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Cooling Event in the Boundary of Middle/Late Eocene of Java

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Abstract: The indication of Eocene climatic changes is defined based on the change of abundance and diversity of palynomorphs occurring in the Nanggulan Formation. This is possible because this formation has been found to yield the richest and most diverse palynomorph assemblages of Eocene age in Southeast Asia. Palynological evidence, from the distribution of index taxa and palynological events, indicates that the Nanggulan Formation was deposited during the Middle to Late Eocene as marked by the constant occurrence of *Longapertites vaneendenbergi*, *Proxapertites operculatus*, *Proxapertites cursus* and *Cicatricosisporites eocenicus*. The Middle Eocene age is characterised by high abundance and diversity of rain forest elements suggesting warm and wet climate which include *Palmaepollenites kutchensis*, *Sapotaceoidaepollenites* spp., *Retitricolporites equatorialis*, *Campnosperma* sp., *Marginipollis concinus* and *Dicolpopollis malesianus*. On the other hand, the Late Eocene age is marked by the appearance of the hinterland element *Podocarpidites* spp. and the disappearance of the main rain forest elements indicating cool and dry climate. In this case, cooling event is defined by the occurrence hinterland element of *Podocarpidites* spp. which can be used for recognising Middle/ Late Eocene boundary.

Key words: cooling event, middle/late eocene boundary, palynomorphs

1. Introduction

Eocene epoch is characterised by global cooling period. However, short periods of warm climate were reported to occur in the high latitude areas as proved by the expansion of some tropical plants. Bosboom et al. (2014) recorded the increase of abundance and diversity of angiosperms in the northern high latitude of Xining Basin (NW China) to indicate the Middle Eocene Climatic Optimum (MECO) [1]. Mean while, a short-lived warming event also appeared in the basal Early Eocene (Early Eocene Climate Optimum: EECO) as reported by Hofmann et al. (2012) [2]. His interpretation was based on common occurrence of tropical floras which were collected from transgressive Krappfeld succession of Eastern Alps, Austria. Similar situation was encountered in the southern high-latitude, where warm climate was interpreted to appear in the transition of Paleocene-Eocene (EECO) of Tasmania [3] and in Southeastern Australia [4]. Plant Communities and Climate Change in Southeastern Australia During the Early Paleogene. The Eocene global cooling is strengthened by the Late Eocene palynological record from Xining Basin of China which showed sudden abundance of conifer forest elements indicating cooling and dry climate [5].

The different situation occurred in the tropical regions, in which Eocene epoch is characterized by high abundance and diversity of palynomorphs especially those of angiosperm indicating widespread development of tropical rain forest as seen in South and Middle America, Africa, India, Australia and Southeast Asia [6]. Rich palynomorphs along the Eocene epoch combined with coals/lignites lithology in Southeast Asia may relate to the time of Eocene thermal maximum, with everwet climates developing as the global climate cooled [7]. Palynological data form the

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Early Eocene succession of the Surkha lignite mine, Cambay Basin, North-Western India suggest a warm and humid tropical-subtropical climate which favoured the growth of coastal palms and evergreen arboreal angiosperms close to the site of deposition [8].

Having the above discussions, it is inferred that in the high latitude, Eocene epoch was indicated by global cooling event with sort periods of warm event. Meanwhile, in the low latitude (tropic), this cooling event might not be easy to recognize as thermal maximum continue to persist. Cooling event appeared at the top Eocene to mark terminal Eocene cooling event. This paper is aimed to observe palynomorph assemblages within the Eocene succession of Java for interpreting paleoclimate occurring in this epoch.

2. Material and Method

Samples used in this work were collected from the Nanggulan Formation which was crouped-out in Central Java, Indonesia (Fig. 1). This because the Nanggulan Formation contains the richest and most diverse palynomorph assemblages of Eocene age between the Gippsland basin (eastern Australia) and India [6]. Sampling was focused on fine grain lithology with dark colour which was predicted to yield high organic content. In addition, this formation represents transgressive sequences in which non-marine setting in the bottom section (as indicated by lignites) gradually changes into transition to shallow marine environment in the middle section (as suggested by abundant marine fossils) and finally ends up with deep marine setting at the top section (as evidenced by the domination of marl lithology). The complete Nanggulan Formation is exhibited in Fig. 2. Having this type of lithology, this formation in fact yields typical Eocene marine faunas such as molluscs, foraminifera, corals, bryozoans, echinoids and crustaceans. Therefore, it is well known to form a classic locality in the Indo-Pacific region for Eocene faunas.

