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Climate Changes Record of Bandung Paleolake

Winantris[#], Lili Fauzielly[#], Lia Jurnaliah[#]

[#] *Departement of Geoscience, Faculty of Geological Engineering, Padjadjaran University, Jatinangor 45363, West Java, Indonesia*
Email: winantris@unpad.ac.id

***Abstract*— The research was carried out on the sediment of Middle Bandung Basin. Samples were taken from a depth of 20 meters to 10 meters, each meter a taken sample for analysis. The characteristics of the sample are greenish grey clay deposits with remnant plant material. Research aims to identify climate change based on palynological data from the Pleistocene-Holocene Boundary. The resulting of radiocarbon dating (14C), shows that age of the sample from the 18 m depth around 11820 years BP. Separation of pollen from sediment used an acetolysis method. Palynomorphs are grouped according to their habitat that related to vegetation zone, i.e., lowland forest zone, submontane forest zone, lower montane forest zone, riparian/open herbaceous swamp vegetation, freshwater algae, and Aquatic plant. The composition of pollen shows a succession of vegetation that reflection of climate changes. From Pleistocene-Holocene boundary at least has been recorded seven times of the shift vegetation zone that is evidence of climate change. The oldest sample at 20 m depth is the coldest temperature occurred in zone one at a depth of 20-19 meters that was dominated by lower montane forest vegetation; the event was around Late Pleistocene. The opposite condition occurred in zone seven at 10 meters depth; temperature becomes warmer that indicated by disappears of pollen submontane forest and dominated by lowland forest pollen similar to the current condition. Climate change is also reflected by fluctuations the quantity pollen of open herbaceous swamp vegetation.**

***Keywords*—paleoclimate record; palynomorphs; Bandung Lake; quaternary.**

I. INTRODUCTION

The significant climate changes have been done during the Quaternary period which associated with the last glacial ice. The Late Glacial interval, corresponding to the last deglaciation periods that caused climate change [1], [2]. Events of the ice age lasted is about 11,000 -12,000 years ago. Although Indonesia is in a wet tropical region with characterized by of two seasons of drought and rainy, but some research evidence shows the existence of climate change during that period. The paleoecological and paleoclimate change from Rawa Danau west Java during Late Quaternary [3]. Climate change can be assessed by pollen analysis [3]–[6], and the lake is the perfect location for this research. The sedimentation in the lake is relatively more stable than in the sea; lake has lower energy levels than the ocean due to there is not influenced by tidal activity like on the sea. The main difference between the faces of marine and lacustrine is the range of depth that affects the development of surface waves and limits the distribution of textures [4]. The history of the formation of the Bandung Basin is a product of tectonic events in the subduction of oceanic crust in Java, which includes the activities of the magmatic arc of central Java and volcanism. Depression reached to the maximum in the Late Pliocene and Quaternary boundary, when magmatic occurred in the middle of the Bandung Zone that the formed dome arc volcano. The events of structural depression that form the Bandung basin were the controls to the formation of lakes and swamps [7], [8]. The study area in Rancasari at a sub-district level Bandung City. The location is at an altitude of 670 masl. The type of vegetation at that altitude included in the lowland forest vegetation. The lowland tropical rainforest grows at elevations less than 1000 masl, characterized by humid and warm condition, with a mean annual temperature of 24.4 C°, the range of temperature about 21-30°C [9], [10].

II. MATERIAL AND METHOD

Samples were taken at coordinates 107º40'37.79" E and 06º57'52.20"S, in the middle part of Bandung Basin Fig.1and Fig.2, it was drilled from 20 to10 meters depth, and each meter was taken 10 grams of sediment for pollen analysis, so there were 11 samples.

