



Late Holocene Pollen Record of Environmental Changes in Karimata Strait, Sunda Shelf Region

EKO YULIANTO¹, WORO SRI SUKAPTI², and KRESNA T. DEWI²

¹Research Center for Geotechnology, Indonesian Institute of Sciences (LIPI)
Jln. Sangkuriang, Bandung 40135 Indonesia
²Centre for Geological Survey, Geological Agency
Jln. Diponegoro no 57 Bandung - 40122 Indonesia

Corresponding author: eko.yulianto@lipi.go.id

Manuscript received: January, 14, 2016; revised: January, 08, 2017;
approved: December, 11, 2018; available online: March, 15, 2019

Abstract - Pollen analysis has been conducted on a 90 cm gravity core taken from the Karimata Strait to reveal pollen facies in marine sediment and Late Holocene environmental changes in the central Sunda Shelf region. The core site is at 32 m water depth and located about 170 km northwest of Bangka Island, Indonesia. Ten samples were collected at 10 cm intervals through the core. The total number of pollen grains counted in the samples varies between very low (<50 grains) to abundant (>200 grains). High frequencies (50 - 70%) of mangrove pollen are found at 90 to 40 cm indicating that pollen facies in offshore marine sediment may be comparable with those in mangrove forest floor sediment. The core site has been in a neritic environment since its early deposition ca. 1,800 yr B.P. (~150 A.D.) when mangroves vastly grew on the tidal flats of the surrounding islands and they persisted to ca. 700 yr B.P. (~1,250 A.D.). In the middle of this period, a catastrophic event speculatively due to the 535 A.D. Krakatau eruption might have responsible for the decrease of mangroves and the disappearance of benthic foraminifers. The deposition of silicious materials (tephra) due to this eruption might have provided an opportunity for benthic foraminifers to increase their population subsequently. From ca. 700 yr B.P. (~1,250 A.D.) mangroves declined, as indicated by lower frequencies of pollen grain in samples from 30 cm deep upward. It occurred simultaneously with the deposition of coarser sediment and the increase of benthic foraminifer abundance. Interplay of anthropogenic activities, strengthening ENSO cycle, and lowering erosion base level might have been responsible for these environmental changes.

Keywords: pollen, mangroves, Karimata Strait, Sundaland, Sunda Shelf, environmental changes, Late Holocene

© IJOG - 2019. All right reserved

How to cite this article:

Yulianto, E., Sukapti, W.S., Dewi, K.T., 2019. Late Holocene Pollen Record of Environmental Changes in Karimata Strait, Sunda Shelf Region. *Indonesian Journal on Geoscience*, 6 (1), p.41-55. DOI: [10.17014/ijog.6.1.41-55](https://doi.org/10.17014/ijog.6.1.41-55)

INTRODUCTION

The Karimata Strait is located in the centre of Sunda Shelf. It connects the Indian Ocean with the South China Sea. Monsoonal circulation has strong influence in this area resulting seasonal variation of wind and sea surface current direction,

and wet-dry months. Along with topographical variation, this variation produces vegetation belts due to temperature changes with raising height.

The Sunda Shelf is sensitive to sea level fluctuation due to its bathymetry. It emerged as a landbridge, connected mainland Asia to the Indonesia Archipelago, and formed the Sundaland

during the Last Glacial Maximum ca. 18,000 yr B.P. when the sea level was about 120 m below the present level (Figure 1). On the emerged land, river networks had also developed (Kuenen, 1950), connected rivers from the surrounding islands. The widening land during the Last Glacial Maximum has changed the regional climates where the monsoonal cycle was weakened and hence the precipitation was declined (Walker and Flenley, 1976; Flenley, 1985; Stuijts *et al.*, 1988; Hope and Tulip, 1994; Kaars, 1998; Wang *et al.*, 1999; De Deckker *et al.*, 2002; Ding *et al.*, 2013; Russell *et al.*, 2014).

Temperature decrease during the Last Glacial Maximum had shifted montane vegetation boundaries in the Sunda Shelf region to lower levels (Flenley, 1996). On the other hand, lower precipitation in this period had changed vegetational landscape on lowland areas (Bird *et al.*, 2005). These environmental changes have been shown in pollen records in lakes and wetlands (Biswas, 1973; Walker and Flenley, 1976; Newsome and Flenley, 1988; Stuijts *et al.*, 1988; Hope and Tulip,

1994; Flenley, 1996, 1998), and marine sediments (e.g. Sun and Li, 1999; Yulianto and Dewi, 2000; Hanebuth *et al.*, 2000; Sun *et al.*, 2000, 2002; Haberle *et al.*, 2001; Wang *et al.*, 2007; Wang *et al.*, 2009; Slik *et al.*, 2011; Reeves, 2013; Raes *et al.*, 2014).

Holocene period had no such prominent environmental changes in tropical areas due to subtle fluctuation of temperature and sea level (Flenley, 1996). Precipitation, however, might have significantly increased in this period due to the onset of ENSO (Moy *et al.*, 2002), and hence facilitated an intensive progradation in the coastal areas where mangroves abundantly grew (Soares, 2009). The increase of civilization might have had significant contribution to the changes of vegetational landscape due to deforestation for dwelling and agricultural purposes.

Despite many palynological studies in marine sediments around the Sunda Shelf concerning the LGM period, there was only few studies concerning the Holocene period. The Late Holocene palynological record in marine sediments

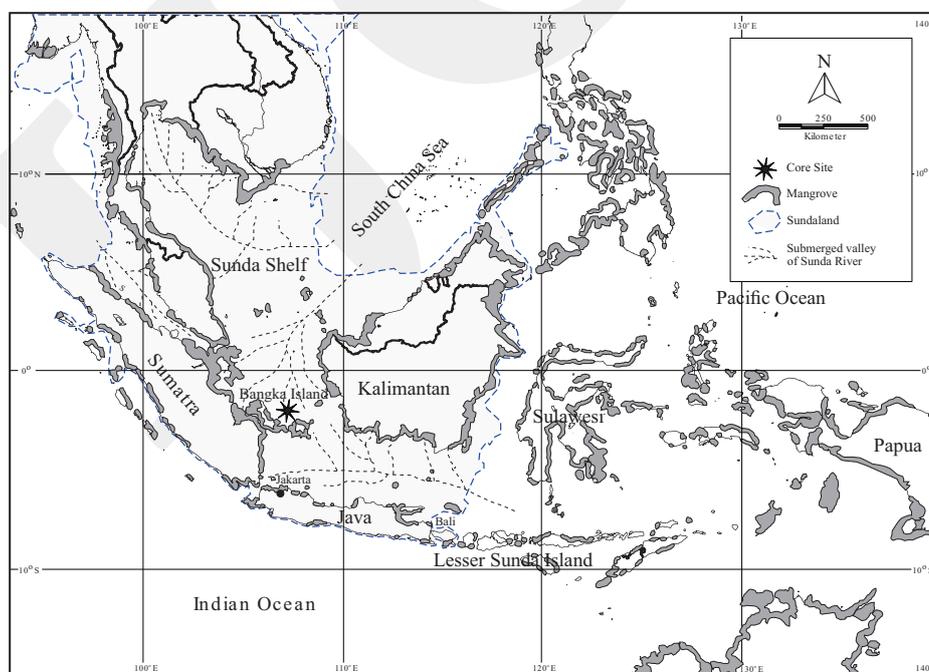


Figure 1. Map showing Sundaland (blue shade area), the core site (black star), and mangrove distribution (dark grey shade). The Sundaland is in its general appearance during the Last Glacial Maximum, 18,000 yr B.P., when sea level was at about 120 m below its present level. This map is compiled and modified from Oo (2004); Sathiamurthy and Voris (2006); Giri *et al.* (2011); Long and Giri (2011); and Solihuddin (2014).

of Sunda Shelf region is expected to provide a general description of pollen facies in an open marine environment, and its relation with the subtle climatic fluctuation such as ENSO and Little Ice Age (LIA), and catastrophic events such as the 535 A.D. and 1883 Krakatau eruptions, as well as the 1815 Tambora eruption.

