Indonesian Journal on Geoscience Vol. 10 No. 1 April 2023: 73-82

INDONESIAN JOURNAL ON GEOSCIENCE
Geological Agency
Ministry of Energy and Mineral Resources

Journal homepage: http://ijog.geologi.esdm.go.id
ISSN 2355-9314, e-ISSN 2355-9306

Age and Depositional Environment of the Sandstone Unit of Ciletuh Formation in Ciletuh-Palabuhanratu Geopark

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Manuscript received: September, 6, 2021; revised: January, 17, 2022;
approved: September, 17, 2022; available online: January, 26, 2023

Abstract - Sandstones form part of the Cenozoic Ciletuh Formation which is widely exposed in The Ciletuh Palabuhanratu Geopark, Indonesia. This study aims to establish the age of these sandstone units, and to evaluate their depositional environment based on palynological data. Five samples from Ciletuh sandstones were collected for palynomorph analysis. Exposed sections were measured and sampled to determine the stratigraphic position, with palynomorphs being separated from the sediment using acetolysis. Cluster analysis was applied to the resultant palynomorph assemblages and interpreted using plant association model, which refered to the depositional environment of different taxa. Two distinct clusters were identified, characterized by different environmental markers. The first cluster is dominated by *Proxapertites operculatus* and *Proxapertites cursus*, while the second cluster is dominated by *Podocarpus* pollen. While the Proxapertites cluster includes *Dicolpopollis kalewensis*, *Palmaepollenites kutchensis*, foraminiferal test linings, dinoflagellates cysts, plant debris, deposited in the marine environment. The *Podocarpus* cluster consists of *Podocarpus* pollen, plant debris, foraminiferal test linings, and dinoflagellate cysts, that was deposited in a more distal marine environment. All samples were deposited during the end of Middle Eocene (E6-zone), as defined by the age markers of *Proxapertites. cursus, P. operculatus, Restioniidites punctulatus,* and *Podocarpus* pollen.

Keywords: Ciletuh-Palabuhanratu Geopark, relative age, depositional environment, palynomorphs

How to cite this article:
Winantris, Rosana, M.F., and Sena, K., 2023. Age and Depositional Environment of The Sandstone Unit of Ciletuh Formation in Ciletuh-Palabuhanratu Geopark. *Indonesian Journal on Geoscience*, 10 (1), p.73-82. DOI: 10.17014/ijog.10.1.73-82

Introduction

Background

The geology of the Ciletuh-Palabuhanratu Geopark area is composed of rocks formed in the Eocene epoch (Sukamto, 1975; Rosana *et al*., 2019). However, other research dates the Ciletuh Formation to a variety ages, between the Paleocene and Eocene based on the larger foraminifer Nummulites, Middle Eocene based on *Globorotalia* (M) *spinulosa* (Schiller *et al*., 1991), and Early Eocene (Martodjoyo, 2003) (Figure 1). The large age range estimated for the Ciletuh Formation is due to the absence or rarity of foraminifera and nannofossils, with most age reconstructions being based on stratigraphic position. Therefore, this study aims to suggest a more specific age based on pollen and spores, in combination with dinoflagellate cysts. Since palynological research from the Eocene is very limited in Indonesia, the Ciletuh Formation has been selected for this research. As well as determining a more precise age for

