EOCENE-OLIGOCENE CLIMATE BASED ON PALYNOLOGICAL RECORDS

by
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I. INTRODUCTION

This study is a part of the investigation on Tertiary paleoclimate conducted by LEMIGAS Stratigraphy Group. The paleoclimate reconstruction covers most area of western Indonesia including South Sumatra Basin, Sunda-Asri Basin, Northeast Java Basin South Kalimantan and Northeast Java Basin, West Natuna and South Sulawesi (Figure 1). This paper is aimed to figure out the regional paleoclimate of western Indonesia which occurred during Eocene-Oligocene. In fact, the knowledge of paleoclimate is useful to define sea level changes which are believed to have relationship with stratigraphy and sedimentology of these areas.

The paleoclimate interpretation can be approached using different tools such as biostratigraphy and geochemistry. In this study, paleoclimate is interpretated based on biostratigraphy (microfossil evidences) including palynomorph and foraminifer. Palynomorphs were mainly applied on the non-marine to transitional sections, whilst foraminifers were used in interpreting shallow to deep marine sediments. In fact, most interpretations rely on palynological evidences as these simply provide suitable data for paleoclimate analysis. In case of both microfossils appear in the same section, the paleoclimate interpretation based on palynomorph can be placed in a certain stratigraphic level which is defined based on the occurrence of the age-restricted foraminifer.

The paleoclimate interpretation of certain stratigraphic level is based on the compilation of palynological and foraminiferal data deriving from different areas. This method is used to obtain representative picture of paleoclimate which occurs in the selected stratigraphic range of the western Indonesia.

II. DATA AVAILABILITY

Data obtained from the area of study was generated from two types of the samples. Firstly, subsurface (well) samples were provided by oil companies which are then considered as confidential data. Secondly, surface samples were mostly collected by LEMIGAS for its in-house research. The later are public domain which need not permission for publications.

It must be noted that this study only refers to the existing palynological and foraminiferal data produced by LEMIGAS and other service companies. This study does not involve re-analysing new samples from the studied areas.

LEMIGAS possesses a large number of biostratigraphic data covering the studied basins (Figure 1). However, data with complete stratigraphic range is actually restricted. Therefore, it is needed to search some decent data to gain accurate interpretation. In addition, LEMIGAS data is mostly concentrated on marine microfossil analysis. On the other hand, palynological data for Paleogene non-marine succession is limited. Having these situations, the author looked for the required data from other sources such as publications which include Paleogene palynology. For the purpose of confidentiality, this paper does not reveal detail information of the data (such as well name, well location, operator, etc) as this data belongs to the LEMIGAS's client.

III. METHOD

Astronomically driven climatic changes have resulted in the successive sequestration of seawater into polar ice caps since the Oligocene or Late Eocene (Abreu and Anderson, 1978) and probably account for most eustatic change over this period (Morley, 2003). 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

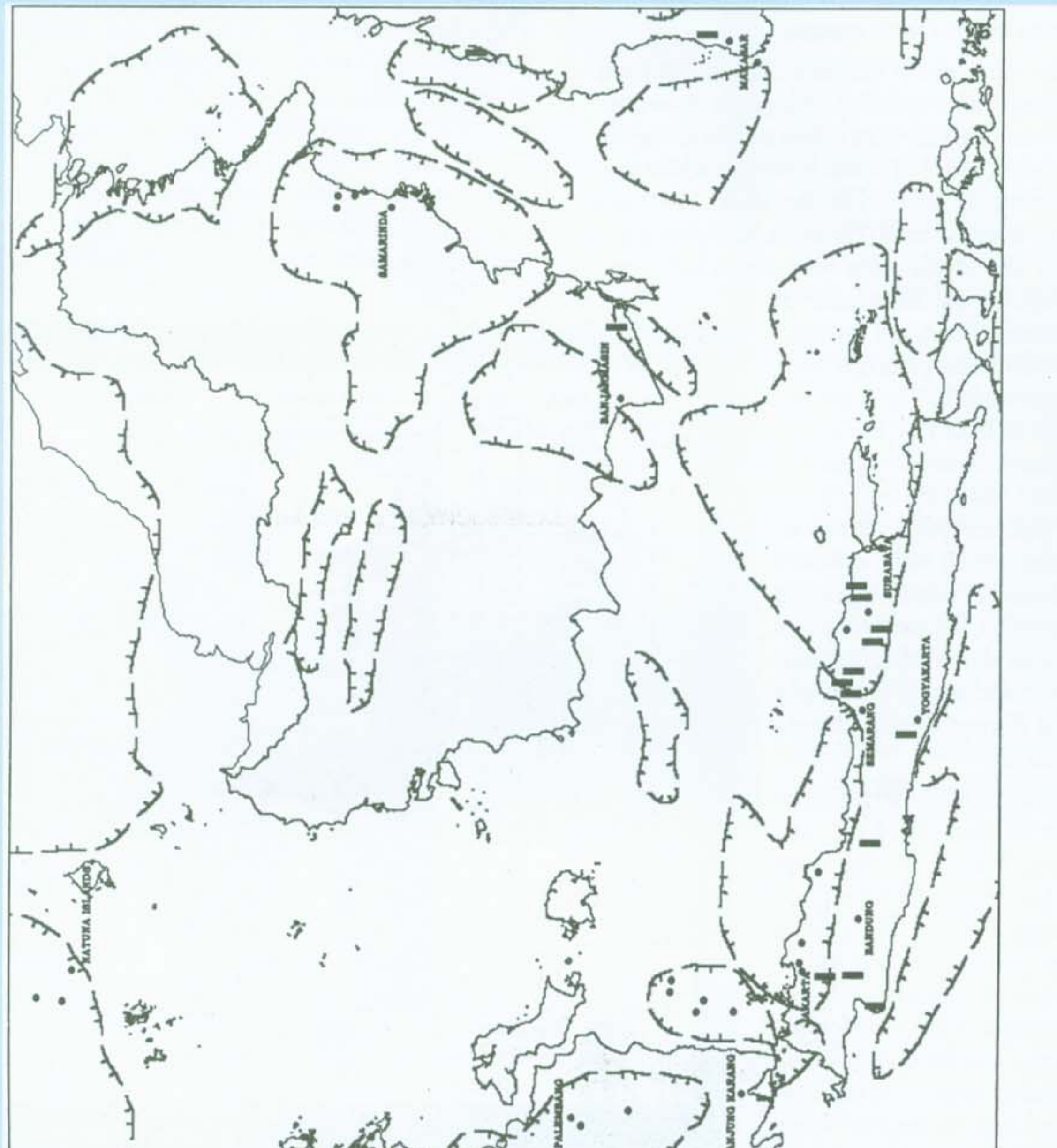

Figure 1
The locations of data collection

(LGM), with reductions of 4° – 6° C (Morley, 2000). Therefore, fossil evidence for climatic change provides a proxy for sea level change.

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 originally constructed by van der Kaas, 1991 and modified by Morley, 2003 (Figure 2). 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 (Morley, 2003).

The changes of global temperature cause the changes of seawater temperature. For the marine zooplankton, for instance foraminifer, these changes affect the size or mean diameter of *Orbulina*, the ratio between *Globigerinoides* or *Globoquadrina* with *Globigerina* assemblages, and the coiling direction of a certain species. In addition, the fluctuation of temperature stimulates precipitation or dissolution of $CaCO_3$ in the marine sediment (Soeka et al., 1994).