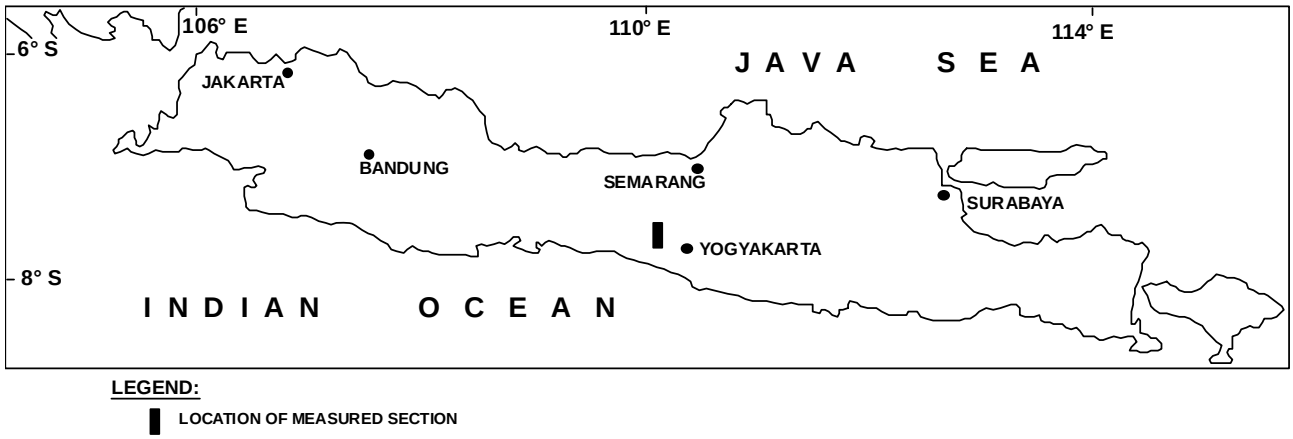

Fig. 1 The area of study is situated in Central Java, Indonesia.

Approximately 5 g of sample was cleaned up to avoid surface contamination. The standard methods of maceration using HCl, HF and HNO_3 were employed to get recovery of plant microfossils. These acid treatments were followed by the alkali treatment using 10% KOH to clear up the residue. Sieving using 5 microns sieve was conducted to collect more palynomorphs by separating them from debris materials. Finally, residue was mounted on the slides using polyvinyl alcohol and Canada balsam.

Palynology has been a veritable tool in vegetation reconstruction for paleoclimatic interpretation [9]. Palynomorphs reflect the vegetation of an area to a reasonable extent as reported by several workers. Meanwhile, astronomically driven climatic changes have resulted in the successive sequestration of seawater into polar ice caps since the Oligocene or Late Eocene [10] and probably account for most eustatic

change over this period [11]. The effect of climatic changes in the low latitude has reduced the temperature and the moisture availability during the periods of low sea level. Temperature reduction was probably universal across the low latitudes during the Last Glacial Maximum (LGM), with reductions of 4°C -6°C [6]. Therefore, fossil evidence for climatic change provides a proxy for sea level change.

