoB 10029-4 (Mohtadi *et al*., 2010), 13GGC (Linsley *et al*., 2010), SHI9034 (Ding *et al*., 2013), MD10-3339 (Gustiantini *et al*., 2015), GEOB10043-3 (Setiawan *et al*., 2015) , SO184-10043 (Li *et al*., 2016), BS-36 (Zuraida *et al*., 2017), BS-24 (Li *et al*., 2018), ST-13 (Damanik *et al*., 2019), STA3 (Hendrizan *et al*., 2019), OS-07 (Damanik *et al*., 2020a, b), and ST-08 (Ardi *et al*., 2019, 2020). Sediment location of Core EW17-09 (red star) (modified from Lückge *et al*., 2009; Mohtadi *et al*., 2010; Li *et al*., 2018). Annual mean SST and salinity in this area are based on the World Ocean Atlas 2009 (Locarnini *et al*., 2006; Antonov *et al*., 2010). (For interpretation of the color references in this image legend, the reader is referred to the Web version of the article.)

with inferred hydroclimate changes since the early Holocene (~11ka) as measured from Core BS24 in eastern Simeulue sub-basin, using proxies of planktonic foraminifera shell Mg/Ca, organic biomarker (TEX86), foraminifera oxygen isotopes, and a terrigenous BIT index. Several vertical planktonic foraminifera studies, such as Hendrizan *et al*. (2019) conducted a downcore study in the Sulawesi Sea (Figure 1) which is affected by the Indonesian Through Flow (ITF) and reported that the composition of foraminifera species indicated an insignificant environmental change along the sediment core. These foraminifera assemblages reflect the characteristics of warm water mass, low oxygen, and high organic intake. At the same time, Ardi *et al*. (2019, 2020) used planktonic foraminifera for a downcore study in Sumba (Figure 1). The relative abundance of thermocline dweller taxa consisted of *Neogloboquadrina (N.) dutertrei, Puleniatina (P.) obliquiloculata* and *Globorotalia (G.) menardii* was used in paleoecological studies that focused on thermocline depth parameters.

Simeulue sub-basin is situated in the low latitudes, located between the west tropical of the Pacific and the east of the Indian Ocean. The Simeulue sub-basin demonstrate surface water characteristics which reflect the contrasting seasonal climate characteristics in every year and is more dynamic (Mohtadi *et al*., 2010). These dynamics are influenced by the interaction between water masses and air-sea, including the Intertropical Convergence Zone (ITCZ) migration, changing intensity of the Asian-Australian monsoon, and the El Nino - Southern Oscillation (ENSO) (Schott & McCreary, 2001; Tomczak & Godfrey, 1994; Rosenthal *et al*., 2003). Upwelling offshore Sumatra is also sensitive to ENSO through changes in ITF intensity driven by easterly wind forces (Susanto *et al*., 2001). Paleoceanography study in this area was previously conducted by Hanebuth *et al*. (2000). They investigated sea level changes during the Last Glacial Maximum (21,000 years BP) across the Sunda Shelf.

With this regard, we conducted this preliminary study and focused on the vertical abundance and diversity of planktonic foraminifera in the Simeulue sub-basin. This study aims to determine the marine ecological characteristics such as salinity, thermocline, upwelling and sedimentation disturbances and their changes. This research is important and significant to better understand conditions of the warmest temperature in the western Sumatra waters (Figure 1). In addition, the waters are the outermost waters in the western part of Indonesia and are influenced by the surrounding land as a response to tectonic and climatic dynamics. We expect this understanding is required in the future to make a connection with Asian monsoon, Warm Pool West Pacific (WPWP) dynamics, El Nino events, and Indian Ocean Dipole (IOD) events.

REGIONAL SETTING

The climate in the western Sumatra is dominated by monsoonal circulation and seasonal migration from the Inter-Tropical Convergence Zone (ITCZ) and land-water distribution in the Malay Archipelago (Verstappen, 1975; Monk *et al*., 1997). During the boreal winter, the ITCZ position in the south and the northwest monsoon collects abundant moistures, while crossing the Southeast Asia and Indonesian seas results in a downpour in Sumatra (van der Kaars *et al*., 2010). In the meantime, during the boreal summer, the southeast monsoon originates from the high- pressure belts in the Southern Hemisphere. As a result, Indonesia becomes relatively dry and cold (van der Kaars *et al*., 2010). This condition creates moistures from the Indonesian seas, Southeast Asian seas, and the ITCZ move northwards and the high precipitation in mainland Southeast Asia.