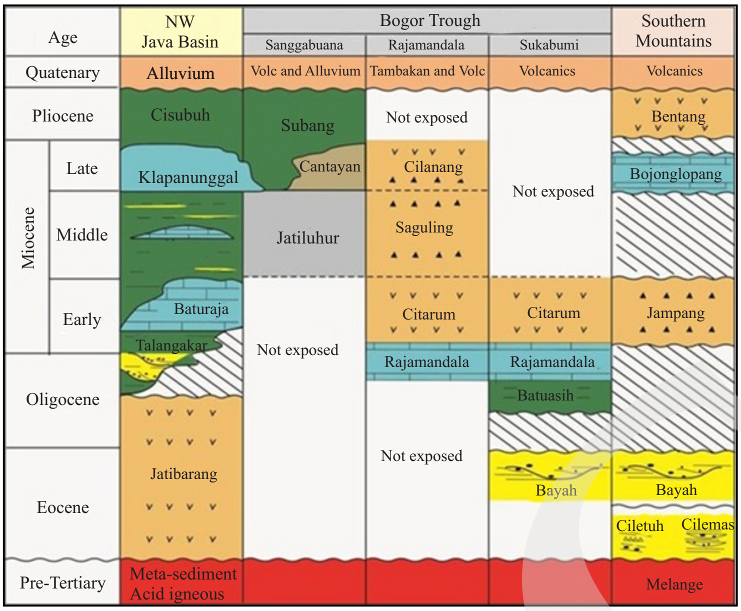

Figure 1. Cenozoic stratigraphic sequence in the Bogor Trough and North West Java Basin (Martodjojo, 2003).

the Ciletuh Formation, palynological data will also be used to investigate the geodiversity of the region over time, which will provide an important foundational dataset for the future research in this region, contributing to the scientific development aims of the geopark.

Stratigraphy

The stratigraphy of the Ciletuh Formation can be grouped into two categories, with rocks from the Pre-Cenozoic and Cenozoic periods (Sukamto, 1975). The Pre-Cenozoic in Java consists of melange formed of a mixture of metamorphic, basic, ultra-basic rock, and basaltic lava of the Citirem Formation, while the Cenozoic rocks include the Ciletuh, Bayah, and Jampang Formations. The Ciletuh Formation is composed of two lithofacies: a conglomeratic quartzose lithofacies and a volcaniclastic lithofacies. The quartzose lithofacies comprised quartz-rich conglomerates and sandstones, which are locally bedded and commonly contain sedimentary structures associated with rapid erosion and deposition. Conglomeratic material is predominantly quartz and typically very well rounded. Sandstones are often texturally immature with angular to subangular grains, which are typically poorly sorted. Deposition of these sandstones has been interpreted to have occurred predominantly in a tidally influenced shallow marine setting (Bemmellen, 1949), but more recent publications suggest that the rocks of The Ciletuh Formation are deposited in a submarine fan environment (Schiller *et al*., 1991). The volcaniclastic lithofacies of the Ciletuh Formation appears to have been deposited in a much deeper-water environment, characterized by a highly polymic breccia-conglomerate at the base (Clements and Hall, 2006). Furthermore, Schiller *et al*. (1991) note that the quartzose sandstone and conglomerate lithofacies occupies the headland area, while volcanic sandstone lithofacies is distributed around Ciletuh Bay. Based on the regional geological map for the Cikadal-Lengkong region, the quartz sandstone that is distributed over the Ciletuh Geopark is part of the Lower Ciletuh Formation (Pecl) from the Eocene epoch (Rosana *et al*., 2019).

Material and Methods

A measured section method was used to determine the stratigraphic position of samples k2.5 (Tegal Pamidangan), cs5 (Pulau Kunti), cs22 (Karang Kapio), cs13 (Legon Bedog), and cs18 (Legon Pandan), for palynological analysis taken from these sites (Figure 2). The character of each sample shown in Figure 3 is as follows:

- cs18; Sandstone, brownish grey to blackish grey fine grained, rounded, floating grains, well sorted, high permeability, noncarbonate, with parallel lamination, mineral content include quartz, and coal flakes.
- cs13; Sandstone, beige to brown, fine- to very fine grained, rounded, floating grains, well sorted, high permeability, noncarbonate, hard, with parallel laminations and cross laminations, quartz minerals, and coal flake.
- cs22; Sandstone. brownish grey to light-yellowish brown, coarse- to very fine- grained, rounded, floating grains, well sorted, high permeability, hard, with parallel laminations, and graded bedding, mineral content consist of quartz and calcite, and the sample contains coaly flakes.
- cs5; Sandstone: light grey to greenish grey, coarse grained sand, subangular, grain supported fabric, poorly sorted, medium permeability, noncarbonate, hard, with quartz, and black and green minerals. Structure: massive, thin interlayering of coaly material.
- k2.5; Sandstone, light grey to black, medium- to fine- grained, subrounded, medium sorted, high permeability, spongy-hard, mineral content is quartz and K- feldspar.

