SCIENTIFIC CONTRIBUTIONS OIL AND GAS
Vol. 41, Number 1, April 2018: 2 of 5
RESEARCH AND DEVELOPMENT CENTRE FOR OIL & GAS TECHNOLOGY LEMIGAS
Journal Homepage:http://www.journal.lemigas.esdm.go.id
ISSN: 2089-3361, e-ISSN: 2541-0520

DRY CLIMATE EXPANSION ON THE PLEISTOCENE OF INDONESIA AS RECORDED IN ITS POLLEN ASSEMBLAGE

EKSPANSI IKLIM KERING UMUR PLISTOSEN DI INDONESIA BERDASARKAN KANDUNGAN POLEN

Eko Budi Lelono
"LEMIGAS" R & D Centre for Oil and Gas Technology
Jl. Ciledug Raya, Kav. 109, Cipulir, Kebayoran Lama, P.O. Box 1089/JKT, Jakarta Selatan 12230 INDONESIA
Tromol Pos: 6022/KBYB-Jakarta 12120, Telephone: 62-21-7394422, Faxsimile: 62-21-7246150
Email: ekobl@lemigas.esdm.go.id; E-mail: ekolelono@esdm.go.id

First Registered on November 11st 2017; Received after Correction on December 8th 2017
Publication Approval on: April 30th2018

ABSTRAK

Para peneliti sepakat bahwa Plistosen dicirikan oleh pergantian periode glasiasi dan inter-glasiasi yang berkaitan erat dengan pembentukan iklim kering/ dingin dan iklim basah/ hangat. Pergantian iklim ini terekam pada kandungan polennya. Iklim kering (glasiasi) ditandai dengan melimpahnya polen Gramineae, sedangkan iklim basah (inter-glasiasi) dicirikan oleh peningkatan polen air tawar dan air payau, tetapi penurunan drastis polen Gramineae. Situasi berbeda terjadi di Jawa dengan kelimpahan tinggi polen Gramineae yang mengindikasikan dominasi iklim kering selama Plistosen. Tulisan ini memaparkan hasil studi yang bertujuan untuk mengevaluasi iklim saat Plistosen di Jawa dan daerah lain di Indonesia. Studi ini memanfaatkan perconto keratan sumur yang berasal dari Jawa Timur dan lepas pantai utara Papua. Perconto diproses memakai standar preparasi untuk mengekstrak palinomorf. Studi ini menerapkan metode kuantitatif yang memungkinkan interpretasi iklim purba lebih rinci. Studi ini membuktikan bahwa Plistosen di Jawa Timur dicirikan oleh kelimpahan tinggi polen Monoporites annulatus (Gramineae), menandai ekspansi padang rumput (savana) selama periode glasiasi. Hal ini didukung oleh fakta tingginya charred Gramineae cuticles yang berasal dari rumput terbakar akibat panas berlebihan terkait aktifitas gunung berapi. Sementara itu, sedimen Plistosen di lepas pantai utara Papua memperlihatkan rekaman polen berbeda, mengindikasikan perulangan iklim kering dan basah dan perulangan naik dan turunnya muka laut. Iklim basah terkait dengan naiknya muka laut pada periode inter-glasiasi ditandai oleh melimpahnya polen air payau dan peningkatan jumlah polen air tawar, termasuk polen peat swamp. Sebaliknya, iklim kering terkait dengan turunnya muka laut pada periode glasiasi ditunjukan dengan penurunan polen air payau dan air tawar secara dramatis.

Kata Kunci: *plistosen, iklim kering, iklim basah, rekaman polen, glasiasi, interglasiasi*

ABSTRACT

Most researchers agree that Pleistocene is characterised by glacial and inter glacial periods which are strongly related to dry/ cool and wet/ warm climates. Apparently these are reflected on their pollen records. The period of dry climate (glacial climate) is characterised by abundant Gramineae pollen, whilst the period of wetter climate (interglacial climate) is indicated by an increase of coastal and mangrove palynomorphs, but greatly reduced frequencies of Gramineae pollen. On the contrary, previous works on the Pleistocene sediments of Java indicated high abundance of grass pollen along this age marking drier climate condition. This paper publishes the study which is intended to evaluate paleoclimate of Java and other area of Indonesia during Pleistocene. For this purpose, some well samples from East Java and Papua were collected. Standar laboratory preparation was employed to extract pollen from the cutting samples. This study applies quantitative method which allows detail climate change interpretation. This study shows that Pleistocene of East Java is characterised by abundant grass pollen of *Monoporites annulatus* which may correspond to the period of expansion of savanna vegetation coinciding with glacial period. More over, it is indicated by abundant charred Gramineae cuticles which derive from burning grass. This might have been caused by extreme heat which could relate to the volcanic activities existed in East Java. Slightly different record appears in Papua which shows repetition of dry/ wet condition or low/ high sea level. The moist climate related to the phase of sea level rise is marked by abundant brackish pollen which possibly represented interglacial period. It is also supported by the increase of peat swamp and freshwater palynomorphs. On the other hand, dry climate representing glacial period is defined by significant decrease of these brackish and freshwater elements.

Keywords: pleistocene, dry climate, wet climate, pollen records, glacial, interglacial

How to cite this article:

Lelono, E.B., 1, 2018, DRY CLIMATE EXPANSION ON THE PLEISTOCENE OF INDONESIA AS RECORDED IN ITS POLLEN ASSEMBLAGE, *Scientific contributions Oil and Gas*, 41 (1) pp, 17-27. DOI: 10.29017/SCOG. 41.1.17-27.

I. INTRODUCTION

Pleistocene is characterised by repeated glacial cycles including glacial and interglacial events (Traverse 1988). The glacial cycle drove the occurrence of dry climate to cause sea level fall exposing continental shelf. On the other hand, interglacial cycle was reponsible for wet climate resulting in sea level rise which submerged high lands. These events affect the depositional process of the sediments. In South American tropical region, the glacial lowstand deposits are marked by high concentration of montane and low land pollen and spore as well as high organic debris. Mean while, the interglacial highstand deposits are defined by low abundance of terrigenous palynological assembalges and a predominance of marine microfossils (Hoorn 1997). Mean while, palynological records from North Antlantic indicates the expansion of ice sheets in the northern hemisphere during Early Pleistocene resulting in global climatic deterioration. Short period of warmer climate occurred based on pollen record (Mc Carthy 2000). Pleistocene climate in the New South Wales, Australia is much drier climate compared to that of the Neogene (Martin 2014). The pollen assemblages of the Pleistocene Napal show that sediments were deposited under cool climate condition (Paudayal and Ferguson 2004).