MATERIALS AND METHODS

Samples for this pollen study were collected from a 90 cm gravity core. The core was taken from a site at 170 km northeast offshore of Bangka Island (Figure 1). The bathymetry of the core site was about 32 m. The core consists of sandy silt (0 - 30 cm) and silt (40 - 90 cm).

The samples were collected at a 10 cm interval. These samples were treated with standard pollen laboratory processing method using fluoric acid (HF), chloric acid (HCl), acetolysis (mixing of sulfuric acid/H₂SO₄ and acetic anhydride/(CH₃CO)₂O, at 9:1 composition, and gravity separation using ZnCl₂ s.g 2.2. Pollen and spore determinations were conducted using a light microscope at 400 and 1,000 magnifications to species and generic level when it was possible, or at the family level. Pollen and spore concentration in each sample was counted based on total pollen. Pollen assemblages in the samples are classified into mangroves, lowland/peatswamp, montane, grassland, and pteridophyte spores. The determined results are presented in a pollen diagram.

ENVIRONMENTAL SETTING

The Southeast Asian region has tropical maritime climates characterized by high precipitation, humidity, and temperatures all year long. The average temperatures range 20 - 28° C with less than 1° C fluctuation (Ewusie, 1990). The passage wind, blowing from the tropics of Cancer and Capricorn to the Intertropical Convergence Zone (ITCZ), has played the main control for precipitation across the region. The occurrence of the extensive land areas of Asian and Australian

continents results in the monsoonal cycle due to periodic south north shifting of ITCZ. A rainy season takes place during December - February when the sun is above the tropical Capricorn. Wind and surface sea currents move from southeast to northwest direction in this season. The dry season takes place during July - September when the sun is above the tropic of Cancer. Wind and surface sea currents move from northwest to southeast direction in this season.

The core site is collected from a shallow marine environment, located at the centre of Sunda Shelf surrounded by several major land areas, *i.e.* Sumatra, Kalimantan, Malay Peninsula, Java, and several smaller islands such as Bangka, Belitung, and Riau Islands. Mangroves grow intensively on the sheltered tidal flats of these islands particularly along the north coast of Java, the east coast of Sumatra, and almost along the coast of Kalimantan (Figure 1). Recently, however, mangroves in these coasts have mostly been deforested due to fishery purposes. Tropical lowland, peatswamp, submontane, and montane tropical rain forests grew widely on these islands prior to intensive deforestation since the 20th century for settlement, agriculture, or industrial plantation purposes. Lowland and peatland tropical forests remain in few areas of Sumatra and Kalimantan, particularly in the National Natural Reserves, but are almost totally disturbed or destroyed in Java. Montane tropical rain forests persist in many mountainous areas in Sumatra and in patchy areas, particularly near the summits of volcanoes in Java.

RESULTS

There are 43 taxa of 5 species, 31 genera, and 36 families identified in pollen assemblages of all samples (Figure 2). The total number of pollen grains in the samples varies from very low (<50 grains) to high (>200 grains). Among the lowest pollen assemblages there are four upper most samples (0, 10, 20, 30 cm) and in sample at 60 cm.

Pollen of mangroves, lowland, peat swamp, montane forest, and open vegetation such as grassland and spores of pteridophytes are present

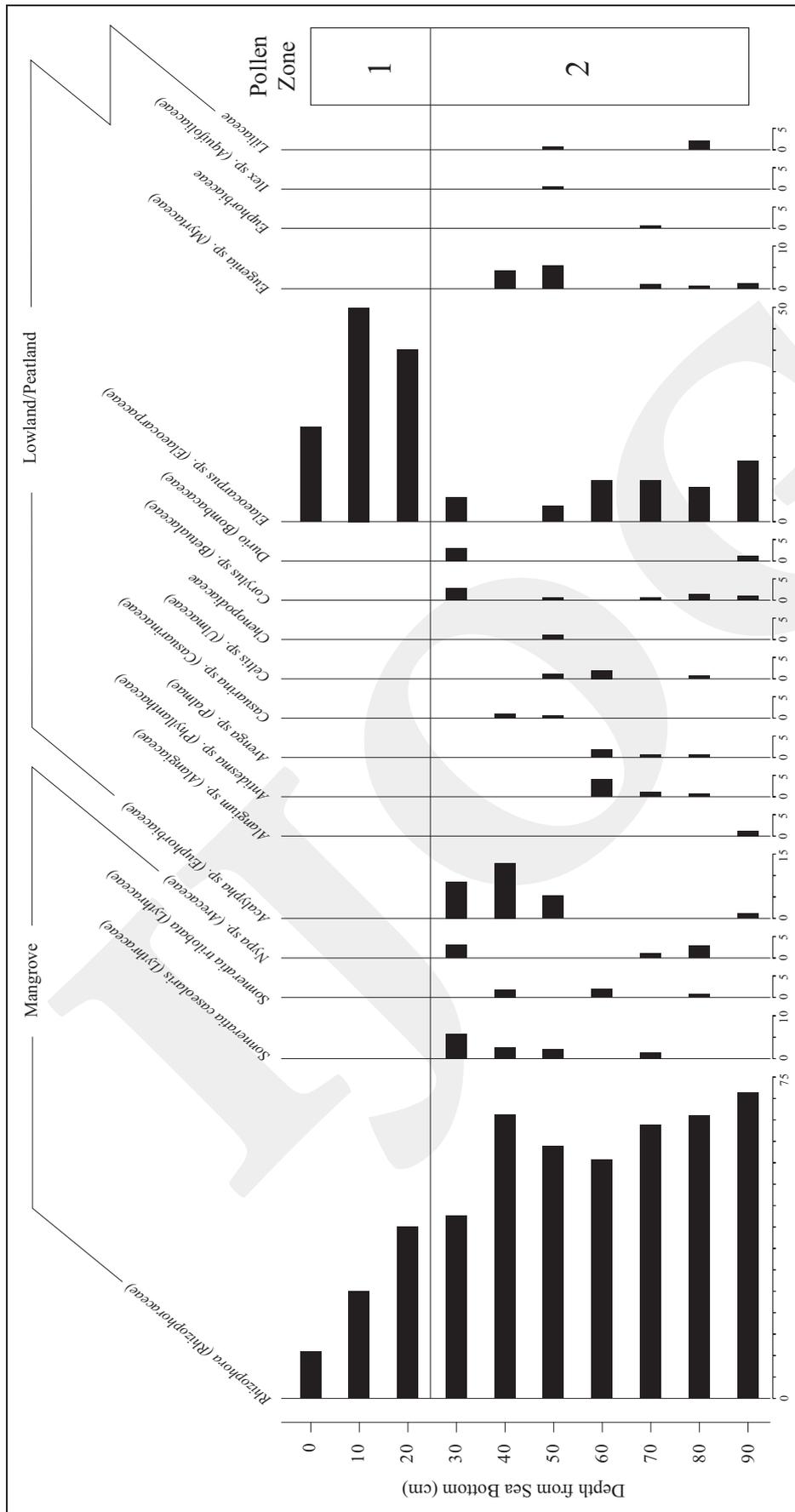


Figure 2. Diagram of pollen of the analyzed core taken from Karimata Strait.

