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Palynomorph Biozonation of the Malawa Formation, Barru Region, South Sulawesi

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ABSTRACT

This study's subject is the Padanglampe traverse in Tanete Riaja, Barru Regency, at coordinates 04^0 30' 25.26" South Latitude and 119^0 41' 43.43" East Longitude. Padanglampe sedimentary deposits of The Malawa Formation were the subject of this study. This study aims to establish the Malawa formation's age based on the presence of palynomorph fossils. Vertical measurement with a track thickness of approximately 10.5 meters was used for field investigation. The sediment's grain size helps to separate the two sections of the Padanglampe traverse. The top layer comprises coal layers and moderately fine- to medium-grained sediments. Coarse-grained sandstone makes up the lowest layer. At any spacing of 25 cm from the measurement of the stratigraphic cross-section, rock sampling was methodically done, yielding 45 lithology samples. A polarizing microscope with a 40x magnification was used to prepare and examine the material. Only 36 samples were used in the subsequent analysis, with nine barren samples. The palynomorph composition of each sample was determined quantitatively and displayed in a palynological diagram using the CONISS technique to measure the data based on life types. Based on the outcomes of observations, 64 pollen taxa and 17 spore taxa were identified. The Moraceae, *Palmaepollenites*, *Spinizonocolpites echinatus*, *Pandanidites*, *Proxapertites operculatus*, *Laevigatosporites*, *Acrostichum*, and *Anthocerisporites* are those with the greatest abundance. It is split into six informal palynomorph assemblage zones, labeled as zone I - zone IV using cluster analysis. Based on the palynomorph data, the age of the Malawa Formation is Middle Eocene – Upper Eocene.

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1. INTRODUCTION

The research area is situated at 04^0 30' 25.26" South Latitude and 119^0 41' 43.43" East Longitude in Padanglampe Village, Tanete Riaja District, Barru Regency, South Sulawesi Province (Figure 1). This area is exposed to coarse-grained sedimentary rock with coal inserts(Hasibuan, 2009; Husainy et al., 2020; Jaya et al., 2011; Sukamto, 1982). The presence of coal indicates that the outcrop has a high organic material content and includes land deposits. So that this outcrop allows the accumulation of high organic material. Therefore, research on the Padanglampe traverse was analyzed using a palynological approach.

The study of palynomorphs, which include sporomorphs (pollen and spores) and other palynomorphs, including dinoflagellates, fungi, and foraminifera test lining, is known as palynology. Palynomorphs comprise 5–500 µm resistant organic compounds like sporopollenin or chitin (Halbritter et al., 2018; Simpson, 2019; Traverse, 2007). Palynology examines plant remains

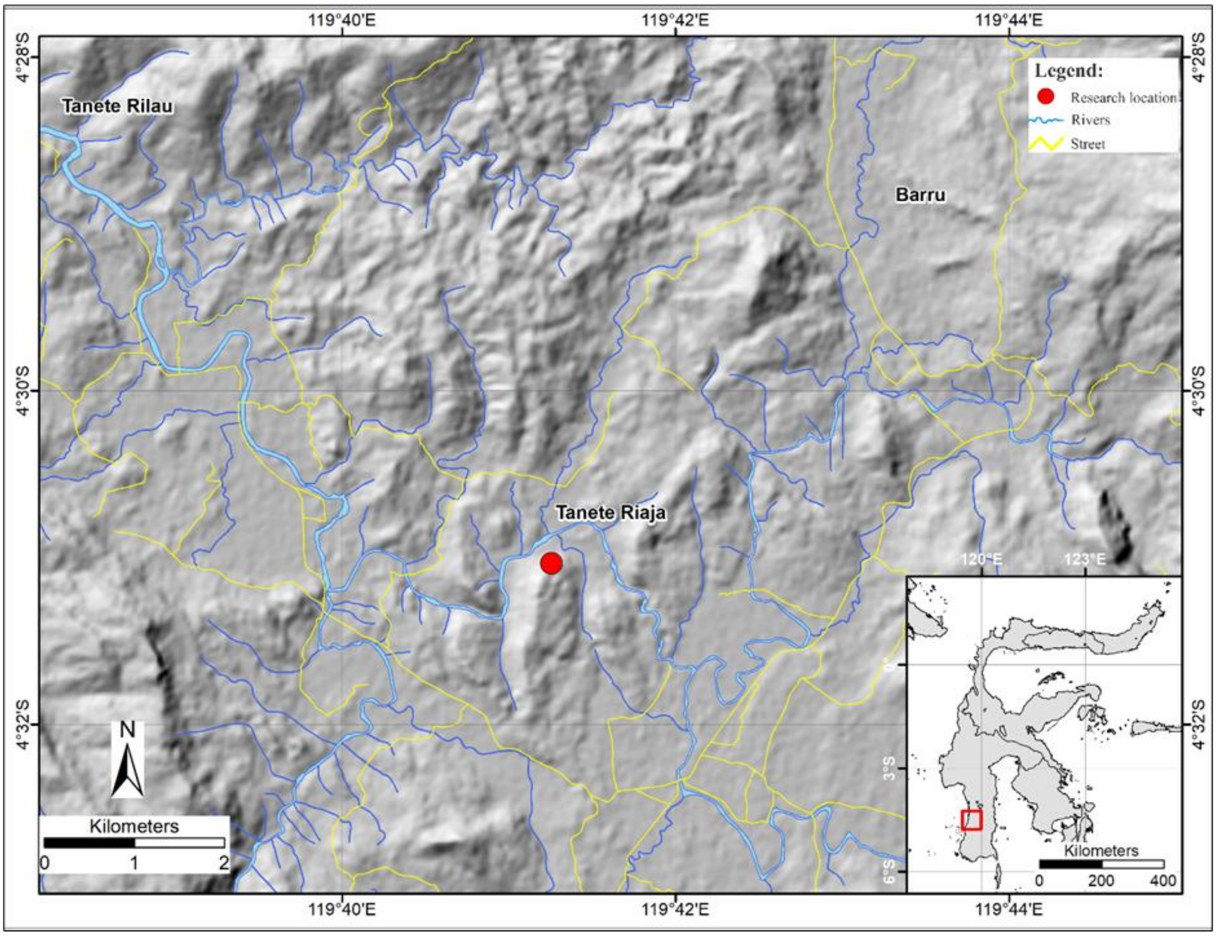

Figure 1. Map of the research area, with a red point representing the observation area in the Padanglampe traverse, while the position of the Barru area is shown as a red box on the index map

found in sedimentary rock layers and used in biostratigraphy applications (Onodoku & Okosun, 2014).

Palynomorphs represent a stage of numerous plants' life cycles that can occasionally evolve quickly, indicating a brief period. Palynomorphs can therefore be employed for geochronology (Traverse, 2007). Due to their tiny size, resistance, and abundance in many types of sedimentary rocks, microfossils, including palynomorphs, can be employed in various geological applications, such as biostratigraphy, correlation, and investigation of depositional settings (Bercovici & Vellekoop, 2017). Additionally, pollen and spores come in various morphological and structural forms, making them crucial for determining plant phylogenetic relationships and taxonomic groups (Simpson, 2019).

The study site is in the Barru region, shown on the Geological Map of Pangkajene and Watampone's western half (Sukamto, 1982). Geologically, the Barru area exhibits South Sulawesi's complex stratigraphy, geological structure, and tectonic conditions (Figure 2). The Barru Block, a complex of bedrock in this region made up of ultramafic and metamorphic rocks and overlying younger sedimentary rock sequences, is the oldest outcrop in the area (Berry & Grady, 1987) (Figure 3). Based on the results of age identification with the youngest detrital Zircon data in the schist sample, the Barru block has a Triassic age (between 243 and 247 Ma) (Jaya et al., 2017). These age data indicate that the protolith formed due to a subduction system. The Barru Block is made of a tectonic stack of different lithological units, such as gneisses, amphibolite, chert, radiolarian mudstone, breccias, shale, phyllite, and mica schist (Maulana et al., 2019).