In southeast Asia, there is clear evidence for the expansion of dry climate during Pleistocene glacial maxima (Morley, 2000). Pleistocene was characterised by repetition periods of progradation and transgression which were driven by glacioeustatic events. These periods determined depositional process of sedimentary rocks occurring in this area. The glacio-eustatic sea-level changes were very distinctive. During lowstands, most of the continental shelf was exposed and sediments of earlier cycles were deeply eroded. Major fluvial channel systems can be clearly observed in shallow seismic across the Sunda Shelf (Morley et al. 2016). In addition, uplift was important element across Java and Sumatra, in which the establishment of Java as an island was essentially a Pleistocene event (Lunt 2013). Open marine sedimentation was ceased during Pleistocene. Therefore, Pleistocene sediments were mostly deposited in the non-marine environment which were unconformably overlaying the older formations (LEMIGAS 2005). The Pleistocene sediment generally consists of volcanoclastic as a result of volcanic activity which related to uplifting period.

Pollen assembalges extracted from Pleistocene sediment of Lombok Ridge present high abundance of grass pollen *Monoporites annulatus* which indicates the expansion of dry climate during Pleistocene glacial maxima (van der Kaas 1991a). The period of dry climate (glacial climate) is characterised by abundant Gramineae pollen, whilst the period of wetter climate (interglacial climate) is indicated by an increase of coastal and mangrove palynomorphs, but greatly reduced frequencies of Graminaae pollen (Morley 2000). More over, pollen zone for Pleistocene age is defined on the basis of maximum occurrence of *Monoporites annulatus* and it is named as *M. annulatus* zone (Rahardjo et al. 1994). Having this information, this paper is published to provide pollen assemblages of Pleistocene Java and Papua for interpreting paleoclimate of Indonesia during Pleistocene.

II. METHODOLOGY

As Indonesia is geologically and biogeographically devided into two major provinces including West and East Indonesia, samples are collected from the locations representing these provinces. West Indonesia is represented by samples obtained from East Java, whilst East Indonesia is represented by samples from off-shore of North Papua (Figure 1). Sampling was focused on fine grain lithology with dark colour which was predicted to yield high organic content.

Samples used for this study are cuttings which are collected from exploration wells. All samples were processed in the LEMIGAS Stratigraphy Laboratory. 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.

The fossil examination was taken under the transmitted light microscope with an oil immersion objective and X 12. 5 eye piece. The result of examination is recorded in the determination sheets and used for the analyses. As this study applies quantitative analysis, it is required to count 250 palynomorphs in each sample. The percentage abundance of palynomorphs from every sample was plotted onto a chart to illustrate temporal abundance fluctuations of each palynomorph type, using a statistically viable population (=count number) of palynomorphs in every sample.

Palynological record is a reliable source for terrestrial paleoenvironments and paleoclimate reconstructions (Birks and Birks 1980). It is a veritable tool in vegetation reconstruction for paleoclimatic interpretation (Adeonipekun et al. 2015). Interglacial periods are associated with relatively warmer and wetter climatic conditions, whilst glacial periods is characterized by cooler and dryer conditions (van Helmond 2010). Fossil pollen evidence for climatic change provides a proxy for sea level changes. The dryier climate associates with low sea level which is marked by abundant grass pollen but low occurrence of brackish and fresh water swamp elements. On the contrary, the wetter climate correlates to high sea level which is defined by the increase of backish and swamp palynomorphs but significant decrease of gramineae pollen (Lelono 2006).

III. RESULTS AND DISCUSSION

Pollen records from the studied locations show moderate abundances which derive from various sources including mangrove, back-mangrove, riparian, peat swamp, freshwater swamp,

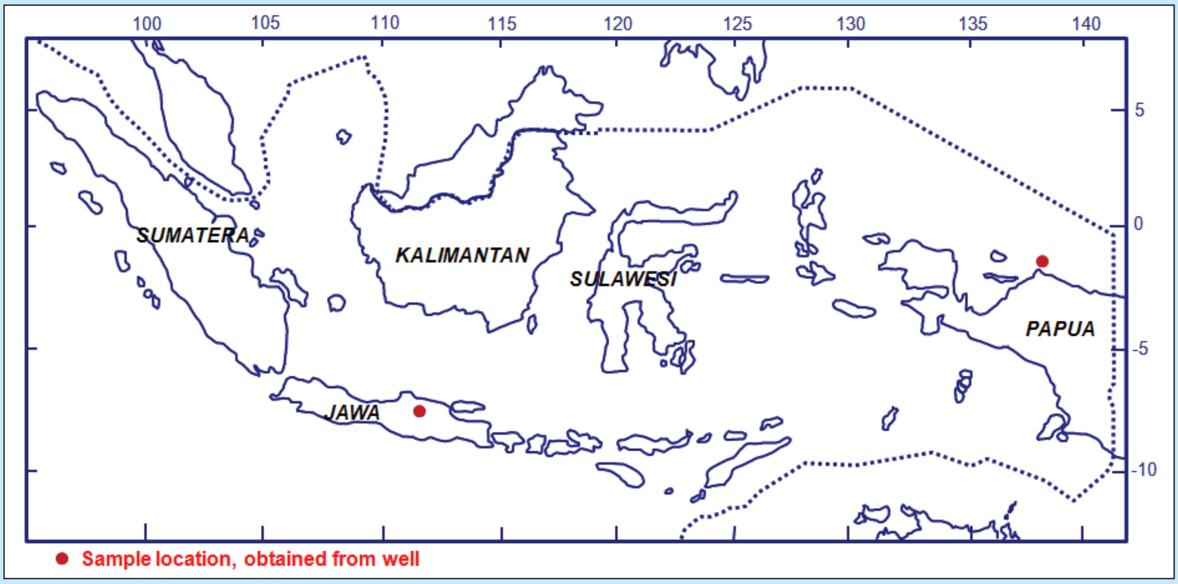

Figure 1
Locations of sampling which are exploration wells situated in East Java and North Papua.

undifferentiated fresh water and montane. Climate indicators appear throughout the sections to indicate climatic changes. Palynological assemblage of Pleistocene East Java is somewhat different to that of North Papua in term of significant occurrence of dry climate elements of grass pollen *Monoporites annulatus* and charred gramineae cuticles. East Java section shows more regular and common these indicators rather than that of North Papua.