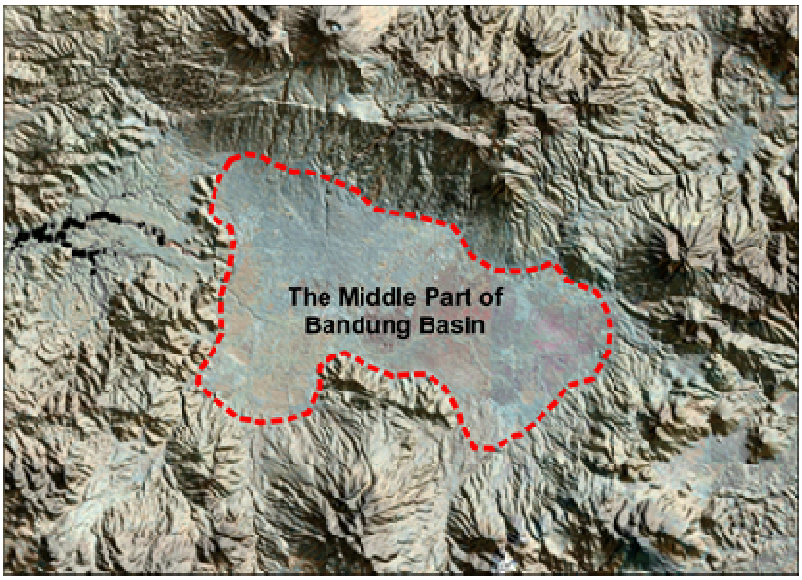


Fig. 1 Middle part of Bandung basin [11].

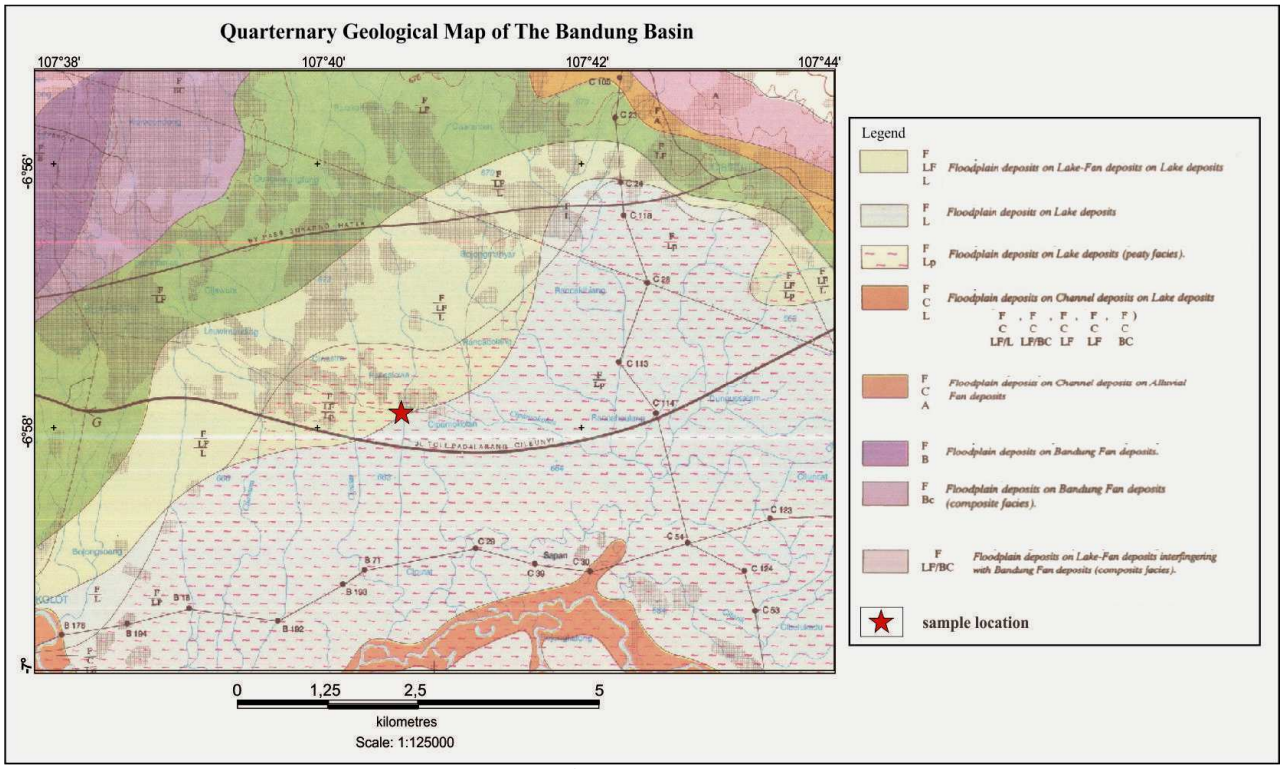


Fig. 2 Quaternary Geological Map of Bandung basin [13] red star is research location sample