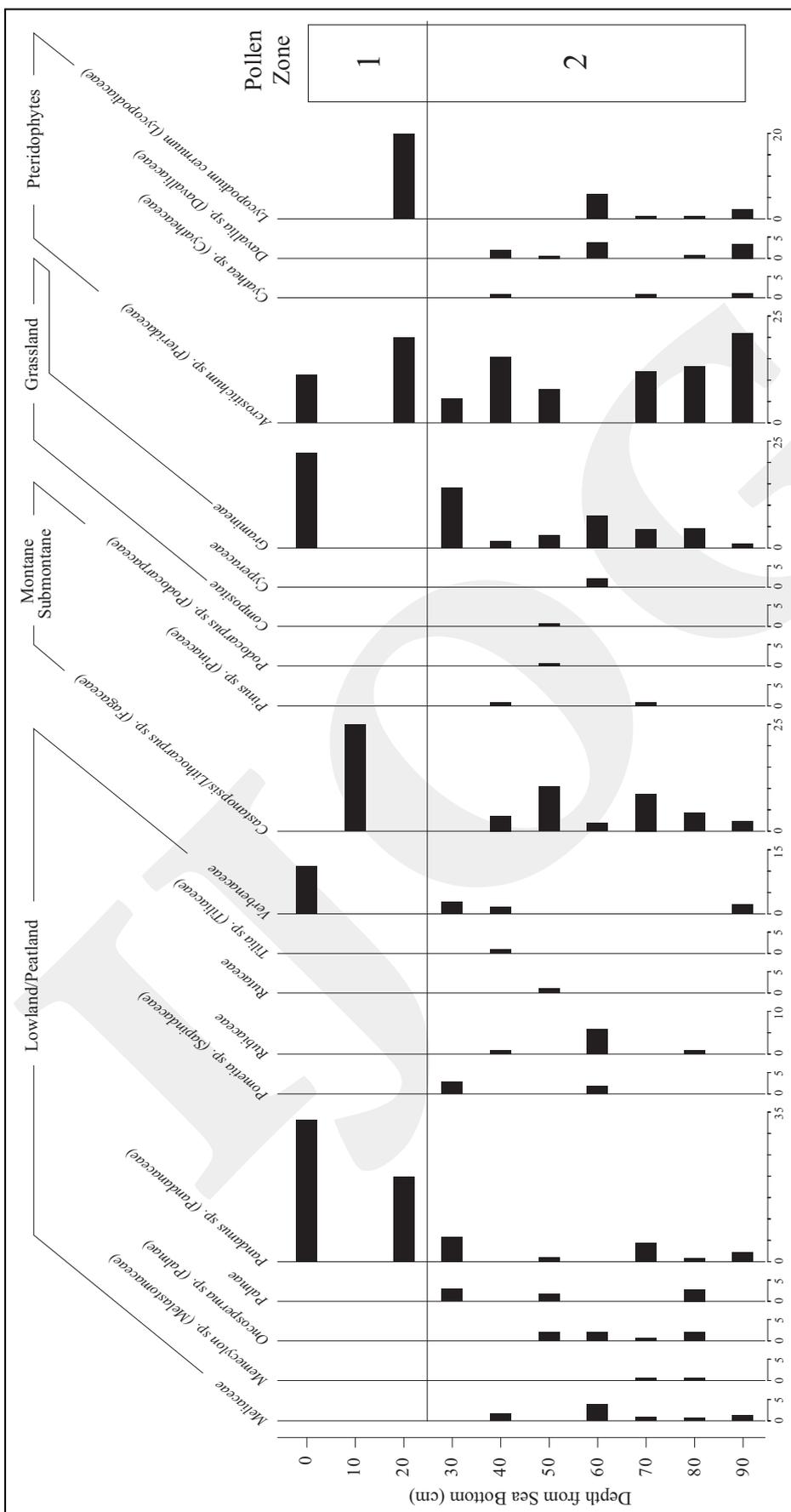


Figure 2. continuation.....

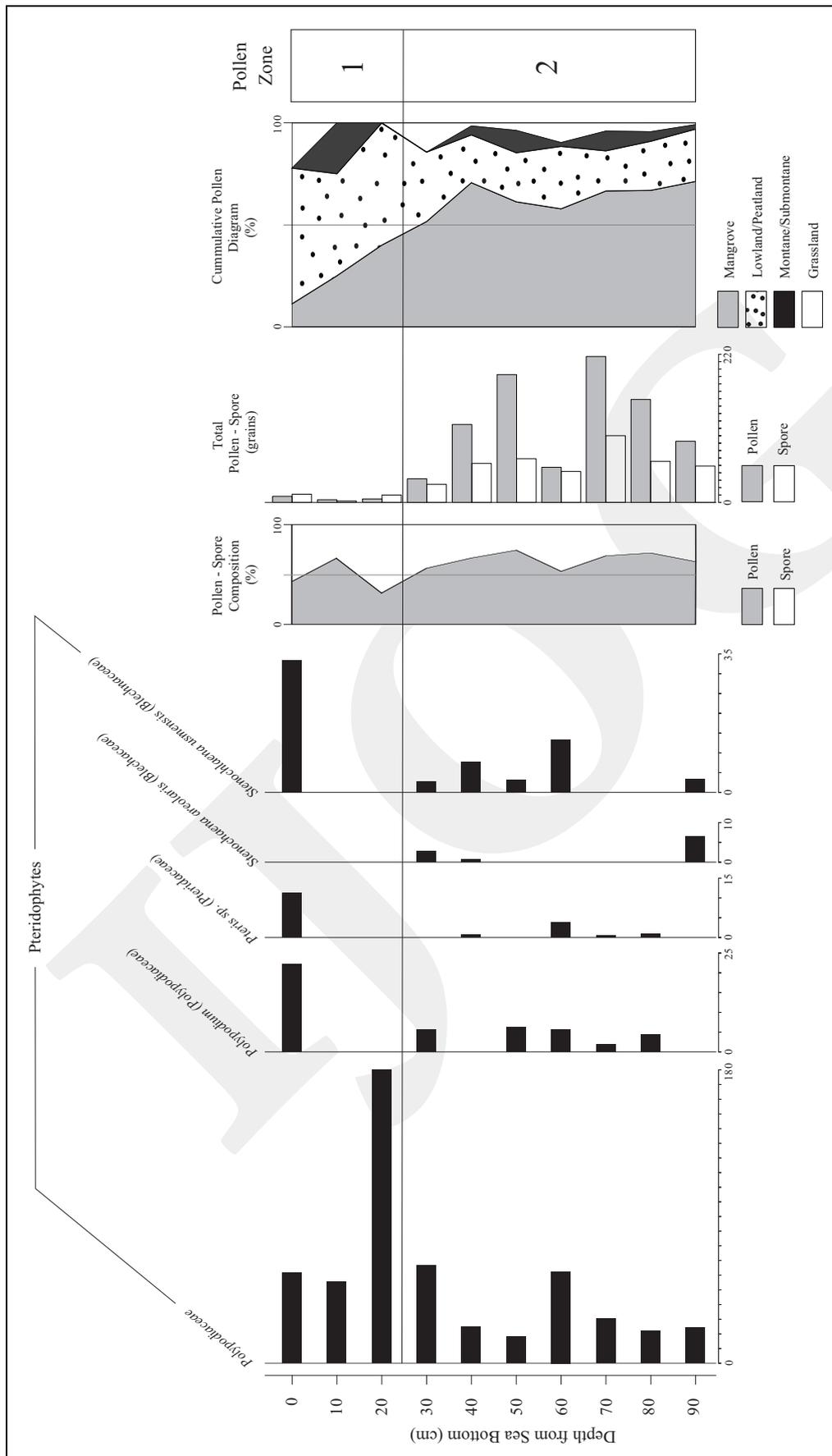


Figure 2. continuation.....

in frequencies ranging consecutively 11 - 71%, 20 - 67%, 0 - 25%, and 0 - 22%. *Rhizophora*, *Sonneratia*, and *Nypa* are among the mangrove pollen types that are present consistently in significant frequencies. *Rhizophora* type pollen shows high frequencies almost in all samples. *Elaeocarpus* type, *Eugenia* type, *Pandanus*, and *Acalypha* type are among the lowland and peatswamp pollen that show significant presence in almost all samples. *Castanopsis* type is among the montane pollen that shows significant frequencies. Gramineae shows the highest frequencies among the pollen from open vegetation.