The temperature gradient between the sea and the nearest continental mainland (East Asia and Australia) produces a monsoon wind blowing from the southeast during winter (August), and reverse direction during the summer (February) (van der Kaars *et al*., 2010).

The ocean currents at the research location move according to the wind regime (Figure 2, Gordon & Fine, 1996; Gingele *et al*., 2002). During the northwest (NW) monsoon, South Java Current (SJC) comes from the Equatorial Counter Current (ECC) and moves southeast to meet the Leeuwin Current (LC) - a narrow passage of warm water carrying saltwater from the eastern part of the Indonesian Archipelago (Tomczak & Godfrey, 1994). The combined the SJC and the LC form the Southern Equatorial Current (SEC) moves westward at -20 ° S (Figure 2). During the southeast (SE) monsoon, SJC takes the opposite direction to the northwest and forms the SEC without a significant contribution from the LC. The fresher water from Java Sea via Sunda Strait and the runoff from Sumatra and Java is responsible for the SJC "tongues" with as low salinity as 32 ‰. The SE wind also encourage the upwelling of the southern Java Sea associated with a decrease in sea surface

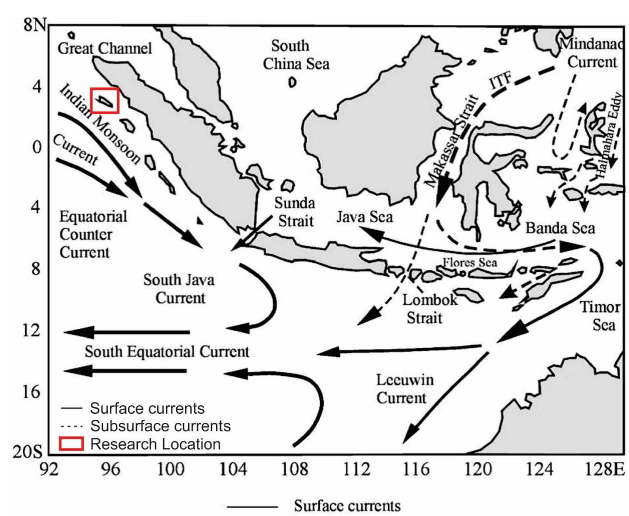

Figure 2: Sea current in Indonesia Archipelago (modified from Gordon & Fine, 1996; Gingele *et al*., 2002).

temperature (SST) and a higher chlorophyll concentration. At the same time, sea level changes between Java and Australia grows, and the Indonesian Throughflow (ITF) reaches its maximum (Tomczak & Godfrey, 1994).

Another important and unique factor is the thick barrier layer in Sumatra which prevents cold thermocline water from entering the mixed layer, and this explains why the SST depression in Sumatra is smaller than the other upwelling areas of the eastern boundary (Du *et al*., 2005). However, on a certain time interval, the highest SST variability in the Indonesian Archipelago occurs along the coasts of Java and Sumatra (> 4 ° C) which indicates a strong long-distance. It influences from the equatorial Indian Ocean via the equatorial Kelvin waves and the Indian Ocean Dipole (IOD, Webster *et al*., 1999) combined with local upwelling (Qu *et al*., 2005). The stronger or weaker coastal upwelling occurs in Java and Sumatra during El Niño (La Niña) events (Susanto *et al*., 2001; Susanto & Marra, 2005).

MATERIALS AND METHODS

A 2 m long gravity core, EW17-09, was taken from Simeulue sub-basin, Aceh, Indonesia. Samples were collected during the Expedition of Widya Nusantara in December 2017, using the "Baruna Jaya VIII" research vessel. Coordinate of the core EW17-09 is at 03028'358 latitude and 96018'788 longitude and the depth of 870 m (Figure 1). The core was analyzed for grain size by Habibi (2018) at the Sedimentology Laboratory, Research Center for Geotechnology, Indonesian Institute of Sciences (LIPI), in Bandung Indonesia. The sediment grainsize of the core was composed mostly by silt (Habibi, 2018).

