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Paleoenvironment of the Miocene Lemau Formation Based on the Palynology Analysis in Seluma, Bengkulu

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ABSTRACT

The Lemau Formation is a rock formation that forms the Bengkulu Basin in the Bengkulu Strip. The rocks in this formation contain hydrocarbon reserves in the form of coal. There has yet to be any research on the palynomorphs in the coal-bearing rocks in this formation. Palynomorph analysis was performed on nine samples from the P.T. Bara Indah Lestari, Seluma. The study aims to reconstruct the paleoenvironment and age of the coal-bearing rocks. The sampling technique uses stratigraphic measurements and hydrogen peroxide preparation. There were four changes in the depositional environment, namely the deposition of BIL 10-BIL 11 in the form of a freshwater peat swamp environment and BIL 12 in the form of a mangrove environment in the Early Miocene marked by the presence of *Florschuetzia levipoli*. The environment changed to a lagoon, indicated by the presence of foraminifera lining test and *dinocyst* in the deposition of BIL 13-BIL 15 samples in the Middle Miocene with a marked presence of *Alnipollenites verus*. The environment changed again during the deposition of BIL 16-BIL 18 to become a mangrove environment in the Middle Miocene. Overall, the paleoenvironment of the Lemau Formation is a freshwater peat swamp to a lagoon. Environmental changes are possible due to tectonic activity and climate change.

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1. INTRODUCTION

The Bengkulu basin is a forearc basin in Indonesia. Based on their stratigraphy, the Bengkulu and South Sumatra basins were once united. They were separated due to the lifting of the Bukit Barisan caused by subduction on the Sumatra island. The subduction zone on Sumatra island has been taking place since the end of the Middle Miocene (Metcalfe, 1996; Trilaksana, 2017). The Bukit Barisan experienced an uplift in the Middle Miocene (Hastuti, 2001; Husein et al., 2018). Tectonic activities on Sumatra Island control the Bengkulu basin on its mainland. Three main structures control Sumatra Island; the Sumatran Subduction Zone, the Sumatran Fault Zone (Semangko Fault), and the Mentawai Fault Zone (Barber et al., 2005).

One of the rock formations that make up the Bengkulu basin is the Lemau Formation. It is in Bengkulu Lane. It consists of epiclastic volcanic breccias, epiclastic volcanic sandstones stacked with dacite, sandstone with coal inserts, sandstones containing mollusks, claystone, and limestones, and of Middle-Late Miocene age (Gafoer et al., 1992). Research conducted on the Bengkulu basin onshore found that the Lemau Formation was deposited in shallow marine environments and lagoons (Yulihanto et al., 1995; Heryanto & Suyoko, 2007).

Hydrocarbon reserves in the Lemau formation consist of the coals from North Bengkulu to Seluma. In some sites, there are coal mining activities by several companies. One of the coal mines is located in Seluma and is run by P.T. Bara Indah Lestari. Research on this coal field found that the coal was deposited in a terrestrial environment with one of the constituents in the form of large trees (Heryanto & Suyoko, 2007).

The identification of these coal-forming plants can be through the presence of palynomorph fossils. Furthermore, the palynomorph association indicates the depositional environment and rock age. The Coal depositional environment can be used to predict the quality of economically existing coal and coal age for coal maturity level. Studies on palynomorphs in the Lemau Formation still need to be expanded, including in other formations in Sumatra. This study aims to reconstruct the paleoenvironment and age of the coal-bearing Lemau Formation in Seluma at the coal mine of PT. Bara Indah Lestari based on palynomorph content and as additional palynology data in Sumatra.

2. METHOD

The rock sampling of the Lemau formation is carried out on the coal intercalation layer at P.T. Bara Indah Lestari in Sekalak village, Seluma, Bengkulu. The layer consists of fine-grained rocks (gray claystone). The location is in the Geological Map Sheet of Bengkulu (Gafoer et al., 1992). The stratigraphic cross-section measured method was used for taking the rock samples at some intervals (5-8cm) in the coordinate $3^0$56'17.30" S, $102^0$36'55.07" E (Figure 1). There are nine rock samples given the number BIL 10-BIL 18.