The pollen diagram can be divided into two pollen zones (Figure 2). Zone 1 consists of samples at 0, 10, 20, and 30 cm, whilst Zone 2 comprises samples at 40, 50, 60, 70, 80, and 90 cm.

High frequencies of lowland/peatswamp pollen, particularly *Elaeocarpus* type, low frequencies of mangroves, montane, and grass pollen characterize Zone 1. *Pandanus* and Verbenaceae are lowland/peatswamp components that show prominent frequencies. *Castanopsis* sp. and Gramineae are derived from montane and grassland vegetation that show high frequencies. Among pteridophyte spores, *Polypodium* type, *Pteris*, and *Stenochlaena palustris* are present in high frequencies.

High frequencies of mangrove pollen, low frequencies of lowland/peatswamp pollen, and consistent low representation of montane and grassland components characterize Zone 2. *Rhizophora* type is a mangrove component that is consistently present in high frequencies. *Elaeocarpus* type, *Castanopsis* type, and *Gramineae* pollen are present in prominent frequencies in this zone. Fern spores show lower frequencies than those in Zone 1, and present consistently along the zone.

DISCUSSION

Chronology

The sea level fluctuation curve for the last 20,000 years (Lambeck *et al.*, 2014) indicates sea level position at ca -30 m about 10,000 years with sea levels rising to a maximum about 5,000 years ago. This means accommodation space of

deposition in the core site might have just commenced after 10,000 years B.P. This gives an idea of a minimum sedimentation rate in the core of less than 0.01 cm/yr.

No absolute dating has been obtained for the core. Previous studies show various sedimentation rates place to place during Holocene in Java Sea. Siregar and Dewi (2014) reported a 0.03 cm/yr of sedimentation rate in Karimata Strait. The Holocene sedimentation rate in South China Sea varies from 0.01 cm/yr (Sun *et al.*, 2002; Wang *et al.*, 2008), 0.02 cm/yr (Wang *et al.*, 2007), and 0.03 cm/yr (Sun and Li, 1999; Sun and Li, 1999; Sun *et al.*, 2000; Hu *et al.*, 2003). Holocene sedimentation rates in the eastern Java Sea, Makassar Strait, northern Java Sea, south of Kalimantan, and offshore of Karimunjawa Island is about 0.007 cm/yr (Gingele *et al.*, 2002) and 0.05 cm/yr (Newton *et al.*, 2011), 0.05 - 0.11 cm/yr (Herbeck *et al.*, 2014), and 0.0054 cm/yr (Hardjawidjaksana, 1990) respectively. Although the sedimentation rates in and surrounding Java Sea vary from 0.005 - 0.03 cm/yr, they mostly vary 0.01 - 0.03 cm/yr. They show a general pattern where high rates occur close to big islands and river mouths, and low rates occur at sites distant from big islands.

The core site was located in eastern offshore of Sumatra where Musi River flows out to Bangka Strait, and separated from the mainland Sumatra by Bangka and Belitung Islands. There is no prominent rivers flow out from Bangka and Belitung Island to Karimata Strait. The core site was located in southeast offshore of Kalimantan where Kapuas, Kahayan, and Sebangau Rivers flow out to Karimata Strait and Java Sea. It was located in northwest of Java Island where Citarum and Ciliwung Rivers flow out to Java Sea. Materials deposited in the core site were probably mostly originated from Kalimantan, Sumatra, and Java Islands, brought by those rivers. Hence, sedimentation rate of the core site is assumed to have been high, about 0.02 - 0.03 cm/yr. This assumption leads to a conclusion that the deposition of the core commenced at ca 1,800 yr B.P. (roughly 150 A.D.) and the boundary of Zone 1 and 2 is at ca 700 yr B.P. (roughly 1,250 A.D.).

Pollen Assemblages and Environmental Changes

Pollen assemblages in the samples show that pollen and spores were deposited in the core site even recently when it was 170 km away from the nearest land. The presence of montane components such as *Castanopsis* type, *Pinus*, and *Podocarpus* shows the pollen sources were not only from the nearby vegetation, but also vegetation from distant surrounding upland areas. The pollen composition, however, indicates the frequencies are out of representation of their ecological composition in the forests. Consequently, the pollen diagram may show vegetational diversity on land to some distance, but it could not be used to reconstruct thorough vegetational landscape. This is in accordance with the result of pollen facies mapping by Lorente (1987).

The occurrence of montane *gymnosperm* pollen may show the role of wind in pollen transportation prior to their deposition in the core site. Higher *angiosperm* pollen frequencies, however, may show stronger role of water agent in transported pollen and spores to the core site. Most of the pollen and spores might have been disseminated by wind to a short distance prior to their farther transportation by rivers to the sea-land-interface areas where their deposition took place. Few pollen and spores might be transported and deposited farther seaward by sea currents as reported by Kaars (2001). Higher frequencies of mangroves than those of other components indicate distance to the pollen sources might have played a crucial role of pollen abundance in their deposition sites. Pollen composition in the pollen diagram probably does not figure out the forest composition. Instead, it may represent changes in the nearest pollen source, mangroves in this instance. Accordingly, mangroves should have grown extensively on land areas close to the core site at least since about 2,700 yr B.P. Although mangroves persist to grow until the present time, its abundance might have significantly declined since about 500 - 750 yr B.P.

Very high frequencies of mangroves in the middle and base of the core indicate mangrove environment occupied the deposition site, or it was very close to mangrove environment. In samples

taken from mangrove forest floor, mangrove pollen frequencies were mostly over 50% (Lorente, 1987; Caratini and Tissot, 1988). The samples also comprise pollen of other components, e.g. lowland/peat swamp, submontane/montane, and grassland, including pteridophyte spores. Taking into account, the present geographical position and bathymetry (more than 30 m deep) of the core site, shallow neritic environment should have occupied the site since the early deposition of the core ca 1,800 yr B.P. The presence of shallow marine benthic foraminifers (Dewi, 2014) supports this argument, and proves that mangroves have been away from the core site when the core was firstly deposited. This study shows fifteen genera of benthic foraminifers identified in samples were taken from Zone 1. Among the prominent ones are *Operculina*, *Elphidium*, *Heterolepa*, and *Quinqueloculina*. These benthic foraminifers are present very prominently in samples of Zone 1 (0 - 40 cm deep), in sample of 60 - 62 cm (ca 1,200 yr B.P. - roughly 750 A.D.), and 80 cm (1,600 yr B.P. - about 350 A.D.). Their abundances decline in the samples of 50 - 52 cm. They disappear in sample of 70 - 72 cm (ca 1,400 yr B.P. - roughly 550 A.D.).

Based on the global sea level curve proposed by Solihuddin (2014) and Sathiamurthy and Voris (2006), accommodation space of deposition should have been available since about 10,000 yr B.P. when a tidal flat environment probably developed in the site. Mangroves might have commenced to grow on this flat as they have extensively grown since Early Holocene in Southeast Asia region (Yulianto *et al.*, 2004). Very high frequencies of mangroves (> 50%) in Zone 2 are not an indication of mangrove environment. Instead, they indicate the abundance of mangroves in the surrounding islands. It is thus likely that offshore sediments may contain over 50% mangroves pollen frequency. Therefore, mangrove dominated pollen assemblages in older sediment rocks should be evaluated very carefully.