The core sediment sample was snipped into a subsample with an 8 cm interval continuously, hence twenty-six subsamples were obtained. All subsamples were prepared using the swirling method in distilled water without Hydrogen Peroxide. This swirling method separates the foraminifera from fine sediments (Putra & Nugroho, 2020). Furthermore, the subsample was oven-dried at 80 °C for 15 minutes and sieved using a 100-mesh screen. All foraminifera specimens were identified, picked and counted under a microscope. At least three hundred foraminifera specimens were separated from each dried subsamples. According to Dennison & Hay (1967), the number could represent approximately 95% of all fossil occurrences in a sample. When the number exceeds, the sample should be splitted before, until the foraminifera number estimated around 300 individual foraminifera in one part (Damanik *et al*., 2020a). Foraminifera identification was conducted by referring to Barker (1960), Postuma (1971), Adisaputra *et al*. (2010) and Holbourn *et al*. (2013). All foraminifera analyzes were completed at the Sedimentology Laboratory, Research Center for Geotechnology, LIPI in Bandung, Indonesia.

The community structure analysis was conducted to determine uniformity index, diversity index, and dominance index of planktonic foraminifera (Simpson, 1949; Odum, 1971; van Morkhoven *et al*., 1986; Murray, 1991; Kurniasih *et al*., 2017). The community structure analysis used all planktonic foraminifera found in the subsample. The Paleontological Statistics (PAST) software with the Paired Group algorithm runs the statistical calculations. The uniformity or the similarity value is expressed in evenness index (e). The index describes a distributional pattern of each foraminifera taxon that shows uniformity or otherwise. A relatively high uniformity index represents an equal distribution of all foraminifera types in waters (Odum & Barrett, 1971). The diversity values are expressed in the Shannon - Wiener index. This index provides more information on environmental stability (Odum & Barrett, 1971). Meanwhile, the dominance index was used to determine a taxa that dominates in a planktonic foraminifera community. The index also illustrates the impact of environmental stress on the community (Boltovskoy & Wright, 1976). The structure of foraminifera community is a biotic parameter for marine ecology, whether habituated or not. This method is reliable to determine any disruption in a living area of foraminifera. This disturbance could occur due to water pollution or sedimentation. In addition, we performed a Q-mode cluster analysis to classify the samples based on similarities in the planktonic foraminifera distribution.

The paleoecological analysis focused on water condition, primary productivity, and thermocline depth (reflecting seawater stratification) by observing the abundance and diversity of planktonic foraminifera. Thermocline dweller foraminifera analyzed for their abundance are *Neogloboquadrina (N.) dutertrei, Puleniatina (P.) obliqueloculata* and *Globorotalia (G.) menardii* (Barmawidjaja *et al*., 1993; Baohua *et al*., 1997; Spooner *et al*., 2005; Ding *et al*., 2006; Sijinkumar *et al*., 2011).

RESULTS

Sediment characteristics

In general, sediment core EW17-09 were mostly composed by fine silt to medium silt (Figure 3). Fine silt had poorly sorted, symmetrically - coarse skewed and leptokurtic - mesokurtic. Meanwhile, medium silt had poor - very poorly sorted, symmetrically - coarse skewed and mesokurtic. There is significant changes in sediment between the lower, middle and upper of the core (Figure 3). At the upper of the core (0-32 cm) is dominated by fine silt with mean values ranges from 7.43 - 7.57 phi, in the time in the middle (48-120 cm) and lower (136-200 cm) are composed by fine to medium silt, with mean values ranges from 6.72 to 7.49 phi. Overall, the sediments are poorly sorted with values 1.44 - 1.99 phi, except at the end of the lower core is very poorly sorted with a value of 2.106 phi.

Planktonic foraminifera assemblages

Observation on 26 subsamples obtained 23 species of planktonic foraminifera. There are three predominantly species, those are *Globigerinoides ruber, Neogloboquadrina*

