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

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**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

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## 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 bathimetry. 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 catasthropic 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 bathimetry 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/$H_2SO_4$, and acetic anhydrite/$(CH_3CO)_2O$, at 9:1 composition, and gravity separation using $ZnCl_2$ 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 cellected 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

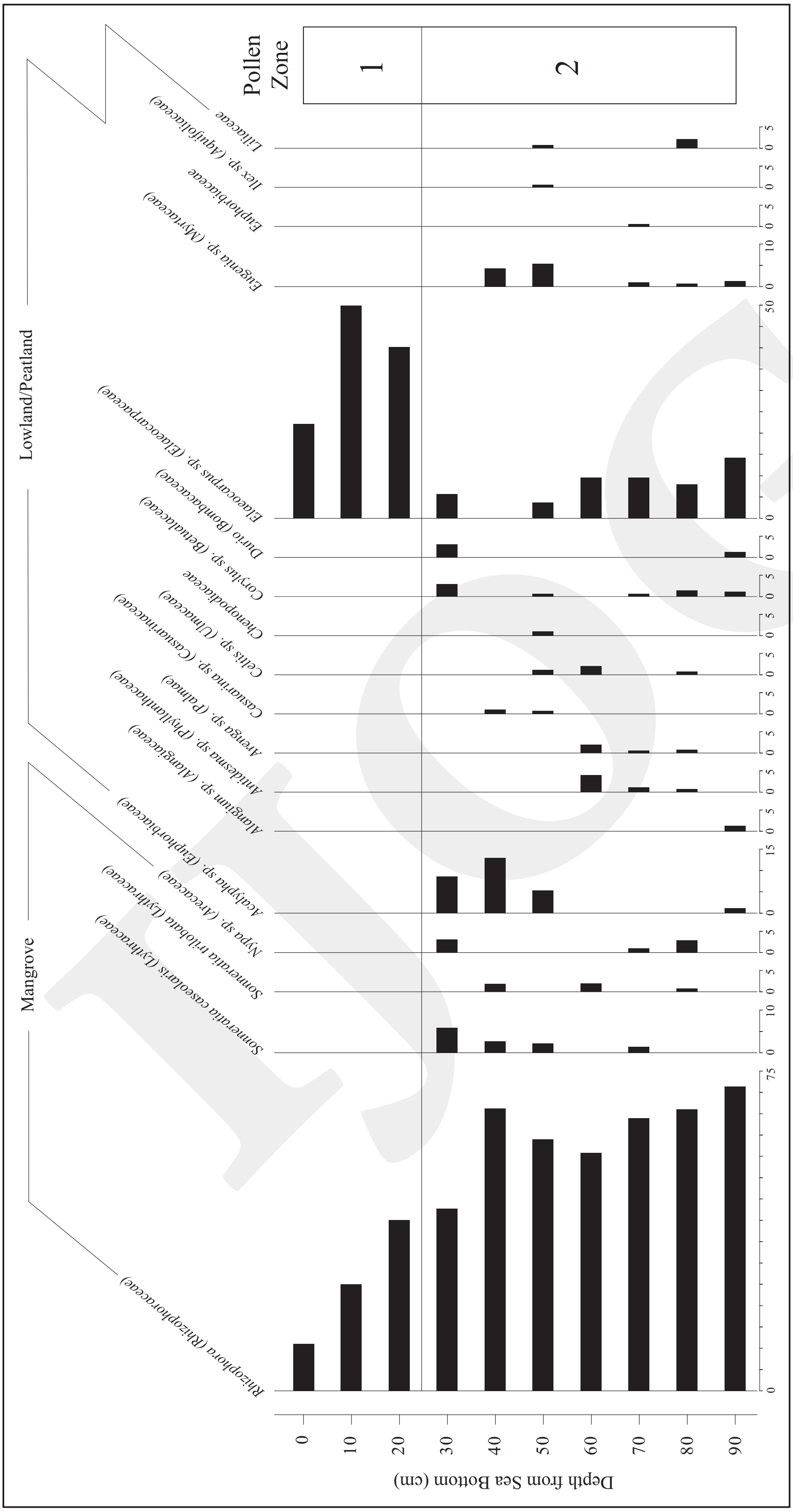
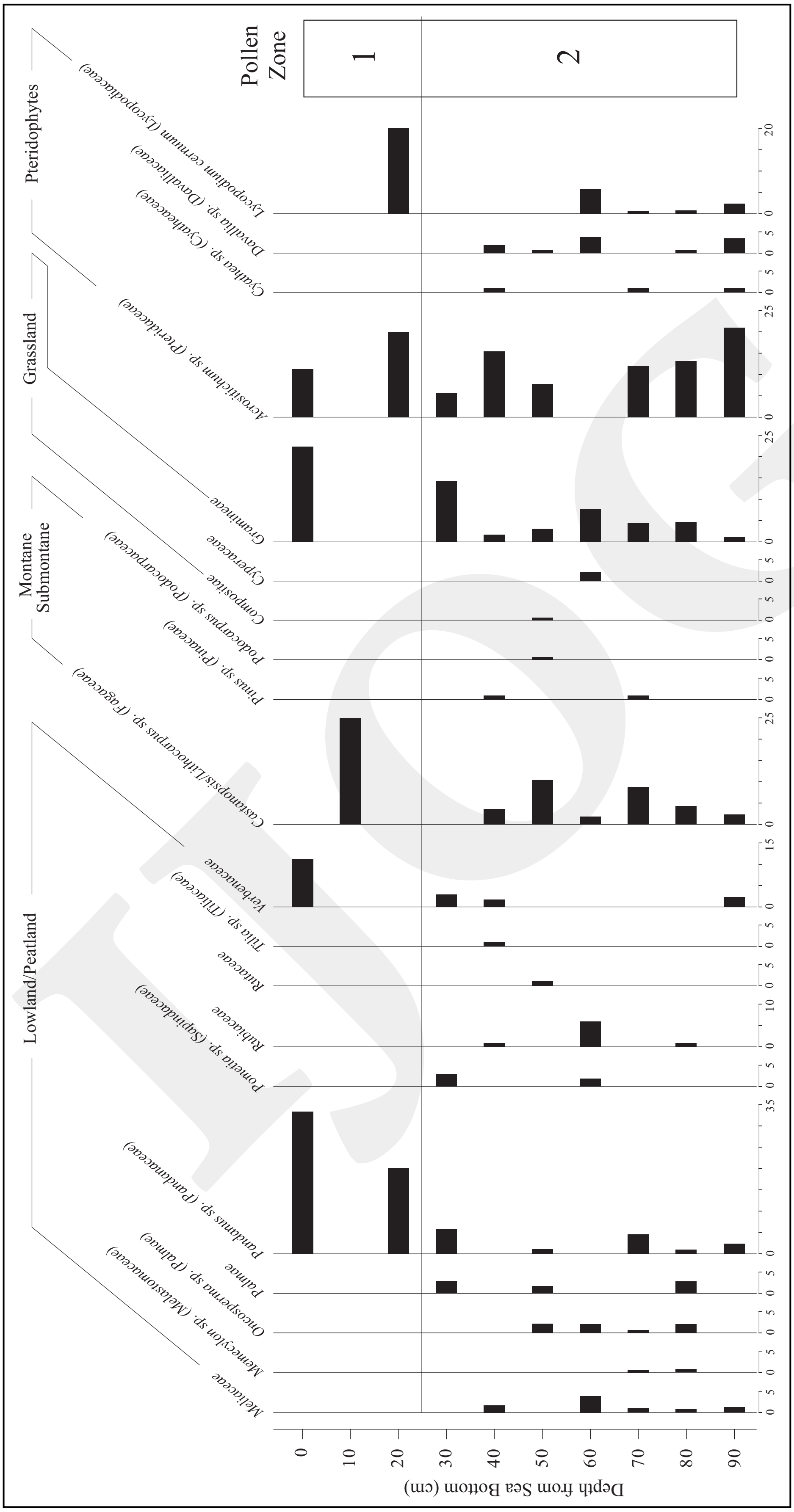


Figure 2. Diagram of pollen of the analyzed core taken from Karimata Strait.