The acetolysis method used for separate pollen is from sediment and others material. Chemicals for acetolysis are sulfuric acid, glacial acetic acid, and acetic anhydride — chloride acid for removing calcium, potassium hydroxide for removing of humic acid and hydrofluoric acid for removing of silicate. Description and identification of pollen used transmission microscope binocular CX 21 LED. The pollen of forest vegetation was grouped according to their habitat. Zone of forest vegetation in West Jave divided into five, i.e., the submontane forest at 1000-1400 masl, lower montane forest I at 1400-1800 masl, lower montane forest II at 1800-2400 msl, upper montane forest/ericoid forest at 2400-3000 msal and subalpine/ericoid scrub forest at 3000-3600 masl [12]. Pollen identification refers to several studies [13]–[16] — palynomorphs from the lake and surrounding that areas were grouped into four types, i.e. riparian and open herbaceous swamp, aquatic vegetation plant, Pteridophyta and freshwater algae. Carbon dating (^{14}C) was taken at 18 m depth of sample core.

III. Result and Discussion

Sediment sample is dominated by gray clay, characteristics of each sample are shown in Table 1

TABLE I.
CHARACTERISTICS OF SEDIMENT

No	The depth of the sample (m)	Characteristics
1	20	greenish grey clay (5Y 4/2) with a gravel-sized fragment
2	19	greenish grey clay (5Y 4/2), homogenous
3	18	greenish grey clay (5Y 4/2), homogenous
4	17	greenish grey clay (5Y 4/2), homogenous
5	16	greenish grey clay (5Y 4/2), homogenous
6	15	greenish grey clay (5Y 4/2), homogenous
7	14	greenish grey clay (5Y 4/2), homogenous
8	13	greenish grey clay (5Y 4/2), homogenous
9	12	greenish grey clay (5Y 4/2), with gravel-pebble-sized and remnants plant which are roots and dried leaves
10	11	greenish grey clay (5Y 4/2), with a gravel-sized fragment
11	10	greenish grey clay (5Y 4/2), with a gravel-sized fragment

The result of carbon dating from 18 m depth is about 11,820 ± 220 years BP. The composition of pollen was not only shown pollen which produces by aquatic plant and lowland forest but also from montane forest vegetation (Fig. 3). Pollen that came from lowland forest produced by the plant which inhabitant at an elevation below 1000 meters, which consist of *Dipterocarpus*, *Cycas*, *Elaeocarpus* and some species from Euphorbiaceae. Vegetation of submontane forest zone occupies at elevation 1000-1400 m, consist of *Quercus, Castanopsis, Altingia exelsa, Celtis* and *Cupressus*. While pollen of lower montane forest was dominated by *Podocarpus neriifolius, Podocarpus imbricatus*, *Casuarina yunghuniana, Engelhadrtia,* and *Thuya*. Riparian group plant dominated by Araceae, Cyperaceae, Asteraceae. The riparian vegetation grows between the aquatic and the terrestrial ecosystem, which is a transition zone or semiterrestrial environment — the most Araceae has grown along river flows [17]. The riparian pollen is generally from herbaceous and was found in high number. Aquatic plant dominated by *Typha angustifolia*, *Nymphoides sp,* and *Eichorrnia crassipes.* Based on pollen dominant could divide into seven type vegetation as follow:

A. Lower Montane Forest Zone

At interval 20-19 m depth, the lower montane forest pollen was highest which dominated by *Thuya Orientalis Taxodium,* and *Alnus* followed by pollen from submontane forest *Quercus* and *Castanopsis.* In this zone, lowland forest pollens the lowest in quantity. Air temperature at the lower montane forest in West Java is about 13.0°C [12]. The condition showed at that time air temperature was more refreshing because based on the position of elevation place at 670 msal generally inhabited by a plant of lowland tropical rainforest. The data annual temperature average at the Bandung Basin is about 23.7 °C [18]. The cold condition was occurring before 11820 years BP, slightly older than that, at the position of samples were deeper 1-2 m than the position of the carbon dating sample. The sedimentation of the sample at that 20 m depth could be around the last ice age event so that the effect of the last ice age in the Pleistocene-Holocene boundary is reflected in the pollen record. In this zone pollen of open herbaceous swamp & Riparian was dominated, at that time the culmination of the development of it.

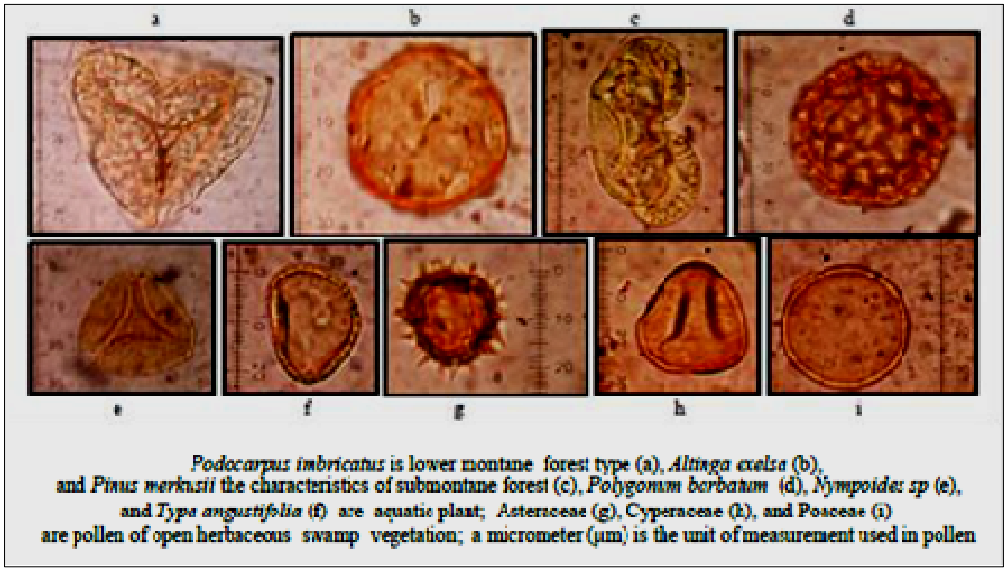
Contrary to pollen from the aquatic plant in that zone was not well developed, it could be related to cold of air temperature which makes the lake's water surface was shrinking Fig.3 and Fig 4. That condition supported by *Type Angustifolia* pollen, which is a wetland species which grows well in shallow marshes, lakes, and ponds. The most common type of *Pteridophyta* found here is *Platycerium bifurcatum*; it grows in dry and cold conditions. The data illustrate that the temperature at that time was cold and dry, and the body of waters in the lake was shallow.

B. Submontane Forest Zone-1st

In the interval a depth of 18 to 17 meters, the quantity of submontane forest pollen increases that replaced the pollen of lower montane forest. The presence of *Castanopsis* and *Quercus* take the place of *Podocarpus imbricatus* and *Podocarpus neriifolius* pollens, beside it in this zone found *Pinus merkusii* and *Celtis sp*. *Pinus merkusii* in West Java grows in the lowland forest until submontane forest zone. The species is the only member of the genus *Pinus* that crosses the equator [19], the area characterized by annual climate is always warm and humid. *Celtis sp* come from submontane forest zone type-1, which grows at 1000-1400 masl. Until now *Podocarpus neriifolius* grows in the same zone as the Bukittunggul mountain, that is located in the north part of Bandung [20]. *Castanopsis* and *Quercus* are the genus of Fagaceae which are important plants in the sub-montane forest zone in West Java, both of them exist in the Salabintana Submontane forest down to date [9]. The *Pteridium aquilinum* is a Pteridophyta that grows in mountain forest to the subalpine zone; it is the most common type of spore here. The change of plant type composition of lower montane forest to the submontane forest is the evidence of an increase in temperature from the previous, this changes happened was about 11820 years BP, but it still cooler than the current situation of Bandung basin. The temperature of the submontane forest zone is 18.7°C [12]. At that time the presence of freshwater algae and aquatic plant increased too.