The preparation process has been done at the Paleontology Laboratory, Faculty of Geological Engineering, Padjadjaran Padjadjaran. The hydrogen peroxide method separates pollen and spores from sedimentary rock/coal. Before the chemical processing, the sample is mashed first. Then, 15% H202 solution was given for 30 minutes and neutralized with distilled water. After being neutral, given a 40% HF solution and neutralized again with distilled water. Then the sample was filtered two times. The residue left behind is then used to make observation plates. Palynomorph fossils are observed using an Olympus CX22 binocular microscope at 10x, 40x, 100x, and 10x

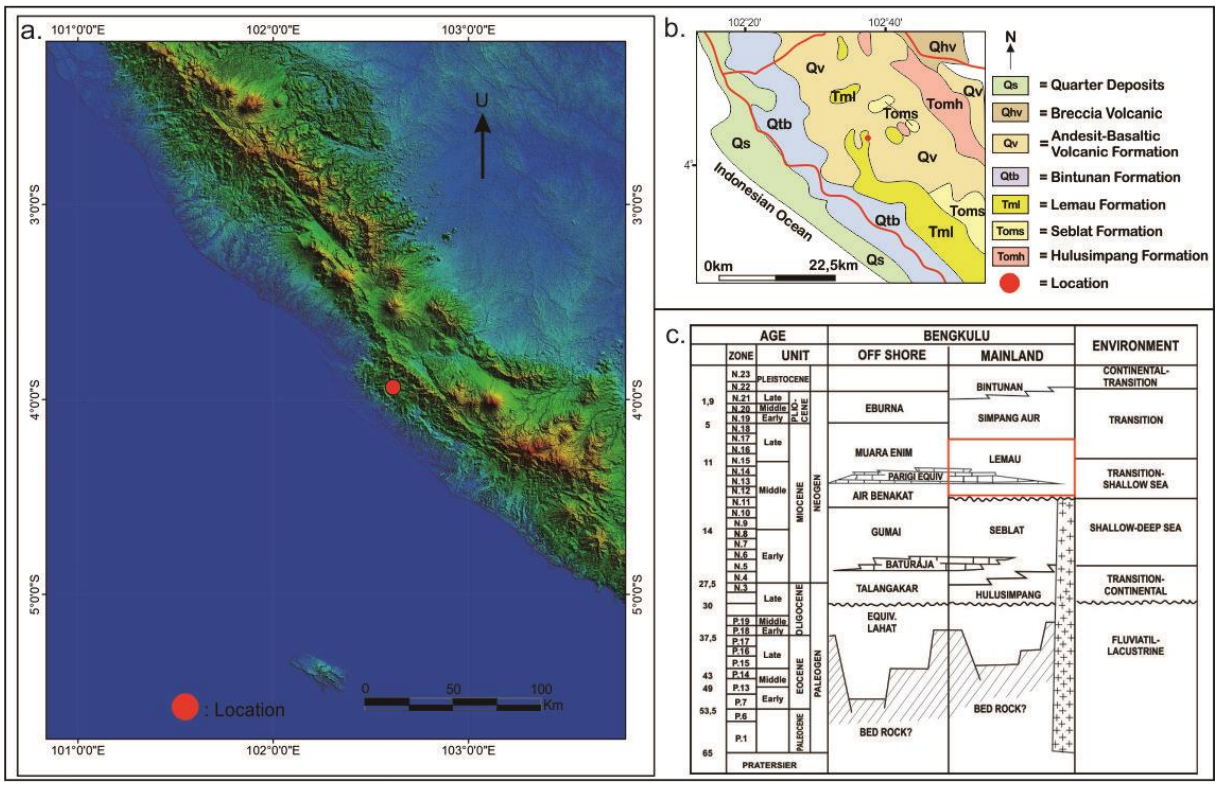

Figure 1. Research sites; a. the research site in Bengkulu DEM Imagery; b. Geological map (simplification from Gafoer et al., 1992; Heryanto & Suyoko, 2007); c. rock formations in the Bengkulu basin stratigraphy (Yulihanto et al., 1995; Heryanto & Suyoko, 2007).

eyepiece magnifications. In identification, the main characters used are unit, aperture, shape and size, and ornamentation on the exterior.

Age determination refers to the division of the age of fossils, according to Morley (1991), while the environment refers to Haseldonckx (1974). The identification of the paleoenvironment is based on fossil associations:

- A montane rainforest environment, characterized by *Pinus, Fagaceae,* and *Dacrycarpidites.*
- Lowland forest environment, dominated by *Dipterocarpaceae*, *Myrtaceae (Eugenia spp.), Calophyllum spp, Annonaceae*, and *Euphorbiaceae.*
- A freshwater peat swamp /alluvial swamp characterized by the presence of *Palmae, Graminae, Calophyllum, Sapotaceoidaepollenites sp.*, *Calamus,* and *Myrica*.
- The Lake environment, a combination of lowland rainforest and freshwater peat swamp/alluvial swamp, is probably found in *Pediastrum.*
- Riparian fringe, characterized by the presence of *Ilex, Pandanus, Gluta,* and *Calamus.*
- Back mangrove environment, characterized by *Nypa, Acrostichum,* and *Sonneratia caseolaris* and the presence of dynocysts.
- Mangrove environment, characterized by the presence of *Rhicoporaceae, Sonneratia,* and the presence of dinocyst and foraminifera test lining.
- Sandy beach and barrier island environment, a collection of *Casuarina, Pandanus, Shorea*, and *Calophyllum.*
- The Lagoon environment is a mixture of mangrove, back mangrove, freshwater peat swamp, and barrier island. Also present were *dinocyst* and foraminifera test linings.
- The sublittoral environment, a mixture of assemblages with high plant debris density, is also present with foraminifera test lining and *dynocysts*.
- Open marine environment, little pollen and spores were found, dominated by foraminifera test lining and *dinocyst.*

3. RESULTS AND DISCUSSION

3.1. Result

The abundance of palynomorphs in each sample shows a difference in species composition. There were 26 types of palynomorphs in the samples analyzed (Figure 2 and Figure 6). It indicates that four have been environmental changes (Figure 3).

3.1.1. Zone 1

It starts with a depositional environment of BIL 10 and BIL 11. There are palynomorph markers from the montane rainforest and freshwater peat swamp. There is 4,2% montane rain forest in the

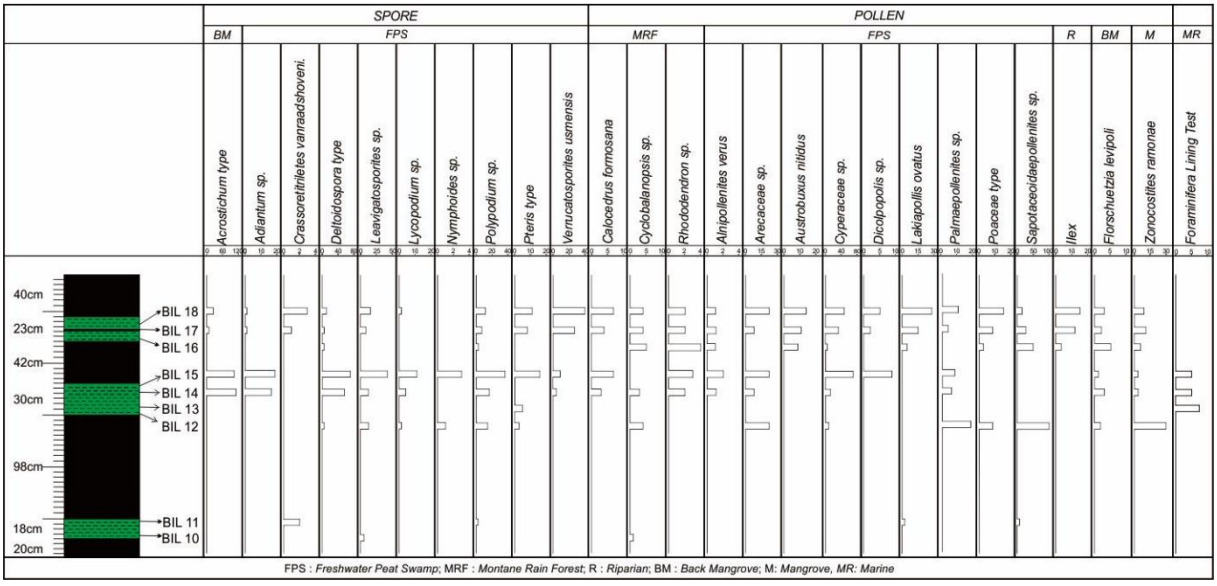

Figure 2. Palynomorph abundance diagram for each sample.