IV. PALEOCLIMATE INTERPRETATION

A. *Eocene paleoclimate*

The tectonic setting of western Indonesia during Eocene is shown in Figure 3. The distribution of Indian pollen of *Palmaepollenites kutchensis* which covers India and west Indonesia suggesting land connection between these areas during Middle Eocene (Figure 3). Middle Eocene Nanggulan Formation is characterised by high abundance and diversity of palynomorphs. On the other hand, Late Eocene Toraja Formation shows significant decrease of palynological assemblage. In addition, Middle Eocene Nanggulan Formation approximately consists of 300 palynomorphs, whilst Late Eocene Toraja Formation only yields 120 different palynomorphs. More over, many index pollen characterising the Middle Eocene

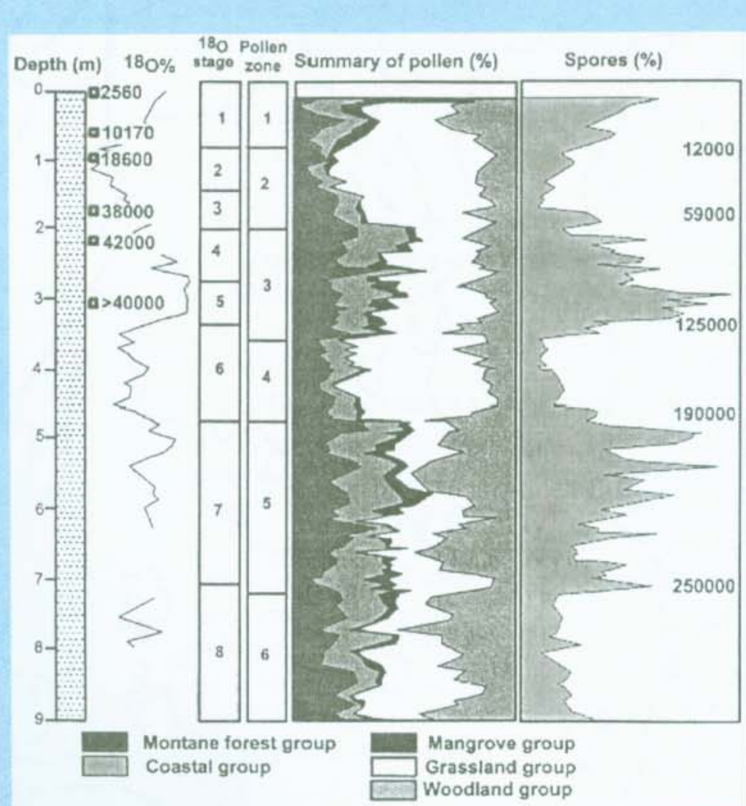

Figure 2
Summary of pollen diagram from a deep marine core of Lombok Ridge, South of Sumbawa, modified from van der Kaas (1991). 'Glacial' climates, coinciding with oxygen isotope stages 2+3, 6 and 8 are characterised by abundant Gramineae pollen, but low representation of pollen of coastal plants, mangroves and fern spores, reflecting periods of widespread savanna vegetation. 'Interglacial' climates coinciding with oxygen isotope stages 4+5 and 7 are characterised by abundant pteridophyte spores, and increased pollen of coastal plants, and mangroves, but greatly reduced frequencies of Gramineae pollen, reflecting periods of forest and mangrove swamp expansion during periods of wetter climates. Dates to left of diagram are radiocarbon dates, whereas those to the right refer to oxygen isotope stage boundaries; note older radiocarbon dates are likely to be significantly underestimated (taken from Morley *et al.*, 2003)

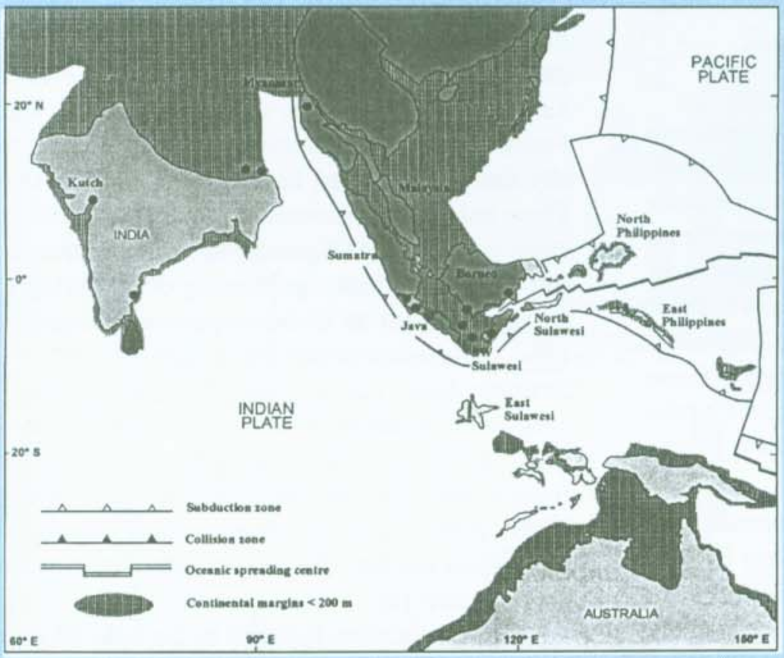

Figure 3
The distribution of Indian pollen of *Palmaepollenites kutchensis* during Middle to Late Eocene in western Indonesia. (Paleogeography of the SE Asian and Australian regions at about 40 Ma is reconstructed by Hall, 1998 whilst geographical distribution of *Palmaepollenites kutchensis* (black circles) is taken from Harley & Morley, 1995)

Nanggulan Formation disappear from the studied sections of the Toraja Formation such as aff. *Beaupreadites matsuokae*, *Ruellia* type, *Polygalacidites clarus*, *Ixonanthes*, *Cupanieidites* cf. *C. flaccidiformis*, *Cicatricosisporites eocenicus*. This indicates that the Toraja Formation is stratigraphicaly younger than the Nanggulan Formation.Therefore, it is concluded that the Nanggulan Formation is assigned to Middle Eocene age, whilst the Toraja Formation is interpreted to be Late Eocene age. However, the upper part of the Nanggulan Formation can be attributed to the Late Eocene age.

Generally, both Nanggulan and Toraja Formations contain high abundance and diversity of tropical rainforest palynomorphs such as *Palmaepollenites kutchensis*, *Palmaepollenites* spp., *Sapotaceoidaepollenites* spp., *Rettricolporites equatorialis*, *Blumeodendron*, *Campnosperma*, *Marginipollis concinus* and *Dicolpopollis malesianus* (Figures 4 and 5). This situation suggests well development of rain-forest vegetation under humid condition during Middle to Late Eocene. The Middle Eocene Nanggulan Formation is indicated by high abundance and diversity of low land rain-forest elements suggesting wet climate (Figure 4). The wet climate condition is represented by high abundance of wet climate indicators such as *Sapotaceoidaepollenites* spp., *Rettricolporites equatorialis*, *Blumeodendron*, *Campnosperma* and *Dicolpopollis malesianus* (Figure 4). On the contrary, the upper Eocene Nanggulan Formation is marked by the decrease of wet climate markers including *Sapotaceoidaepollenites* spp., *Rettricolporites equatorialis*, *Blumeodendron*, *Campnosperma* and *Dicolpopollis malesianus* (Figure 4). More over, it is also indicated by the significant appearance of dry climate elements such as *Podocarpidites* spp. (Figure 4). These evidences suggest the influence of drier climate during Late Eocene compared to that of Middle Eocene. Similar situation occurs in the Late Eocene Toraja Formation of South Sulawesi, in which wet climate indicators shows low abundance and diversity such as *Lakiapollis ovatus*, *Malvacipollis diversus*, *Sapotaceoidaepollenites* spp. and *Stemonurus* type (Figure 5). In addition, the dry climate element appears within the Late Eocene Toraja Formation as shown by the existence of *Monoporites punctatus* (Graminae; Figure 5).