Palynomorphs were separated from the sedimentary rocks using the acid digestion method utilizing HF, NaOH, KOH, CHCOOH, and HCl. A compound microscope was used for identification using 10x ocular magnification with 10x, 40x, and 100x objective magnifications. Pollen and spores were identified to the genus or species level. Dinoflagellate cyst identification was made at the genus level, by referring to Davey and Williams (1966) which described the genus *Hystrichosphaeridium* and its allies. The foraminiferal test linings were identified based on morphological descriptions, using the Hottinger (2006) for classifying the chamber arrangement types. Interpretation of the depositional environment was based on the plant association model of Haseldonckx (1974) and also the pattern of transportation of pollen into marine environments, as discussed in Morley (1991). Cluster analysis has been used to determine the similarity between the palynomorph assemblages of the five samples. For palynomorphs, these assemblages groups

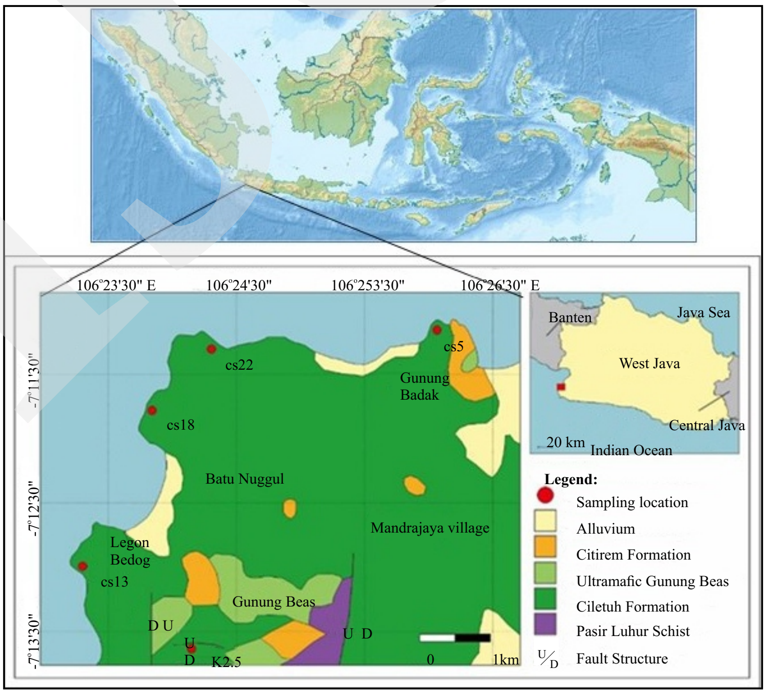

Figure 2. Researched location and selected sampling sites for palynological analysis.

