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RESEARCH ARTICLE

Depositional Environment of the Late Miocene of Lemau Formation from Bengkulu Basin Based on Palynology in Seluma, Bengkulu, Indonesia

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Abstract

Indonesia has several sedimentary basins, one of which is the Bengkulu Basin. One of the rock formations that make up this basin is the Lemau Formation, which is of Middle-Late Miocene age. Determining the depositional environment can use pollen and spore fossils stored in rocks. In the Lemau Formation, very little has been done to determine the depositional environment using pollen and spores. This research aims to reconstruct the sedimentary environment of the Lemau Formation rocks in the Late Miocene. Analysis was carried out on ten rock samples from Seluma, Bengkulu, Indonesia. Data collection used the stratigraphic measurements method, and laboratory analysis used the hydrogen peroxide method. There were five changes in the depositional environment, starting from the *mangrove* environment in sample BIL 21. The shallow environment became *back mangrove* in sample BIL 22, shallowing again became *a peat swamp* environment in samples BIL 23-BIL 26, the flooded environment became *mangrove* in sample BIL 27 and shallowing returned to a *freshwater* environment in samples BIL 28-BIL 30. Determination of the Late Miocene age used the presence of the *Stenochlaenidites papuanus* index fossil found in sample BIL 21. This environmental change was possible due to tectonic activities on the island of Sumatra in the Late Miocene and global eustatic changes.

Keywords: Depositional environment, Lemau Formation, Palynology, Late Miocene, Bengkulu Basin.

1. Introduction

Indonesia contains several sedimentary basins that span the country from east to west. The collision of the Indo-Australian Ocean crust and the Sundaland continental crust creates basins in Indonesia. Due to the collision, sedimentary basins formed west of Sumatra Island (Curray et al., 1979). This collision or subduction also creates magmatic pathways, fore-arc and back-arc (Bishop, 2001). The Bengkulu Basin is one of the sedimentary basins located in front of the arc around Sumatra Island. One of the rock formations that make up the Bengkulu Basin is the Lemau Formation. The Lemau Formation, which is Middle-Late Miocene in age (Gafoer et al., 1992), is formed of claystone, limestone, coal, sandstones, and conglomerates and overlies the unconformable Seblat Formation (Yulihanto et al., 1995; Heryanto & Suyoko, 2007).

The Lemau Formation was deposited in a shallow marine environment and lagoon on its onshore part (Yulihanto et al., 1995). According to the mineral content and sediment structure, this formation was deposited in a riverine environment (Haryanto & Suyoko, 2007); however, according to the foraminiferous content, it was deposited in a deltaic to the shallow marine environment, where it was associated with the formation of marsh/swamp, lagoon, backbarier, and foreshore environments (Tarigan et al., 2018). Meanwhile, based on pollen and spore content, this formation was deposited in a lagoon to a freshwater environment during the Early-Middle Miocene (Mentari et al., 2023). The Lemau Formation is equivalent to the Muara Enim Formation in the South Sumatra Basin, according to Yulihanto et al. (1995).

The depositional environment is a characteristic of a geomorphic setting in which physical, chemical, and biological occur to produce certain deposits (Boggs, 1995). The presence of forming plants cannot be separated from coal deposition in the Lemau Formation. Existing plants produce pollen and spores, which are then stored in the rock. Because pollen and spores are so extensively scattered, they can be used to define the age and environment when deposited (Erdtman, 1966; Morley, 1990). Pollen and spore identification can also be used to reconstruct local and regional vegetation changes surrounding the depositional environment (Moore & Webb, 1978; Morley, 1990; Birks & Birks, 2005; Traverse, 2007). Pollen and spores can be preserved in environments ranging from terrestrial to marine.

In the Middle Miocene, there was an uplift of the Bukit Barisan Hills on Sumatra Island (Hastuti et al., 2001; Husein et al., 2018). This tectonic activity caused environmental changes in rock deposition before and after the tectonic activity occurred. The pollen and spores present can be utilized to determine the depositional environment of rocks after the Middle Miocene. The goal of this research is to reconstruct the depositional environment of the Lemau Formation in the Late Miocene based on the content of pollen and spores.