Cretaceous sedimentary rocks of the Balangbaru Formation are unconformity overlain on terrestrial sediments of the Malawa Formation. Balangbaru Formation is in the upper of the basement complex, Barru Block. The Malawa Formation gradually contacted the Tonasa Formation above it, demonstrating their conformity relation (Sukamto, 1982). The Malawa

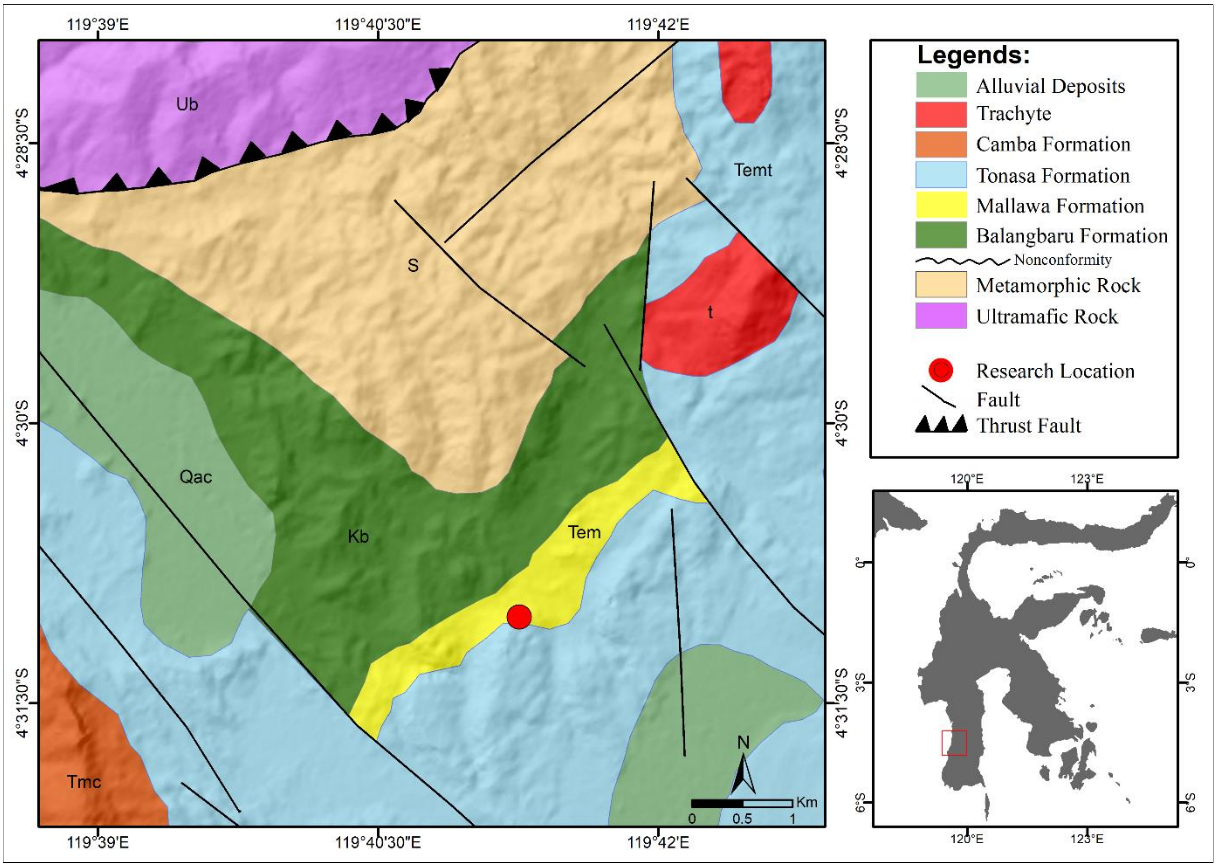

Figure 2. Regional geological map of the Barru area (modification from Sukamto, 1982)

Formation, which includes sandstone, siltstone, claystone, marl, conglomerate, coal intercalation, and limestone, is the subject of the study. The Malawa Formation was deposited in a transitional region during the Eocene and is often characterized by quartz-rich sandstones, according to (Sukamto, 1982), while (Wilson & Bosence, 1996) showed that the Malawa Formation was deposited in a terrestrial or transitional environment and transgressively became a shallow marine. The Malawa Formation can generally be found in the Doidoi area, Malawa, along the Duri River, Gatareng, Umpung River, Birane, Tondongkura, and Padanglampe as a research area. The distribution of the Malawa Formation in Sulawesi is shown by (Hasibuan, 2009).

Analysis of the Malawa Formation's age with palynomorph data has been carried out by Crotty & Engelhardt (1993) in Hasibuan (2009) but is not yet detailed. That research just found *Retitribrevicolporites matamanadhensis* and some dinoflagellate species to determine the age of the Malawa Formation. Therefore, through this study, palynomorph data of this study was taken systematically to display paleovegetation patterns to examine the Malawa Formation's age. In addition, the results of this age determination can be used for other applications such as the reconstruction of paleoenvironment, climate change, and correlation analysis. This research aims to determine the Malawa Formation's age based on a palynomorph proxy.

2. METHOD

The Padanglampe traverse, a stratigraphic segment in the study area, served as the primary data source for this study. Rock samples for palynological investigation and lithological descriptions make up the data. Forty-five samples were taken in coarse to fine-grained clastic sedimentary rock of the Mallawa Formation. The sample was carried out systematically in each 25 cm interval.

2.1. Palynology Extraction

The preparation process consists of chemical extraction performed in the Palynology Laboratory with standard preparation following standard procedures from The Palynology Laboratory of Geological Engineering Institut Teknologi Bandung. The chemical extraction