A. Pleistocene East Java

The Pleistocene palynology is defined by the appearance of pollen *Dacrycarpidites australiensis* and *Monoporites annulatus* in the absence of spore *Stenochlaenidites papuanus*. In addition, it is characterized by abundant grass pollen *Monoporites annulatus* suggesting dry climate condition (Figure 2). This might correspond to the period of expansion of savanna vegetation which coincided with glacial period. Referring to the pollen zonation of Java, East Java section can be assigned to pollen zone of *Monoporites annulatus* (Rahardjo et al. 1994, see Figure 4). This pollen zone is defined by the occurrence of nannoplankton of *Gephyrocapsa eocenica* suggesting nanno zone of NN19 (Martini 1971). It also equals to benthic zone of lower NB1 which is equivalent to planktonic zone of N22 (Early Pleistocene) based on the appearance of *Asterorotalia gaimardii* and *Pseudorotalia schroeteriana* in the absence of *Asterorotalia gaimardii inermis*, *Pseudorotalia schroeteriana angusta*, *P. alveiformis*, *Asanoina globosa* and *Ammonia ikebei* (Berggren 1973). More over, another marker characterising Pleistocene East Java is common charred Gramineae cuticle which is generated from burning grass (Figure 3). This might have been caused by extreme heat which could relate to the volcanic activities existed in East Java during uplifting period. Apparently, the occurrence of volcanic activities is indicated by high percentage of volcanic materials found in the studied sediment (LEMIGAS 2005). Another Pleistocene marker is absent from East Java. This marker is Australian montane pollen of *Phyllocladus hypophyllus* which is assumed to fisrtly appear in the Plio-Pleistocene boundary (Morley 2000). This pollen immediately dispersed into Southeast Asia after a shift in the movement of the Sorong fault zone and is thought to relate to the uplift of mountains in the South Phillipines (van der Kaas 1991b).

The uplifting episods during Pleistocene caused the formation of uplands which was responded by the appearance of high altitude collonisation producing gymnosperm pollen such as *Dacrycarpidites australiensis*, *Dacrycarpidites* sp., *Podocarpus polystachyus* and *Podocarpus* sp. These vegetations were originally Australian floras which migrated into Sunda region following the formation of high lands in East Indonesia and Sunda due to Late Tertiary uplifting event. The existence of uplands as indicated by the presence of montane pollen was thought to correlate with the glacial maxima period which promoted cooling climate condition.

In West Indonesia (especially Java), grass pollen of *Monoporites annulatus* played important role at Plio-Pleistocene indicating the expansion of savanna vegetation during dry climate phase (Figure 4). The presence of this pollen was often combined with abundant charred gramineae cuticles which possibly indicated savanna fire (Lelono 2006). Morley (2000) reported that abundant grass pollen was usually found together with abundant *Casuarina* pollen in the Pliocene sections of Java suggesting an open sclerophyllous savanna with the domination of *Casuarina*. The appearance of *Casuarina* savanna might relate to the phases of forest destruction due to volcanic activity, as this pollen recently lives on the volcanoes of East Java and Nusa Tenggara which is called fire-climax forest (Morley 2000).

Dry climate domination in the Pleistocene East Java might be responsible for the less development of low land forest as indicated from the pollen record provided in Figure 2. Common charred Gramineae cuticle of burning grass might relate to volcanism causing extreme heats to limit the expansion of low land forest. However, there was an indication of wet climate within Pleistocene dry condition as evidenced by significant occurrences of peat swamp and freshwater swamp pollen of *Cephalomappa*, *Calophyllum* type and *Casuarina*. These pollen suggested the existence of low land forest under moist climate which related to the phase of sea level rise as marked by abundant mangrove pollen of *Zonocostites ramonae* possibly representing interglacial period.

B. Pleistocene North Papua

The Pleistocene palynology of North Papua clearly demonstrates repetions of dry/wet condition or low/high sea level (Figure 5). This is distinct from that of Plesitocene East Java which is characterised