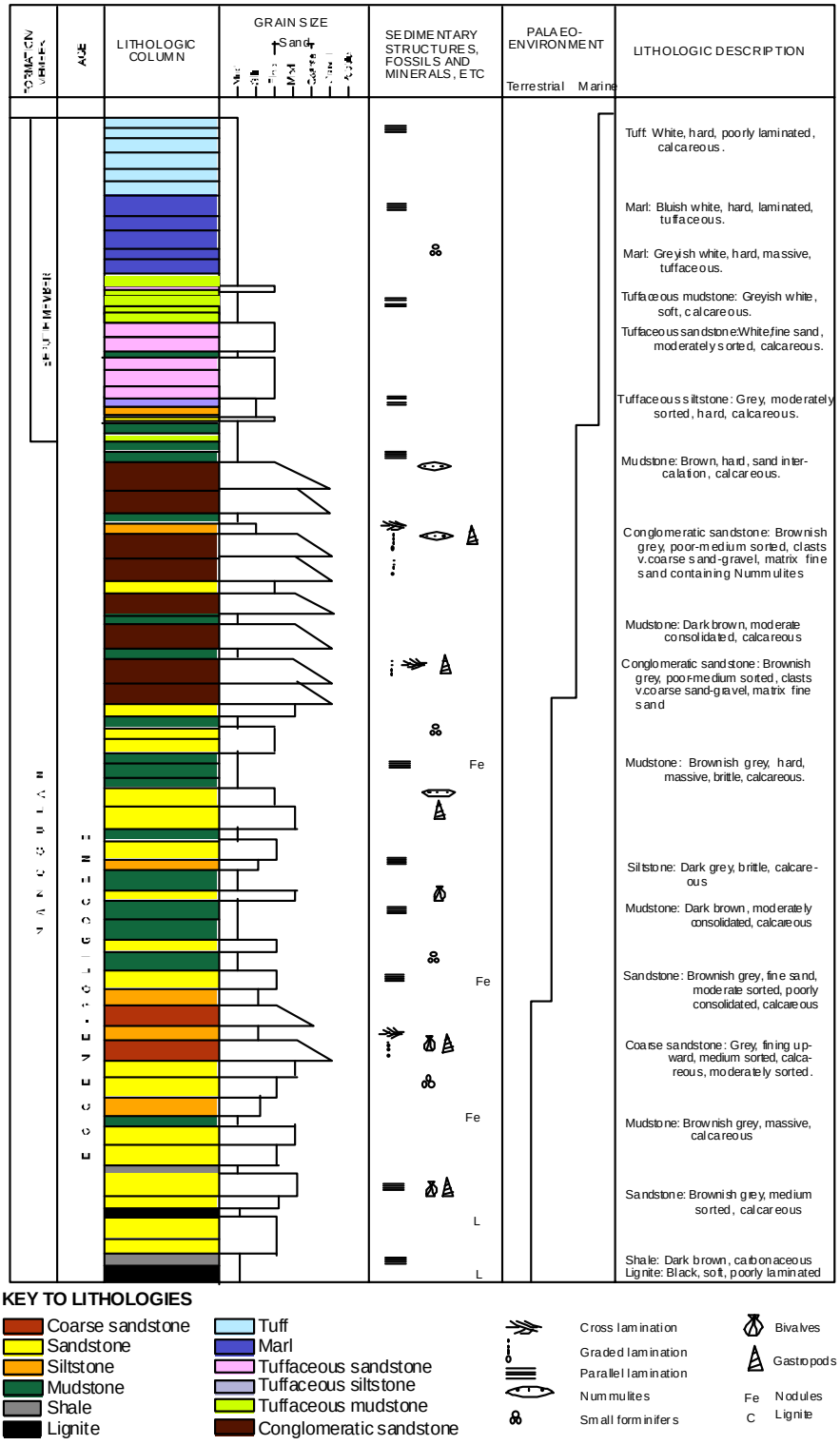

Fig. 2 Lithological column of the Naggulan formation (unscaled).

A clear relationship between climatic and sea level changes with vegetation changes is shown by pollen evidence deriving from a deep marine Holocene core of Lombok Ridge of South Sumbawa which was constructed by van der Kaas, 1991 [11]. The glacial climates/low sea levels were very dry which were characterised by the abundance of the Gramineae pollen, but low representation of coastal plant and mangrove palynomorphs. These dry climates were reflected by the period of widespread savanna vegetation. On the other hand, the interglacial climates/ high sea levels were moderately moist which were indicated by the increase of coastal plant and mangrove pollen, but great reduction of Gramineae pollen reflecting periods of forest and mangrove swamp expansion during wetter climate [11].