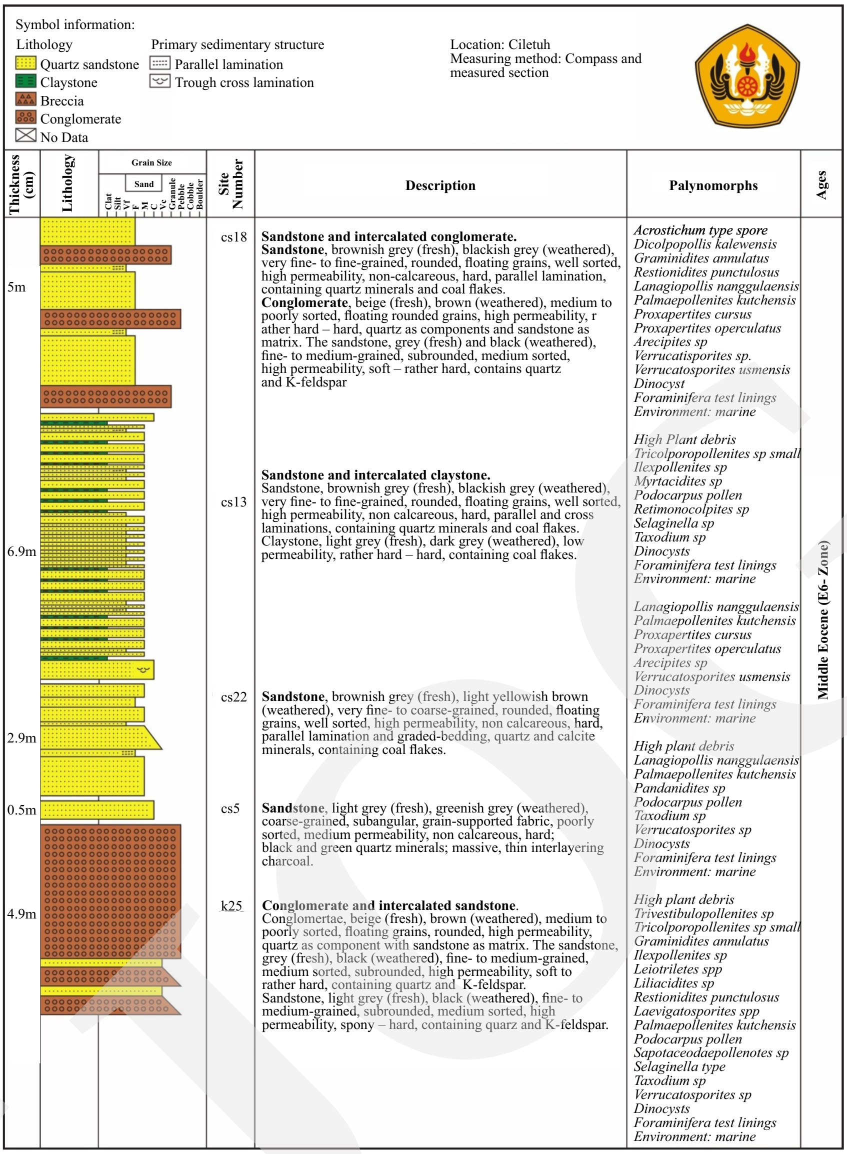

Figure 3. The composite log shows the depositional environment, relative age, and lithology.

similar depositional environments and palynomorph transportation mechanisms. The analysis of age refers to the "Palynological zonation for Indonesia" compiled by Morley (1991, 2013, and 2020) (Figure 4).

Results and Discussion

The characteristics of the sequential sandstone samples from the bottom to the top is illustrated in Figure 3. Pollen preservation in sandstones and conglomerates is generally poor, hence the diversity of palynomorphs from the five samples analyzed is low. Only six types of fern spores and eighteen types of pollen were obtained in total. Pollen and spores are better preserved in unoxidized, fine-grained, primarily dark-coloured sediments, such as mudstones, siltstones, micritic limestones, cherts, and coals (Askin and Jacobson, 2003). According to Dupont *et al.* (2007), the pollen dispersal is controlled by the characteristics of pollen species, habitat types, aerodynamics, hydrodynamics, and taphonomy.

In the researched area, besides the lithology factor of grain size, the rarity of pollen in sandstone is caused by a high energy level during deposition. Sandstone was deposited by

