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Paleolimnology analysis: the reconstruction of Lake Maninjau with pollen as the proxy

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Abstract. Lake Maninjau is a lake formed due to volcanic processes. Located in Agam Regency, West Sumatra Province, the detail of lake genesis remains a debate among experts. The study of paleolimnology to the reconstruction of Lake Maninjau based palynomorph aims to find out how climate change is happening at Lake Maninjau after the formation of the lake as well as how environmental change such as land use in the area around the lake. Using lake sediment samples, this research will address the specific reconstruction of the lake using pollen as the proxy. Based on the result of the study showed that 150 years ago, Lake Maninjau had a dry climate with climate change become humid 20 years later. Changes from warm to humid climate from 150 years ago can be seen from the growth of vegetation in wetlands, swamps to the mountain rain forest.

1. Introduction

Lake of Indonesia according to the constituent process is divided into several types of which are a volcanic lake, tectonic lake, exposure to flooding and oxbow lake. Based on the process of lake formation, Lake Maninjau is a type of the volcanic lake formed by caldera collapse and explosive eruption that can move the materials in the center of the eruption with large quantities [1]. Lake Maninjau is one of 15 lakes in Indonesia which were included In the national priorities for the conservation period 2010 – 2014, based on the National Conference of Indonesia Lake II in Bali, 2009 on the sustainable management of the lake [2]. The utilization of the lake is for power plants that produce an average annual energy 205 Giga Watt hours (GWh), irrigation water, fish cultivation in floating cages, and as tourism destination. The surface area of water Lake Maninjau is 97,375 ha, maximum length 1646 km, maximum depth 165 m, average depth 105 m, and catchment area 13,260 ha [3]

Maninjau Caldera is a giant caldera which was the result of a giant eruption which produced pyroclastic deposits ranging from 220 - 250 km³, spread as far as 75 km from the center of the eruption [4]. The Maninjau Caldera is known as a volcano-tectonic depression, similar to Lake Toba, in a smaller size. Maninjau Caldera wall has a height of 1,200 – 1,400m above sea level, or 459 m from the surface of the lake which has a depth reaching 157 m [5]. Lake Maninjau is bordered by steep cliffs, especially on the southern wall, which has been hit by residual and former volcanic eruptions. Most of the areas occupied by lava deposits are associated with Maninjau Caldera eruption products, especially the northwest, west, and southeast regions. These lava deposits gradually develop into river deposits, which form an alluvial fan when they reach the coastal plain to the north of Pasaman. These



lava deposits cover almost the entire northeast and east zone of this area whose flow is blocked by older ridge rock units.

The study area is included in the Padang Sheet Geological Map [6], scale 1: 250,000. In this area there are several volcanoes, including Mount Marapi, Mount Singgalang and Tandikat, active type A mountains, which erupted after 1600 [7]; Maninjau Caldera (quaternary) and Sirungan (initial quaternary).

The Quaternary acidic volcanic activity in this area is found along the Sumatra Great Fault zone. The existence of pyroclastic flows found in the Padang Highlands area is related to the volcanic activity of Maninjau Caldera which is located in the Great Sear zone of Sumatra [8].

According to Pribadi *et al* [4] the mechanism of formation of the Maninjau Caldera (figure 1),

- Maninjau Caldera was originated from a composite stratovolcano that developed in the tectonic zone of the Sumatra Great Fault system.
- Maninjau Caldera eruption begins with the process of dismantling the crater and the eruption is interpreted to have an eruption column that is not too high (A).
- This eruption continues and was accompanied by a collapsing column (B) sliding through the upper slope of the volcano, and forming turbulent currents. This process results in the deposition of base surge (a) and followed by the deposition of ignimbrite units (b), which is one of the typical features of a caldera eruption.
- Paroxysmal eruption (climax) occurs by spewing large amounts of magma material, along with the formation of a collapsed caldera (C), which is triggered by a rock mass deficit due to the rapid release of magma to the surface of the soil. At this stage, the characteristic eruption of the typical eruption is rich in lytic fragments (c) originating from the destruction process of the volcanic crater associated with paroxysmal eruptions.

The eruption is continuing with intensity begin to decline. After the crater system has been opened, it was followed by the process for achieving equilibrium gradually (D).