3. Result and Discussion

As Indian micro-continent arrived at Asia in Middle Eocene, many Indian affinity migrated to Southeast Asia [12]. This might happen due to the occurrence of land connection and the experience of similar climate between two continents. In addition, previous study by Morley (2000) indicated the distribution of Indian pollen of *Palmaepollenites kutchensis* which covers India and western Indonesia suggesting land connection between these areas during Middle Eocene [6]. This pollen abundantly appears in the Nanggulan Formation representing well development of tropical rain forest under warm climate influence during Middle Eocene (Fig. 3). Approximately 300 different species were found in this study. Most of key fossils have Indian affinity including aff. *Beaupreadites matsuokae*, *Ruellia* type, *Polygalacidites clarus*, *Ixonanthes*, *Cupanieidites* cf. *C. flaccidiformis* and *Cicatricososporites eocenicus* (Fig. 4). The occurrence of these pollen defines the age of Eocene [6].

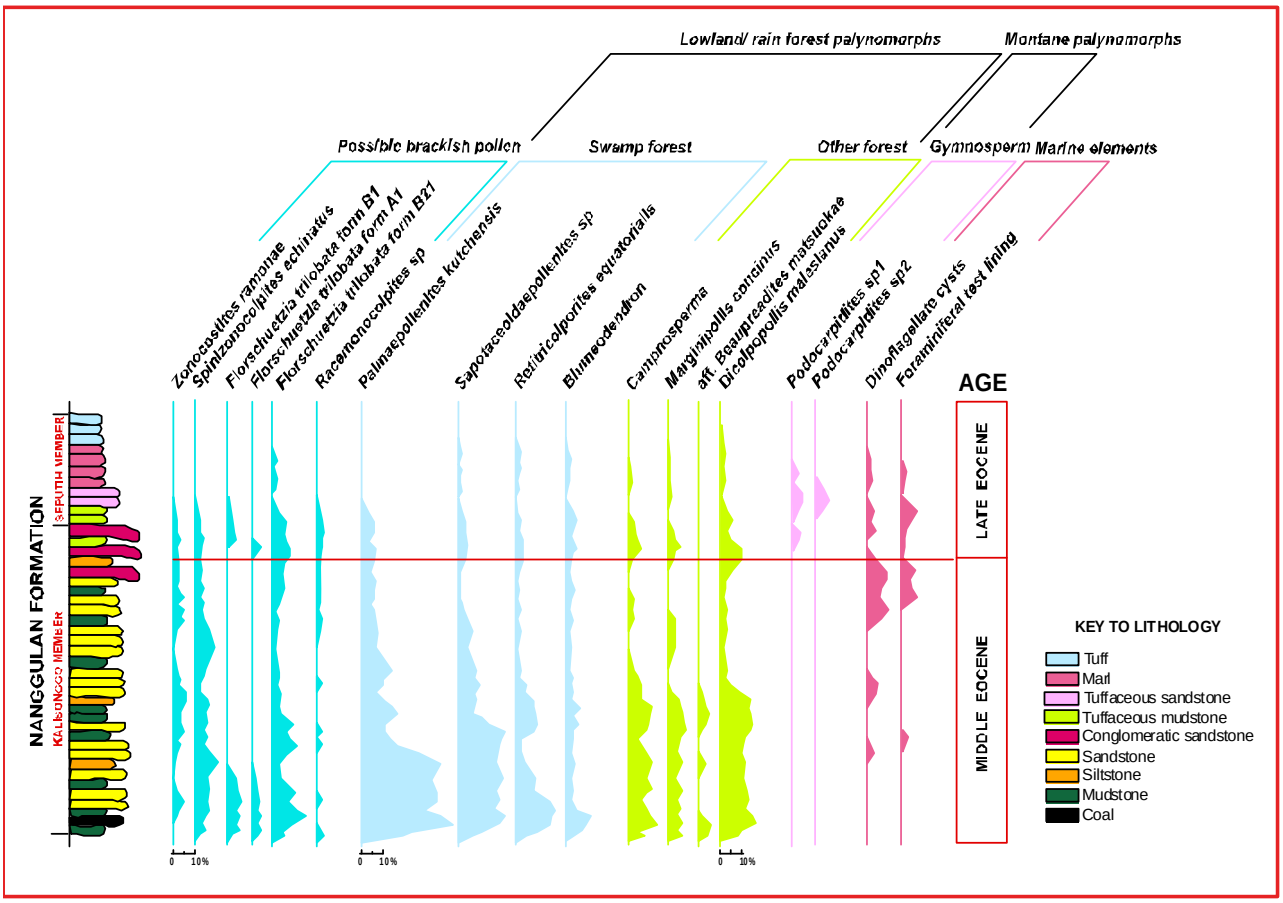

Fig. 3 Pollen record from middle to late Eocene Nanggulan Formation of Central Java.