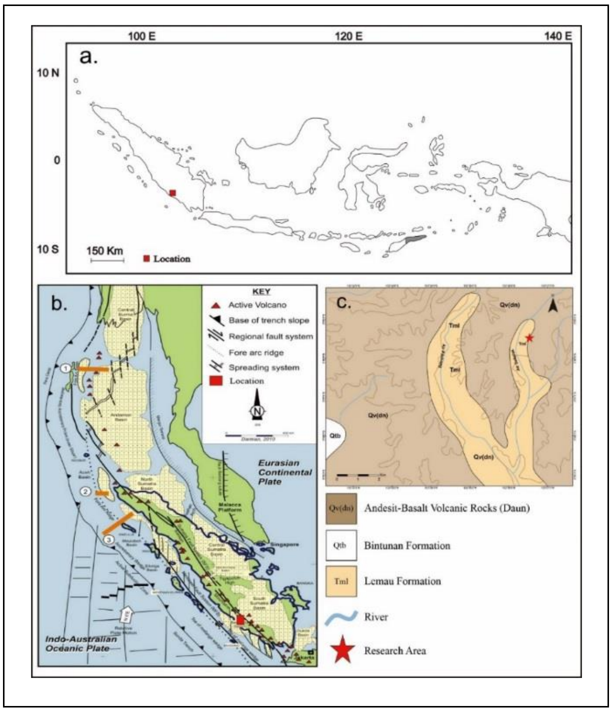

Fig 1. Location of the study area. a. on the map of Indonesia, b. on the tectonics of Sumatra Island (Darman, 2011), c. on a geological map (Gafoer et al., 1992).

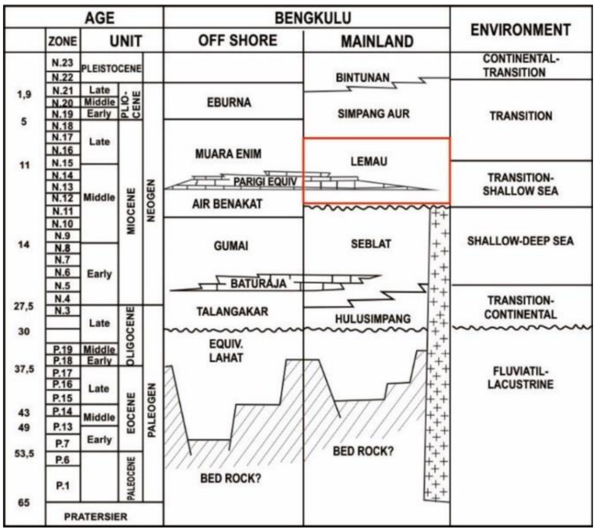

Fig 2. Stratigraphy of the research area (Yulihanto et al., 1995)

2. Material and Method

The sample data are from parting layers based on stratigraphic measurements in the coal field of the Bengkulu Basin at PT Bara Indah Lestari, Sekalak Village, Seluma, Bengkulu, Indonesia. Ten samples were obtained and given the labels BIl 21 to BIL 30.

Laboratory analysis was conducted at the Micropaleontology Laboratory of the Padjadjaran University Faculty of Geological Engineering using the hydrogen peroxide method. Existing samples were pulverized, and up to 20 grams were taken, then given 10% H_2O_2 liquid for 30 minutes. After that, the sample was neutralized with distilled water. After neutralization, the sample was given 40% HF liquid and neutralized again. After neutralization, the sample was filtered twice, and the remaining residue was taken to be utilized in making specimen samples (modify from Riding et al., 2007). A binocular microscope with objective magnifications of 10x, 40x, and ocular 10x was used to make the observations.

The association of characteristic fossils according to the Haseldonckx (1974: Rahmad et al., 2013) classification is used to determine the depositional environment (Table 1), while to determine the age using the presence of index fossils refer to the Morley table (1991) (Figure 3).