The paleoenvironment of the Middle to Late Eocene succession is depicted in Figure 6. It shows well development of low land vegetation during Middle Eocene. On the other hand, low land area gradually decreased toward Late Eocene which was then replaced by hinterland (Figure 6).

Overall, it can be concluded that the Eocene climate varied from wet climate in Middle Eocene to dry climate in Late Eocene. The appearance of dry climate in Late Eocene might be influenced by the global event, so called "terminal Eocene cooling" as

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occurred in West and Central Europe (Collinson, 1992), North America (Wolfe, 1992) and Central America (Graham, 1994).

B. *Oligocene paleoclimate*

Generally, the Oligocene successions are characterised by the decrease of palynological assemblages compared to those of the Eocene sediments. Many Eocene palynomorphs disappear from the Oligocene sections. Although, the geographical position of Southeast Asia during Oligocene was about the same as that in Middle-Late Eocene (Figure 7), in fact, everwet climate locally developed across Southeast Asia during Oligocene as indicated by the restricted occurrence of tropical rain-forest in this area (Figure 8).

In Sunda Sub-basin, the Oligocene sections are indicated by high abundance of fresh-water lake algae of *Pediastrum* suggesting lacustrine environment (Figure 9). The dry climate indicators moderately appear together with this algae including *Monoporites annulatus* (Graminae) and Cyperaceae (Figure 9). The sections with abundant *Pediastrum* may be attributed to Early Oligocene age due to the absence of pollen *Meyeripollis naharkotensis* (Morley, 1991). Mean while, *Pediastrum*, *M. annulatus* and Cyperaceae gradually disappear toward Late Oligocene successions. These palynomorphs were absence during middle to upper parts of Late Oligocene age. On the other hand, wet climate markers significantly occur during Late Oligocene such as *Campnosperma*, *Calophyllum* type, *Sapotaceoidaepollenites* spp. and *Striatricolpites catatumbus*. These evidences suggest wetter climate than that of Early Oligocene age. This interpretation is supported by the increase of marine and brackish indicators such as Dinoflagellates, *Zonocostites ramonae* and *Discoidites borneensis* marking the occurrence of marine influence (Figure 10).

Similar situation is found in the Late Oligocene sections of Northwest Java-Basin where fresh wa-

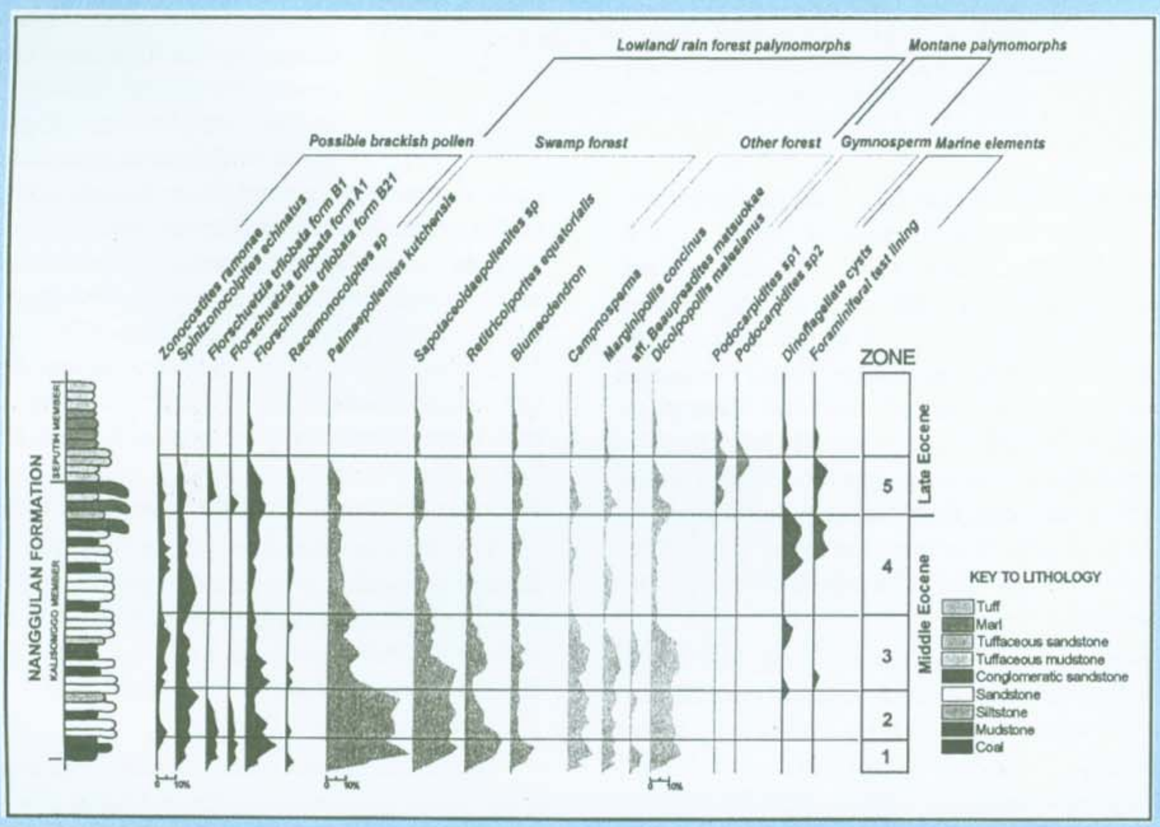

Figure 4
Pollen record from Middle to Late Eocene Nanggulan Formation of Central Java