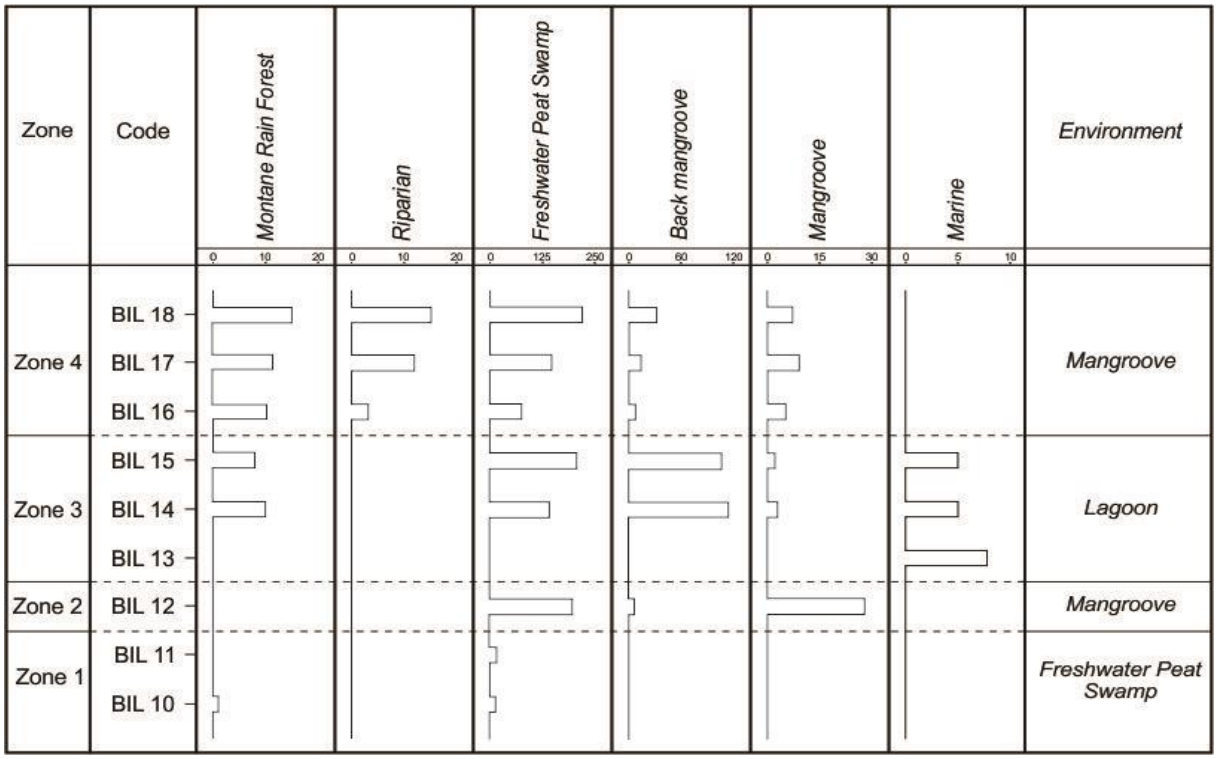

Figure 3. Diagram of the presence of environmental identification fossils.

form of *Cyclobalanopsis* and 88.1% freshwater peat swamp environmental characteristics including *Crassoretitriletes vanraadshoovenii, Lakiapollis ovatus, Laevigatosporites sp., Lycopodium sp., Nymphoides sp., Poaceae type, Polypodium sp., Sapotaceoidaepollinates sp., Pteris type*, and *Verrucatosporites usmensis*. The lithology covers blackish-gray claystone. Based on the environmental division (Haseldonckx, 1974), the depositional zone is a freshwater peat swamp (Figure 4).

3.1.2. Zone 2

It starts with the depositional environment of BIL 12. There are palynomorph markers from the mangroves, back mangroves, freshwater peat swamp, and montane rain forest with the highest percentage presence of freshwater peat swamp characteristics (Figure 3). There are 20,3% mangrove markers in the form of *Zonocostites ramonae*, 4,4% back mangrove characteristics in the form of *Florschuetzia levipoli*, and 72,4% freshwater peat swamp environmental characteristics including *Arecaceae sp, Crassoretitriletes vanraadshoovenii, Laevigatosporites sp., Lycopodium sp., Nymphoides sp., Poaceae type, Polypodium sp., Sapotaceoidaepollinates sp., Pteris type*, and *Verrucatosporites usmensis*. Meanwhile, there are 2.9% of identifiers for the montane rainforest environment (*Cyclobalanopsis*).

The lithology covers blackish-gray claystone and little reaction to HCl. The BIL 12 observation plate contains many pyrite minerals and some plant residue (body fruiting). There is also a high presence of pollen from the *Sapotaceoidaepollenites sp.* in the BIL 12 sample. The finding of fossils that characterize the mangrove environment indicates deposition in this area. Thus, based on the association of the characteristic fossils, according to Haseldonck (1974), the depositional environment in this zone is a mangrove environment (Figure 4). In the BIL 12 sample, *Florschuetzia levipoli* was found to be present starting in the Early Miocene, according to Morley (1991). Thus, based on the presence of these index fossils, it is known that the BIL 12 sample in Zone 2 is Early Miocene based on the first appearance of *Florschuetzia levipoli* (Figure 5).