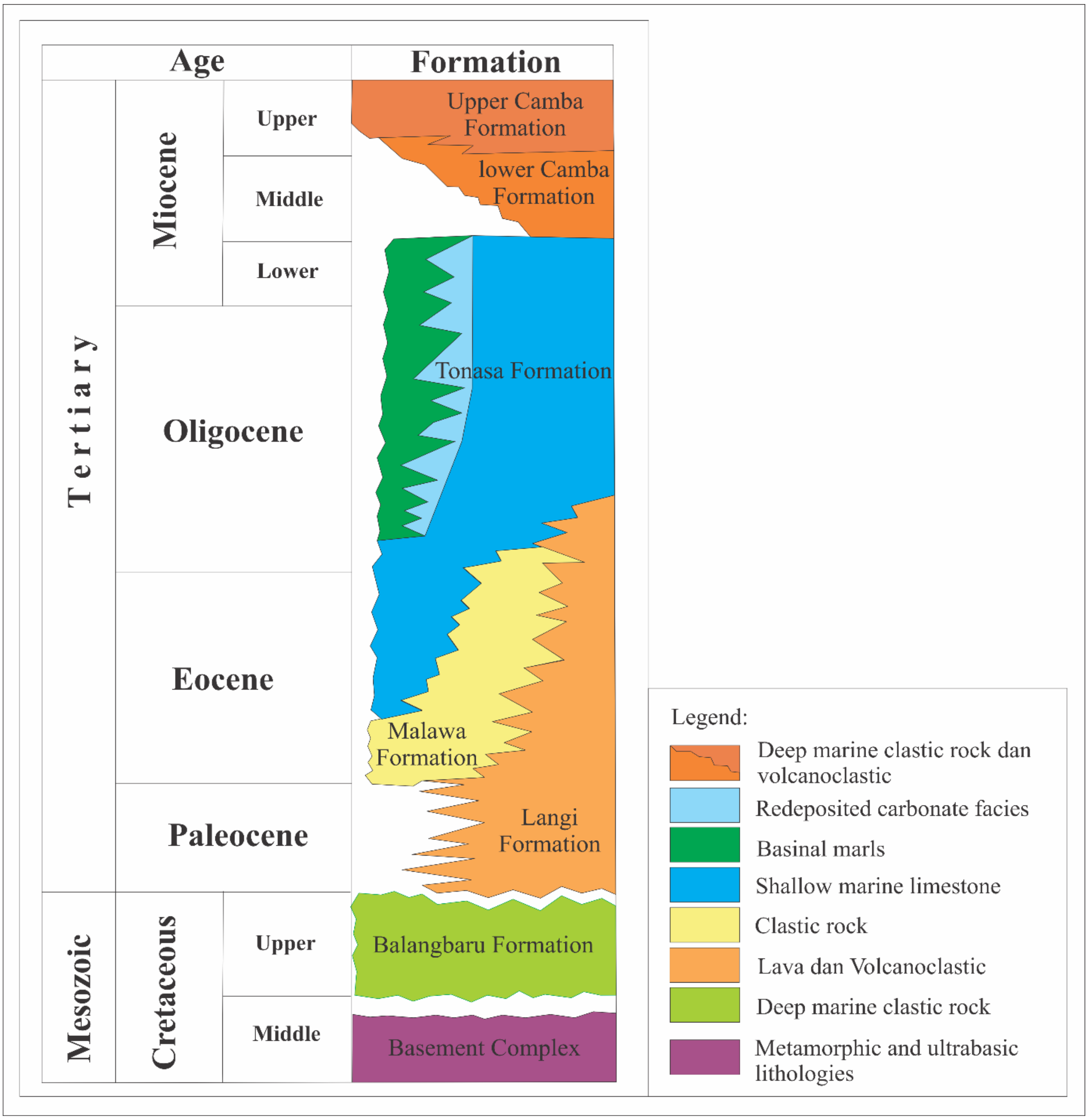

Figure 3. Regional stratigraphy of South Sulawesi (Wilson & Bosence, 1996)

process uses HCl, HF, HNO_3, and KOH. The palynomorph extraction process from rocks consists of the following:

a. The samples were cleaned to avoid contact with the lithology in the layers above and below and the recent palynomorphs.
b. The sample is crushed to 1-2 mm, then soaked in 40% HCl for 12 hours to remove the carbonate content and neutralized using distilled water by centrifugation until the residue reaches a neutral pH.
c. The sample is immersed in 40% HF for 24 hours to remove silica content and neutralize again.
d. The sample is immersed in hot 40% HCl for six hours to remove residual fluoride in the residue and neutralize.
e. The residue is mixed with 5 – 7 ml of HNO_3, heated for 15 minutes, and neutralized.
f. The residue is mixed with 10-15 drops of KOH, heated for 15 minutes, and neutralized while filtered and stored in vial bottles.
g. The mounting process is carried out by dripping the residue onto the prepared glass smeared with glycerin, then covered with a cover glass by adding entellan as an adhesive. The sample is ready to be observed under the microscope.

2.2. Palynomorph Determination

Palynomorphic fossils are identified quantitatively by counting them on a single slide while being observed using a binocular microscope at 400x magnification. Data are displayed as a percentage of all taxa combined with the total population (1). At the same time, the proportion of trees (AP) and non-trees (Nonarboreal Pollen/NAP) for categorization based on vegetation (2 and 3). Estimating the ratio of spores to pollen, pteridophytes are determined based on the total amount of pollen and spores (4). Additionally, the grouping of marine and non-marine species is employed to demonstrate the impact of the sea during deposition (5 and 6).

$$\% \text{ Taxon} = \frac{\text{Number of taxon individuals}}{\text{Individual totals}} \text{ x } 100\% \quad (1)$$

$$\% \text{ AP} = \frac{\sum \text{AP}}{\sum \text{AP} + \text{NAP}} \text{ x } 100\% \quad (2)$$

$$\% \text{ NAP} = \frac{\sum \text{NAP}}{\sum \text{AP} + \text{NAP}} \text{ x } 100\% \quad (3)$$

$$\% \text{ Spore} = \frac{\sum(\text{Spore})}{\sum(\text{Pollen } + \text{Spore})} \text{ x } 100\% \quad (4)$$

$$\% \text{ Marine} = \frac{\sum \text{Marine}}{\sum(\text{Marine } + \text{Nonmarine})} \text{ x } 100\% \quad (5)$$

$$\% \text{ Non} - \text{marine} = \frac{\sum \text{Non} - \text{marine}}{\sum(\text{Marine } + \text{Nonmarine})} \text{ x } 100\% \quad (6)$$

The results of determining palynomorphs are displayed as a palynology diagram using the Tilia v.2.11 software. Division of palynomorph biozonation was made based on cluster analysis data. This cluster is a grouping based on taxa with nearby properties and characteristics based on the distance function. Cluster analysis was created using the Constrained Incremental Sum of Squares (CONISS) application in the Tilia v.2.11 software (Grimm, 1987), which was used to do this calculation utilizing stratigraphic considerations.

The geographical position of an area greatly affects the type of vegetation that develops in that area. The western portion of Indonesia's flora migrated eastward throughout the Pre-Tertiary period until it reached the southern arm of Sulawesi. The distribution of West Indonesian vegetation was constrained to South Sulawesi to the east of the Wallace Line following the division of the Makassar Strait in the Late Eocene (Morley, 1998). The taxa discovered in the study area also share traits with plant species found in western Indonesia, including *Palmaepollenites kutchensis, Beaupreadites matsukae, Dicolpopolis*, etc. So, biostratigraphy analysis to determine the age of the Malawa Formation was carried out using the Western Indonesian palynology zonation according to Rahardjo et al. (1994) (Figure 4).

3. RESULTS AND DISCUSSION

3.1. Lithology Data

The lithology data of Padanglampe traverse comprises sandstone, claystone, coal, and limestone layers. There are two sections of the Padanglampe traverse, the upper and lower parts, after a blank zone of 12 meters. The lower section tends to be coarse-grained sand to gravel sedimentary rock, with a thickness of 1.5 m, while the upper layer has a comparatively fine to medium-grained clastic sedimentary rock and intercalated with coal with a thickness of 10.5 m (Figure 5).

The outcrop of the lower Padanglampe traverse is characterized by lithology in the form of brownish-grey sandstones, relatively coarse-grained, poorly sorted, and composed of quartz minerals and rock fragments. At the bottom, the grain size is gravel that gradually becomes coarse sand to the top layer. Variations in grain size indicate a normal-graded bedding structure. Based on the composition characteristic, that outcrop is quartz sandstone (Figure 6).

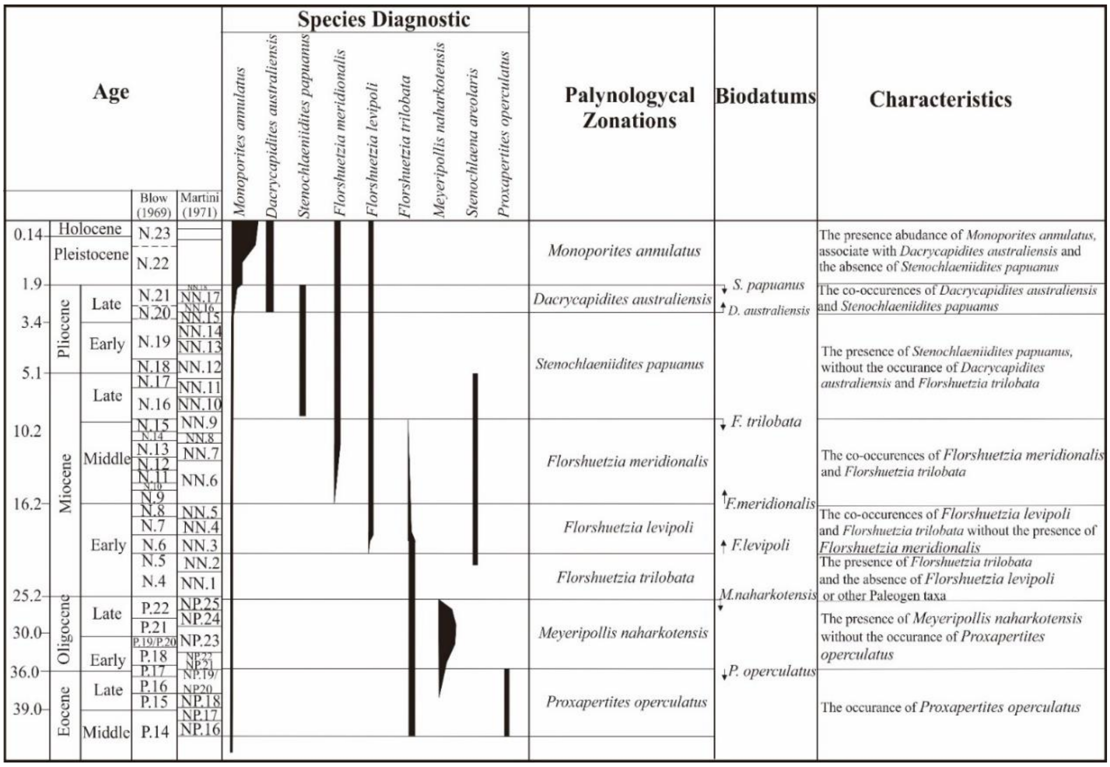

Figure 4. Palynology zonation for age determination according to Rahardjo et al. (1994)