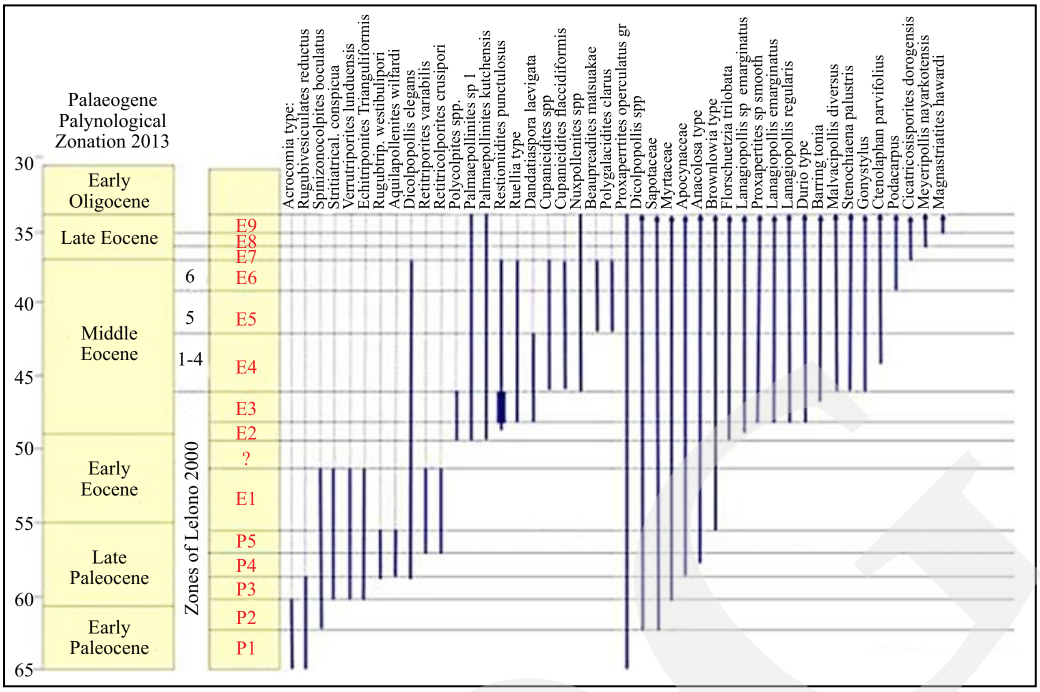

Figure 4. Paleogene Palynological Zonation (Morley, 2013, 2020).

turbidity current (Schiller *et al.,* 1991), so pollen grains become very difficult to preserve under these conditions. The same thing happened in the study of palynomorphs at Arshad Sandstone which is poorly preserved pollen (Kumar, 2018). To overcome this, palynomorph analysis was completed in conjunction with analysis of foraminiferal test linings and dinoflagellate cysts. Each sample analyzed included a mixture of marine and terrestrial palynomorphs (Figure 5). Two clusters were obtained from the cluster analysis conducted on five samples. The cluster name is based on the most common pollen type.

Age Analysis

Age interpretation was completed based on the "Palynological zonation for Indonesia" (Morley, 1991, 2013, 2020). Pollen markers and the corresponding age range of each sample are displayed in Table 1.

The sediment age was determined by the overlap range of *Restioniidites punctulosus* and *Podocarpus* pollen in the bottom sample k2.5, coupled with the absence of taxa that characterize the Late Eocene, such as *Magnastriatites grandiosus* and *Meyeripollis naharkotensis*. *Podocarpus* pollen has the youngest age range of the pollen markers found in these samples. *Podocarpus* pollen appears from E6 until the present day (Lelono, 2000; Morley, 2011, 2013, 2018, and 2020). Both pollen taxa is also found in the cs18 at the top of the sample. *Restioniidites punctulosus* is found in the E2-E6 range. As the age range of these two pollen types overlaps in zone E6, the age of the sedimentary rocks from these samples must be dated to the end of Middle Eocene in E6 zone (Figures 5 and 6). On the other hand, *Restioniidites punctulosus* was reported to significantly occur at the end of the Middle Eocene of Nanggulan Formation (Lelono, 2000).

Environment Analysis

Cluster analysis of these five samples identifies two clusters, namely *Proxapertites* and *Podocarpus* clusters (Figure 7).

The *Proxapertites* cluster, consists of cs18 and cs22 samples, characterized by the dominance of *Proxapertites* spp. Most of the pollen found in samples in this cluster are from the Araceae and Arecaceae families, including *Proxapertites operculatus*, *Proxapertites cursus*, *Dicolpopollis kalewensis, Palmaepollenites kutchensis,* and *Arecipites* sp. The quantity of *Dicolpopollis* is the