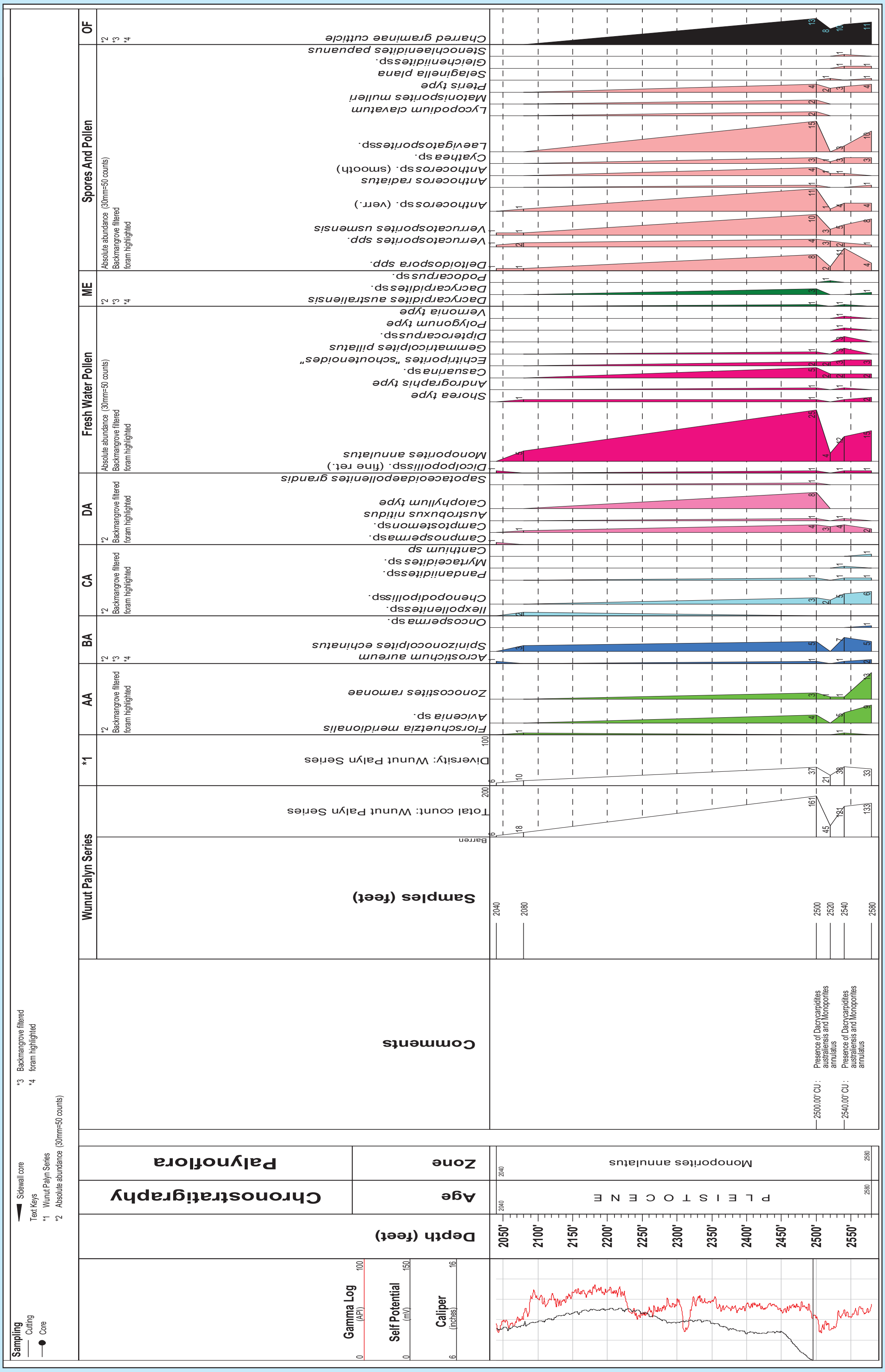

Figure 2
Pollen assemblage of Pleistocene East Java is characterised by abundance of grass pollen of *Monoporites annulatus* and burning grass of charred cuticles suggesting dry climate condition.

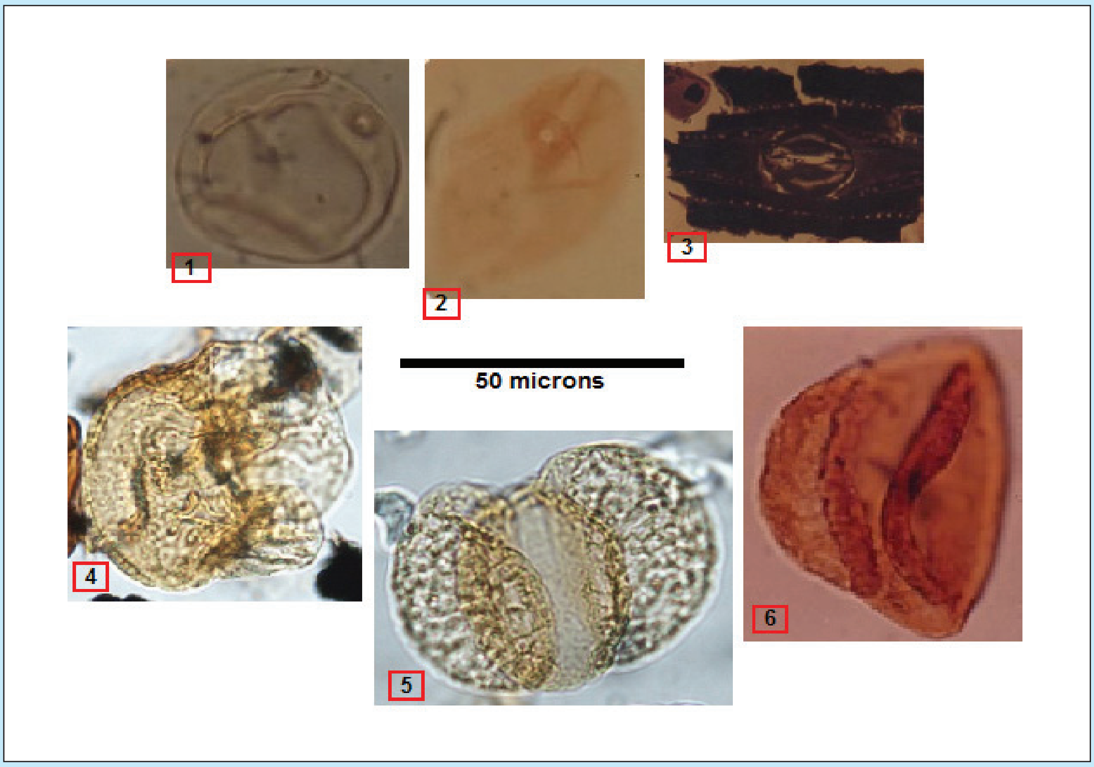

Figure 3
Cool/dry climate indicators characterise Pleistocene east Java: Monoporites annulatus (1 and 2), charred gramineae cuticle (3). and gymnosperm pollen of Podocarpus imbriatus (4). Podocarpus polystachyus (5). and Pinuspollenites sp (6).

by maximum abundance of grass pollen *Monoporites annulatus* and burning grass of charred gramineae cuticles indicating dry climate domination. In Pleistocene of North Papua, *M. annulatus* is low occurrence whereas gramineae cuticle is unrecorded. Further more, current Papuan floras show differences compared to those of West Indonesia as they are occupied by typical East Indonesian vegetation which is relatively closed to the Australian flora. This is due to Papua was a part of the Australian elements which appeared in East Indonesian region at about Middle Miocene (Hall 1995). Mean while, some Asian floras migrated to Papua following the collision between Australian elements and Asian continental at Late Oligocene. Another possible contributors are Pacific/ Philippines continent as they were mostly dominated by Asian floras during Early Tertiary (Good 1962). This situation is assumed to cause the diferences between Pleistocene assemblages of Java and Papua (see Figures 4 and 6).