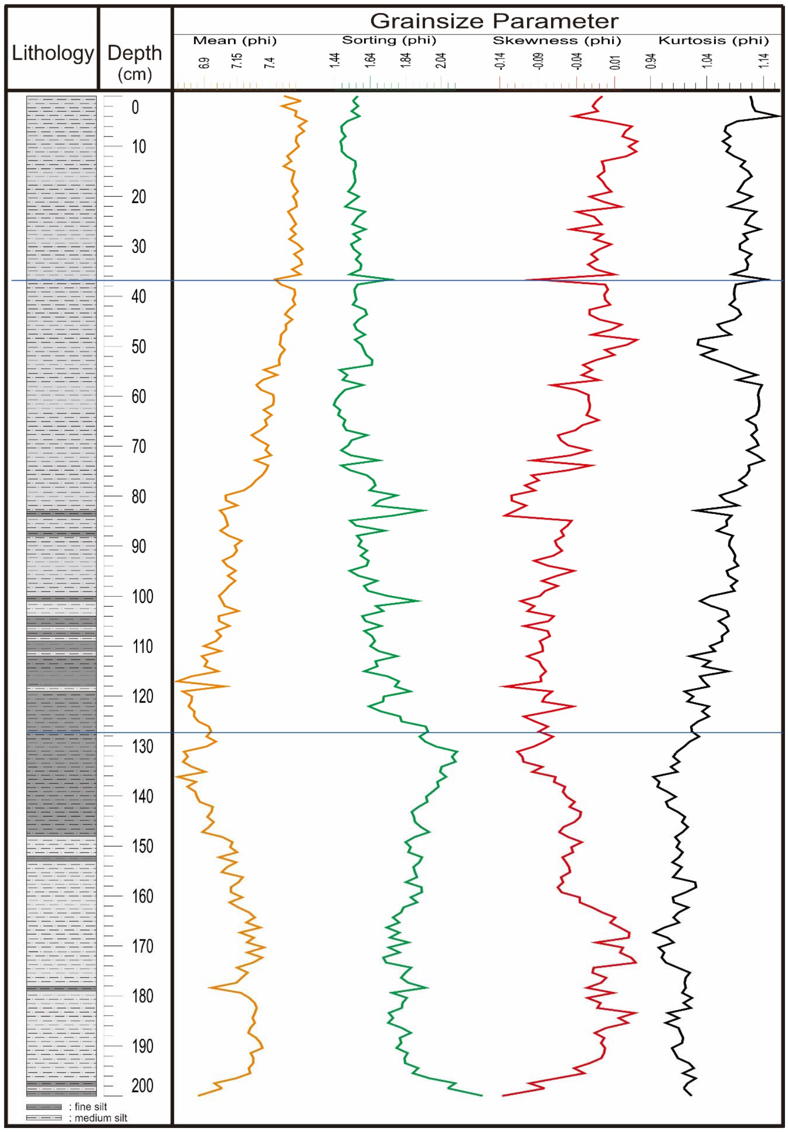

Figure 3: Grain size of EW17-09 sediment core (modified from Habibi, 2018).

dutertrei and *Puleniatina obliquiloculata* with average abundances of 26.85%, 19.8% and 10.22% respectively (Figure 4). The species diversity in subsamples is different ranges from 258 to 441 species. In general, the abundance and diversity of planktonic foraminifera in the EW17-09 core can be classified into three major groups (Figure 4): Cluster I at the lower, Cluster II at the middle, and Cluster III at the top of the core. Three thermocline dweller species are present in the assemblages i.e. *N. dutertrei, P. obliqueloculata* and *G. menardii*. In addition, 20 mixed-layer species were identified in the assemblages, of which 5 species are present in prominent frequencies i.e. *G. ruber, G. bulloides, G. trilobus, G. calida calida* and *G. sacculiferus* (Figure 4).

Biogeographic distribution

Referring to Boltovskoy (1969), Boltovskoy & Wright (1976) and Banerji *et al*. (1971), 19 planktonic foraminifera obtained in this study are typical of tropical to warm subtropical species (Table 1). There are only 4 species belonging to the cosmopolitan foraminifera. Among the cosmopolitan species, *B. adamsi* is present in a small frequency only in subsample 1 individu. This species may be long distant component transported to the site by any global ocean currents.

The community structure of planktonic foraminifera

Result of dominance index calculation using software PAST (Figure 5) shows a low dominance index (D) of all samples ranges between 0.107 - 0.276. Hence, there is no single planktonic species that dominates the foraminifera community. The highest and lowest indexes are at subsample of 128 cm and 168 cm depths respectively. A comparable result was demonstrated from the analysis of the level of uniformity (e) where all samples show moderate values