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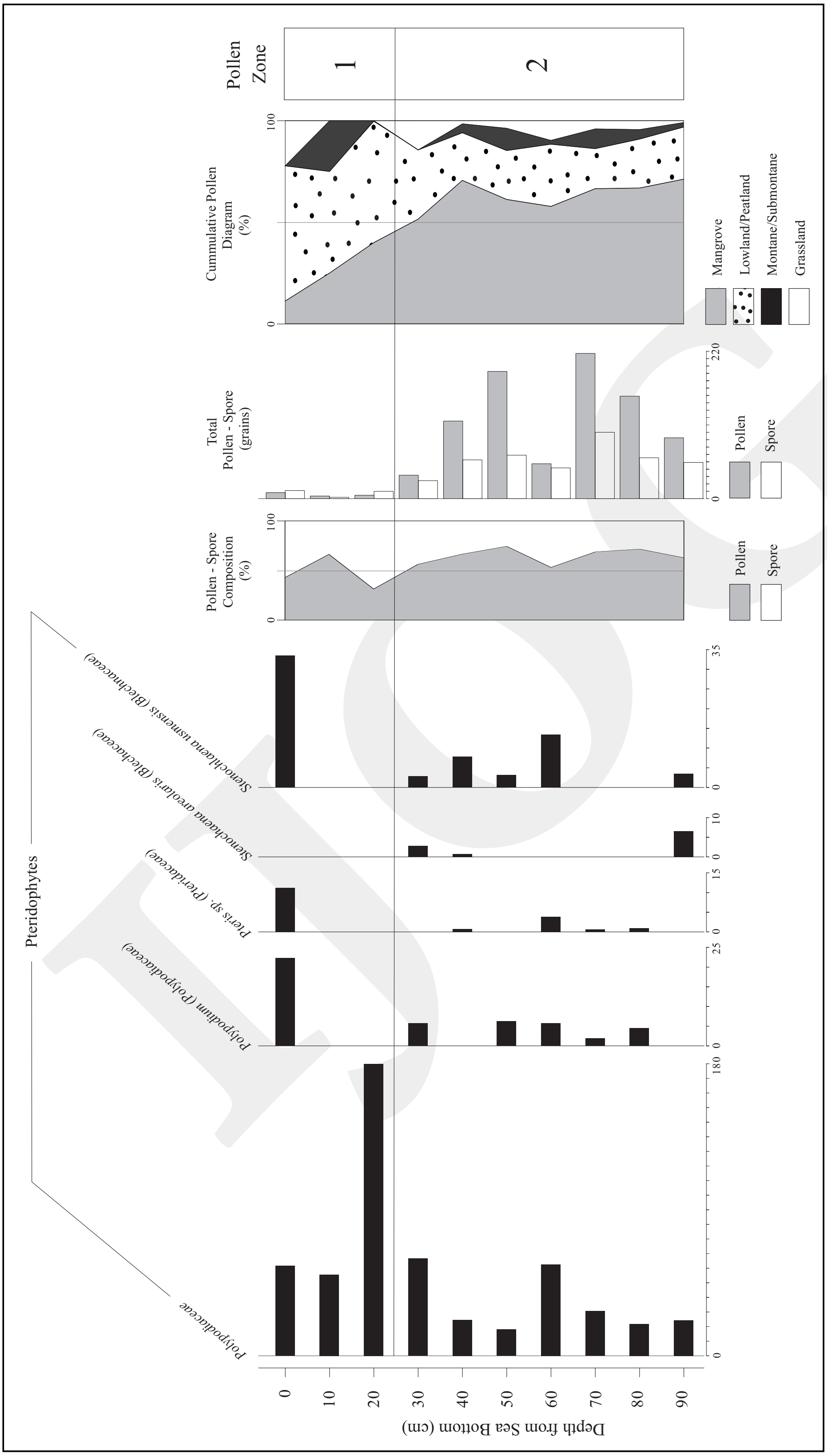


Figure 2. continuation.....

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 bathimetry (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), accomodation 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.