Changes of pollen composition from 30 cm deep (ca 700 yr B.P.) upward occur simultaneously with changes of sedimentology and abundance of benthic foraminifers. In general, changes in the upper part of the core may be simply perceived as

a consequence of intensive anthropogenic activities due particularly to deforestation, including mangrove deforestation for various purposes such as agriculture and settlement. Increasing frequencies of Gramineae pollen may be interpreted due to either extensive planting of rice or extensive growing of wild grasses in more open forest environments following deforestation processes.

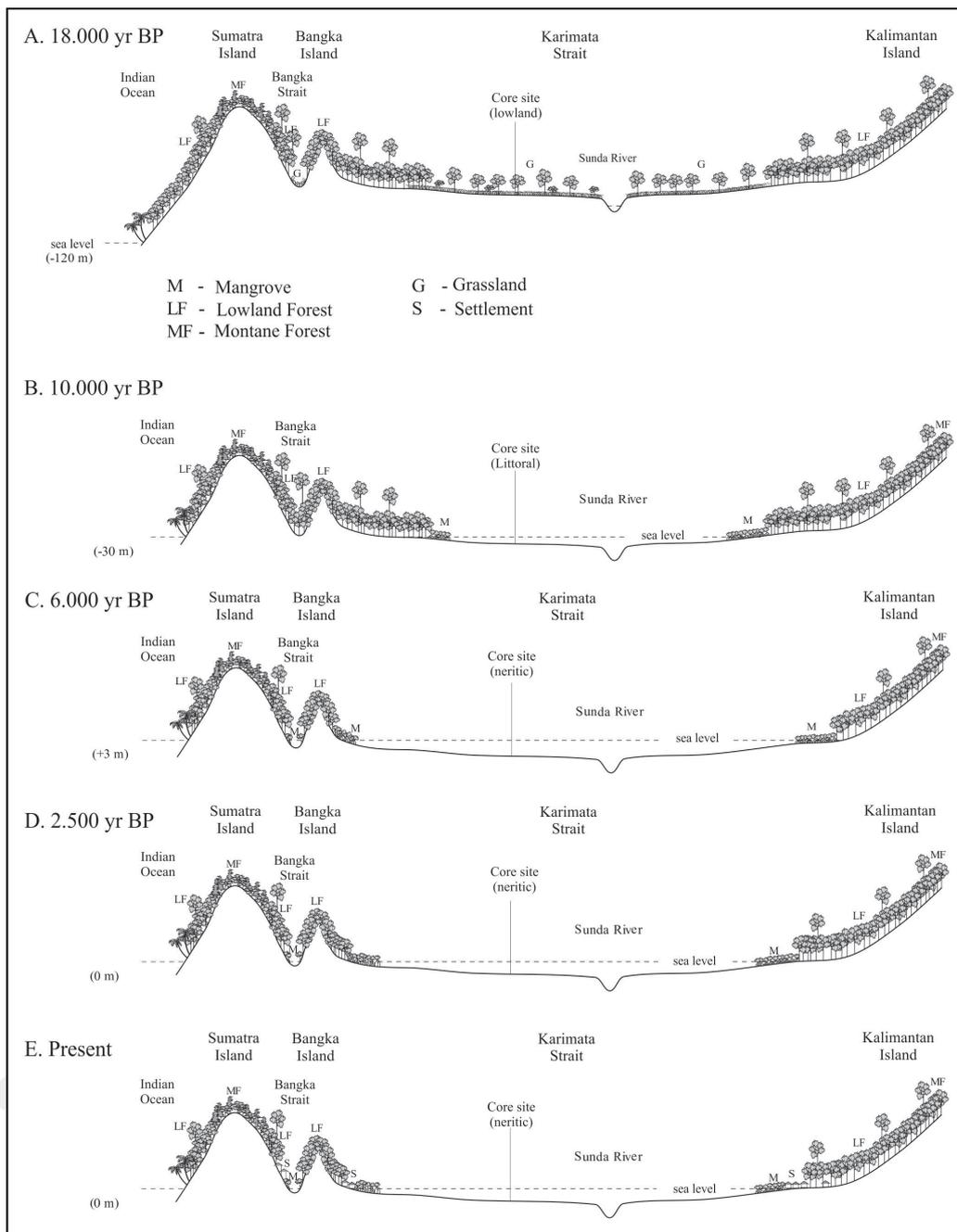
On the other hand, strengthening ENSO cycle has started since Mid-Holocene and reached its peak period from ca 2,000 yr B.P. (Moy *et al.*, 2002). The ENSO onset should have triggered higher precipitation during Late Holocene. In more open forest environments, higher precipitation and lowest erosion base level due to maximum sea level drop after the Holocene Maximum Transgression (HMT) might enable a higher rate of erosion and nutrient-enriched coarser clastic material deposition in the sea. Increasing nutrient deposition in the sea might have caused a higher marine productivity that increased benthic foraminifer abundances in marine sediments.

Another factor that might have played a role in sedimentological and micropaleontological changes in the upper samples was the catastrophic events, *i.e.* volcano eruptions and tsunamis of Krakatau in 535 A.D. (Southon *et al.*, 2013) and 1883 A.D. (Pararas-Carayannis, 2003), and of Tambora in 1815 A.D. These eruptions should have deposited more silicious materials of coarser grains to the marine environments including in the Karimata Strait. The 1883 Krakatau eruption has provoked tsunami that reached as far as the Jakarta Bay (Simskin and Fiske, 1983), and deposited tephra almost throughout the world (Simskin and Fiske, 1983). The tsunami reached Karimata Strait after about two hours (Simskin and Fiske, 1983). The 1815 Tambora eruption had thrown million tons of pumice and had covered seas around the volcano for years (Oppenheimer, 2011). These two volcano eruptions, which occurred in the last 200 years, have deposited sand-size materials in Karimata Strait and its surrounding areas. The deposition of this silicious material might also have played a role in increasing benthic foraminifer population in shallow marine environments. In the modern ocean, recolonization by benthic

foraminifera has been observed in shallow water environments following artificial disturbance (Ellison and Peck, 1983; Schafer, 1983), and following local volcanic ashfalls (Finger and Lipps, 1981). In an experiment using recolonization trays at an abyssal site in the Panama Basin, Kaminski *et al.* (1988a, b) identified several species of benthic foraminifera as opportunistic, including *Psammosphaera*, *Reophax excentricus*, and *Reophax dentaliniformis*. The initial stage of recolonization of modern deep-sea benthic foraminifera (largely by species of *Reophax*, *Subreophax*, and a minute organically cemented species of *Textularia*) in a vast disturbed habitat on top of the tephra layer were deposited in the South China Sea. It is as a result of the 1991 eruption of Mount Pinatubo in the Philippines reported by Hess and Kuhnt (1996) and Hess *et al.* (2002) that begun three years the eruption. The sampling resolution of this study, however, is not likely to obviously show this record.

According to the document of “Kitab Raja Purwa” the 535 A.D. (it was probably misleadingly written as 416 A.D. in this document), as documented by Wichmann (1918), the Krakatau eruption had separated Java from Sumatra Islands. The magnitude of this eruption, its catastrophic impacts, the amount of erupted materials, and its tephra thickness were probably much bigger than that of the 1883 one. This catastrophic event might speculatively have caused the disappearance of foraminifers in the sample at 70 - 72 cm and the drop of pollen and spore influx at 60 cm. The abundant occurrence of benthic foraminifers is in the sample at 60 - 62 cm. On the other side, it is speculatively caused by the abundant deposition of silicious materials of this eruption in Karimata Strait. The lapse time onset of foraminifer and mangrove responses indicates collateral impacts of the eruption to marine ecologies in distant areas might have occurred instaneously, and those impacts to terrestrial ecologies might have occurred lately.