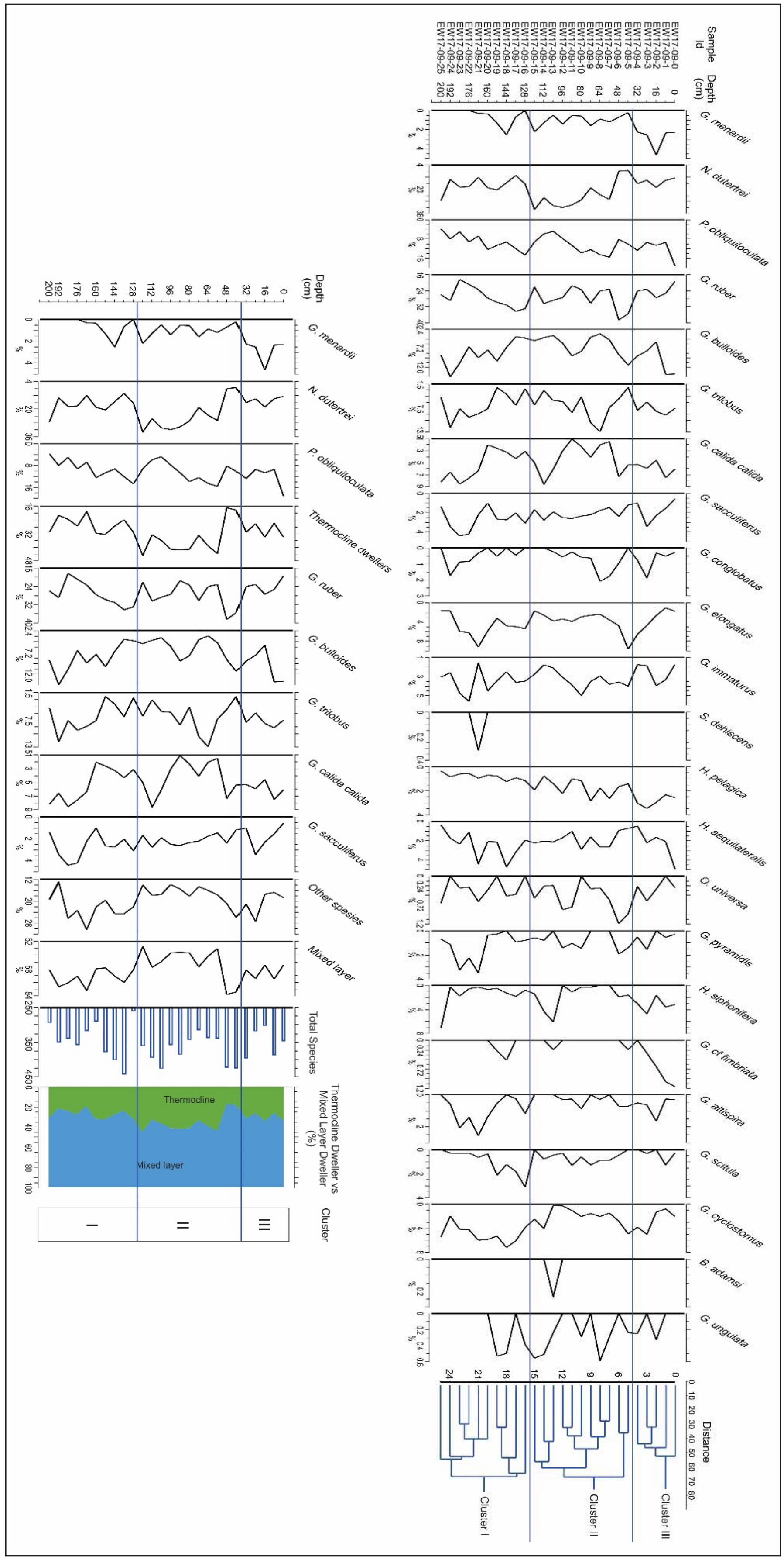

Figure 4: The percentage of planktonic foraminifera abundance and their cluster. Temporal changes of thermocline are indicated by changes in relative proportions of thermocline dweller and mixed layer dweller.

Table 1: Biogeographic distributions of planktonic foraminifera in the EW17-09 core based on Boltovskoy (1969), Boltovskoy & Wright (1976) and Banerji *et al.* (1971).

Globorotalia menardii	Tropical to warm subtropical
Globorotalia ungulata	
Neogloboquadrina dutertrei	
Globigerinoides sacculiferus	
Globigerinoides conglobatus	
Globigerinoides elongatus	
Globigerinoides ruber	
Pulleniatina obliquiloculata	
Sphaerodinella dehiscens	
Hastigerina pelagica	
Hastigerina aequilateralis	
Globigerina calida calida	
Globigerinoides pyramidis	
Hastigerina siphonifera	
Globorotalia cf fimbriata	
Globoquadrina altispira	
Globorotalia scitula	
Globigerinoides cyclostomus	
Boliella adamsi	
Globigerinoides immaturus	Cosmopolitan (low to high latitudes)
Globigerinoides trilobus	
Globigerina bulloides	
Orbulina universa	

(0.347 - 0.601), of which the lowest and highest values are at the depths of 128 cm and 184 cm respectively (Figure 5).