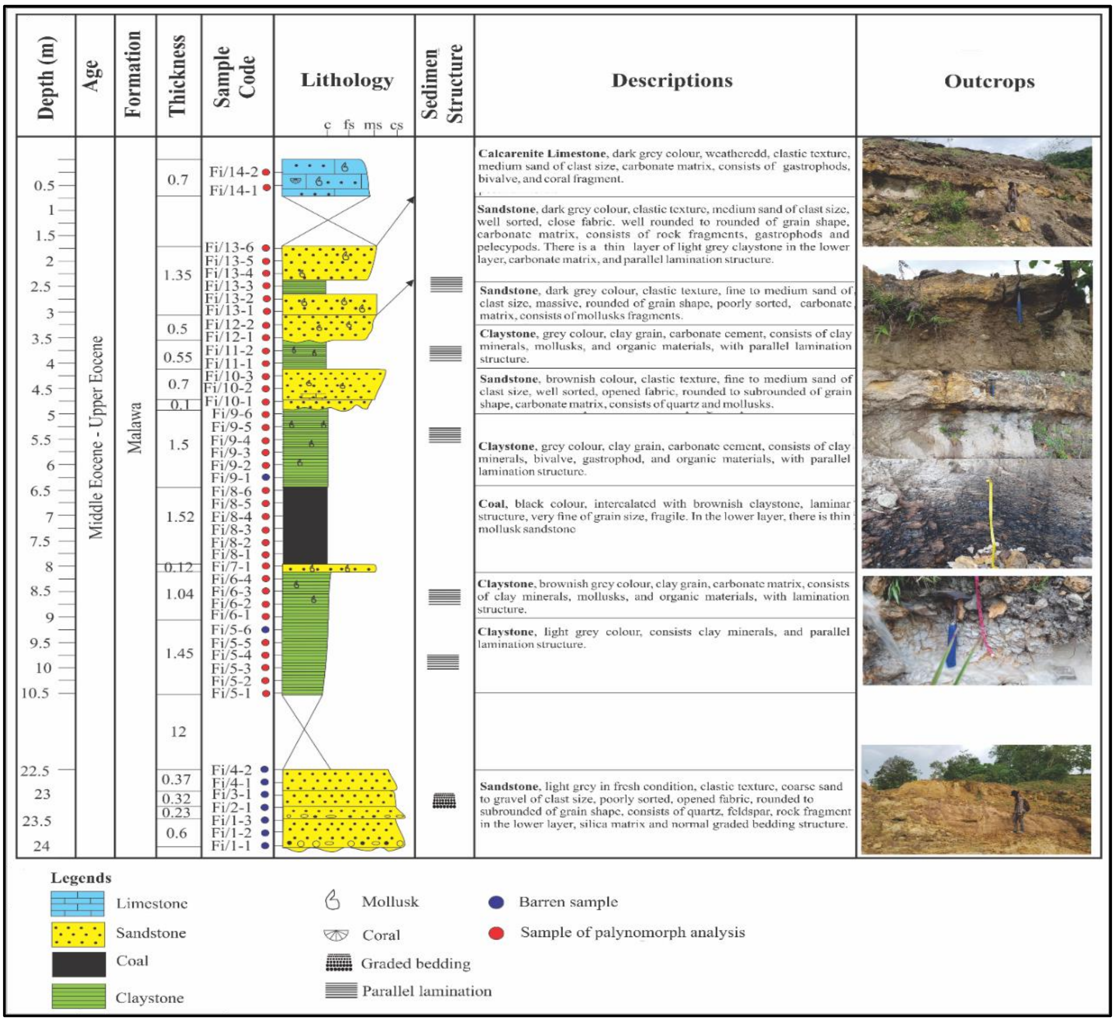

Figure 5. Stratigraphic column of Padanglampe traverse and sampling outcrop

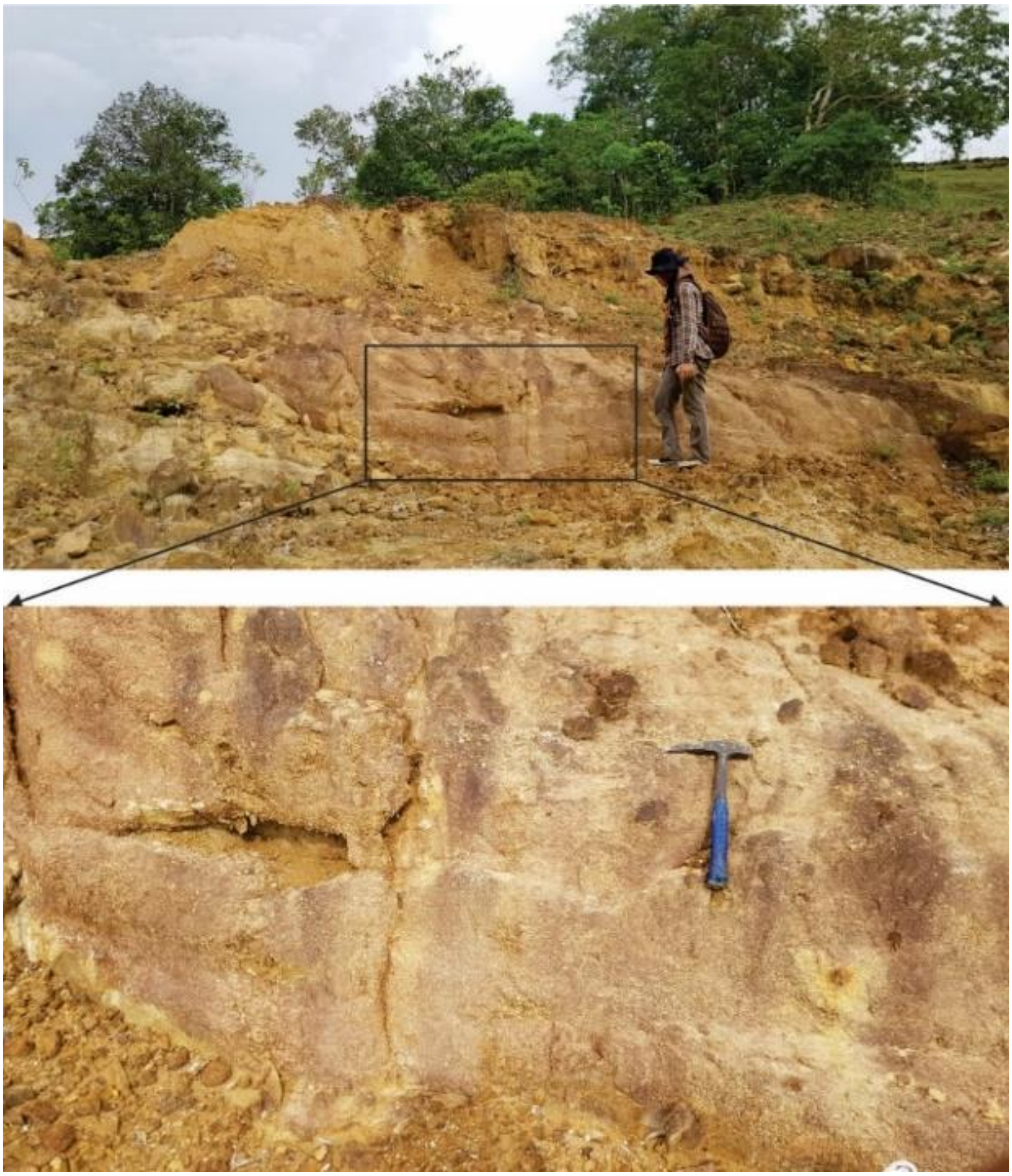

Figure 6. Sandstone outcrops on the lower Padanglampe traverse

The upper part of the Padanglampe traverse has characterized by intercalated claystone and sandstone with a coal layer (Figure 7). The characteristic of claystone is a light grey clay particle size, carbonate cement with a laminated structure, and the presence of mollusks like gastropods and bivalves. The sandstone has brow, fine-to-medium-sized grains, is well-sorted, including carbonate cement, and is rich in mollusks. Coal layers come in sheets up to one meter thick, brittle, and have a blackish appearance. A thin layer of brownish claystone indicates parallel laminations between the coal seams. The limestone at the top still has a sandy texture, is