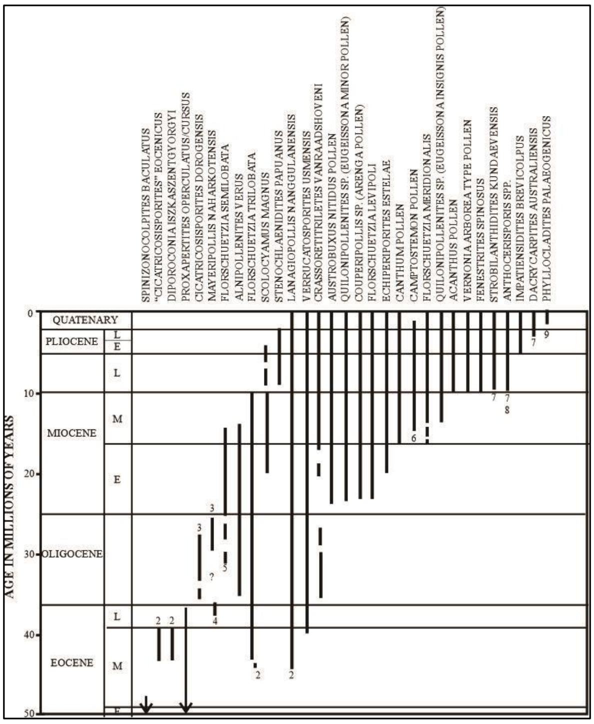

Fig 3. Age zone (Morley, 1991)

Table 1. Depositional environment and characteristic fossils (modification Haseldonckx, 1974; Rahmad et al., 2013).

No	Environment	Fossil
1	Montane Rain Forest	*Dominated group Fagaceae (Quercus, Lithocarpus, Castanopsis), together with Lauraceae, Dacrydium, Engechardia and Podocarpus sp.*
2	Lowland Forest	*Dominated group Dipterocarpaceae bersama dengan Myrtaceae (Eugenia spp.), Calophyllum, Annonaceae, Euphorbiaceae, Flacourtaceae, Rubiaceae and Calamus spp.*
3	Riparian Fringe	*including Pandanus, Barringtonia, Gluta, Calophyllum, Dipterocarpaceae, Oncosperma, and Calamus*
4	Lake	*combination of groups lowland rain forest and peat swamp/alluvial swamp.*
5	Freshwater Peat Swamp/Alluvial Swamp	*a mix of local assemblages, including Blumeodendron, Ctenolophon, Durio, Gonystylus, Sapotaceae/Meliaceae, Rubiceae (Canthium), Longelia, Cephalomappa, Shorea spp., Campnosperma, Myrtaceae and Stenochlaena palutris, Pandanus, Koompassia and Malvaceae.*
6	Back Mangrove	*Brownlowia, Nypa, Acrostichum, attendance varies from Pediastrum and Dinocyst.*
7	Mangrove	*Rhizoporaceae, Sonneratia, Avicennia and pollen variations upstream. Also present were Dynocyst and Foraminifera test lining.*

8	Sandy Beach And Barrier Island	*the group includes Casuarina Equisetifolia, Calophyllum, Cycas, Terminalia, Pandanus, Shorea spp. and Eugenia spp.*
9	Lagoon	*a mixture of pollen from mangroves, back mangrove, freshwater peatswamp/alluvial swamp and barrier island. Also present were Dynocyst and Foraminifera test linings.*
10	Sublittoral	*a mixture of plant collections with high plant debris density. Also present were Dynocyst and Foraminifera test linings.*
11	Open Marine	*palynomorph concentrations decrease towards the sea, small grains such as Rhizophora sp. may be carried to the coastline. The number of Dynocyst and Foraminifera test linings increased.*

3. Results and Findings

3.1 Lithology

The lithology is blackish to light gray carbonaceous claystone and very fine-grained sandstone. Some partings include oxidation and the appearance of quartz and feldspar minerals. The outcrop's upper part is formed of pieces of rock from mining land clearing (Figure 4).

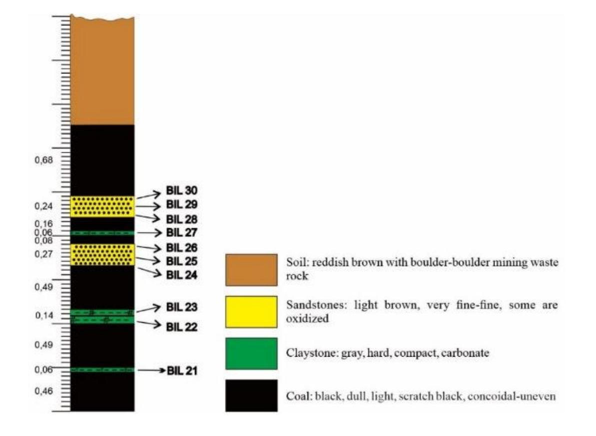

Fig 4. The lithology of the research area and sample locations as a result of measured stratigraphic measurements.