The Shannon - Wiener (H) diversity index of foraminifera in the EW17-09 core ranges 1.83-2.491 (Figure 5). Subsamples at depths of 168 and 184 cm show prominent diversity index (H) i.e., 2.491 and 2.435, respectively. A high H value indicates equal distribution of abundance among species in the assemblage. The more prominent H values were observed at Cluster III (0-32 cm) dan I (136-200 cm). Cluster II (48-120 cm) shows slightly lower H values compared to those of Cluster I and III. The diversity index (H) is inversely proportional with the domination index (D) and is directly proportional to the level of uniformity (e) (Figure 5).

DISCUSSION

In this preliminary study, biozonation of foraminifera abundance was conducted using hierarchical cluster analysis (Figure 4). We speculatively interpret the hierarchical clusters (Table 2) represent the environmental changes. A more extensive study is recommended to verify the correlation between planktonic foraminifera abundance and the environmental change. In this discussion, we refer to the results of Ding *et al.* (2006) and Mohtadi *et al.* (2007; 2009) as a modern analogous of correlation between foraminifera abundance in the surface sediments and their environmental characteristics.

Cluster I (depth interval of 128 - 200 cm) shows comparable values of diversity index, dominance index, uniformity index and sediment composition with those of Cluster III (0-32 cm). The fine sediment composition in these clusters might show less dissolved particles led to an increase in water clarity and primary productivity through photosynthesis. In general, we observed lower domination indexes and higher diversity and uniformity indexes compared to those of Cluster II and III (Figure 5, Table 2). The co-existence of *G. ruber, N. dutertrei, P. obliquiloculata, G. sacculiferus* and other mixed layer species suggested an oligotrophic environment and warm condition. The prominent frequencies of *G. ruber* support the onset of an oligotrophic environment and warm conditions. This species most commonly lives in a warm mixed layer above the thermocline (Fairbanks *et al*., 1982). The composition of foraminifera assemblages in these clusters are comparable with those of surface sediments reported by Ding *et al.* (2006) and Mohtadi *et al.* (2007). The low frequencies of *N. dutertrei* as a thermocline dweller and low representation of thermocline dweller in these clusters indicate high salinity and deeper thermocline as suggested by Wang *et al*. (2003), Spooner *et al*. (2005) and Sijinkumar *et al*. (2011).

Cluster II (depth interval of 40 - 128 cm) shows higher dominance indexes, lower diversity and uniformity indexes, and finer sediment composition compared to those of Cluster I and III (Figure 3). This might have been triggered by the onset of upwelling that also improves the primary productivity. The onset of upwelling during the deposition of sediment in Cluster II is also slightly indicated by lower frequencies of *P. obliquiloculata* at the lower part of Cluster II. The upwelling onset at about this period was also reported by Pflaumann & Jian (1999) to occur since the early-mid Holocene and is supposed to be related to the strengthening of eastern monsoon. On the other hand, the prominent representation of thermocline dweller and high frequencies of *G. ruber* suggest shallow thermocline and low salinity (Wang *et al*., 2003; Spooner *et al*., 2005; Sijinkumar *et al*., 2011). Increase frequencies of *G. ruber* and some mixed layer species (e.g. *G. immaturus,* and *O. universa*) suggest the onset of higher water temperature, medium level of oxygen supply and weakened bottom-currents. The core of EW17-09 (this study) and BS04 (Li *et al*., 2018) were located in the Simeulue sub-basin, hence, they assumed to have a similarity on sedimentation rate and no other disturbances.

Even though the paleooceanography conditions of the Cluster III are comparable to those of Cluster I, there are some differences. Slightly higher frequencies of *N.*