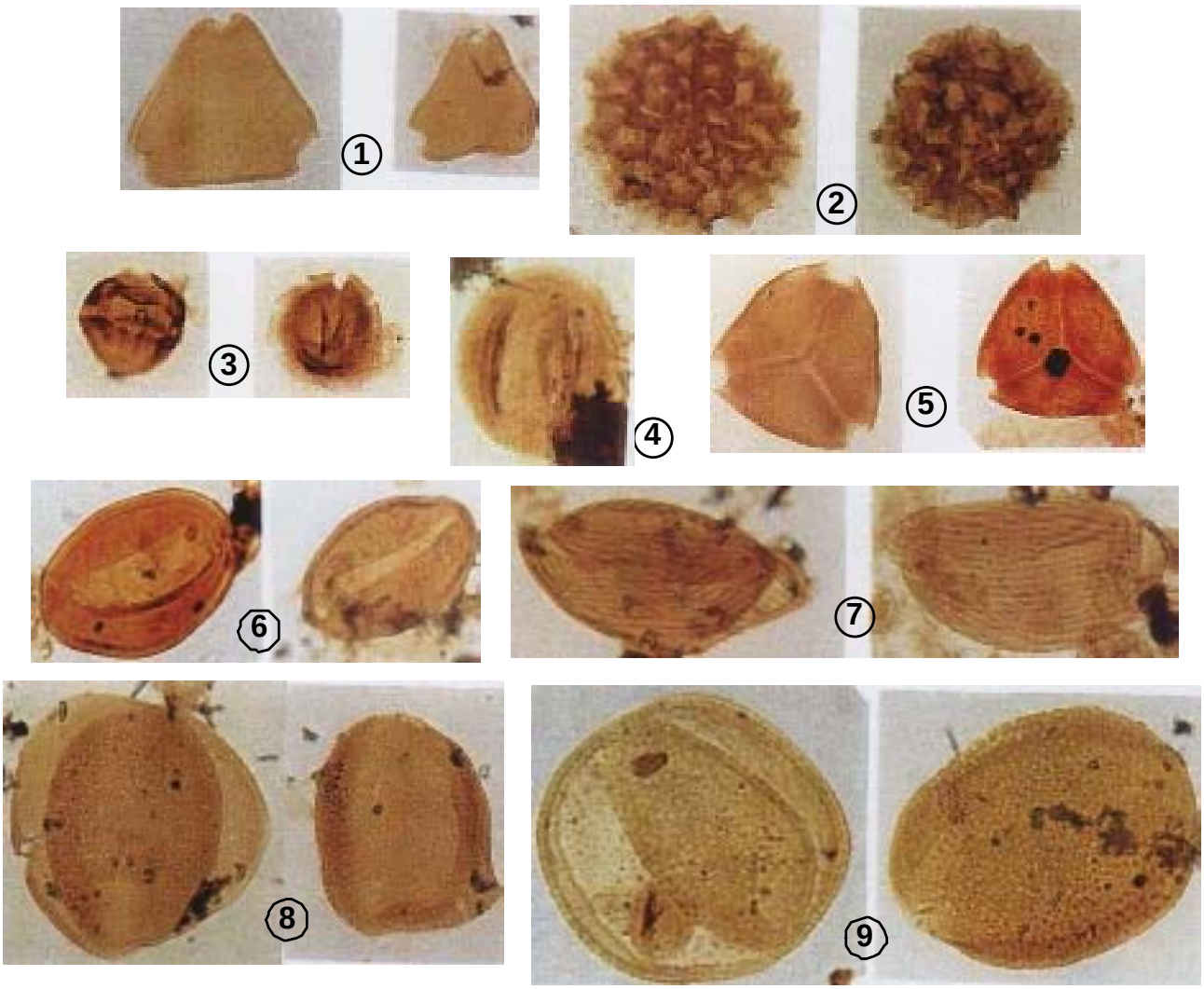

Fig. 4 Key palynomorphs to designate the Eocene age. All taxa are 1000×. (1) aff. Beaupreadites matsuokae; (2) Ruellia type; (3) Polygalacidites clarus; (4) Ixonanthes type; (5) Cupanieidites cf. flaccidiformis; (6) Palmaepolienites kutchensis; (7) Cicatricososporites eocenicus; (8) Proxapertites operculatus; (9) Proxapertites cursus.

The Middle Eocene Nanggulan Formation is characterised by high abundance and diversity of palynomorphs especially those representing the elements of lowland/ rain forest such as *Palmaepollenites kutchensis*, *Sapotaceoidaepollenites* spp., *Retitricolporites equatorialis*, *Blumeodendron* (swamp forest), *Campnosperma*, *Marginipollis concinus*, aff. *Beaupreadites matsuokae* and *Dicolpopollis malesianus* (other forest) as shown in Fig. 5. In addition, Eocene markers with Indian affinity are abundant throughout the Middle Eocene section. In fact, high abundance of lowland/ rain forest palynomorphs combined with abundance of Indian pollen mark the Middle Eocene age [6]. The wet climate indicators appear in high abundance suggesting wet climate condition. These pollen include *Sapotaceoidaepollenites* spp., *Rettricolporites equatorialis*, *Blumeodendron*, *Campnosperma* and *Dicolpopollis malesianus* (Fig. 5). Based on the above data, it is inferred that Middle Eocene age is characterized by well development of lowland/ rain forest under the wet climate influence. On the other hand, the abundance and diversity of palynomorphs significantly decrease toward the Late Eocene age including those of Indian affinity. The Middle/ Late Eocene boundary is defined on the basis of two