3.2 Pollen dan Spores

The abundance of pollen and spores varied in each sample. Based on the results of quantitative analysis, 551 individuals of pollen and spores were found in the ten samples. There are 14 pollen types and 12 spore types (Figure 5 and Table 2). The majority of pollen and spores were discovered in samples BIL 21 and BIL 27. Pollen and spores were not discovered in samples BIL 29 and 30.

Table 2. Palynomorphs and their environment.

No.	Ecological Group	Palynomorphs
1.	*Mangrove*	*Florschuetzia meridionalis*
		Zonocostites ramonae
2.	*Back Mangrove*	*Acrostichum type*
		Discoidites pilosus
		Florschuetzia levipoli
3.	*Peat Swamp*	*Lakiapollis ovatus*
		Lanagiopollis rugulatus
		Retistephanocolpites williamsi
		Sapotaceoidaepollenites sp.
4.	*Riparian*	*Ilex*
5.	*Freshwater*	*Adiantum sp.*
		Cyathidites australis
		Cyperaceae sp.
		Deltoidospora type
		Leavigatosporites sp.
		Magnastriatites sp.
		Palmaepollenites sp.
		Poaceae type
		Polypodium sp.
		Pteris type
		Stenochlaenidites papuanus
		Verrucatosporites sp.
		Verrucatosporites usmensis
6.	*Montane Rain Forest*	*Alsophila sp.*
		Cyclobalanopsis
		Podocarpidiites

4. Discussion

4.1 Age

Regionally, the Lemau Formation is Middle-Late Miocene in age (Gafoer et al., 1992). *Stenochlaenidites papuanus* was found in sample BIL 21. In the Sunda region, the presence fossil of *Stenochlaenidites papuanus* can be used as an indicator of Late Miocene and Pliocene (Morley, 1991; Fig 3). The presence of this index fossil is the outcrop's initial age limit. Thus, given the presence of index fossils and regional age, the Lemau Formation on this outcrop is Late Miocene in age.

4.2 Depositional Environment

Several types of fossilized pollen and spores were discovered using a microscope. Figure 6 shows the abundance of fossilized pollen and spores that characterize the environment. Fossils that characterize the *mangrove* environment were discovered in BIL 21; the deposition environment of this sample is a *mangrove* environment.

In sample BIL 22, fossils that characterize the *mangrove* environment were not found, while fossils that characterize the *back mangrove* environment were discovered. It indicates that the environment became shallower from sample BIL 21 to sample 22. Following the deposition of samples BIL 23-BIL 26, fewer fossils were discovered than previously. The *peat swamp* environment characterizes the fossils discovered. In the deposition of sample BIL 27, the environment became more inundated again because fossils that characterize the *mangrove* environment were found. So, the environment changed from a *peat swamp* to a *mangrove* environment. There were fewer fossilized pollen and spores found in samples BIL 28-BIL 30. This sample's lithology is sandstone, with some oxidation and the appearance of quartz and feldspar minerals. Based on the presence of fossils that characterize the environment, samples BIL 28-BIL 30 were deposited in a *freshwater* environment.

The depositional environment at the study area, from BIL 21 to BIL 26, experienced shallowing toward land. According to Yasrullah (2018), the Lemau Formation was deposited under regressive marine conditions. Furthermore, in the Middle Miocene, uplift of the Bukit Barisan Mountains began Sumatra Island (Hastuti et al., 2001; Husein et al., 2018). Uplift occurred at the edges of basins on Sumatra Island in the Intra Miocene, followed by clastic material deposition (Pulunggono et al., 1992). This condition is indicated to be one of the causes of the shift in depositional environment in sample from BIL 21 to BIL 26 toward land. Haq et al. (1987) indicated that global sea level change occurred in the Late Miocene (Fig.7). The study area, located in the transition zone, records these sea level changes. Changes in sea level can be seen in environmental changes in samples BIL 26 to BIL 27 with experienced environmental changes towards the sea, then in sample BIL 28 to BIL 30 it became shallowes towards the land.