3.1.3. Zone 3

Next, there is a change in the environment during the deposition of BIL-13 with decreasing palynomorph. The relatively low palynomorph indicates that the deposition is influenced by seawater (Yulianto et al., 2019). The presence of the foraminifera lining test and dinocyst supports this. In the next depositional zones (BIL 14 and BIL 15), the environment is shallow again with

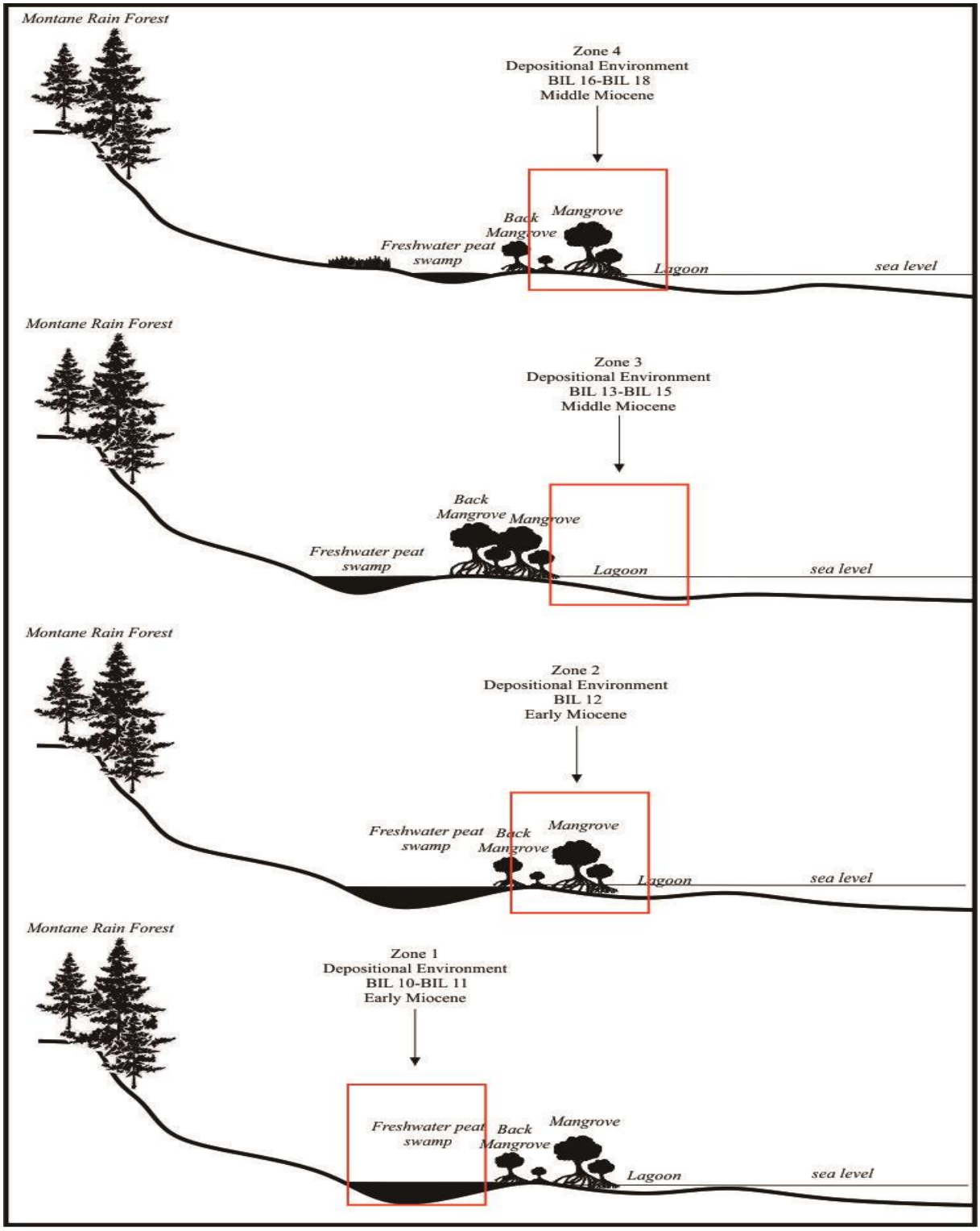

Figure 4. Changes in the depositional environment of the Lemau Formation (modification from Yulianto et al., 2019).

the abundant presence of *Acrostichum type* (Figure 3). Some palynomorphs characterize mangroves, back mangroves, freshwater peat swamps, and montane rain forests, but there is still a foraminifera lining test in these samples.