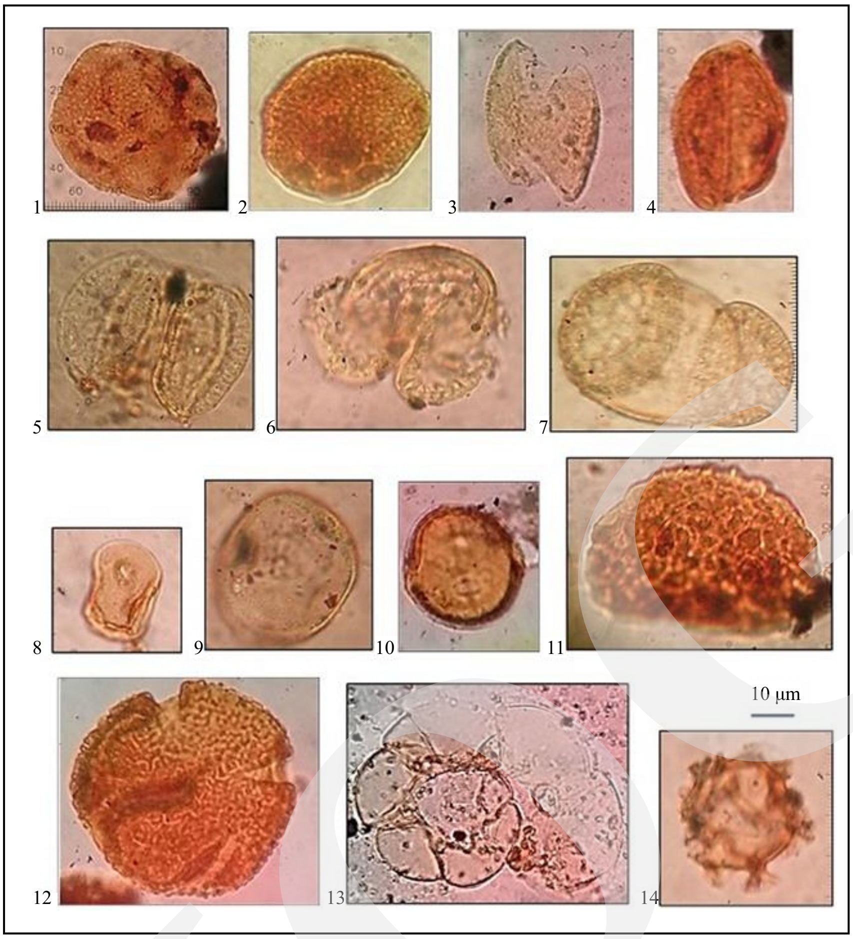

Figure 5. Photomicrographs of palynomorphs recognized. 1 *Proxapertites operculatus; 2. Proxapertites cursus; 3. Dicolpopollis kalewensis; 4. Palmaepollenites kutchensis; 5-7. Podocarpus* pollen*; 8. Graminidites annulatus; 9. Restioniidites punctulosus; 10. Sapotaceodaepollenites* sp.*; 11. Verrucatosporites* sp.; 12. *Lanagiopollisnanggulaensis,* 13. Foraminiferal test lining; 14. Dinoflagellate cysts.

Table 1. Pollen-based Age Determinations for the Ciletuh Formation

Sample	Age Marker		Conclusion
CS18	*Proxapertites operculatus*	Paleocene zone P1–Eocene zone E9 (Morley, 2020)	Middle Eocene (E6 Zone)
	Proxapertites cursus	Paleocene - Eocene (Morley, 1991)	
	Restioniidites punctulosus	Middle Eocene zone E2–E6 (Morley, 2013, 2020).	
CS13	*Podocarpus pollen*	From Middle Eocene E6 onward, (Morley, 2020)	
CS22	*Proxapertites operculatus*	Paleocene zone P1 - Eocene zone E9 (Morley, 2013, 2020)	
	Proxapertites cursus	Paleocene - Eocene (Morley, 1991)	
CS5	*Podocarpus* pollen	From Middle Eocene E6 onward, (Morley, 1988, 2020)	
K2.5	*Restioniidites punctulosus*	Middle Eocene zone E2 - E6 (Morley, 2013, 2020).	
	Podocarpus pollen	From Middle Eocene E6 onward (Morley, 2013, 2020)	

second after *Proxaperites* in the cs18 sample. *Dicolpopollis malesianus* is shown to be a synonym of *Dicolcopollis kalewensis* (Huang *et al*., 2020). The occurrence of these pollen is indicative of derivation within a coastal environment (Tripathi *et al*., 2009, Huang *et al*., 2020), but these pollen types are readily transported into marine environments, and so Hammen (1956) found *Proxapertites* commonly in marine environments. The parent plant of *Dicolpopollis* may grow in a freshwater swamp environment (Muller, 1968), it may occur in any setting from lowland forest