phenomenon. Firstly, the first occurrence of hinterland element of *Podocarpidites* spp. [13]. This gymnosperm pollen appears regularly along the Late Eocene. Secondly, the dramatic decline of Eocene markers [14].

Unlike the Middle Eocene with high occurrence of tropical rain forest elements, the Late Eocene Nanggulan Formation is characterized by low occurrence of these elements. It is also marked by the decrease of wet climate markers including *Sapotaceoidaepollenites* spp., *Rettricolporites equatorialis*, *Blumeodendron*, *Campnosperma* and *Dicolpopollis malesianus* (Fig. 3). The number of pollen per gram of sample decreases significantly, whilst the diversity of pollen remains stable (Fig. 6). On the contrary, cool/dry climate indicator of *Podocarpidites* spp. commonly appears along the Late Eocene succession. These facts suggest the occurrence of dry climate which reduces lowland forest. Moreover, similar situation occurs in the Late Eocene Toraja Formation of South Sulawesi, in which many Middle Eocene markers disappear from this formation [14]. The number of lowland/rain forest drops dramatically. About 120 different palynomorphs were extracted from the Toraja Formation compared to 300 palynomorphs of the Nanggulan Formation. Interestingly, grass pollen of *Monoporites annulatus* and *M. punctulosus* indicating dry climate are found throughout this formation (Fig. 7). Another grass pollen of *Restioniidites punctulosus* was reported to significantly occur in the Late Eocene sediment of Makassar Strait as shown in Fig. 8 [15]. This sediment showed low assemblage of rain forest palynomorphs indicating dry climate condition.