dark grey, has medium sand of grains and carbonate of cement, and is abundant with mollusks like gastropods, bivalves, and pelecypods.

Close to the Padanglampe traverse is contact between sandstones and shale (Figure 8). The sandstone is considered the sandstone of the Malawa Formation, while the shale is part of the Balangbaru Formation. This Balangbaru Formation is of the Late Cretaceous age, deposited in a deep marine environment (Sukamto, 1982). The contact relation between these formations is disconformity (Sukamto, 1982). The shale shows dark grey, fissility structure, and has a clay composition. The sandstone shows brown color, medium-grained sand.

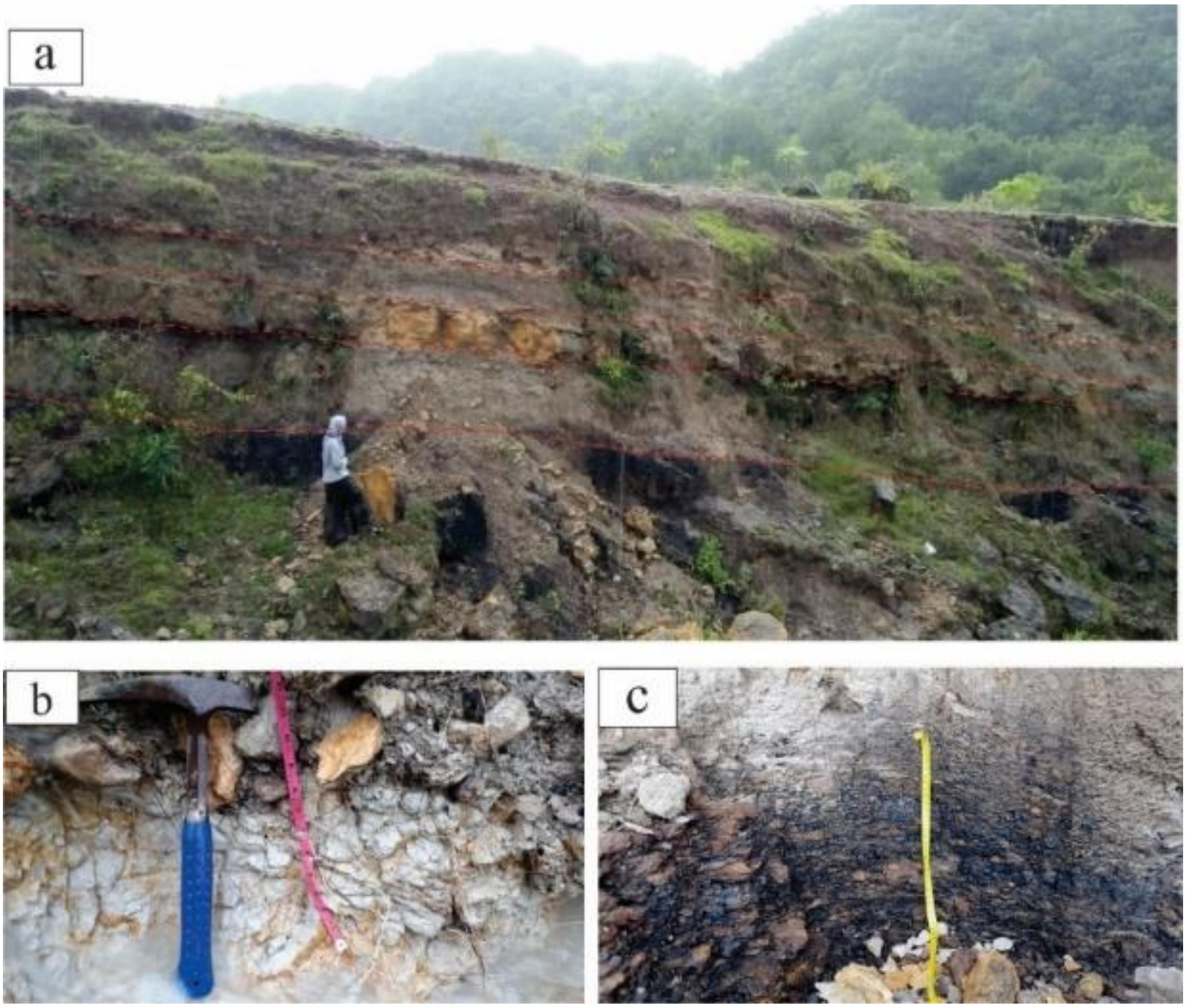

Figure 7. Outcrop appearance on the upper section of the Padanglampe Traverse, (a) the intercalated claystone and sandstone, (b) the lowest claystone layers, and (c) coal layers