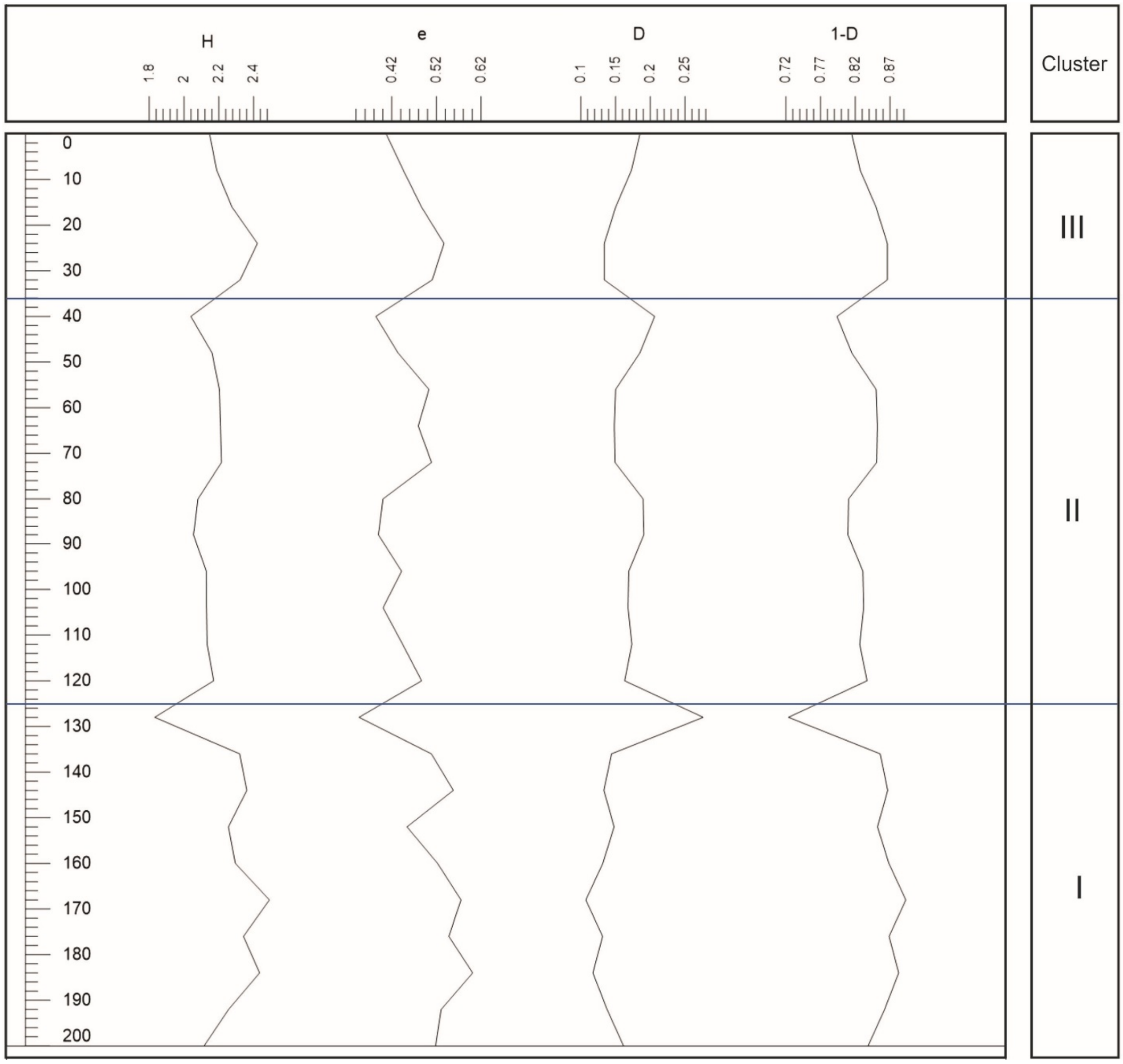

Figure 5: Index of community structure on planktonic foraminifera of EW17-09.

dutertrei and *G. menardii* in subsamples above 16 cm depth probably suggest shallower thermocline. This shallower thermocline may relate to records of Kwiatkowski *et al.* (2015) that reported the occurrence of a shoaling of the thermocline after 3 ka. These conditions may indicate an increase in upwelling fluctuations during Late Holocene and may represent a change in the IOD-like mean state of the Indian Ocean. The foraminifera distribution on the top-core of EW17-09 were relatively corresponding to the foraminifera distribution on surface samples, as reported by Ding *et al.* (2006) and Mohtadi *et al.* (2007).

Previous studies suggested that *G. ruber* and *G. sacculiferus* are species living in warm waters and the upper part of the water column that is well stratified (e.g., Duplessy *et al*., 1981; Peeters *et al*., 2002; Stoll *et al*., 2007). From the data obtained, *G. ruber* and *G. sacculiferus* were present in a high abundance throughout the EW17-09 core interval (Figure 5) along with other taxa such as *N. dutertrei, P. obliquiloculata, Globigerina calida, G. elongates,* and *G. cyclostomus.* In vertical, these species were abundant and equally distributed in the core of EW17-09. The persintence of warm water taxa indicates the warm water condition during the period. The findings of *G. immaturus, G. trilobus*, and *G. bulloides* in the EW17-09 sample indicate that those species may be cosmopolitan.