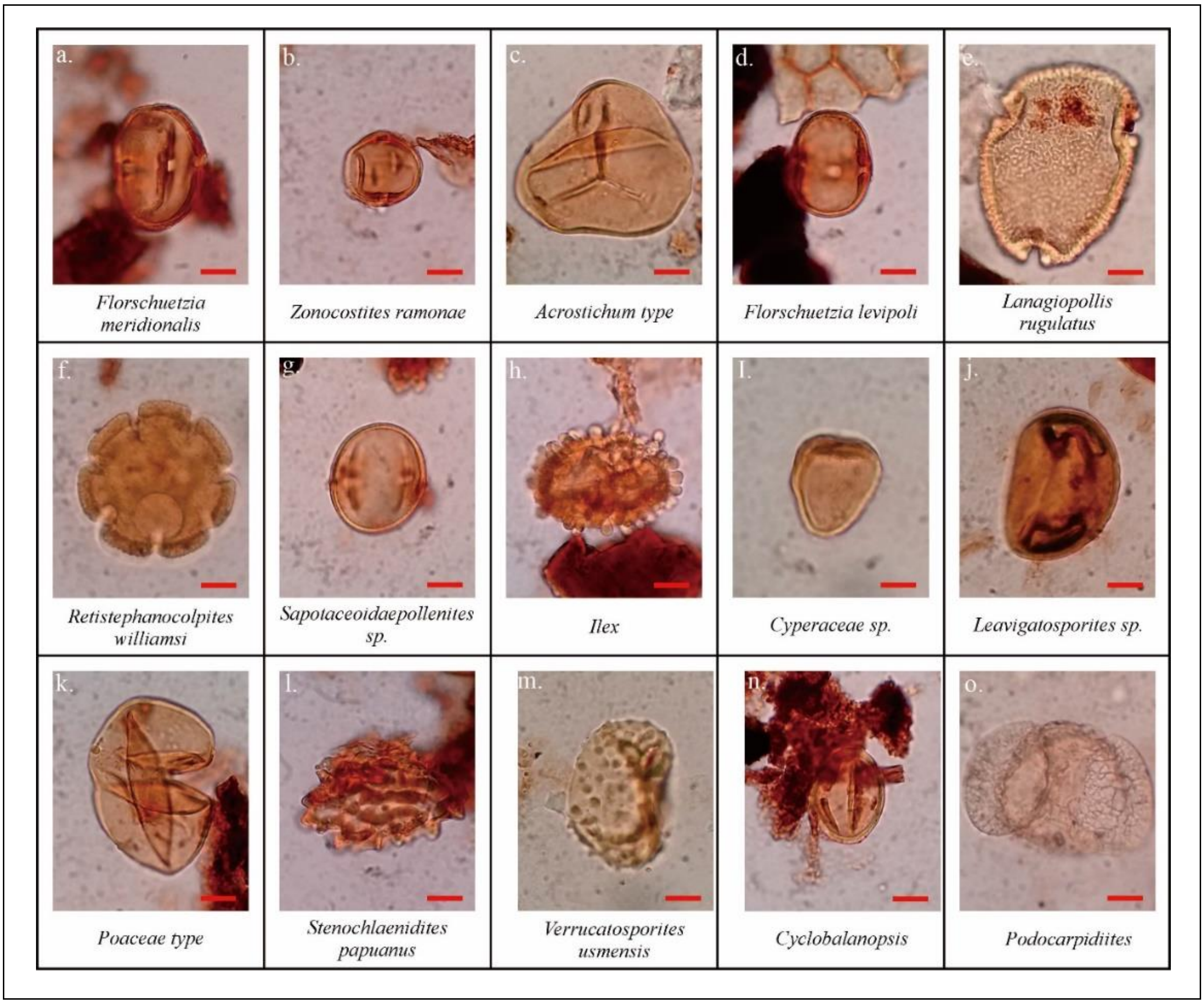

Fig 5. Pollen and spore fossils in the study area.