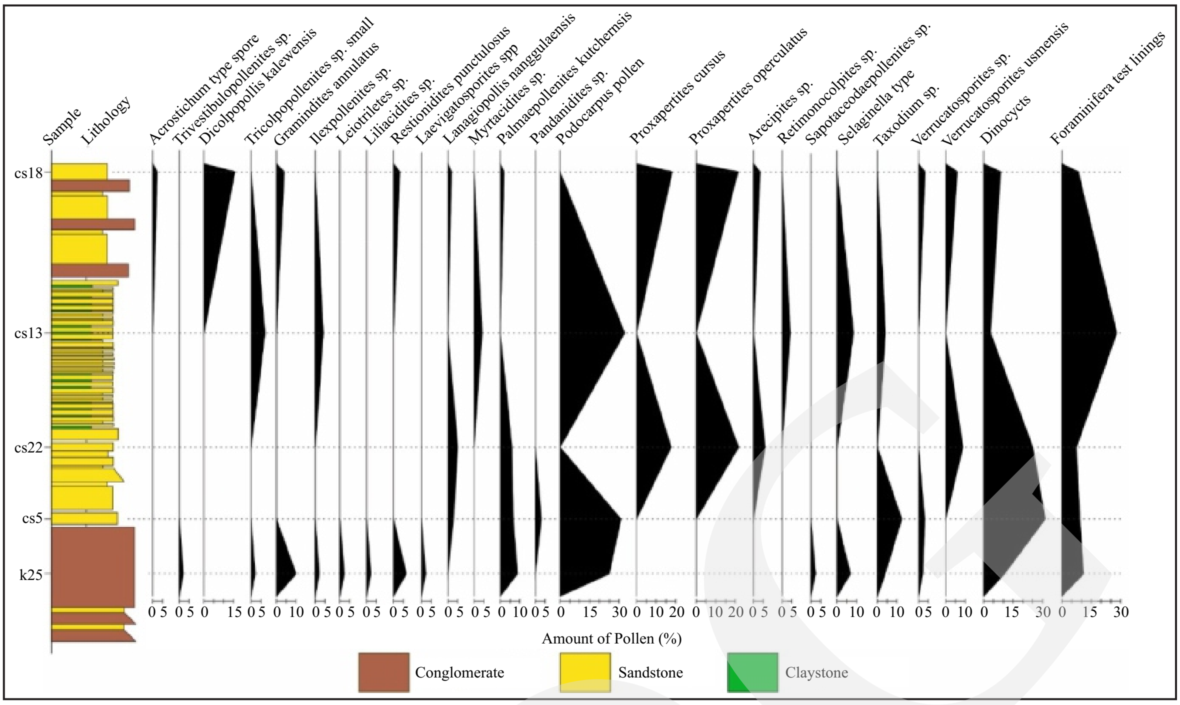

Figure 6. Stratigraphic plot of Palynomorphs contained within the samples analysis.

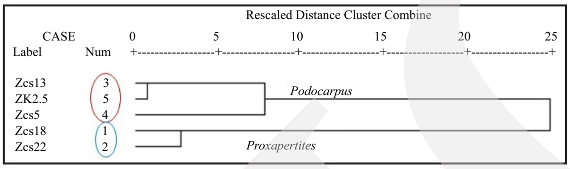

Figure 7. A dendrogram shows the members of each cluster.