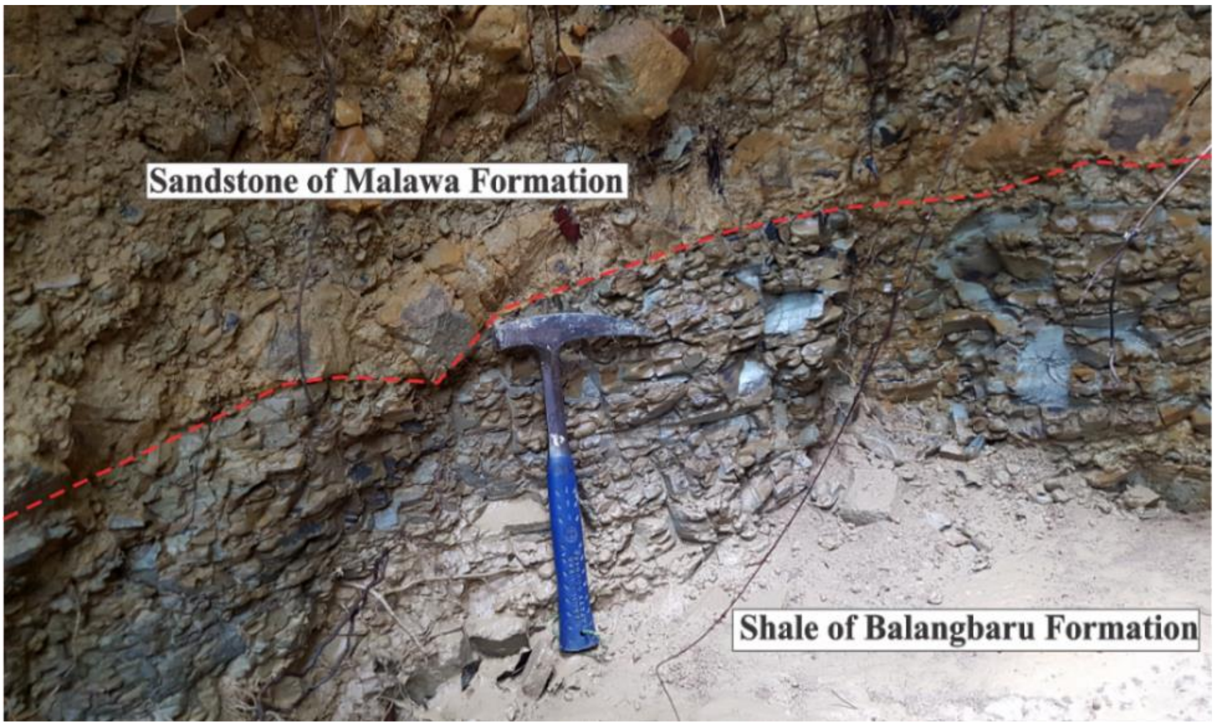

Figure 8. Contact between the Balangbaru Formation and the Malawa Formation

3.2. Palynology Data

Forty-five samples were processed in the laboratory and examined under a microscope to determine the palynomorph content based on stratigraphic cross-sectional measurements. Observation results identified nine barren samples of palynomorphs; hence, only 36 samples were used in the subsequent analysis. Palynomorph has a tiny-sized, micro-sized, so it is difficult to find in coarse-grained sedimentary rocks. Palynomorphs are abundant in rocks with a high carbon and organic material composition. As same as the sample at the study site. The lower part of the Padanglampe traverse comprises coarse-grained sandstone, so the sample is barren of palynomorph taxa.

Based on the results of palynological determination, 81 taxa have been identified, divided into 64 pollen taxa and 17 spore taxa (Figure 9). The percentage of observed palynomorphs from all samples showed that the highest abundance was pollen, as much as 44%, and the least was 2% of fungi (Figure 10a). The percentage of sporomorph abundance shows that pollen is more abundant than spores. A total of 64 species of pollen, including 62 gymnosperms and two angiosperms, as well as 17 taxa of spores from lower plants, were identified. Based on the type of growth, pollen grouping consists of Arboreal Pollen/AP (woody trees) and Nonarboreal Pollen/NAP (non-woody plants), with the dominance of abundance from the arboreal pollen group. The proportion of non-marine or terrestrial palynomorphs from the observed samples was more abundant than that of marine palynomorphs (Figure 10b).

3.3. Biozonation of Palynomorph

The zonation of palynomorph has shown in the diagram (Figure 11 and Attachment 1). The palynology diagram shows the division of taxa groups based on their life form. The plant groups are the taxa of trees and shrubs, aquatic plants (freshwater plants), grasses, terrestrial herbs, ferns and mosses, fungi, and marine taxa consisting of dinoflagellates and foraminifera test lining. Based on the palynomorph diagram analysis results, six biozones can be identified from the cluster analysis results using the CONISS approach in Tilia v.2. 11.

3.3.1. Zone I

This zone is at a depth of 10.5 – 9.5 m. This zone has a proportion of abundant pollen of 64.1%, 20.5% of spores, and 15% of marine palynomorphs. The proportion of AP taxa is more abundant than that of NAP. An abundance of trees and shrubs 48.7% was indicated by the abundance of Moraceae, *Pandanidites, Proxapertites operculatus*, and *Iugopolis*, the abundance of grasses was 7.7% with the presence of *Monoporites*, and the abundance of terrestrial herbs was 7.7% in the taxa *Randiapollis*. Spores were dominated by the presence of *Elphidium, Laevigatosporites*, and *Selaginella vaginala*. The presence of dinoflagellates characterizes marine palynomorphs.

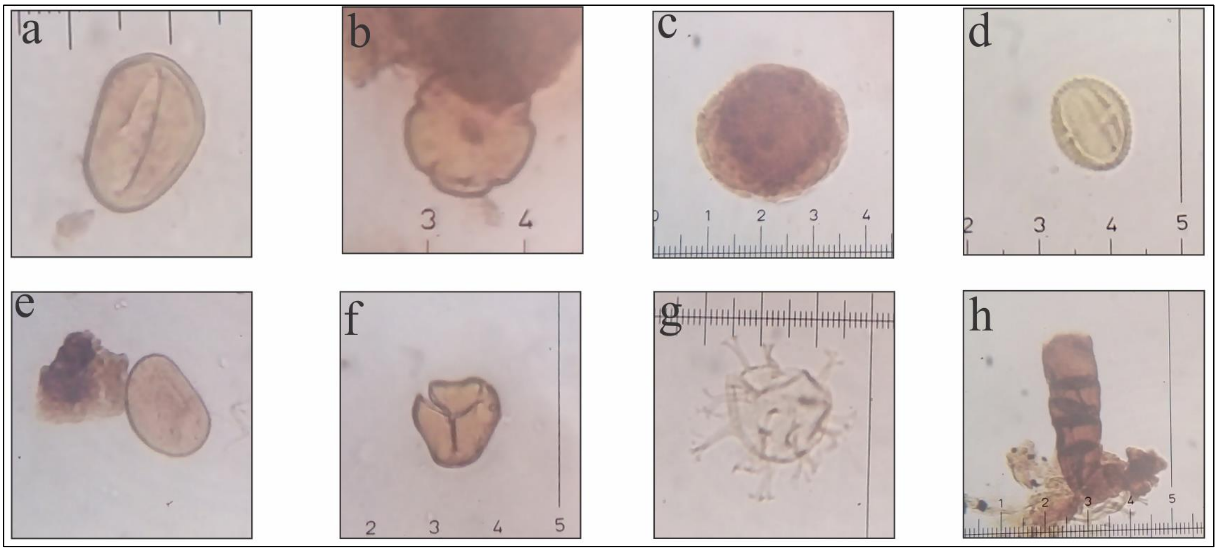

Figure 9. Some palynomorph fossils were found at the research area, (a) *Palmaepollenites kutchensis*, (b) *Retistephanocolpites williamsi*, (c) *Proxapertites operculatus*, (d) *Illexpollenites*, (e) *Laevigatosporites*, (f) *Acrostichum aureum*, (g) Dinoflagellates, (h) Fungi

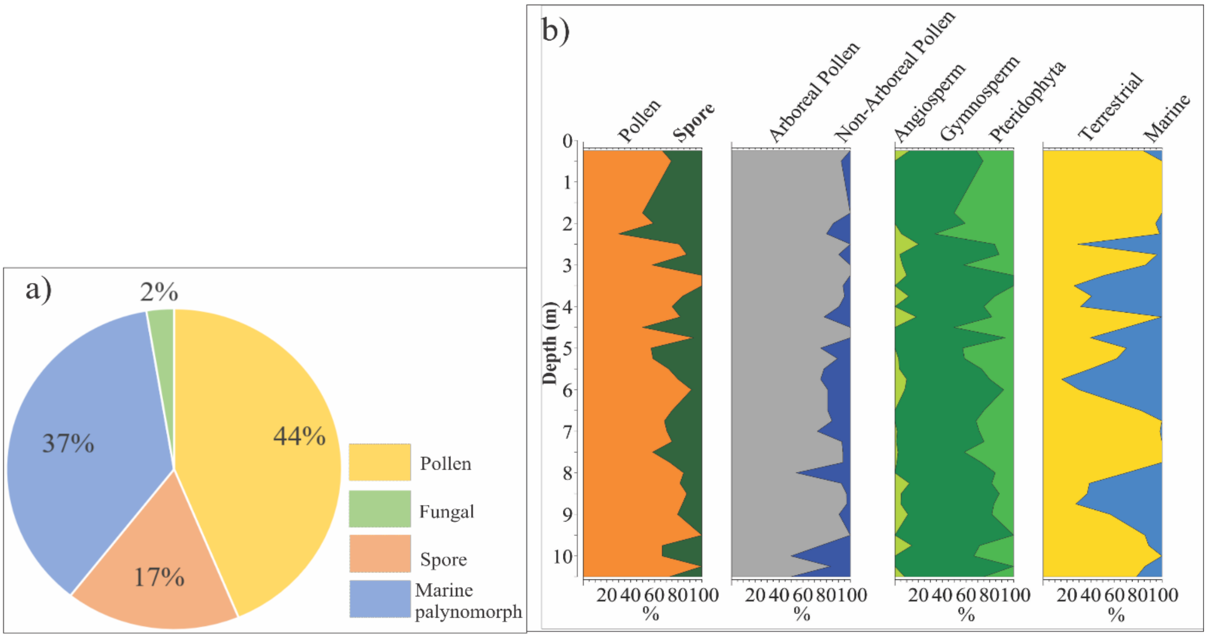

Figure **10.** a) The percentage of palynomorph abundance; b) The proportion of palynomorph abundance