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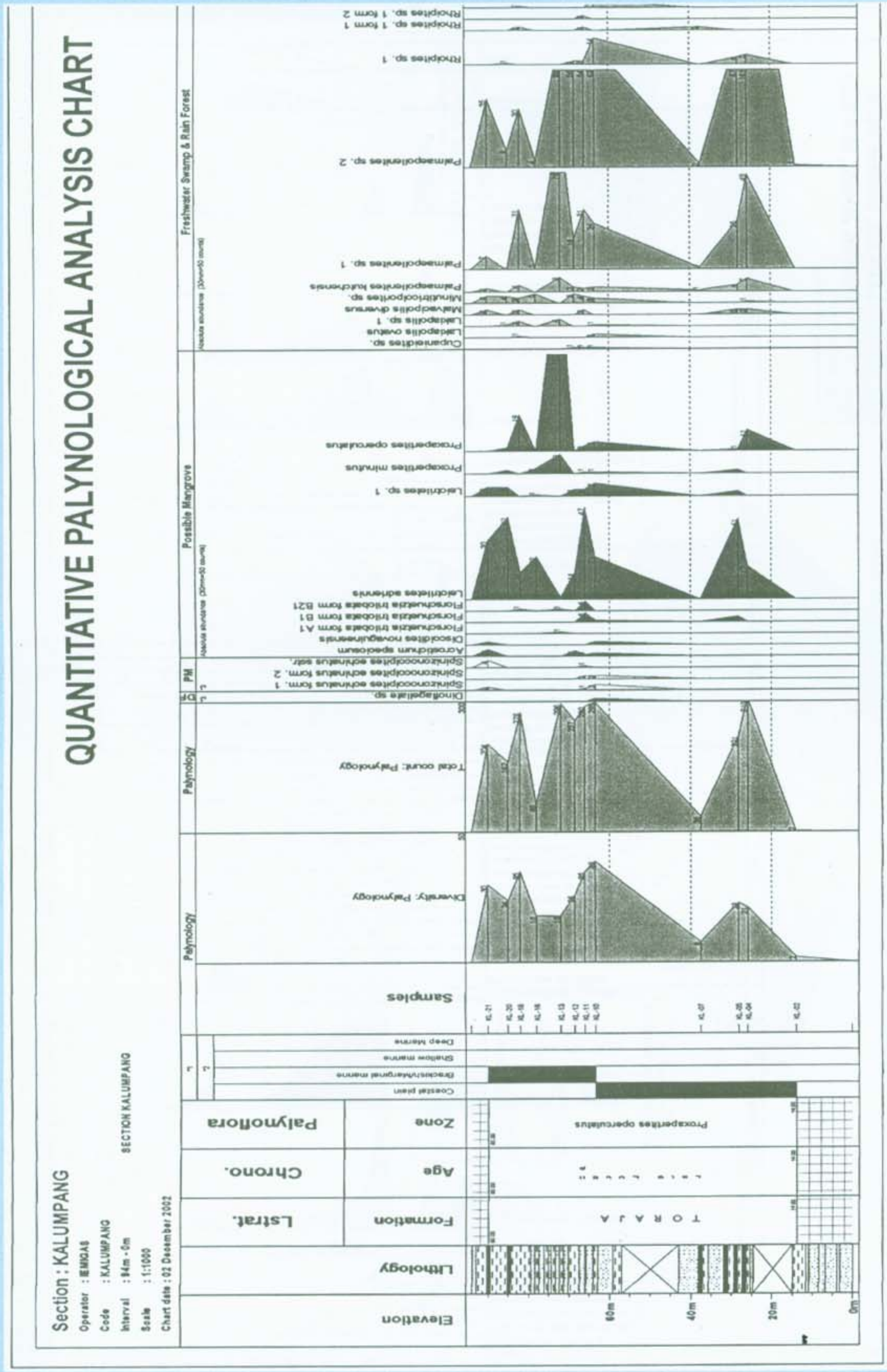

Figure 5
Pollen diagram from the Kalumpang section shows the polynomorph assemblage existing in the Toraja of South Sulawesi