to the mountains (Huang *et al.*, 2020), whereas the parent plant of *Palmaepollenites kutchensis* probably grew in peat swamps, shown by their dominance in a coal from the Middle Eocene Nanggulan Formation (Morley, 2000), but may also have grown in more terrestrial environments (Polhaupessy, 2009; Huang *et al.,* 2020). The presence of dinoflagellates and foraminiferal test linings are both indicative of marine environments (Fakhruddin, 2019). The percentage of marine fossils such as foraminifera test linings and dinocysts is high enough, 18.2% at cs18 and 34.30% at cs22 to indicate the sedimentation process in the marine system. Overall, palynomorph characteristics indicate the marine environment. Samples of cs18 and cs22 were taken from non-calcareous sandstones with parallel laminated sedimentary structures and coal flakes; this sample occupies the headland of Ciletuh area when referring to Schiller *et al.* (1991), and is classified as Tb facies in the Bouma sequence indicating a deposition by turbidite mechanism.

The *Podocarpus* cluster includes cs13, k2.5, and cs5. It is characterized predominantly by conifer pollen, including *Podocarpus* and *Taxodium* sp., as well as the high abundance of fossil plant debris. The genus *Podocarpus* is a montane forest tree that grows in West Java at an elevations of 1,500-3,000 m a.s.l. (Stuijts, 1993), and elsewhere it may found a lower altitude of 1,100-1,300 m a.s.l. in West Kalimantan (Ronaldo *et al.*, 2019). However, some species of *Podocarpus* occur in Kerangas forests, Sarawak (Jacobs, 1988). The *Podocarpus* type pollen first appeared in the Sundaland region in the Middle Eocene, and is therefore used as a biostratigraphic marker (Morley, 2011, 2013, 2020). In each sample of the *Podocarpus* cluster, marine fossils including foraminiferal test linings and dinoflagellate cysts were also found. All samples within the *Podocarpus* cluster showed a higher percentage of foraminiferal test linings than in the *Proxapertites* cluster. Marine fossils such as foraminiferal test linings and dinoflagellate cysts reach 32% at cs13, 40.6% at cs5, and 21.3% at k2.5. Foraminiferal test linings indicate near shore to marine habitats (Emery and Myers, 1996), but can be transported into deeper marine settings. Still, recent research states that foraminifera test linings are more than an indicator of the lack of availability of calcium carbonate, reflecting a reduction in carbonate dissolution (Morley *et al*., 2021). The *Podocarpus* cluster includes gymnosperms, for which the pollination process is supported by the wind or anemophily (Lu *et al*., 2011). Therefore, Gymnospermae pollen is often dispersed further away from the parent plant than for Angiosperms, which can explain its presence in predominantly open marine deposits. Apart from these genetic factors, in this case, the Neves effect is more critical in transporting pollen into the deep sea. Terrestrial sediments containing pollen are found in marine environments with high salt content, where they do not support living flora; upland pollen like *Podocarpus* is transported to a marine and deposited there (Traverse, 2007). Overall, these characteristics indicate a marine depositional environment, possibly deep marine, marked by a high percentage of foraminifera test linings and wind-transported pollen.

Conclusions

This study involved a stratigraphic reconstruction of the Ciletuh Formation using five samples from the Ciletuh-Palabuhanratu Geopark area. Cluster analysis of the resultant palynomorph assemblages revealed two distinct groups, termed the *Proxapertites* cluster and the *Podocarpus* cluster based on the most common pollen taxa present. Results shows that the position of *Proxapertites* clusters from cs22 (Karang Kapio) and cs18 (Legon Pandan) occupies the middle and upper part of the succession. Meanwhile, samples from the *Podocarpus* cluster occur mainly in the lower part. *Podocarpus* appear from the Middle Eocene until the present day. Based on these reconstruction results, all samples were deposited in the end of Middle Eocene, in the E6 zone of Morley (2020) specifically, and were deposited in a marine environment.

Acknowledgments

The authors would like to thank Universitas Padjadjaran, which has supported us by Academic Leadership Research Grant. Special thanks to our laboratory team: Ria Fitriyani and Mr. Dayat. The authors are also very grateful to Dr. Robert J. Morley, who helped extensively with issues concerning the identification and naming of palm pollen, with age interpretation, and also interpretation of depositional environments, and many other important matters to reach the high standard of journals.

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