3.3.2. Zone II

This zone is at a depth of 9.5 – 8 m. At a depth of 9.5 – 9.25 m, no palynomorphs were found, while at a depth of 9 – 8 m, there were palynomorphs dominated by marine palynomorphs of 58.9%, pollen of 33.4%, and spores of 7.74 %. The proportion of abundant AP reaches 93%, while the NAP is only 7%. The abundance of trees and shrubs was 31% which was dominated by *Arenga, Dicolpopolis, Psilatricolporites, Timonius, Spinizonocolpites echinatus, Proxapertites operculatus*, and *Lugopollis*, the abundance of grasses was 1.63% with the presence of *Monoporites*. The *Acrostichun aureum*, *Elphidium*, and *Laevigatosporites* dominated spores. The marine palynomorphs found were dinoflagellates and foraminifera test lining.

3.3.3. Zone III

This zone is at a depth of 8 – 6.5 m, with the highest pollen abundance of 65.2% and 34.64% of spores, while marine palynomorphs are very few, even less than 1%. The proportion of AP is 89.9%, while the proportion of NAP is only 10.1%. The abundance of trees and shrubs was 58.65%, including Moraceae, *Proxaperties operculatus, Psilatricolporites, Polygalacidites clarus, Retistephanocolpites williamsi, Lugopollis*, and *Palmaepollenites kutchensis*. Monoporites dominate the abundance of grasses at 4.5%. The abundance of terrestrial herbs at 2% is dominated by *Randiapollis*. *Acrostichum aureum*, *Anthocerisporites laevigatus*, *Laevigatosporites*, *Verrucatosporites usmensis*, and fungi spores.

3.3.4. Zone IV

This zone is from 6.5 – 4.25 m in depth. There is no palynomorph content at a depth of 6.5 – 6.25 m. Meanwhile, at a depth of 6.25 – 4.25 m, the highest abundance of marine palynomorphs was 58.3%, pollen was 29.2%, and spores were 12.5%. The percentage of AP is 81.3%, while the proportion of NAP is only 18.7%. The abundance of trees and shrubs is 23.7%, dominated by *Florschuetzia trilobata, Palmaepollenites, Pandanidites, Spinizonocolpites echinnatus*, and *Retistephanocolpites echinatus*. *Monoporites* dominate the abundance of grasses at 4.17%. The abundance of terrestrial herbs was only 1.28%, with the presence of *Randiapollis*. Spores have been dominated by *Acrostichum, Anthocerisporites laevigatus, Laevigatosporites*, and fungi spores. The marine palynomorphs found were dinoflagellates and foraminifera test lining.

3.3.5. Zone V

This zone is at a depth of 4.25 ¬– 1.75 m, with the highest abundance of palynomorphs being marine palynomorphs at 45.6%, pollen at 36.12%, and spores at 18.23%. The percentage of very abundant AP reached 92.7%, while the proportion of NAP was only 7.3%. The abundance of trees

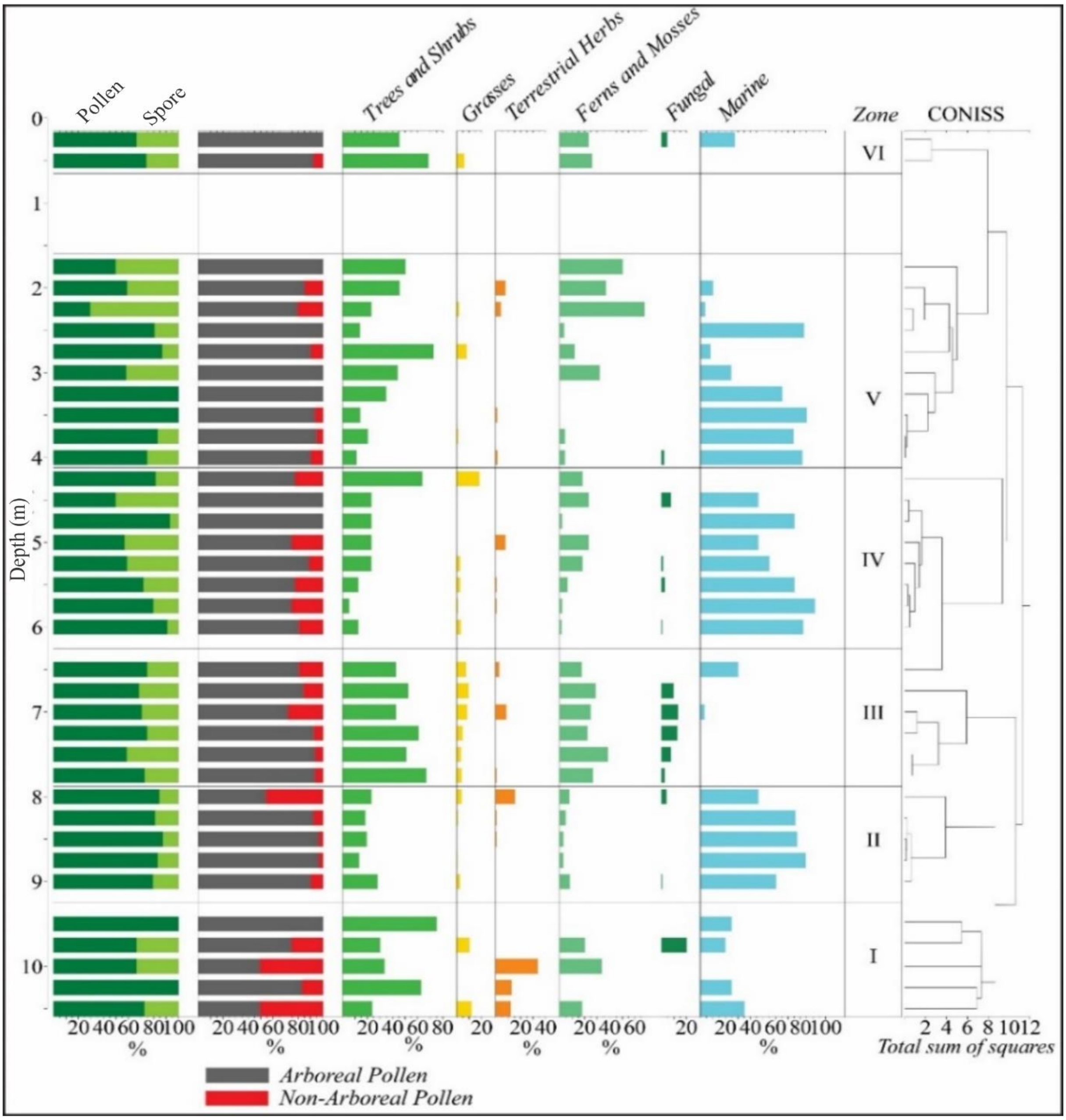

Figure 11. Grouping of palynomorph taxa based on their life form, zonation, and a dendrogram was calculated using the cluster analysis method

and shrubs was 33.5%, which was dominated by *Arenga*, *Haloragacidites harrisii*, *Malvaceae, Marginopollis continues*, Moraceae, *Palmaepollenites, Pandanidites, Rubiaceae, Timonius*, and *Spinizonocolpites echinatus*. The abundance of grasses is only 1.1%, dominated by *Resionidites punctulosis*. The abundance of terrestrial herbs is 1.5%, dominated by *Randiapollis*. Spores have been influenced by *Acrostichum*, *Anthocerisporites laevigatus*, *Elphidium, Laevigatosporites*, and fungi spores. The marine palynomorphs found were dinoflagellates and foraminifera test lining.