CONCLUSION

Planktonic foraminifera distribution study of core EW17-09 shows marine ecological conditions during their deposition. There were 23 species identified and some of the taxa are present in high frequencies i.e. *G. ruber, N. dutertrei, P. obliquiloculata, Globigerina calida calida, G. elongates, G. cyclostomus,* and *G.sacculiferus*. The vertical distribution of the foraminifera assemblages of core EW17-09 can be classified into three groups i.e. Cluster I, Cluster II, and Cluster III. Cluster I was dominated by *G. ruber, N. dutertrei, P. obliquiloculata, G. bulloides,* and *G. Trilobus*, indicative of warm water, high salinity, deeper thermocline,

Table 2: Summary of hierarchical cluster based on the vertical distribution of planktonic foraminifera.

Cluster	Interval (cm)		*G. ruber*	*N. dutertrei*	*P. obliquiloculata*	*G. bulloides*	*G. trilobus*	*G. calida calida*	*G. sacculiferus*	*G. Menardii*	Other species (mixed layer)	Termocline dweller	H	e	D	(1-D)
III	0 - 40	Min	19.36	12.72	9.30	5.63	5.97	4.64	0.58	2.28	16.80	25.84	2.15	0.41	0.13	0.81
		Max	27.48	18.87	19.08	13.70	9.30	7.49	3.46	4.64	27.36	34.11	2.42	0.54	0.19	0.87
		Average	23.90	15.28	12.21	9.98	7.83	5.90	1.78	2.82	20.30	30.31	2.27	0.48	0.16	0.84
II	40 - 128	Min	21.56	7.78	4.71	3.56	2.36	1.04	1.18	0.24	14.01	16.86	2.04	0.38	0.15	0.79
		Max	38.48	33.61	15.63	11.32	13.35	8.63	2.79	2.22	25.95	45.00	2.22	0.51	0.21	0.85
		Average	27.77	24.10	10.25	6.35	6.72	4.24	2.08	1.01	17.48	35.36	2.14	0.44	0.17	0.83
I	128 - 200	Min	18.34	11.11	3.75	7.00	2.38	2.08	1.04	0.00	12.89	19.05	1.83	0.35	0.11	0.72
		Max	34.24	27.65	14.73	10.32	12.32	8.58	4.44	2.50	30.48	32.54	2.49	0.60	0.28	0.89
		Average	27.33	17.33	9.18	7.61	6.70	5.27	2.73	0.52	22.53	27.02	2.27	0.52	0.15	0.85

and medium sedimentation disruption. Cluster II was dominated by *G. ruber, N. dutertrei*, *P. obliquiloculata, G. Trilobus* and *G. bulloides*, indicative of the warmer water conditions and oligotrophic waters with low salinity, shallow thermocline, and medium sedimentation disturbances. In the lower part of this cluster, there was an intensification of tropical upwelling. Cluster III was dominated by *G. ruber, N. dutertrei, P. obliquiloculata, G. bulloides,* and *G. Trilobus,* indicating oligotrophic waters, high salinity, deeper thermocline and low sedimentation disturbances. At the end period of this cluster, there were a shoaling of the thermocline that may occur due to the strengthening of upwelling and changes in the IOD-like mean state of the Indian Ocean.

ACKNOWLEDGEMENTS

The research was funded in full or partially by the Indonesian government through the ‘flagship’ of LIPI, Expedition of Widya Nusantara (EWIN) in the 2017 budget year. We thank the Research Center for Oceanography of LIPI, especially Dr. Aan Johan Wahyudi as the coordinator of EWIN 2017, Nurul Fitirya M.Sc as the chief scientist, captain, and all crew of the Baruna Jaya VIII Research Vessel. We thank also to all scientists and technicians who collaborated and helped in the EWIN 2017. High appreciation goes to Ahmad Fahri Habibi for the assistance in sampling in the laboratory. We are also very grateful to two anonymous reviewers for their useful critical reviews.

AUTHOR CONTRIBUTIONS

SHN designed the research concept, prepared and wrote the manuscript. AK contributed to data processing. PSP contributed by providing suggestions and input, as well as review-edited the manuscript. SPAW prepared the samples and tools in the cruise and AA in the laboratory. YZ, EY, and YR contributed to the writing and editing of this manuscript. PSP, SHN, SPAW joined the EWIN cruise and obtained the samples.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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Manuscript received 25 May 2020;
Received in revised form 8 March 2021;
Accepted 10 March 2021
Available online 16 November 2021