C. Lowland Forest Zone-1st

At a depth of 16m there is an anticlimax of pollen of lower montane forest, so does the submontane forest vegetation decreases drastically. The decreased pollen of lower montane forest does not as much as lower montane pollen. This indicates that the temperature conditions were getting warm and moist. That fact supported by an increase in riparian vegetation that previously decreased mainly



Podocarpus imbricatus is lower montane forest type (a), *Altinga exelsa* (b), and *Pinus merkusii* the characteristics of submontane forest (c), *Polygonum barbatum* (d), *Nympoides sp* (e), and *Typa angustifolia* (f) are aquatic plant; Asteraceae (g), Cyperaceae (h), and Poaceae (i) are pollen of open herbaceous swamp vegetation; a micrometer (µm) is the unit of measurement used in pollen

Fig. 3 Pollen and spores

From the Araceae which grows optimally in humid conditions at temperatures ranging from 21-27°C [21], and the most common pollen is a member of the Family Araceae. Increasing of air temperatures clearer at a depth of the 15 m samples caused the pollen from the lowland forest was increased significantly, so it could be said that forest condition has reentered the lowland forest zone which characterized by found *Dipterocarpus sp* and *Araucaria sp*. Genus *Dipterocarpus* often found in altitudes range 800 - 1000 masl. *Polypodium* is the most common genus of Pteridophyta that found in this zone; it has good adaptability so doesn't specifically indicated of temperature and humidity. In general, lowland tropical rainforest develops at an average temperature of 21-30°C [9], [10]. It is the fact that time temperature is warmer than before. The increase of temperature caused the open herbaceous swamp vegetation more developed than before.

D. Submontane Forest Zone-2ed

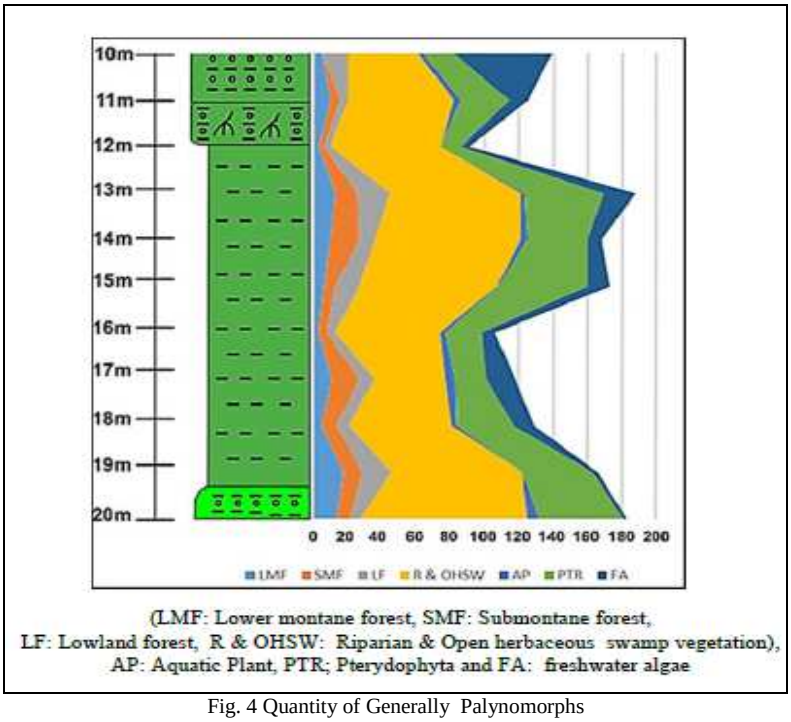
After a significant rising in temperature, at a depth of 14 m, the quantity pollen of submontane forest increases dramatically as a sign of a decrease in temperature, followed by decreased lowland forest pollen. *Castanopsis*, *Quercus* from Submontane forest dominated this zone followed by *Podocarpus imbricatus, Taxodium sp,* from the lower montane forest, at that time a temperature change which causes the change of plant structure from lowland forest to submontane forest, the air temperature returns to around 18.7°C. In many places, *Podocarpus imbricatus* found growing from an altitude of 1800 masl [22]. *Altingia exelsa* also found which characteristics of this zone in West Java [12], [23]. The existence of that species until now can be found in Gede Pangrango mountain, West Java [9]. Pollen of aquatic plant which dominant in this depth is *Pistia stratiotes*, it grows well in clean water lake, this species indicated that the lake environment in that time was right. *Platycerium bifurcatum* one species of Pteridophyta which dominated in this zone, these data was proved that the temperature was cooler and drier than before.