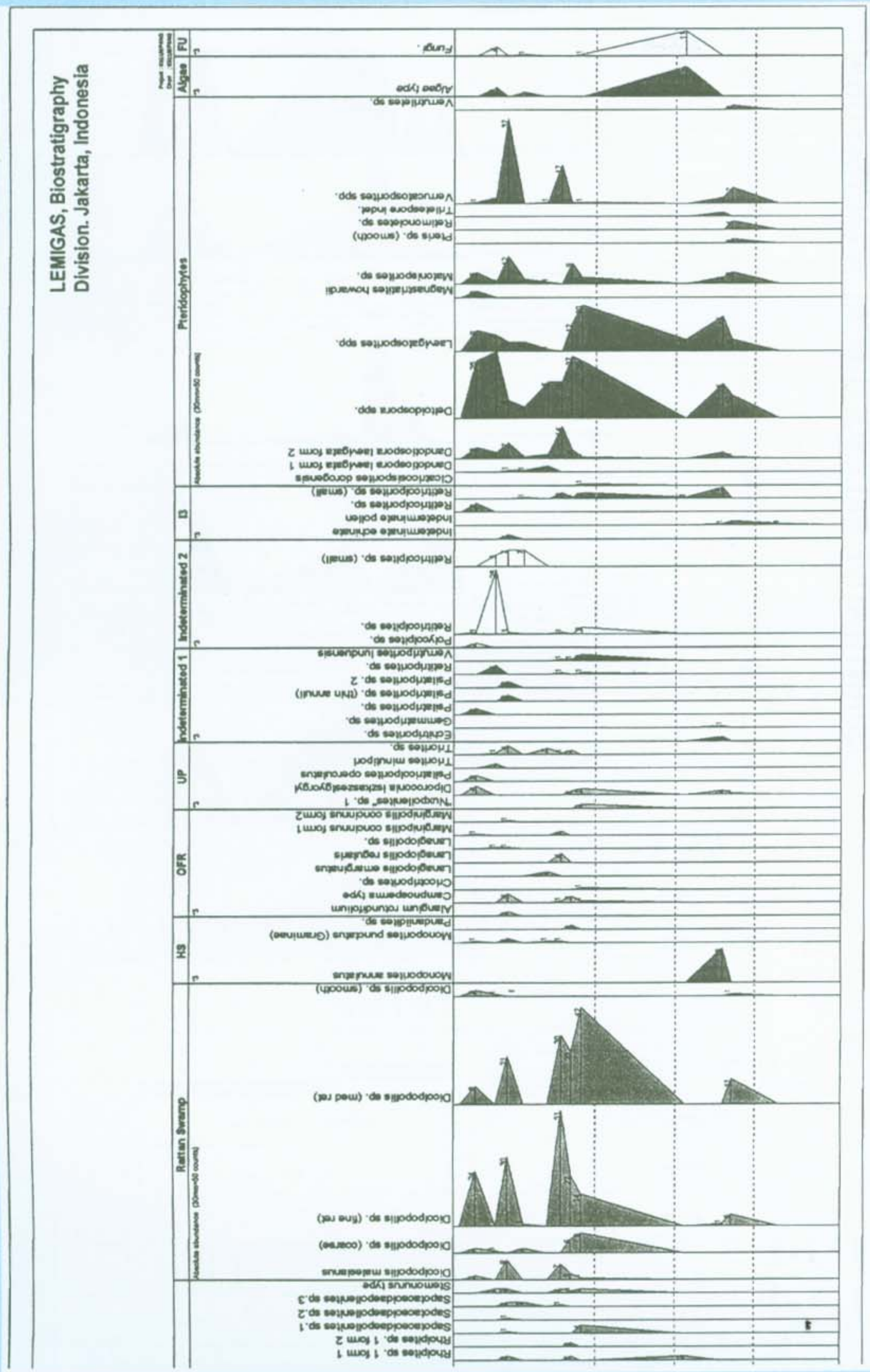

Figure 5
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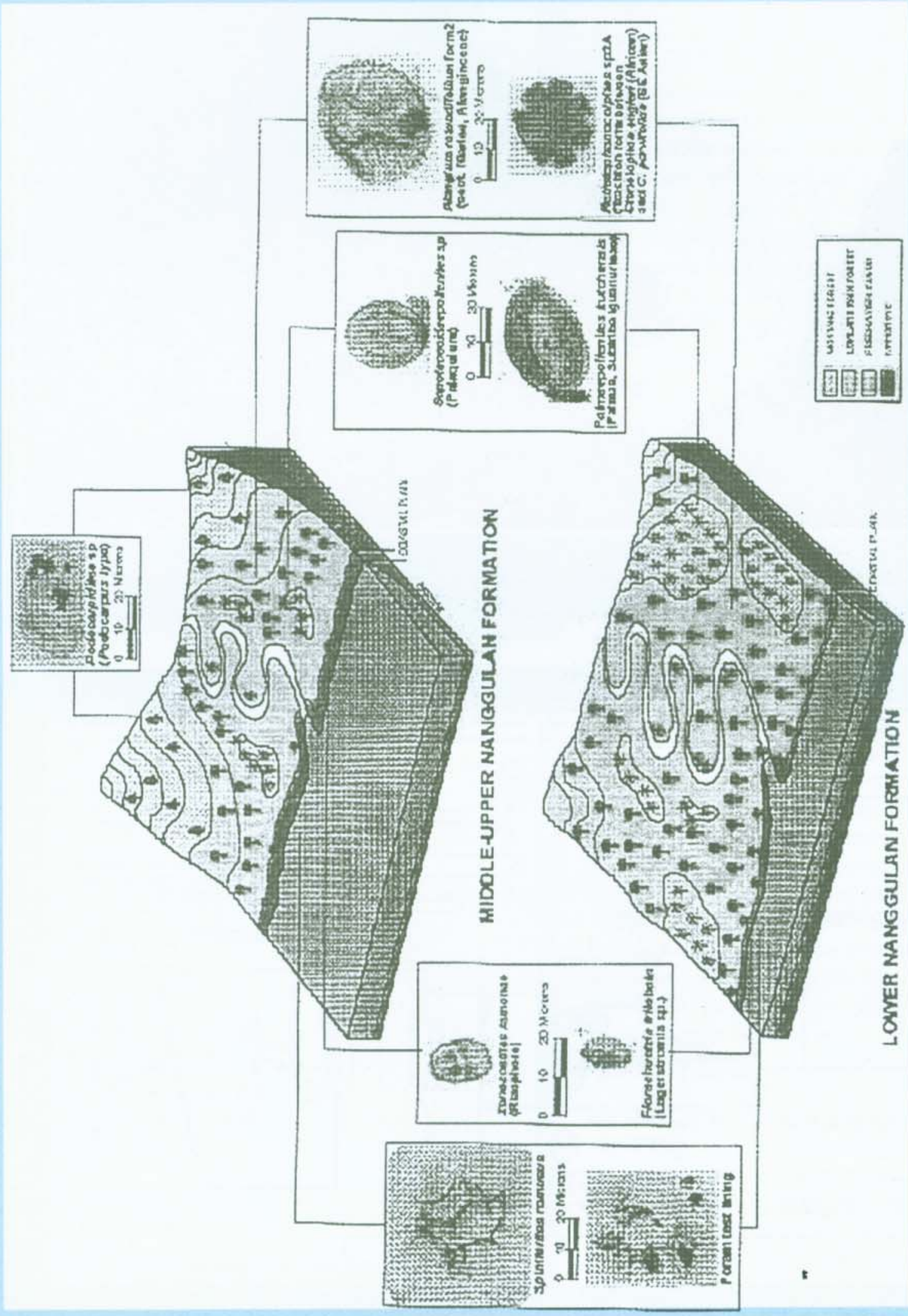

Figure 6
Palaeoenvironment reconstruction of the Middle to Late Eocene Nanggulan Formation

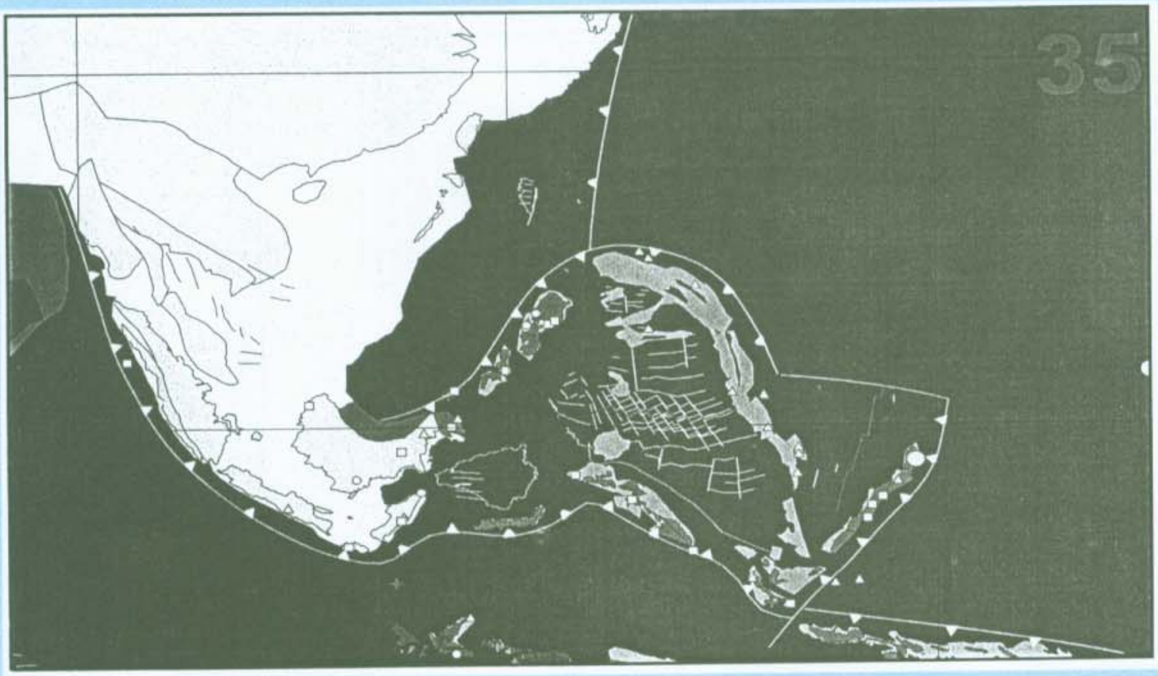

Figure 7
Oligocene plate tectonic setting and paleogeography of SE Asia and East Pacific (Hall, 2002)