3.3.6. Zone VI

This zone is at a depth of 0.5 m to the surface, dominated by the great abundance of pollen at 63%, spores at 28.8%, and marine palynomorphs at 8.2%. The proportion of AP is more dominant, with a percentage of 95.65%, while the portion of NAP is only 4.35%. The abundance of tree and shrub taxa was 60.27%, dominated by the taxa Moraceae, *Proxapertites, Polygalacidites clarus, Blumeodendron*, and *Nuxpollenites*. The abundance of grasses taxa at 2.74% has been dominated by *Resionidites punctulosis*. *Anthocerisporites laevigatus*, *Baculatisporites scabridus*, *Laevigatosporites*, *Microfoveolatisporites*, and fungi spores dominate spores.

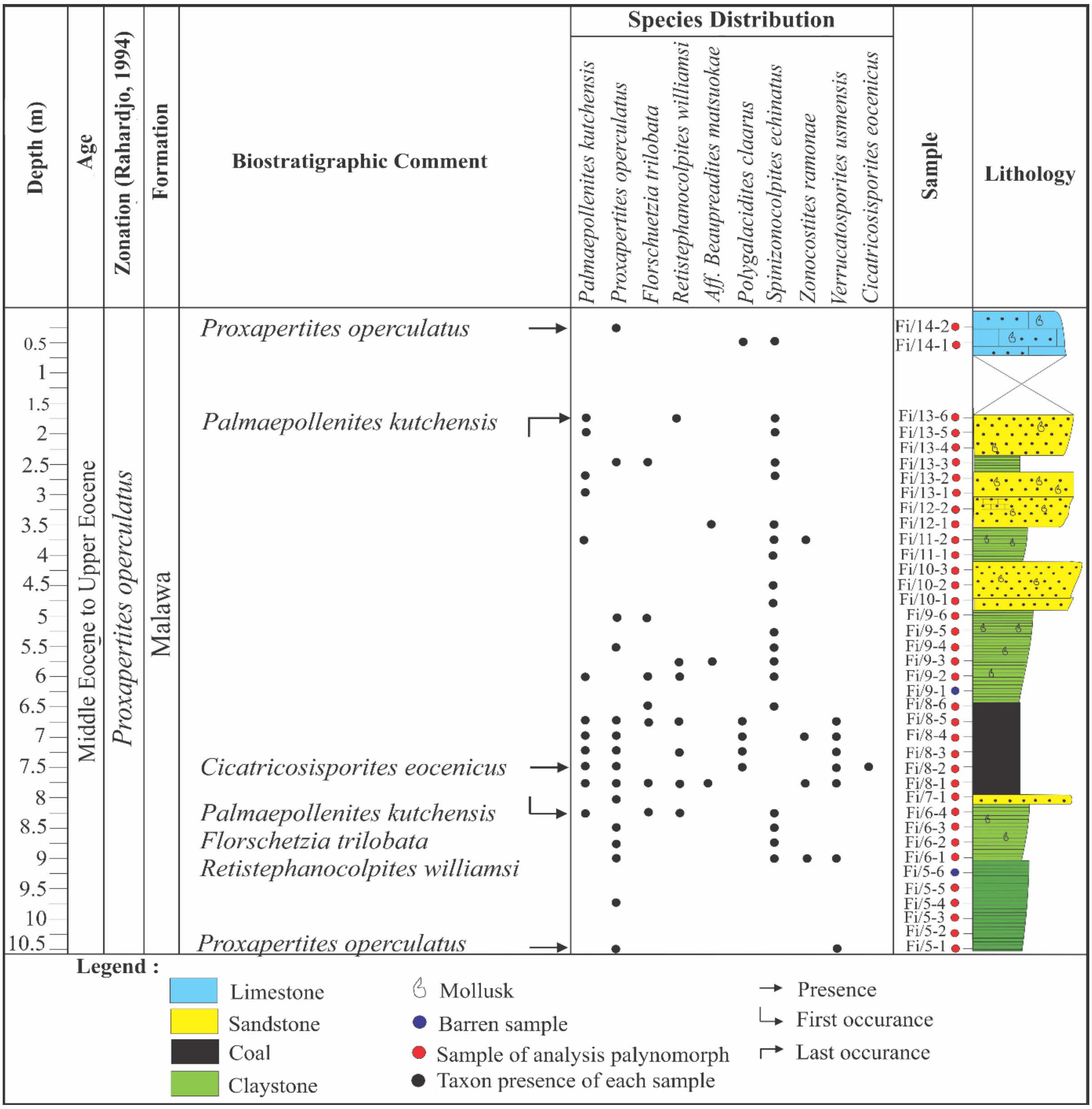

Figure 12. Biozonation of Padanglampe traverse

Based on the abundance of sporomorph taxa, biostratigraphy analysis can be determined. Referring to biozonation palynology (Rahardjo et al., 1994) showed *Proxapertites operculatus* as a biodatum in identifying the age of the research area. Apart from *Proxapertites operculatus*, use other species as datums in determining the chronostratigraphy of the Padanglampe traverse (Figure 12). These species are *Palmaepollenites kutchensis*, *Florschuetzia trilobata*, *Cicatricosisporites eocenicus,* and *Retistephanocolpites williamsi*. That is due to the first appearance (First Appearance Datum/FAD), late appearance (Last Appearance Datum/LAD), and the presence of the sporomorph species.

Based on the identification results of the biodatum mentioned above, it can be interpreted that the Malawa Formation on the Padanglampe traverse included in the *Proxapertites operculatus* zone (Rahardjo et al., 1994), which has characterized by the presence of *Proxapertites operculatus* in the lower sample of Fi/5-1 to the presence of *Proxapertites operculatus* in the top sample of Fi/14-2. The *Proxapertites operculatus* zone is equivalent to the Middle–Late Eocene age (Rahardjo et al., 1994). So, the age of Padanglampe traverse of the Malawa Formation is Middle to Late Eocene.

Based on the proportion of terrestrial palynomorph and marine palynomorph, the depositional environment of the Malawa Formation fluctuates from terrestrial or freshwater, brackish water, and marine environments. This analysis shows the depositional processes in a transitional environment characterized by a mixture of terrestrial and marine materials due to tidal influences.

4. CONCLUSIONS

This study consisted of one observation on the Padanglampe traverse with a track height of 10.5 m. Lithology samples have taken using the measuring section method at 25 cm intervals. The outcrops show the alternation of sandstone, claystone, coal, and limestone. A total of 45 samples have taken for palynology analysis. There are nine barren samples after the determination, so the palynomorph determination is only 36. The palynomorph data consisted of 64 pollen taxa and 17 spore taxa. The division of palynomorph taxa groups based on their life form includes the taxa groups of trees and shrubs, aquatic plants, grasses, terrestrial herbs, ferns and mosses, fungi, and marine taxa (dinoflagellates and foraminifera test lining). The data has presented in a diagram palynology. The division of biozones based on cluster analysis consists of six zones. The abundance of certain palynomorph taxa characterizes each zone. The common fossils found in every layer of rock are *Proxapertites operculatus*, *Palmaepollenites kutchensis*, *Florschuetzia trilobata*, *Retistephanocolpites williamsi*, *Cicatricosisporites eocenicus, Polygalacidites clarus, Spinizonocolpites echinatus*, and *Beaupreadites matsukae*. Based on the results of biozonation analysis, the Malawa Formation of the Padanglampe traverse is included in the *Proxapertites operculatus* zone with a Middle Eocene to Late Eocene age range.

5. ACKNOWLEDGMENTS

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Attachment 1. Palynology diagram based on the life form of palynomorph