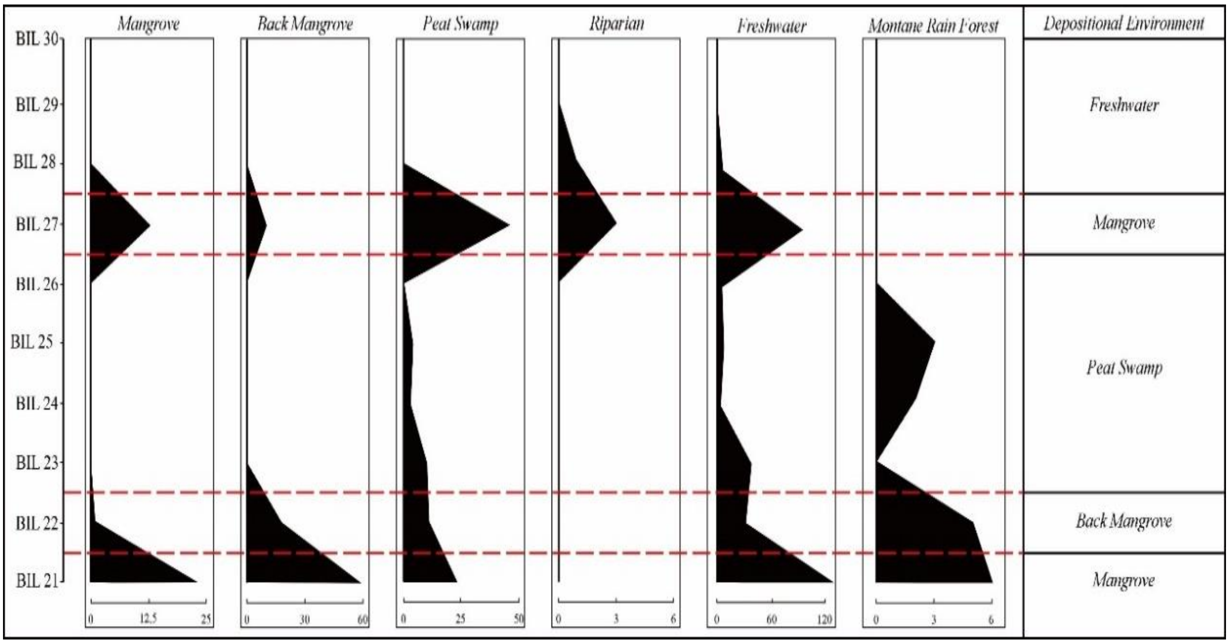

Fig 6. The abundance of fossils that characterize the environment of each sample.

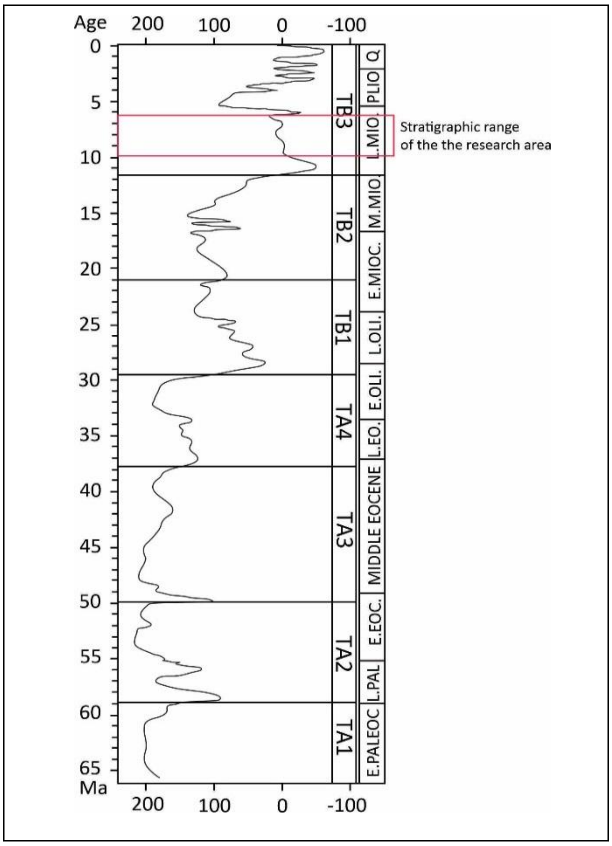

Fig 7. Global Eustatic Curve (Haq et.al., 1987)

5. Conclusion

In Samples BIL 21-BIL 30 in Seluma, Bengkulu, the Lemau Formation is Late Miocene in age and characterized by the presence of *Stenochlaenidites papuanus*. Based on the presence of fossils that characterize its environment, this formation was deposited in a transitional environment, ranging from mangrove, backmangrove, peat swamp, and freshwater environments. This change in depositional environment is likely the result of the uplift of the Bukit Barisan Hills on Sumatra Island that began in the Middle Miocene and also global eustatic changes.

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