The chronology of environmental and vegetation landscape changes in the studied site and its surrounding areas from the LGM to the present is schematically drawn in Figure 3.



Gambar 3. Schematic chronology of environmental changes in Karimata Strait and its vicinity since the Last Maximum Glacial. A-B is reconstructed based on results of this study and several references; C-E is reconstructed based on Solihuddin (2014): (A) 18,000 yr B.P., sea level dropped to its lowest level about 120 m below the present sea level. Karimata Strait and Sunda Shelf emerged and occupied by open forest and savannah (Verstappen, 1975; Morley dan Flenley, 1987; Morley, 1998, 2000; Gathorne-Hardy *et al.*, 2002; Bird *et al.*, 2005; Wurster *et al.*, 2010); (B) at about 10,000 yr B.P., post LGM sea level rise reached -30 m from its present position (Solihuddin, 2014), flooded Karimata Strait partially. The core site was in a littoral environment where mangroves were growing; (C) at about 6,000 yr B.P., post LGM sea level rise reached its maximum position (Holocene Maximum Transgression-HMT), sea level position in Sundaland region was about 3 - 5 m above the present sea level (Tjia *et al.*, 1977, 1983, 1996; Parham *et al.*, 2014), the coastal flat around Karimata Strait was flooded and intensively occupied by mangroves, the core site was in a shallow neritic environment; (D) at about 2,500 yr B.P., the sea level has been at about its present position, mangroves were intensively growing on the tidal flat around Karimata Strait, the core was in a shallow neritic environment, deposition of the core commenced; (E) At present, environmental changes started since about 500 - 750 yr B.P. as indicated by the deposition of coarser clastic material in the core site, more abundant occurrence of benthic foraminifer, and the decrease of mangrove pollen grain, the core site was in a shallow neritic environment.

CONCLUDING REMARKS

This study shows that pollen and spores were deposited in moderate amounts, in the marine gravity core taken from a site at 170 km offshore in Karimata Strait. The pollen record gives a picture of pollen facies in marine sediments and Late Holocene environmental changes of Sunda Shelf.

The results of this study show mangrove pollen may present over 50% of the pollen assemblages in marine sediments that were deposited well away from the mangrove forests, emphasizing that mangrove pollen can be extensively transported, as first demonstrated by Muller (1959) in his classic study of Orinoco Delta pollen transportation. Facies interpretation based on the abundance of mangrove pollen, consequently, should be conducted very carefully.

The deposition of the core started ca 1,800 yr B.P. (roughly 150 A.D.) when the core site was in a neritic environment as it is recently. At this time, mangroves intensively grew on tidal flats of surrounding islands and their abundance persisted to ca 700 yr B.P. (roughly 1,250 A.D.). A catastrophic event that destroyed benthic foraminifers and reduced mangroves occurred in the middle of this period, probably due to the 535 A.D. Krakatau eruption. Benthic foraminifers responded instantaneously to this event, and mangroves responded later. The deposition of silicious materials (tephra) in Karimata Strait due to this eruption, however, might have facilitated the increase of benthic foraminifer abundance.

The environmental changes occurred since ca 700 yr B.P. (roughly 1,250 A.D.) as indicated by lower frequencies of mangroves in pollen assemblage, the deposition of coarser sediment, and the increase of benthic foraminifer abundance. The interplay of increasing anthropogenic activities due to settlement and agriculture, strengthening ENSO cycle and its collateral consequences, and lowering of erosion base level due to maximum sea level drop after HMT might have been responsible for these environmental changes.

Acknowledgement

The authors convey their gratitude to Sri Arfia, Khrisnawati, and Sumarjadi of Quaternary Laboratory, Centre for Geological Survey, Geological Agency, for their assistance in doing laboratory preparation. The authors also convey their gratitude to Marine Geological Institute for allowing them to use the core for this study. In preparing this paper, E. Yulianto is responsible in presenting data in figures, transforming pollen and spore counts in pollen diagram, and writing the manuscript. W.S. Sukapti is responsible in laboratory preparation and pollen determination. Kresna T. Dewi is responsible in providing data and information concerning sedimentology and foraminifer content of the core.

REFERENCES

- Bird, M.I., Taylor, D., and Hunt, C. 2005. Palaeoenvironments of insular Southeast Asia during the Last Glacial Period: a savanna corridor in Sundaland? *Quaternary Science Reviews*, 24, p.2228-2242. DOI: 10.1016/j.quascirev.2005.04.004
- Biswas, B., 1973. Quaternary Changes in Sea-Level in the South China Sea. *Geological Society of Malaysia Bulletin*, 6, p.229-256.
- Caratini and Tissot, 1988. Paleogeographical evolution of Mahakam Delta in Kalimantan, Indonesia during the Quaternary and Late Pliocene. *Review of Palaeobotany and Palynology*, 55, 217pp. DOI: 10.1016/0034-6667(88)90087-5
- De Deckker, P., Tapper, N.J., and Kaars, S.V. 2002. *The status of the Indo-Pacific Warm Pool and adjacent land at the Last Glacial Maximum. Global and Planetary Change*, 35, p.25-35. DOI: 10.1016/s0921-8181(02)00089-9
- Dewi, K.T., 2014 Ostracoda from Subsurface Sediments of Karimata Strait as Indicator of Environmental Changes. *Bulletin of the Marine Geology*, 29 (1), p.1-10. DOI: 10.32693/bomg.29.1.2014.60

- Ding, X., Bassinot, F., Guichard, F., and Fang, N.Q., 2013. Indonesian Throughflow and monsoon activity records in the Timor Sea since the last glacial maximum. *Marine Micropaleontology*, 101, p.115-126. DOI: 10.1016/j.marmicro.2013.02.003
- Ellison, R.L. and Peck, G.E. 1983. Foraminiferal recolonization on the continental shelf. *Journal of Foraminiferal Research* 13, p.231-241. DOI: 10.2113/gsjfr.13.4.231
- Ewusie, J.Y., 1990. *Ekologi Tropika*. Bandung, Penerbit ITB, 251pp.
- Finger, K.L. and Lipps, J.H., 1981. Foraminiferal decimation and repopulation in an active volcanic caldera, Deception Island, Antarctica. *Micropaleontology*, 27, p.111-139. DOI: 10.2307/1485283
- Flenley, J.R., 1985. Relevance of Quaternary palynology to geomorphology in the tropics and subtropics. In: Douglas, I., Spencer, T. (eds), *Environmental Change and Tropical Geomorphology*. Allen and Unwin, London, p.153-164.
- Flenley, J.R., 1996. Problems of the Quaternary on mountains of the Sunda–Sahul Region. *Quaternary Science Review* 15, 549–555. DOI: 10.1016/0277-3791(96)00017-0
- Flenley, J.R., 1998. Tropical forest under the climate of the last 30,000 years. *Climate Change*, 39, p.177-197.
- Gathorne-Hardy F.J., Syaukani, Davies, R.G., Eggleton P., and Jones D.T., 2002. Quaternary rainforest refugia in south-east Asia: Using termites (Isoptera) as indicators. *Biological Journal of the Linnean Society*, 75, p.453-466. DOI: 10.1046/j.1095-8312.2002.00031.x
- Gingele, F.X., De Deckker, P., Girault, A., and Guichard, F. 2002. High-resolution history of the South Java current during the past 80 Ka. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 183, p.247-260. DOI: 10.1016/s0031-0182(01)00489-8
- Giri, C., Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Masek, J., and Duke, N., 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography*, 20, p.154-159. DOI: 10.1111/j.1466-8238.2010.00584.x
- Haberle, S.G., Hope, G.S., and Kaars, S.V., 2001. Biomass burning in Indonesia and Papua New Guinea: Natural and human induced fire events in the fossil record. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 171, p.259-268. DOI: 10.1016/s0031-0182(01)00248-6
- Hanebuth, T., Statterger, K., and Grootes, P.M., 2000. Rapid flooding of the Sunda shelf - a Late-Glacial sea-level record. *Science*, 288, p.1033-1035. DOI: 10.1126/science.288.5468.1033
- Hardjawidjaksana, K., 1990. Laporan Penyelidikan Geologi dan Geofisika Kelautan Lembar Peta 1410, Karimunjawa. Pusat Pengembangan Geologi Kelautan, Bandung, 40pp. DOI: 10.32693/jgk.10.2.2012.220
- Herbeck, L., Kwiatkowski, C., Mohtadi, M., and Jennerjahn, T. 2014. Late Holocene carbon and nitrogen input into the Java Sea recorded in sediment cores off rivers from Java and Kalimantan. *Geophysical Research Abstracts*, 16, EGU2014-11418, EGU General Assembly 2014.
- Hess, S. and Kuhnt, W., 1996. Deep-sea benthic foraminiferal re-colonization of the 1991 Mt. Pinatubo ash layer in the South China Sea. *Marine Micropaleontology*, 28, p.171-197. DOI: 10.1016/0377-8398(95)00080-1
- Hess, S., Kuhnt, W., Hill, S., Kaminski, M.A., Holbourn, A., and De Leon, M., 2002. Monitoring the recolonisation of the Mt. Pinatubo 1991 ash layer by benthic foraminifera. *Mar. Micropaleontol.*, 43, p.119-142. DOI: 10.1016/s0377-8398(01)00025-1
- Hope, G.S. and Tulip, J., 1994. A long vegetation history from lowland Iran Jaya, Indonesia. *Paleogeography Paleoclimatology Palaeoecology*, 109, p.385-398. DOI: 10.1016/0031-0182(94)90187-2
- Hu, J. Y., Kawamura, H., Tang, D.L. 2003. Tidal front around the Hainan Island, northwest of the South China Sea. *Journal of Geophysical Research*, 108 (C11), 3342pp. DOI: 10.1029/2003jc001883