The lithology of the BIL 13-BIL 15 sample is a bright gray claystone that reacts with HCl. *Acrostichum types* and the presence of palynomorphs that characterize the high freshwater peat swamp and other environments are abundant. There are also foraminifera lining tests and *dinocysts.* They indicate that the depositional environment is close to the sea and is a mixing area. So, based

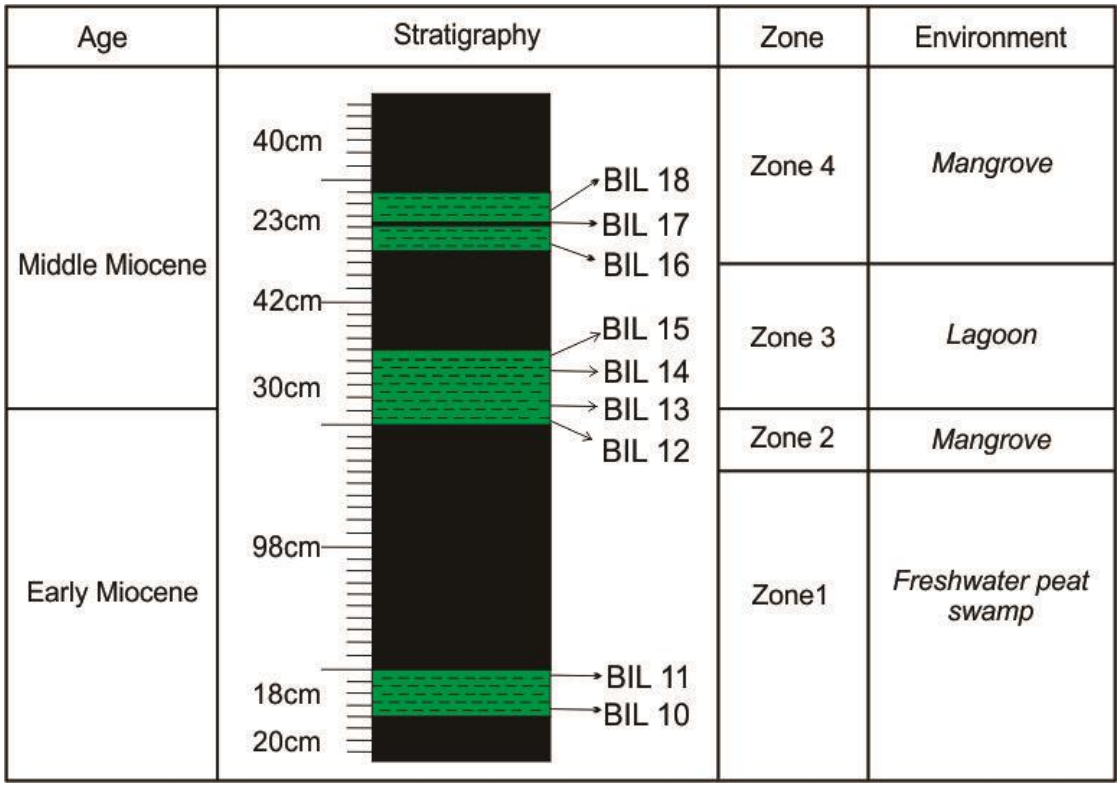

Figure 5. Relationship between ages and environmental changes.

on the environmental division (Haseldonckx, 1974), the depositional zone is a lagoon environment (Figure 4). Pollen and spores that characterize mangroves are 0.8% in the form of *Zonocostites ramonae*, 33,5% in the environment of back mangroves in the form of *Acrostichum type,* and *Florschuetzia levipoli*, 63,7% in the form of freshwater peat swamp and *Adiantum sp., Arecaceae sp., Alnipollenites verus, Cyperaceae sp., Deltoidospora type, Dicolpopollis sp., Lakiapollis ovatus, Laevigatosporites sp., Nymphoides sp., Polypodium sp., Pteris type*, and *Verrucatosporites usmensis*. There is 2.7% pollen that characterizes the montane rain forest, namely *Calocedrus formosana, Cyclobalanopsis sp*, and *Rhododendron sp.* (Figure 3). The presence of marine *palynomorphs* compared to land *palynomorphs* is 4.1%.

There is *Alnipollenites verus* found in samples BIL 14 and BIL 15. The last appearance of this pollen was in the Middle Miocene (Morley, 1991). Thus, these index fossils conclude that the age of the rocks in Zone 3 is the Middle Miocene (Figure 5).