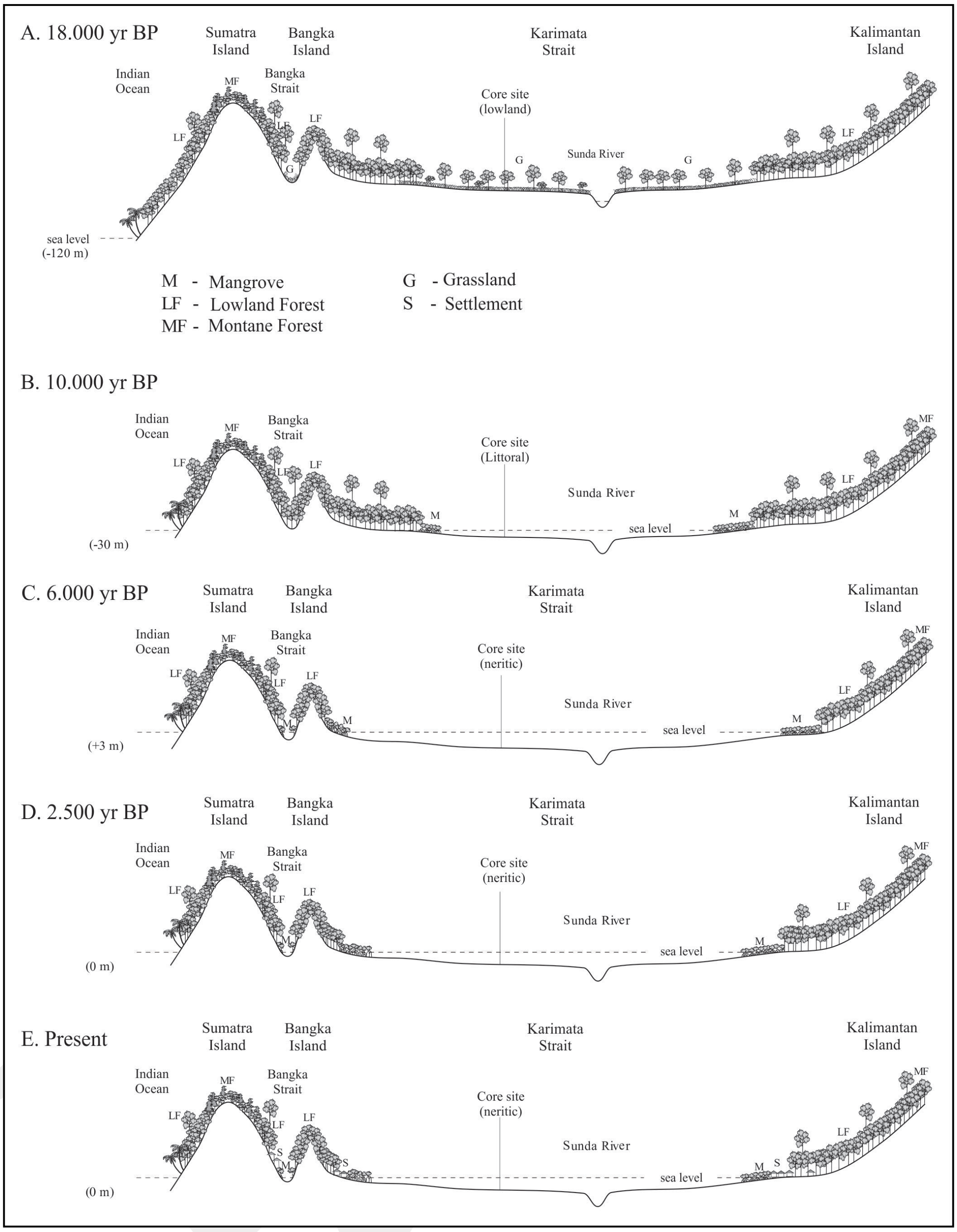
Changes of pollen composition from 30 cm deep (ca 700 yr B.P.) upward occur simultaneously with changes of sedimentology and abundance of benthic foraminifers. In general, changes in the upper part of the core may be simply perceived as a consequence of intensive anthropogenic activities due particularly 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 catasthropic impacts, the amount of erupted materials, and its tephra thickness were probably much bigger than that of the 1883 one. This catasthropic 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 Trasgression-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 catasthropic 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 instaneously 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.

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