- Kaminski, M.A., Gradstein, F.M., Berggren, W.A., Geroch, S., and Beckmann, J.P., 1988a. Flysch-type agglutinated foraminiferal assemblages from Trinidad: Taxonomy, Stratigraphy and Paleobathymetry. In: Gradstein, F.M. and Rogl, F. (eds), *Proceedings of the Second Workshop on Agglutinated Foraminifera*, Vienna 1986. Abh. Geol. Bundesanst, 41, p.155-228. DOI: 10.1007/978-94-011-3350-0_14
- Kaminski, M.A., Grassle, J.F., and Whitlatch, R.B., 1988b. Life history and recolonization among agglutinated foraminifera in the Panama Basin. In: Gradstein, F.M. and Rogl, F. (eds), *Proceedings of the Second Workshop on Agglutinated Foraminifera*, Vienna 1986. Abh. Geol. Bundesanst, 41, p.229-244. DOI: 10.1007/978-94-011-3350-0_14
- Kaars, S.V. 1998. Marine and terrestrial pollen records of the last glacial cycle from the Indonesian region: Bandung basin and Banda sea. *Palaeoclimates*, 3, p.209-219.
- Kaars, S.V., 2001. Polen distribution in marine sediment from south-eastern part of Indonesian waters. *Paleogeography, Paleoclimatology, Paleoecology*, 171, p.341-361.
- Kuenen, P.H. 1950. *Marine Geology*. John Wiley and Sons, Inc., New York Chapman & Wall, Limited, London. 601pp.
- Lambeck, K., Rouby, H., Purcell, A., Sun, Y.Y., and Sambridge, M., 2014. Sea level and global ice volumes from the Last Glacial Maximum to the Holocene. *Proceedings of the National Academy of Sciences, U. S. A.*, 111, p.15296-15303. DOI: 10.1073/pnas.1411762111
- Long, J.B. and Giri, C., 2011. Mapping the Mangrove Forests Using Landsat Imagery. *Sensors*, 11, p.2972-2981. DOI: 10.3390/s110302972
- Lorente, M.A., 1987. *Palynology and palynofacies of the Upper Tertiary in Venezuela*. Berlin, J. Cramer, 222pp.
- Morley R.J. and Flenley, J.R., 1987. Late Cenozoic vegetational and environmental changes in the Malay Archipelago. *Oxford Monographs on Biogeography*, 4, p.50-59.
- Morley R.J., 1998. Palynological Evidence for Tertiary Plant dispersals in the S.E. Asia region in relation to plate tectonics and climate. In: Hall, R. and Holloway, J.D. (eds.), *Biogeography and Geological Evolution of S.E. Asia*, (Backhuys, Leiden, The Netherlands), p.211-234.
- Morley R.J., 2000. *Origin and Evolution of Tropical Rain Forests*. John Wiley & Sons Ltd., 362pp.
- Moy, C.M., Seltzer, G.O., Rodbell, D.T., and Anderson, D.M., 2002. Variability of El Niño/Southern Oscillation activity at millennial timescales during the Holocene epoch. *Nature*, 420, p.162-165. DOI: 10.1038/nature01194
- Muller, J. 1959. Palynology of Recent Orinoco Delta and Shelf Sediments: Reports of the Orinoco Shelf Expedition. *Micropaleontology*, 5 (1), p.1-32. DOI: 10.2307/1484153
- Newsome, J. and Flenley, J.R., 1988. Late Quaternary vegetational history of the central highlands of Sumatera.II. Palaeopalynology and vegetational history. *Journal of Biogeography*, 1, p.555-578. DOI: 10.2307/2845436
- Newton, A., Thunell, R., Stott, L. 2011. Changes in the Indonesian throughflow during the past 2000 yrs. *Geology*, 39 (1), p.63-66. DOI: 10.1130/g31421.1
- Oo, N.W., 2004. Changes in Habitat Conditions and Conservation of Mangrove Ecosystem in Myanmar: A Case Study of Pyindaye Forest Reserve, Ayeyarwady Delta. Status Report for MAB Young Scientist Award 2004, 14pp.
- Oppenheimer, C., 2011. *Eruptions that Shook the World*. Cambridge University Press, 406pp.
- Pararas-Carayannis, G., 2003. Near and far-field effects of tsunamis generated by the paroxysmal eruptions, explosions, caldera collapses and massive slope failures of the Krakatau volcano in Indonesia on August 26-27, 1883. *Science of Tsunami Hazards*, 21 (4), p.191-221.
- Parham, P.R., Saito, Y., Sapon, N., Suriadi, R., and Mohtar, N.A., 2014. Evidence for ca 7-ka maximum Holocene transgression on the Peninsular Malaysia East coast. *Journal of*