E. Lowland Forest Zone-2ed

The existence of pollen lower montane forest zone covers 13- 12 m depth. The composition of pollen at 13 m depth was dominated by lowland tropical rainforest followed by submontane and lower montane forest. *Araucaria sp* was the most pollen in this position. The shift of the forest vegetation from the submontane to the lowland forest indicated the temperature rise from 18.7°C to be 21-30°C. [9], [10]. Pollen of open herbaceous swamp vegetation dominated by *Polygonum barbatum*. *Athyrium esculentum* is the most commonly Pteridophyta which found here, it grows in valleys on the banks of rivers, in protected areas and wet, on soils rich in organic matter, can live from a height of 350-1600 masl. Entering the 12 m depth both submontane forest and lower montane forest pollen was decreasing significantly, which reinforces the fact of increasing temperature Fig.5. At this depth found pollen of *Elaeocarpus, Cycas,* and *Dipterocarpus,* that are characteristic of plants from the tropical lowland rainforest. The pollen of aquatic plants consists of *Nymphaea alba* and *Ottelia alismoides*; both are typical of a shallow water pond or lake. The Isosceles is shallow water fern that is the type of Pteridophyta. All species are reflecting a shallow water environment of the lake.

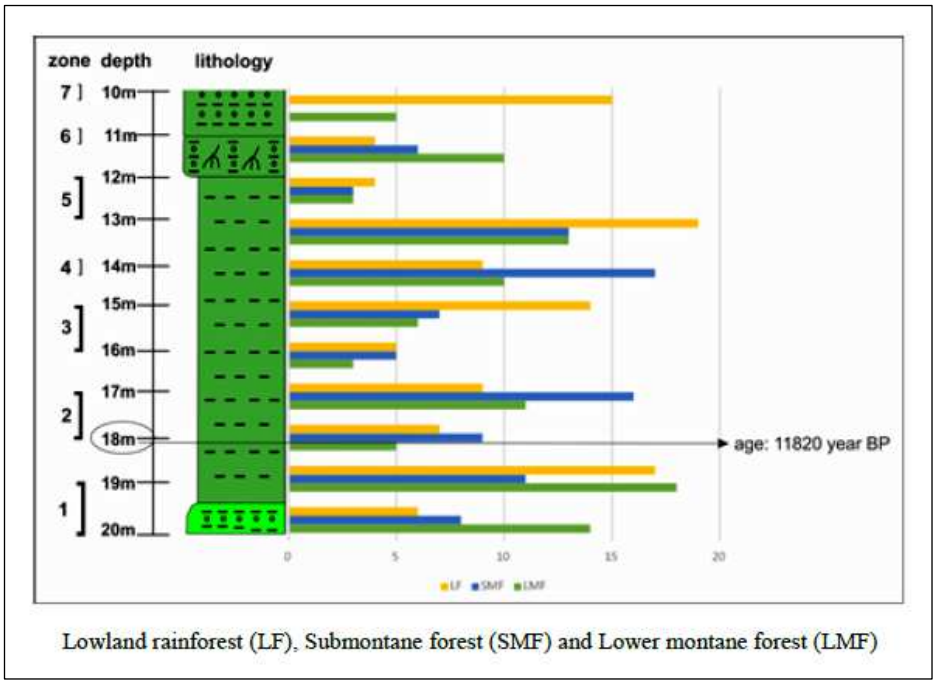
F. Lower Montane Forest Zone-2^{ed}

The pollen of the lower montane forest increased significantly followed by submontane forest pollen. The data are evidence that plants developing in this zone are plants of lower montane and submontane forest. The phenomenon was caused by climate change that indicated the decrease in temperature from about 23-28°C become 13-18.7°C, that cooler than before, At a sample depth of 11 m, the *Podocarpus* was genus increased significantly than previously, especially the *Podocarpus neriifolius* that grows on the lower montane forest, while the open herbaceous swamp vegetation has not undergone significant changes. *Quercus sp* and *Castanospis argentea* which came from submontane forest found in few quantities.



(LMF: Lower montane forest, SMF: Submontane forest, LF: Lowland forest, R & OHSW: Riparian & Open herbaceous swamp vegetation), AP: Aquatic Plant, PTR; Pterydophyta and FA: freshwater algae

Fig. 4 Quantity of Generally Palynomorphs



Lowland rainforest (LF), Submontane forest (SMF) and Lower montane forest (LMF)

Fig.5 Group of pollen-based on habitat elevation.

Castanopsis argentea one of indigenous species in Java Island has an essential role in mountain ecosystems; this species grows optimally at 1500 masl [24]. *Lycopodium phlegmaria* and *Salvinia natans* are Pteridophyta members present in this zone. *Lycopodium phlegmaria* is a fern of the epiphytic type that is very drought resistant, whereas *Salvina natans* are floating ferns, especially in shallow and stagnant water. this is same as pollen of *Nymphoides indica* which the plant characterized by growing in shallow, stagnant water and edges of lakes, can adapt until up to 1900 masl, those data illustrate that water surface of the lake was shallow