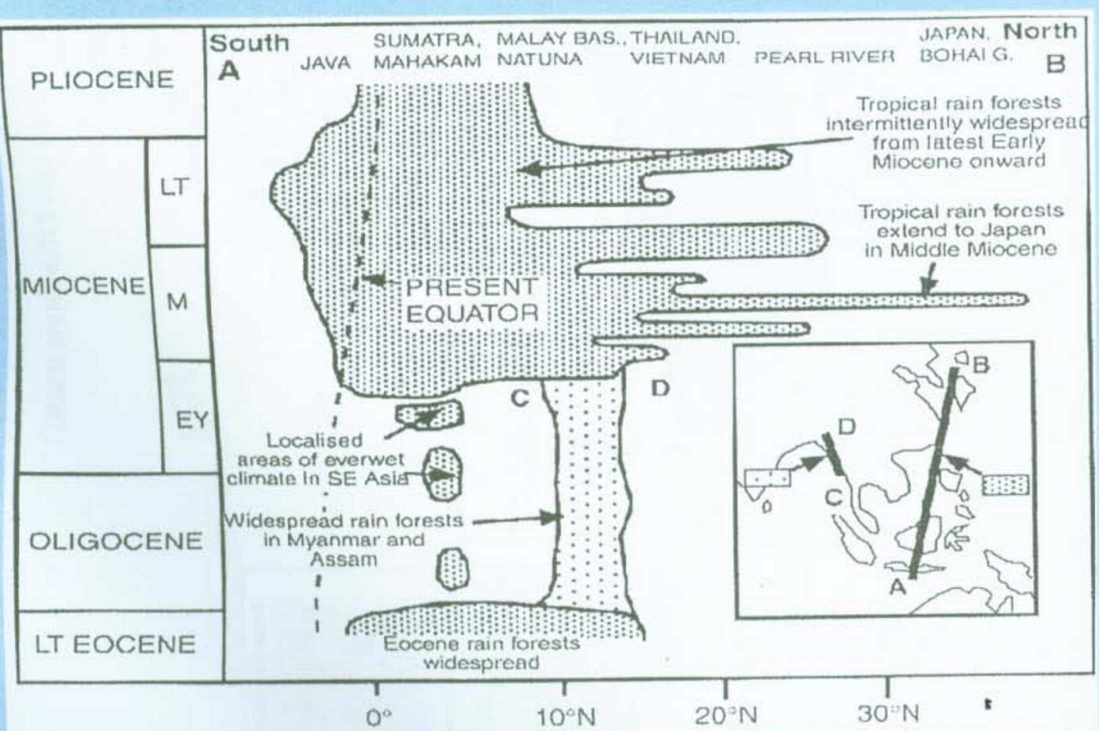

Figure 8
The distribution of tropical rain forest during Late Eocene to Pliocene (Morley, 2000)

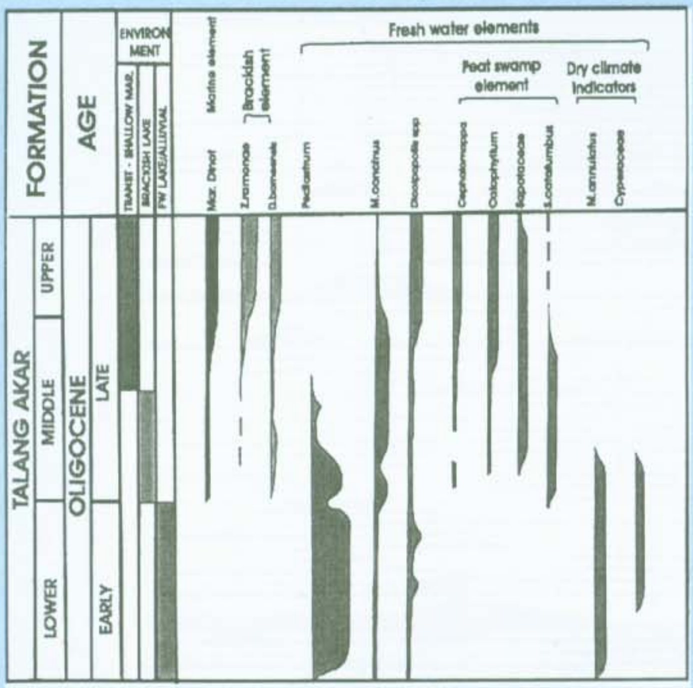

Figure 9
The summary of the palynological record of the Sunda Sub-basin

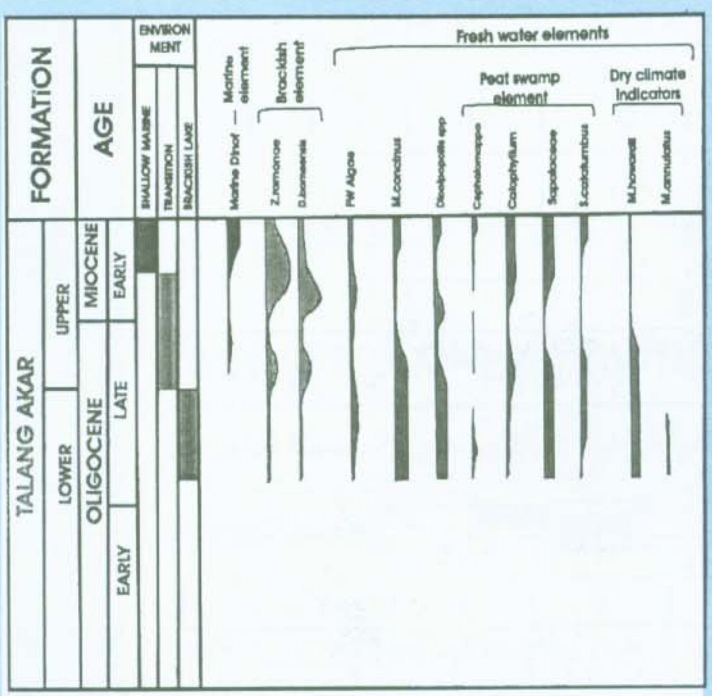

Figure 10
The summary of the palynological record of the Asri Sub-basin

ter and brackish palynomophs are dominant (Figure 11). Lacustrine marker of *Pediastrum* is absent from these sections. In addition, Wet climate indicators are more abundant and diverse than the dry climate elements (Figure 12). It is concluded that the Late Oligocene sediment of Northwest Java Basin was formed under wet climate condition.

In the Natuna Basin, the Oligocene climate varied from dry to wet climate which is characterised by the various abundance of Gramineae along Oligocene section (Figure 13). Gramineae increased significantly during dry climate. On the other hand, this pollen decreased during wet climate (Figure 13). The fresh water algae of *Pediastrum* and *Bosedinia* occurred along the Oligocene succession. These algae tended to be abundant in the dry season, whilst in the wet season they showed some decreases (Figure 13).

Overall, it can be concluded that the Oligocene climate shows some gradation from dry climate in the lower section to wet climate in the upper section.

V. SUMMARY

The Tertiary paleoclimate is interpreted based on longer time scale (possibly second order). Data used for this interpretation consists of palynology and foraminifer. As paleoclimate changes cover large area of western Indonesia, therefore it is used biodata collected from the separate basins which are located within this area. This paper tends to figure out the regional paleoclimate which occurred during Eocene-Oligocene in western Indonesia (Figure 14). The Middle Eocene climate is indicated by high abundance and diversity of low land rain-forest palynomorph suggesting well development of rain-forest vegetation under humid condition. In addition, it is also characterised by high abundance of wet climate element indicating the occurrence of wet climate. On the other hand, the opposite situation appears within the Late Eocene in which, the low land rain-forest