- Quaternary Science*, 29 (5) p.414-422. DOI: 10.1002/jqs.2714
- Raes, N., Cannon, C.H., Hijmans, R.J., Piessense, T., Saw, L.G., van Welzena, P.C, and Slik, J.W.F., 2014. Historical distribution of Sundaland's Dipterocarp rainforests at Quaternary glacial maxima. *PNAS*, 111(47), p.16790-16795. DOI: 10.1073/pnas.1403053111
- Reeves, J.M., Barrows, T.T., Cohen, T.J., Kiem, A.S., Bostock, H.C., Fitzsimmons, K.E., Jansen, J.D., Kemp, J., Krause, C., Petherick, L., Phipps, S.J., and OZ-INTIMATE Members, 2013. Climate variability over the last 35,000 years recorded in marine and terrestrial archives in the Australian region: an OZ-INTIMATE compilation. *Quaternary Science Reviews*, 74, p.21-34. DOI: 10.1016/j.quascirev.2013.01.001
- Russell, J.M., Vogel, H., Konecky, B.L., Bijaksana, B., Huang, Y., Melles, M., Wattrus, N., Costa, K., and King, J.W., 2014. Glacial forcing of central Indonesian hydroclimate since 60,000 yr B.P. *Proceedings of the National Academy of Sciences of the United States of America*, 114 (14), p.5100-5105. Doi: 10.1073/pnas.1402373111. DOI: 10.1073/pnas.1402373111.
- Sathiamurthy, E. and Voris, H.K., 2006. Maps of Holocene Sea Level Transgression and Submerged Lakes on the Sunda Shelf. *The Natural History Journal of Chulalongkorn University*, Supplement 2, p.1-44.
- Schafer, C.T., 1983. Foraminiferal colonization of an offshore dump site in Chaleur Bay, New Brunswick, Canada. *Journal of Foraminiferal Research*, 12, p.317-326. DOI: 10.2113/gsjfr.12.4.317
- Simskin, T. and Fiske, R.S., 1983. *Krakatau 1883: The volcanic eruption and its effects*. Smithsonian Institution Press, Washington, D.C., 464pp.
- Siregar, D. and Dewi K.T., 2014. Analisis penarikan radiokarbon untuk penentuan fluktuasi muka laut di sebelah utara pulau Bangka. *Jurnal Geologi Kelautan*, 12 (3), p.135-144. DOI: 10.32693/jgk.12.3.2014.253
- Slik, J.W.F., Aiba, S.I., Bastian, M., Brearley, F.Q., Cannon, C.H., Eichhorn, K.O.A., Fredriksson, G., Kartawinata, K., Laumonier, Y., Mansor, A., Marjokorpi, A., Meijaard, E., Morley, R.J., Nagamasu, H., Nilus, R., Nurtjahya, E., Payne, J., Permana, A., Poulsen, A.D., Raes, N., Riswani, S., Schaik, C.P.V., Sheil, D., Sidiyasa, K., Suzuki, E., Valkenburg, J.L.C.H.V., Webb, C.O., Wichu, S., Yoneda, T., Zakaria, R., and Zweifel, N., 2011. Soils on exposed Sunda Shelf shaped biogeographic patterns in the equatorial forests of Southeast Asia. *PNAS*, 108 (30), p.12343-12347. DOI: 10.1073/pnas.1103353108
- Soares, M.L.G., 2009. A Conceptual Model for the Responses of Mangrove Forests to Sea Level Rise. *Journal of Coastal Research*, Special Issue 56, p.267-271.
- Solihuddin, T., 2014. A Drowning Sunda Shelf Model during Last Glacial Maximum (LGM) and Holocene: A Review. *Indonesian Journal on Geoscience*, 1 (2), p.99-107. DOI: 10.17014/ijog.v1i2.182
- Southon, J., Mohtadi, M., and de Pol-Holz, R., 2013. Planktonic Foram Dates from the Indonesian Arc: Marine 14C Reservoir Ages and a Mythical A.D. 535 Eruption of Krakatau. *Radiocarbon*, 55 (2-3), p.1164-1172. DOI: 10.1017/s0033822200048074
- Stuijts, I., Newsome, J.C., and Flenley, J.R., 1988. Evidence for late Quaternary vegetational change in the Sumatran and Javan Highlands. *Review of Paleobotany and Palynology*, 55, p.207-216. DOI: 10.1016/0034-6667(88)90086-3
- Sun, X. and Li, X., 1999. A pollen record of the last 37 ka in deep sea core 17940 from the northern slope of the South China Sea. *Marine Geology*, 156, p.227-244. DOI: 10.1016/s0025-3227(98)00181-9
- Sun, X., Li, X., Luo, Y., and Chen, X., 2000. The vegetation and climate at the last glaciation on the emerged continental shelf of the South China Sea. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 160, p.301-316. DOI: 10.1016/s0031-0182(00)00078-x

- Sun, X., Li, X., and Luo, Y. 2002. Vegetation and climate on sundashelf of the south china sea during the last glaciation-pollen result. *Acta Botanica Sinica*, 44 (6), p.746-752.
- Tjia, H.D., Fum, S., and Kiooshi, K., 1977. Changes of sea-level in the southern part of the South China Sea area during Quaternary times. *United Nations, ESCAP-CCOP Technical Bulletin*, 5, p.11-36.
- Tjia, H.D., 1983. Aspek geologi kuarter Asia Tenggara. *Buletin Geologi, Jurusan Geologi-ITB*, 9, p.1-21.
- Tjia, H.D., 1996. Sea-level changes in the tectonically stable Malay-Thai Peninsula. *Quaternary International*, 31, p.95-101. DOI: 10.1016/1040-6182(95)00025-e
- Verstappen, H.T., 1975. The effect of Quaternary tectonics and climates on erosion and sedimentation in Sumatra. *Proceedings of the 4th Indonesian Petroleum Association Annual Convention*, Jakarta, Indonesia. DOI: 10.29118/ipa.1046.49.53
- Walker, D. and Flenley, J.R., 1976. Late Quaternary vegetational history of the Enga District of upland Papua New Guinea. *Philosophical Transactions of the Royal Society*, B 286, p.265-344. DOI: 10.1098/rstb.1979.0034
- Wang, L., Sarnthein, M., Erlenkeuser, H., Grimm, J., Grootes, P., Heilig, S., Ivanova, E., Keinast, M., Pelejero, C., and Pflaumann, U., 1999. East Asian monsoon climate during the Late Pleistocene: High resolution sediment records from the South China Sea. *Marine Geology*, 156, p.245-284. DOI: 10.1016/S0025-3227(98)00182-0
- Wang, X.M., Sun, X.J., Wang, P.X., and Stattegger, K., 2007. A high-resolution history of vegetation and climate history on Sunda Shelf since the last glaciation. *Science China Series D-Earth Science*, 50 (1), p.75-80. DOI: 10.1007/s11430-007-2067-4
- Wang, X.M., Sun, X.J., Wang, P.X., and Stattegger, K., 2008. The records of coastline changes reflected by mangroves on the Sunda Shelf since the last 40 ka. *Chinese Science Bulletin*, 53(13), p.2069-2076. DOI: 10.1007/s11434-008-0278-5
- Wang, X.M., Sun, X.J., Wang, P.X., and Stattegger, K., 2009. Vegetation on the Sunda Shelf, South China Sea, during the Last Glacial Maximum. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 278, p.88-97. DOI: 10.1016/j.palaeo.2009.04.008
- Wichmann, A., 1918. Die Erdbeben des Indischen Archipels Bis Zum Johpe 1857, Koninklijke Nederlandse Akademie van Wetenschappen, Verhandeligen 2nd, 20, 193pp.
- Wurster, C.M., Bird, M.I., Bull, I.D., Frances, B., Charlotte, D., Jennifer A.J., and Paz, V., 2010. Forest contraction in north equatorial Southeast Asia during the Last Glacial Period. *Proceedings of the National Academy of Sciences of the United States of America*, 107 (35), p.15508-15511. DOI: 10.1073/pnas.1005507107
- Yulianto, E. and Dewi, K. T., 2000. An evidence on narrowing and/or shallowing process of Makassar Strait. Prosiding. PIT IAGI ke 29.
- Yulianto, E., Sukapti, W. S., Rahardjo, A. T., Noeradi, D., Siregar, D.A., Suparan, P., and Hirakawa, K., 2004. Mangrove shoreline responses to Holocene environmental change, Makassar Strait, Indonesia. *Review of Palaeobotany and Palynology*, 131 (3), p.251.268. DOI: 10.1016/j.rev-palbo.2004.03.009