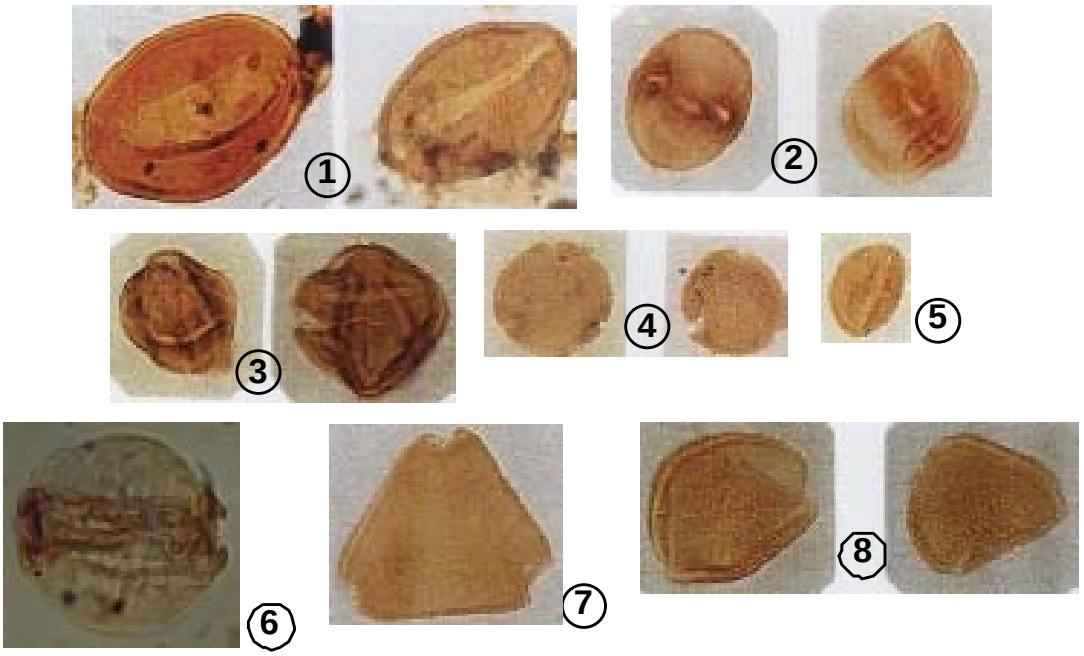

Fig. 5 Some palynomorphs represent lowland/rain forest elements and wet climate indicators. All taxa are 1000×. (1) Palmaepollenites kutchensis; (2) Sapotaceoidaepollenites spp.; (3) Retiricolporites equatorialis; (4) Blumeodendron; (5) Campnosperma; (6) Marginipollis concinus; (7) aff. Beaupreadites matsuokae; (8) Dicolpopollis malesianus.

After all, it can be interpreted that Middle Eocene was represented by warm/wet climate, whilst Late Eocene indicated cool/dry climate. The boundary of Middle/Late Eocene is defined by first occurrence of cool climate indicator of *Podocarpidites* spp. indicating cooling event. The cooling period dominated Late Eocene as proved by significant decrease of rain forest element, but common occurrence of Gramineae pollen reflecting the period of widespread savanna vegetation.

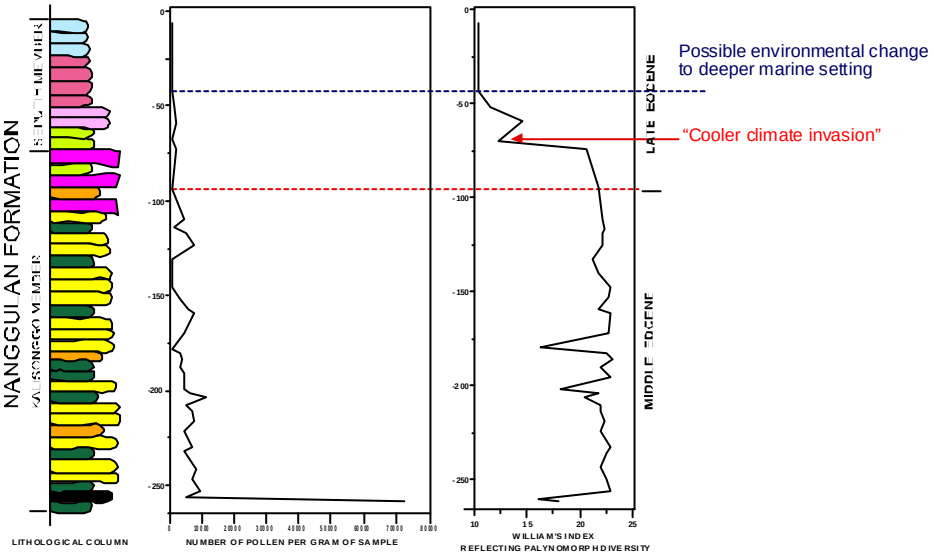

Fig. 6 The occurrence of cooler climate in Late Eocene as indicated by dramatic decrease of abundance and diversity of palynomorphs.