G. Lowland Forest Zone 3rd

This is a critical zone at 10-meter depth for changes in vegetation composition. The pollen from the submontane forest disappears altogether, and the pollen from the lower montane forest that has previously dominated was declined sharply, whereas the pollen from the lowland forest increased significantly from the fewest number in zone six become dominant in this zone. *Pinus merkusii* found in this zone; it is a type of plant that grows well in the lowland and submontane forest zones. *Microlepia strigosa* is a pteridophyte with a widespread from lowland until

submontane forest zone in the wet area, the existence of it indicates that the condition was humid, similar to *Vittaria elongata* is an epiphytic fern in trees, living in a humid environment, spreading from an altitude of 5-1050 masl, very commonly found in the lowland forest zone. The pollen of aquatic plants consists of *Nymphaea alba* and *Ottelia alismoides; both* are typical of a shallow water pond or lake. Pollen of open herbaceous swamp vegetation decreased, as well as aquatic pollen has decreased significantly. In this position, the air temperature was similar to the current condition at the temperature of the lowland forest zone with an average of 23.7°C [12]. Such conditions correspond to the climatic data of a Statistical Agency of Bandung City which record from 2015. The average of humidity was 74,5% and range of temperatures 23.20°C-24.50°C [20].

IV. CONCLUSIONS

Based on an analysis of the composition and quantity of pollen of forest plants, herbaceous pollen, Pteridophyta spores and freshwater algae, known that climate changes have occurred. From depth interval 20-10m it is found seven shifted of forest zones, two times lower montane forest, two times submontane forest and three times lowland forest. It is evidence of climate change. The fact of climate change is supported by fluctuations in the quantity of aquatic pollen, composition of open herbaceous swamp vegetation and Pteridophyta spores. The coldest conditions occurred in the first zone, at 20 -19 meters depth, based on carbon dating the event more than 11800 years BP ago, may be due to the effects of the last glacial that occurred in the late Pleistocene was an ongoing process. The warmest temperature occurred at 10 meters depth which similar to the current condition. Based on recorded of aquatic pollen plants and freshwater algae, there were changes of lake water level.

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