Some key palynomorphs characterising Pleistocene of Papua are shown in Figure 7. Pollen assemblage of the North Papua yields moderate abundance and diversity of palynomorphs deriving various sources which allow interpretations of sea level changes and paleoclimates. Some key pollen used for these interpretations include *Zonocostites ramonae*, *Florschuetzia meridionalis* (mangrove), *Florschuetzia levipoli*, *Acrostichum aureum* (back-mangrove), *Blumeodendro*, *Cephalomappa* type, (peat swamp), *Casuarina*, *Dacrydium*, *Monoporites annulatus*, *Dicolpopollis* sp. (fresh water), *Pinuspollenites* sp., undifferentiated bisaccates (montane) and *Verrucatosporites usmensis* (spore). Sea level changes are chronologically as follows: It was started by sea level fall (SL 1) as suggested by the increase of mangrove element *Camptostemon*. The expansion of this pollen during sea level drop coincided with the period of dry climate (Chow 1996). Sea level was rising in SL 2 as indicated by considerable increase of pollen *Florschuetzia levipoli* suggesting the development of back-mangrove vegetation. Sea level rise might correlate to wet climate as supported by the decrease

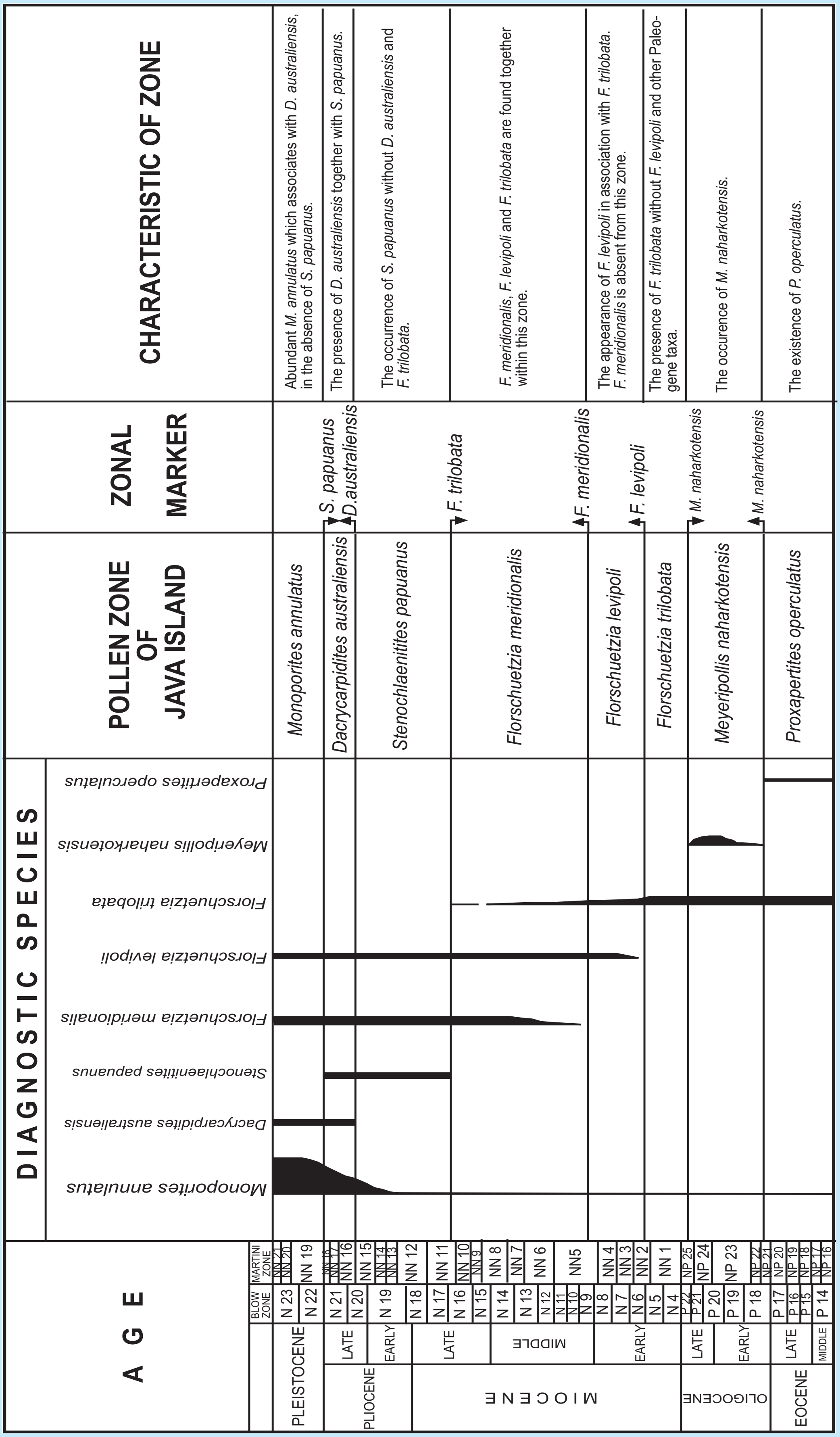

Figure 4
Pollen zonation of Java by Rahardjo et al. (1994) shows hih to maximum abudance of dry dimate indicator of monoporites annulatus.