Fig. 7 Cool/dry climate indicators which commonly occur in the Late Eocene. All taxa are 1000×. (1) Podocarpidites spp.; (2) Restioniidites ounctulosus.

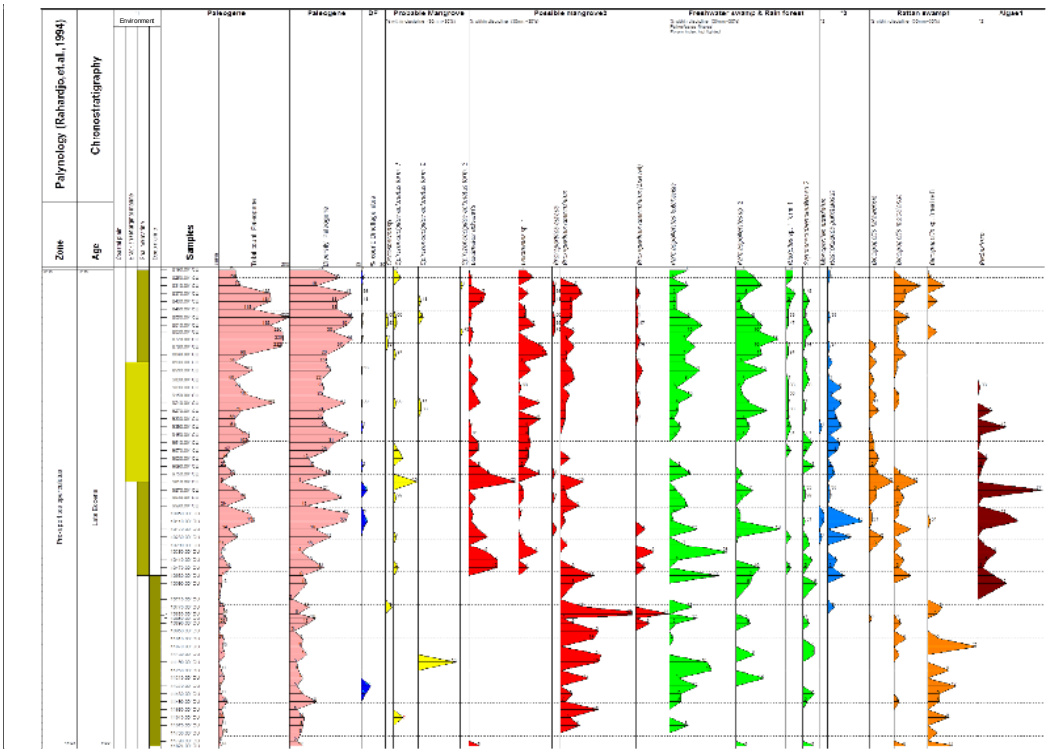

Fig. 8 Polen record from the Late Eocene section of Makassar Strait showing common grass pollen Restoniidites punctulosus (blue color) indicating dry climate condition.

4. Conclusion

This paper figures out Eocene paleoclimate occurring in Java based on palynomorphs which were obtained from the Nanggulan Formation of Central Java. This is supported by the appearance of climate indicators in the Toraja Formation of South Sulawesi and in the Late Eocene section of Makassar Strait. Middle Eocene was very wet as characterized by high abundance of lowland forest palynomorphs reflecting forest expansion. On the contrary, Late Eocene was dry as suggested by the abundance of the Gramineae pollen, but low representation of lowland forest palynomorphs. The first occurrence of hinterland pollen within the Middle/Late Eocene boundary confirms the commencement of cooling event which persists along Late Eocene.

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