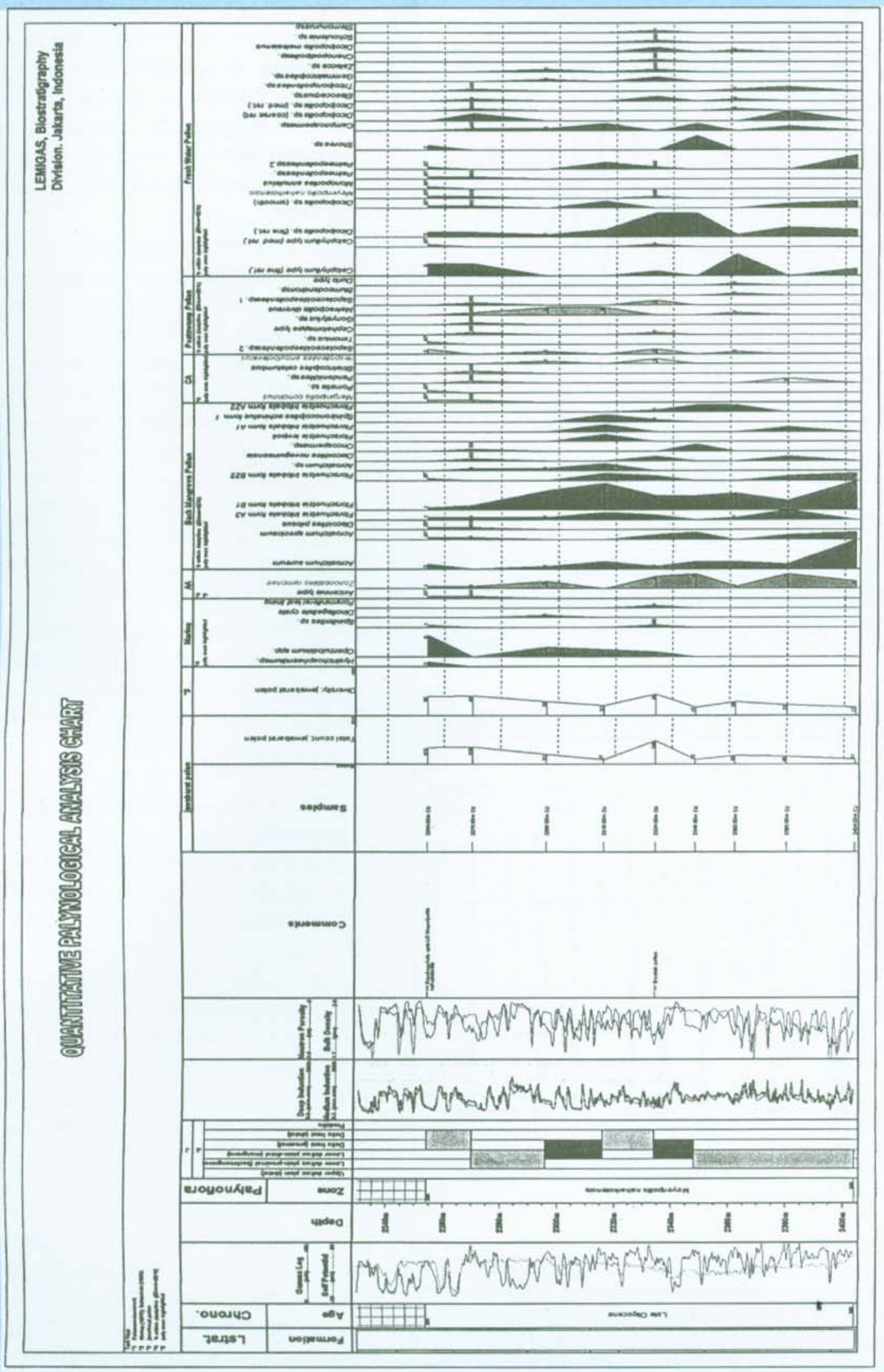

Figure 11
The summary of the palynological record of the Jatibarang Sub-basin

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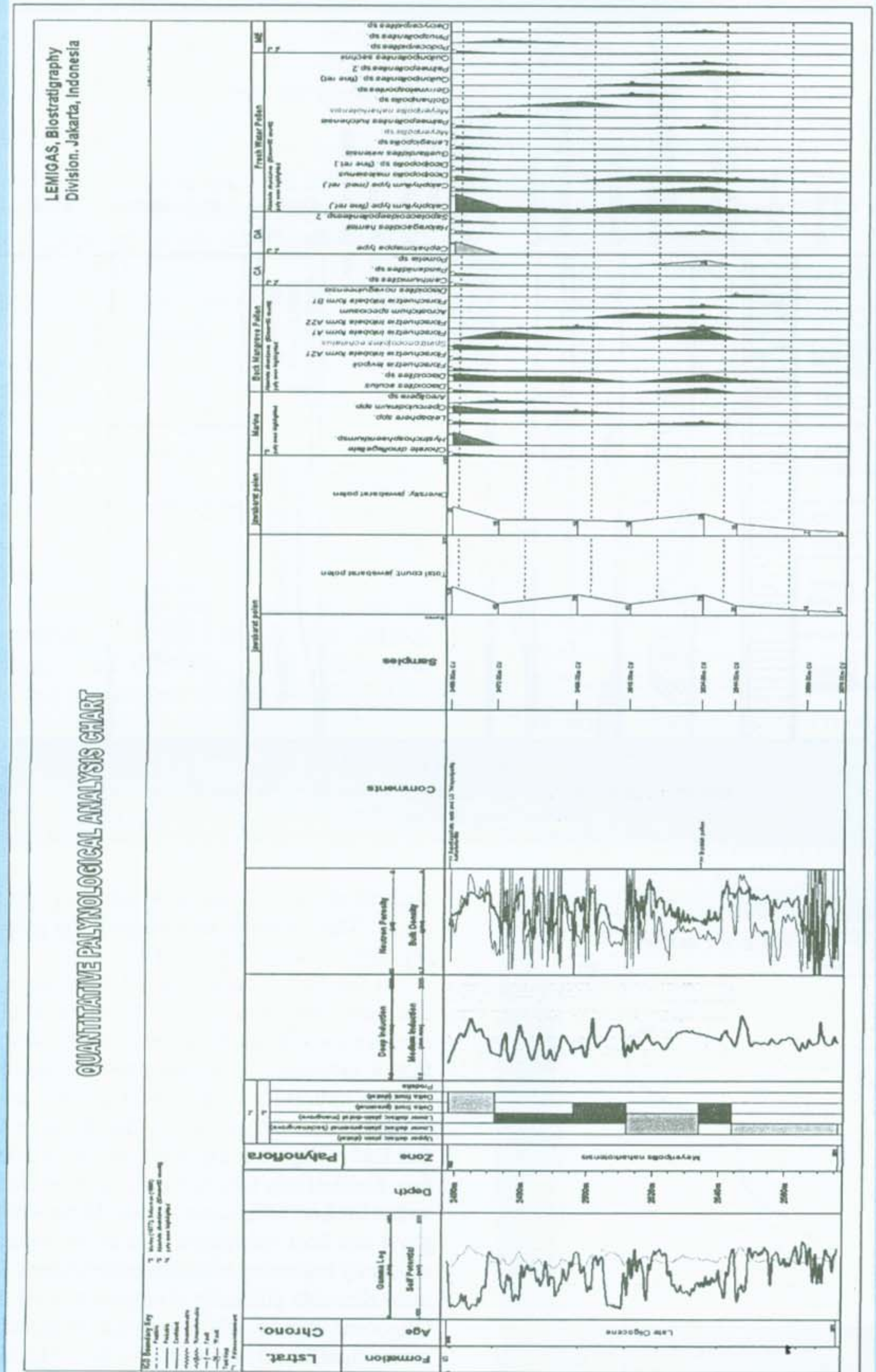