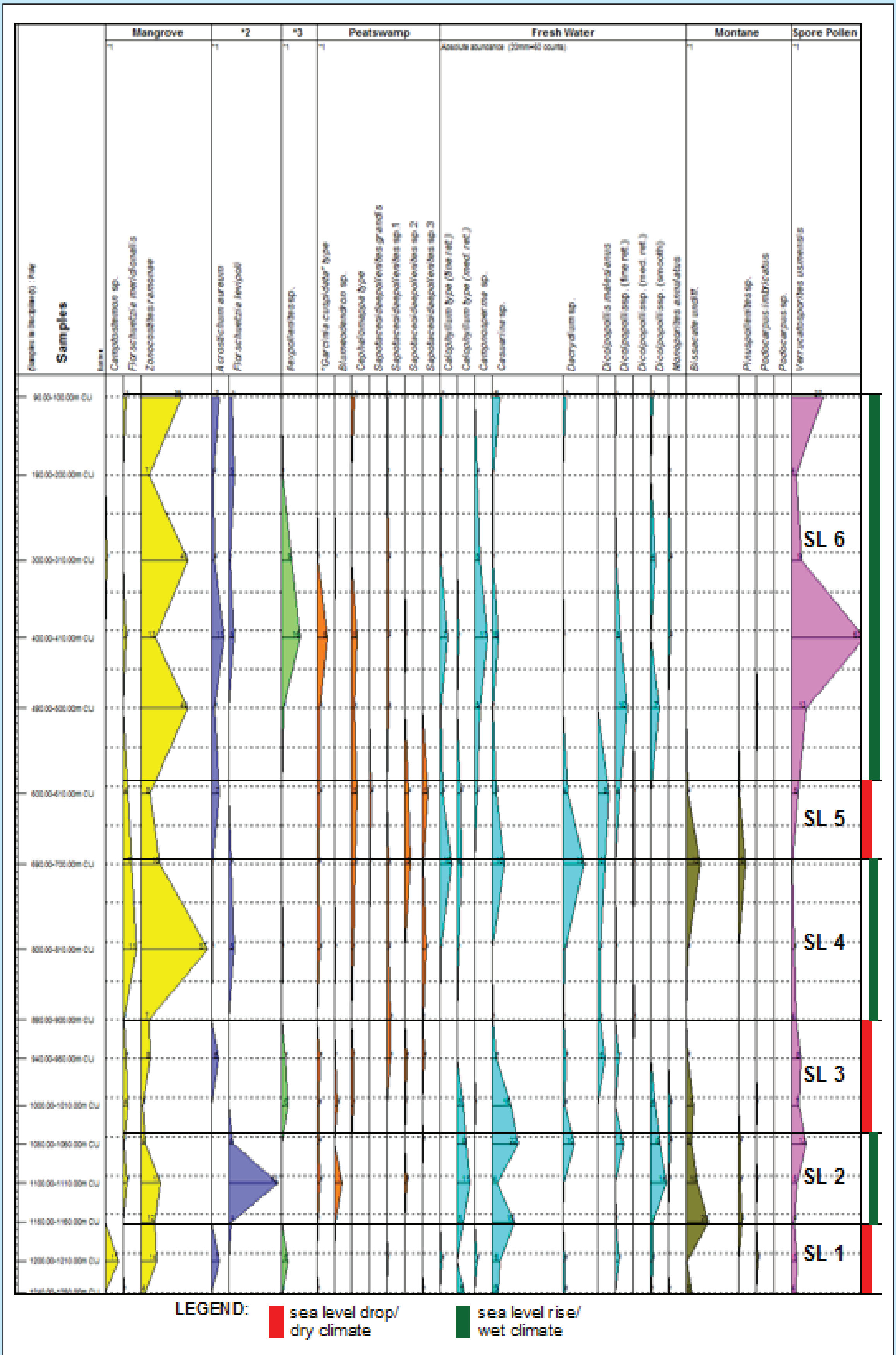

Figure 5
Pollen assemblage of Pleistocene of North Papua shows possible sea level changes (SL) which are correlative to climate changes.