3.1.4. Zone 4

The deposition in Zone 4 occurs in the BIL 16 to 18. There is a shallower depositional environment. In this zone, the spores that characterize the back mangrove have decreased (Figure 3). The lithology is gray claystone, with no foraminifera lining test, dinocyst, and little reaction to HCl. Fossils that characterize the mangrove environment are still high in this zone. Based on the association of fossils with environmental characteristics and their lithology, it is known that BIL 16-BIL 18 samples deposition is in the form of a mangrove environment (Figure 4). In this zone, the land began to develop with a marked presence of *Poaceae,* which began to increase.

There are 3,9% pollen and spores that characterize mangroves, i.e., *Zonocostites ramonae,* 9,2% *Acrostichum type,* and *Florschuetzia levipoli* characterizing back mangroves, a riparian environment of 5.5% (*Ilex*), freshwater peat swamp environment of 75,5% *Adiantum sp.*, *Alnipollenites verus, Arecaceae sp., Austrobuxus nitidus Crassoretitriletes vanraadshoovenii, Cyperaceae sp., Deltoidospora type, Dicolpopollis sp., Lakiapollis ovatus, Laevigatosporites sp., Lycopodium sp., Nymphoides sp., Poaceae type, Polypodium sp., Pteris type, Sapotaceoidaepollenites sp.* and *Verrucatosporites usmensis.* The environmental characteristics of the montane rain forest are 5.9%, including *Calocedrus formosana, Cyclobalanopsis sp.,* and *Rhododendron sp* (Figure 3). The age of the rocks in Zone 3 is the Middle Miocene (Figure 5). This finding is based on the last appearance of *Alnipollenites verus.*