Figure 12
The summary of the palynological record of the Jatibarang Sub-basin

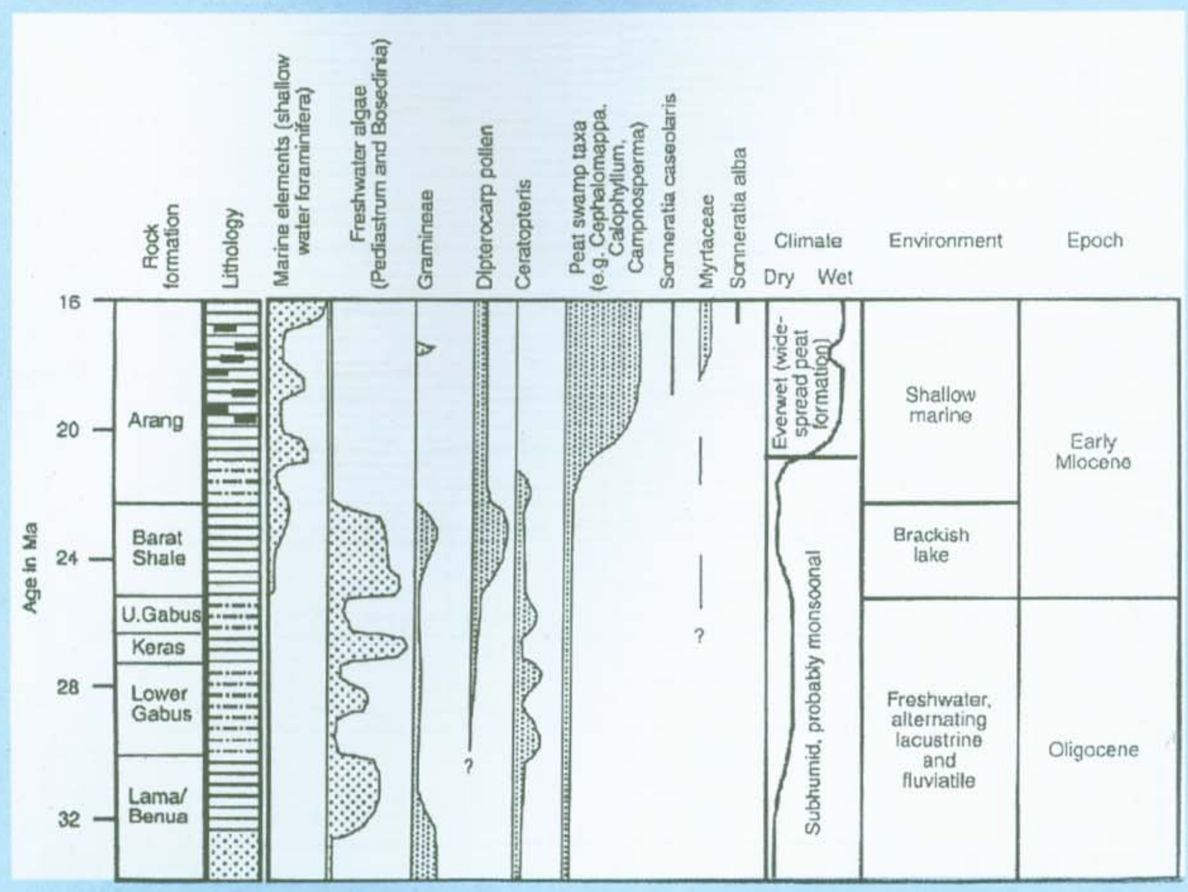

Figure 13
The summary of the palynological record of the West Natuna Basin (taken from Morley, 2000)

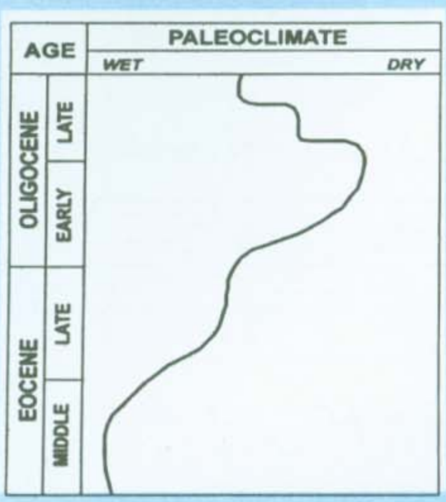

Figure 14
Paleoclimatic curve during Eocene-Oligocene in western Indonesia

element and wet climate indicator decrease significantly. This situation may suggest the presence of dry climate during the Late Eocene.

In Sunda Sub-basin, Early Oligocene is clearly characterised by abundant freshwater algae of *Pediastrum* suggesting lacustrine environment. In fact, it associates with moderate abundance of dry climate indicators such as *Monoporites annulatus* (Gramineae) and *Cyperaceae*. This situation suggests that Early Oligocene experienced dry climate condition. Unlike Early Oligocene, *Pediastrum* disappears within the Late Oligocene section. Mean while, mangrove and back-mangrove vegetations increase significantly indicating brackish environment. Dry climate elements gradually disappear toward the Late Oligocene section, whilst wet climate indicators increase significantly along this section. This situation suggests the existence of wet climate during the Late Oligocene.

VI. ACKNOWLEDGMENT

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REFERENCES

1. Abreu, V. S. and Anderson, J. B., 1998. Glacial Eustasy During The Cenozoic: Sequence Stratigraphic Implications. *The AAPG Bulletin*, 82 (7), pp. 1385 – 1400.
2. Collinson, M. E., 1992. Vegetational And Floristic Changes Around The Eocene/ Oligocene Boundary In Western and Central Europe. In: Prothero, D. R. and Berggren, W. A. (eds.), *Eocene-Oligocene Climatic And Biotic Evolution*, Princeton University Press, pp. 437 – 450.
3. Graham, A., 1994. Neotropical Eocene Coastal Floras and $^{18}O/\ ^{16}O$ – Estimated Warmer Vs. Cooler Equatorial Waters. *American Journal of Botany*, 81 (3), pp. 301 – 306.
4. Hall, R., 1998. The Plate Tectonics of Cenozoic SE Asia and the Distribution of Land and Sea. In: Hall, R. and Holloway, J. (eds.), *Biogeography and Geological Evolution of SE Asia*, Backhys Publishers, Amsterdam, pp. 99 - 132.
5. Hall, R., 2002. Cenozoic Geological and Plate Tectonic Evolution of SE Asia and the SW Pacific: Computer-Based reconstruction, Model and Animations. *Journal of Asian Earth Sciences, Vol. 20, No. 4.*
6. Harley, M. M and Morley, R. J., 1995. Ultrastructural Studies of Some Fossil and Extant Palm Pollen, and the Reconstruction of the Biogeographical History of Substribes Iguanurinae and Calaminae. *Review of Palaeobotany and Palynology*, 85, pp. 153-182.
7. Kaas, W. A. van, 1991a. Palynology Of Eastern Indonesian Marine Piston-Cores: A Late Quaternary Vegetational And Climatic History For Australasia. *Palaeogeography, Palaeo climatology, Palaeoecology*, 85, pp. 239 – 302.
8. LEMIGAS, 1970-2003. *Unpublished Service Reports.*
9. Morley, R. J., 1991. Tertiary Stratigraphic Palynology in Southeast Asia: Current Status and New Directions. *Geol. Soc. Malaysia*, Bulletin 28, pp. 1-36.
10. Morley, R. J., 2000. *Origin and Evolution of Tropical Rain Forests*. Wiley, London.
11. Morley, R. J., Pribatini, H and Restrepo-Pace, P., 2003. Unravelling the Tectonically Controlled Stratigraphy of the West Natuna Basin by Mean of Paleo-Derived Mid Tertiary Climate Changes. *Proceeding Indonesian Petroleum Association*, 29th Annual Convention and Exhibition, Jakarta.
12. Soeka, S., Suhaeli, E. T., Priyomarsono, S., Widiastuti, R. and Aritonang, P. 1994. *Sea Level Changes in East Java Basin*. LEMIGAS internal *report.*
13. Wolfe, J. A., 1994. Tertiary Climatic Changes at Middle Latitudes Of Western North America. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 108, pp. 195 – 205. •