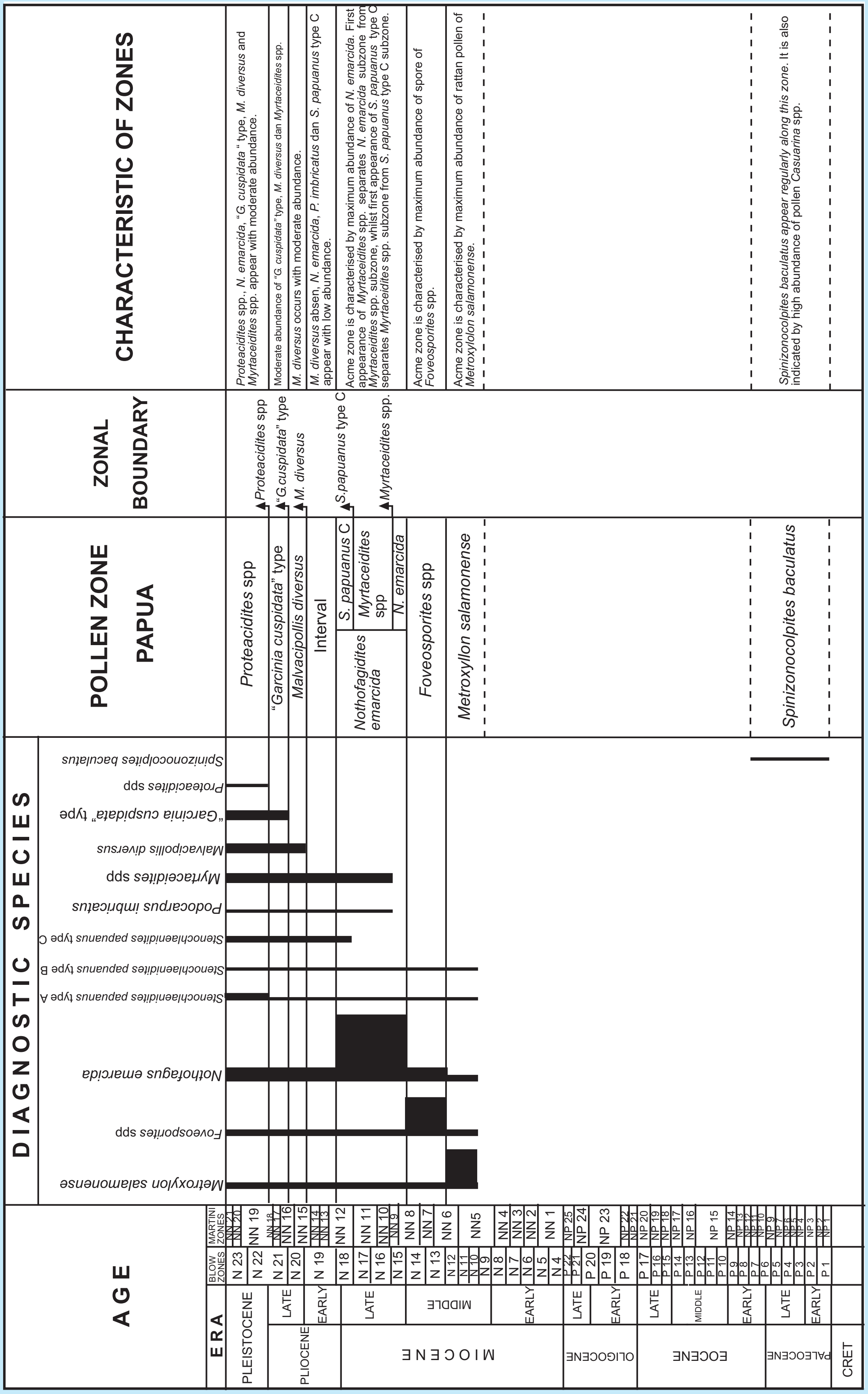

Figure 6
Pollen zonation of Papua by Lelono et al. (1996) shows vertical distribution of some key palynomorphs.

of seasonal climate indicators including *Casuarina* and *Dacrydium*, but the increase of peat swamp pollen of *Blumeodendron* and *Cephalomappa*. Sea level subsequently droped in SL 3 which was suggested by the increase of *Casuarina* combined with grass pollen of *Monoporites annulatus*. In addition, montane pollen of undifferentiated bisaccates increased significantly to mark dry climate condition. Sea level then turned to rise in SL 4 as indicated by the increase of mangrove community including *Zonocostites ramonae* and *Florschuetzia meridionalis* (Rugmaia et. al. 2008). This coincided with wet climate as as proved by considerable decrease of some seasonal markers including *Casuarina* and *Dacrydium*. Sea level drop in SL 5 is defined by the decrease of *Zonocostites ramonae*. In contras, seasonal indicators increase to indicate dry climate including *Casuarina*, *Dacrydium*, *Pinuspollenites* sp. and undifferentiated bisaccates. Finally, sea level rise dominated the top section (SL 6) as marked by the increase of brackish palynomorphs such as *Zonocostites ramonae*, *Florschuetzia levipoli* and *Acrostichum aureum*. More over, some fresh water pollen increase including *Dicolpopollis malesianus* and *Dicolpopollis* spp. Pteridophyte spore of *Verrucatosporites usmensis* suggesting moist condition is abundant throughout this interval. Mean while, most seasonal climate indicators decline significantly as shown by montane elements of *Pinuspollenites* sp. and undifferentiated bissacate pollen (Figure 5).

IV. CONCLUSION

Pleistocene palynological data from on-shore of East Java and off-shore of North Papua represent the extention of dry climate in Indonesia where previously postulated as the epoch of ice age which was a time sensitive to climatic and sea level changes. However, the presence of drier climates is also driven by uplifting tectonic to make the formation of uplands as indicated by the occurrence of various montane pollen such as *Dacrycarpidites*, *Pinuspollenites*, *Podocarpidites* and undifferentiated bisaccates. There is a difference in vegetation between two areas, in which savana expanded in East Java, but rarely occurred in North Papua.

Some series of low/high sea levels can be constructed based on the existence of mangrove/fresh water palynomorphs and dry/wet indicators. These