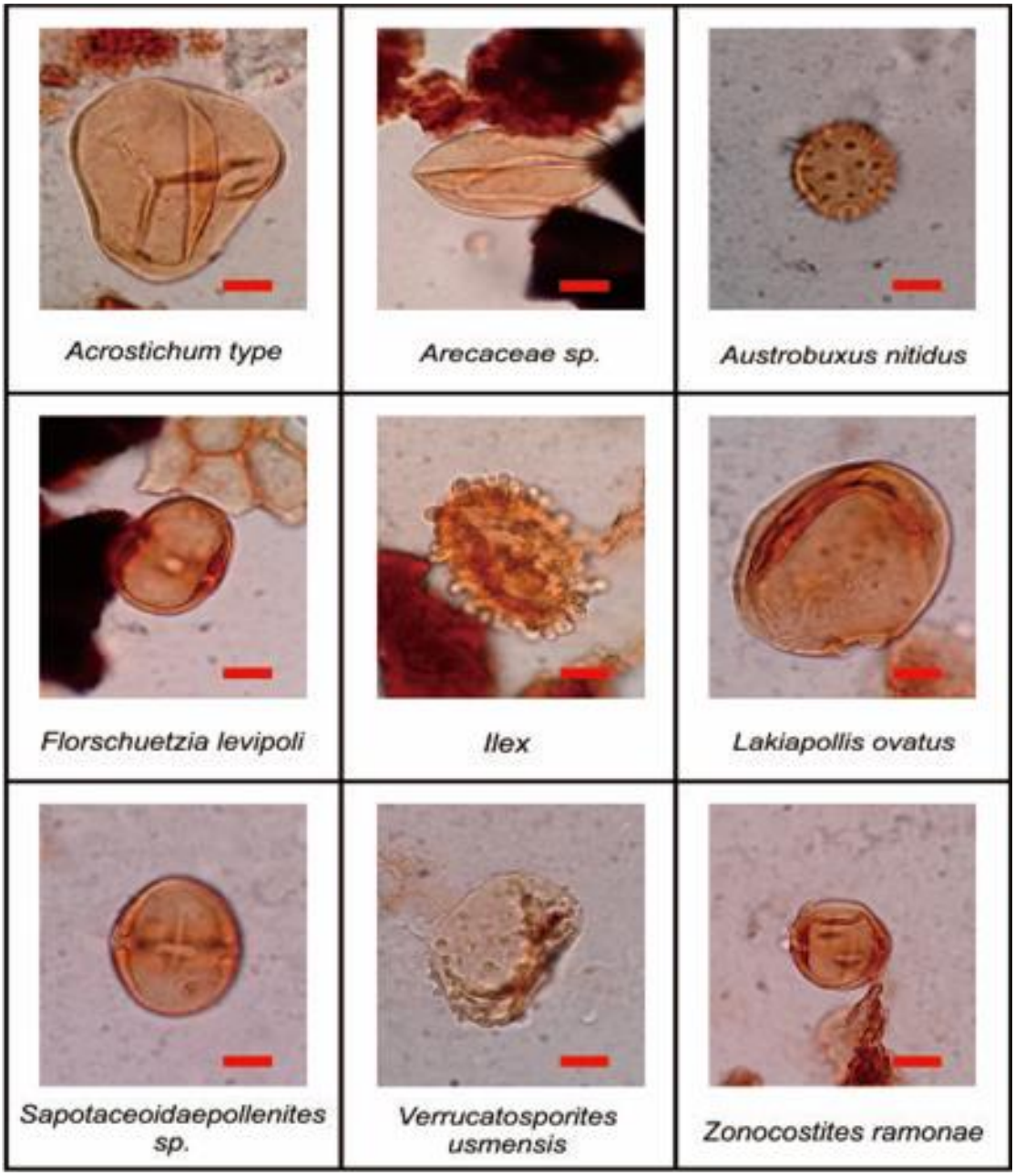

Figure 6. Some palynomorph fossils were found at the research site.

3.2. Discussions

Several changes occurred at different ages during the deposition of BIL 10-BIL 18. They were beginning with the deposit of BIL 10-BIL 11 in Zone 1 with a freshwater peat swamp environment. The environment changed to a mangrove environment in Zone 2 sample BIL 12 and is Early Miocene based on the presence of *Florschuetzia levipoli* index fossils. The environment changed back to the lagoon environment in the deposition of Zone 3 of the Middle Miocene BIL 13-BIL 15 samples marked by *Alnipollenites verus*. Furthermore, the environment was slightly shallow to become a mangrove environment in the deposition of Zone 4 samples BIL 16-BIL 18 in the Middle Miocene (Figure 5).

In the Miocene or Intra Miocene, the third phase of tectonic activity occurred on the island of Sumatra and resulted in the lifting of the banks of the basin (Pulunggono et al., 1992). Evidence of tectonic activity is the uplift of the Barisan Mountains in the Middle Miocene as a separator for the Bengkulu Basin and the South Sumatra Basin. One evidence of this separation is the deposition of

the Lemau Formation and Muara Enim Formation, which are stratigraphic of the same age. The Lemau Formation, a constituent of the Bengkulu Basin, was deposited near seawater. In contrast, the Muara Enim Formation in the Central Palembang Sub Basin was deposited in an environment that is not affected by seawater (Purnama et al., 2018).

From Zone 1 to Zone 3, the environment slowly draws closer to the ocean. This change is caused by tectonic influences and climate change based on the abundance of palynomorphs. In Zone 2, the quantity is dominated by arboreal pollen. While Zone 3 is dominated by spores. The dominance of spores and low-elevation plants indicates a hot climate (Adojoh et al., 2015; Fajrina, 2016). A higher spore count suggests that the environment has a hot and humid climate. Therefore, Zone 2 has a cool climate with moderate humidity, and Zone 3 has a warm climate with high humidity.

In the deposition of Zone 4, the environment is relatively shallow to become a mangrove environment. The land began to develop, marked by the increasing presence of Poaceae and the typical riparian pollen. Environmental changes are possible due to the isostatic uplift of Bukit Barisan that occurred in the Middle Miocene on Sumatra Island (Hastuti, 2001; Husein et al., 2018).

Overall, the depositional environment of the Lemau Formation based on a palynomorph in the form of a freshwater peat swamp to lagoon environment has the same results as the analysis results using foraminifera in Tanjungdalam, North Bengkulu. Based on the foraminifera content, this formation was deposited in a delta to shallow sea environment associated with forming swamps, swamps, and lagoons and is Middle Miocene in age (Tarigan et al., 2018).

4. CONCLUSIONS

There were four changes in the depositional environment of the Lemau Formation in BIL 10-BIL 18 samples with different ages. I was starting from the freshwater peat swamp environment in zone 1 of the BIL 10-BIL 11 sample and the mangrove environment in the deposition of zone 2 of the BIL 12 sample with an Early Miocene age which is marked by the age of the first appearance of *Florschuetzia levipoli*. Furthermore, the environment changed to a lagoon environment in zone 3 of BIL 13-BIL 15 samples. It was of the Middle Miocene age, marked by the age of the last appearance of *Alnipollenites verus*. Furthermore, the environment changed shallowly in the deposition of Zone 4 sample BIL 16-BIL 18 to become a mangrove environment. Overall, the Lemau Formation in Seluma was deposited in a freshwater peat swamp to a lagoon environment. Environmental changes are possible due to the tectonic activities of Sumatra Island during the Miocene age and climate change characterized by changes in humidity from moderate to high based on the presence of spores (sample BIL 12-BIL 14). The environmental analysis results of deposition using pollen and spores in the Lemau Formation have the same results as those of foraminifera in Tanjungdalam, North Bengkulu.

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