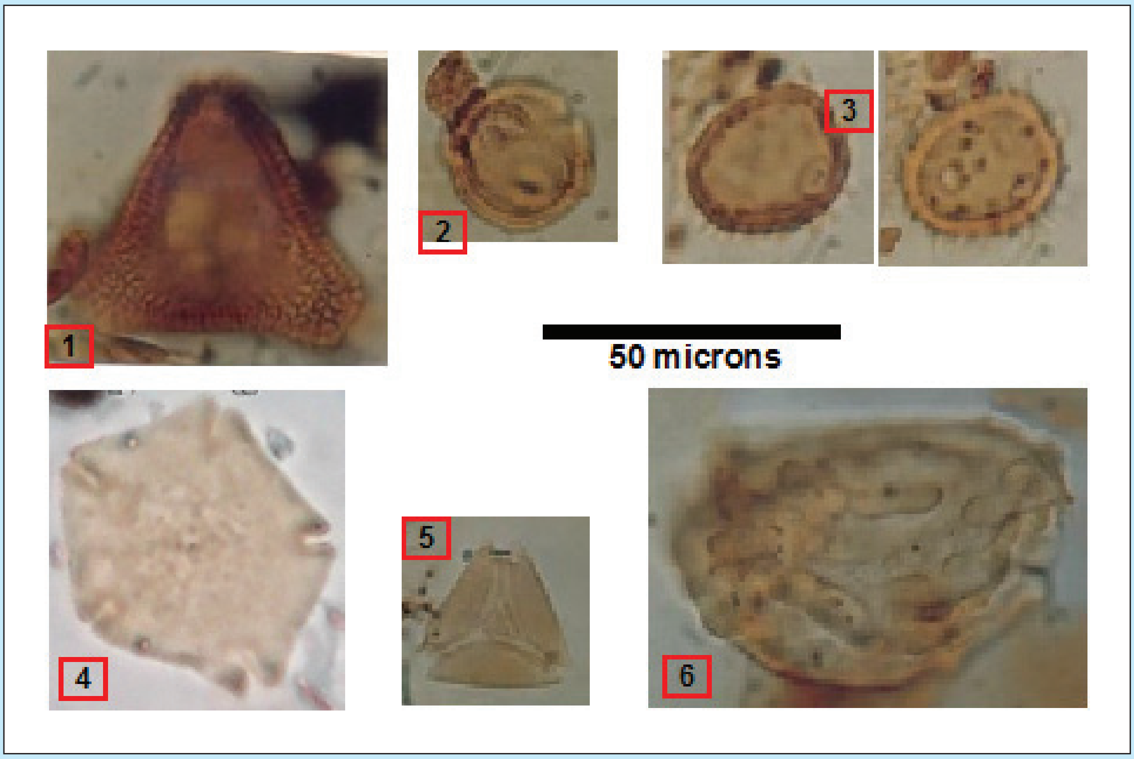

Figure 7
Key palynomorphs of Pleistocene Papua: Proteaceidites spp. (1), Garcinia cuspidata (2), Nothofagidites emarcida (4), Myrtaceidites sp. (5), and Stenochlaenidites papuanus (6).

sea level changes are possibly caused by glacial/ inter glacial events. The low sea level is defined by low appearance of mangrove pollen but significant grass and montane elements. On the contrary, high se level is indicated by considerable increase of mangrove community but greatly reduced abundances of montane and grass pollen.

ACKNOWLEDGMENT

The author is grateful to colleagues in LEMIGAS Stratigraphy Group for their supports in performing biostratigraphic analyses of the subsurface samples from on-shore of East Java and off-shore of North Papua.

REFERENCES

Adeonipekun, P. A. and **Oyelami, A.** 2015. Palynology of Late Paleocene-Earliest Eocene Outcrop Sediments from Benin Basin, SW Nigeria: Implication for Paleoclimatology and PETM Record in the Tropics. *Global Journal of Science Frontier Research (C)*, Volume 15, Issue 3, Version 1, pp. 15-26.

Birks, H. J. B., and **Birks, H. H.** 1980. *Quaternary Palaeoecology*. Edward Arnold, London. 289 pp.

Berggren, W. A., 1973. Messinian Events. *Med. WHOI Tech. Report*, pp. 73-140.

Chow, Y. C., 1996. Application of Climatic Biosignals to Stratigraphic Studies Offshore Sabah/ Sarawak, Malaysia. *Proceedings of the 9th International Palynological Congress*, Houston Texas, June 1996, Abstract, p. 25.

Good, R., 1962. On the Geographical Relationships of the Angiosperm Flora of New Guinea. *Bulletin of the British Museum (Natural History), Botany 12*, pp. 205-226.

Hall, R., 1995. Plate Tectonic Reconstructions of the Indonesian Region. *Proceedings 24th Annual Convention, Indonesian Petroleum Association*, pp. 71-84.

Hoorn, C. 1997. Palynology of the Pleistocene Glacial/ Interglacial Cycles of the Amazon Fan (Holes 940A, 944A, and 946A). In: Flood, R. D., Piper, D. J. W., and Peterson, L. C. (Eds.), *Proceedings of the Ocean Drilling Program, Scientific Results*, Vol. 155, pp. 397-409.

Lelono, E. B. 2006. Eocene-Oligocene Climate Based on Palynological Record. *Lemigas Scientific Contribution*, No. 1, pp. 8-23.

LEMIGAS, 2005. *Hydrocarbon Evaluation of North East Java (Madura)*. Unpublished In-house Research.

Lunt, P., 2013. The sedimentary geology of Java. *Indonesian Petroleum Association*, Jakarta, 346 pp.

Martin, H. A. 2014. A Review of the Cenozoic Palynostratigraphy of the River Valleys in Central and Western New South Wales. *Proceedings of the Linnean Society of New South Wales*, Vol. 136, pp. 131-155.

Martini, E., 1971. Standard Tertiary and Quaternary Calcareous Nannoplankton Zonation in Farinacci, A. (Ed), *Proc. 2nd Plank. Conf. Roma*, pp. 739-784. Edizioni Tecnoschienza, Roma.

McCarthy, F. M. G., Gostlin, K. E., Mudie, P. J., and **Scott, D. B.** 2000. Synchronous Palynological Changes in Early Pleistocene Sediments off New Jersey and Iberia, and a Possible Paleoceanographic Explanation. *Palynology*, Vol. 24, pp. 63–77.

Morley, R. J., Morley, H. P. and **Swiecicki, T.,** 2016. Mio-Pliocene Palaeogeography, Uplands and River Systems of the Sunda Region Based on Mapping within a Framework of VIM Depositional Cycles. *Proceedings Indonesian Petroleum Association, 40th Annual Convention*, Jakarta.

Morley, R. J. 2000. *Origin and Evolution of Tropical Rain Forest*. John Wiley and Son Ltd. Chichester.

Paudayal, K. N. and **Ferguson, D. K.** 2004. Pleistocene palynology of Nepal. *Qarternary International*, vol. 117, issue 1, pp. 69-79.

Rahardjo, A. T., Polhaupessy, A. A., Wiyono, S., Nugrahaningsih, L. and **Lelono, E. B.,** 1994. Zonasi Polen Tersier Pulau Jawa. *Proc. IAGI, 23rd Annual Convention*.

Rugmaia, W., Grotea, P. J., Chonglakmanic, C., Zetterd, R., and Fergusond, D. K. 2008. A Late Pleistocene palynoflora from the coastal area of Songkhla Lake, southern Thailand. *Science Asia*, Vol. 34, pp. 137-145.

Traverse, A. 1988. *Paleopalynology*. Unwin Hynman, Boston, 600 p.

Van der Kaas, W. A., 1991a. Palynology of Eastern Indonesian Marine Piston-Cores: A Late Quaternary Vegetational and Climatic History for Australasia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 85, pp. 239-302.

Van der Kaas, W. A., 1991b. Palynological Aspects of Site 767 in the Celebes Sea. *Proceedings of the Ocean Drilling Program, Scientific Results* 124, pp. 369-374.

Van Helmond, N. A. G. M. 2010, *Palynological and organic geochemical characterization of marine and terrestrial Early Pleistocene climate in northwest Europe*. MSc Thesis, Utrecht University, Holland.