Paleolimnology is freshwater environmental science that used a proxy from irrisediment core to reconstruct environmental and climate change in the past [9]. The study of paleolimnology needs to be developed as a basis for planning future lake, also tools in planning of global response to climate change mitigation based on correlation with a trace of the past. According to Hehanusa and Handayani [10], paleolimnology has not been too pursued in Indonesia. This research aims to uncover the phenomenon of past climate (paleolimnology) and environmental change conditions on Lake Maninjau.

The research aims are to reveal the phenomenon of the past by conducting a quantitative analysis of taxon-taxon from arboreal and non-arboreal pollen, and also to carry out the reconstruction of the land use changes due to climate change that occurred in the time period determined by the analysis of ^{210}Pb on the sediment samples. A sediment sample from the bottom of the lake with pollen as the proxy was used in this research. It will focus on the vegetation changes in response to climate and environmental changes around Lake Maninjau. The results can be used as an indicator of sensitivity from the formation of vegetation response to climate change. The lack of research about paleolimnology creates problems arising such as the absence of pollen database or other proxies that support the study of paleolimnology to the tropics or Indonesian lake environment.

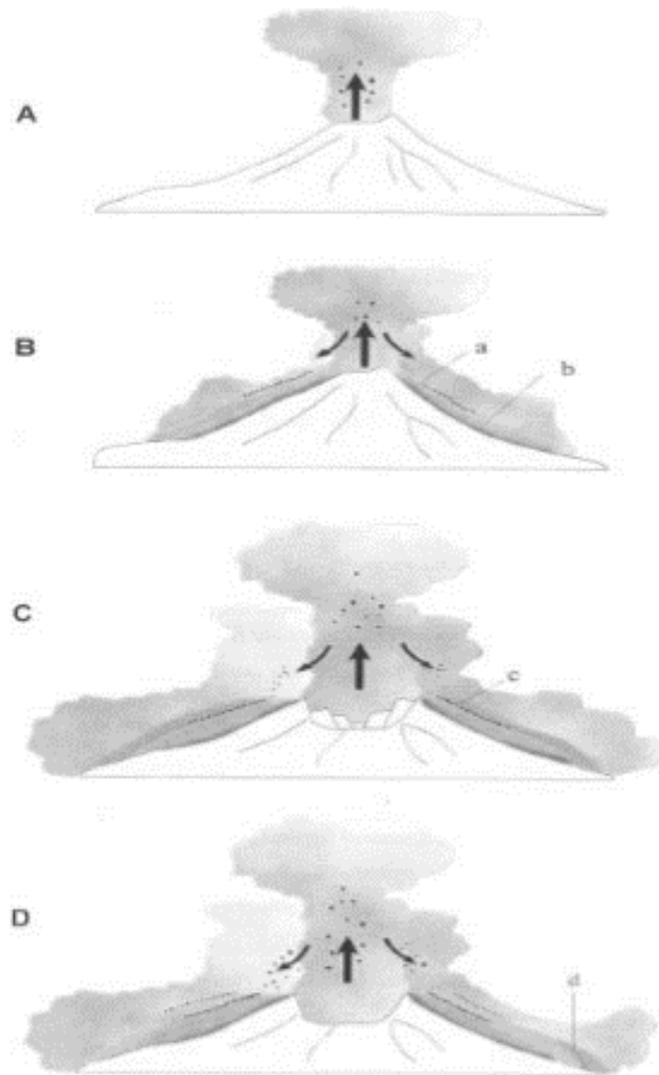


Figure 1. The mechanism of Maninjau Caldera formation [4]

2. Materials and Methods

Lake Maninjau by geographically located on $0^{\circ} 12' 26,63''$ LS – $0^{\circ} 25' 02,80''$ LS and $100^{\circ} 07' 43,74''$ BT - $100^{\circ} 16' 22,48''$ BT, administratively located Tanjung Raya Subdistrict, Agam Regency (figure 1), West Sumatra Province, Indonesia. At present Das Maninjau is dominated by forests (45.3%), shrubs (12.3%), agriculture (39.9%) and settlements, only 2% of which are mostly inhabited by Minang people.

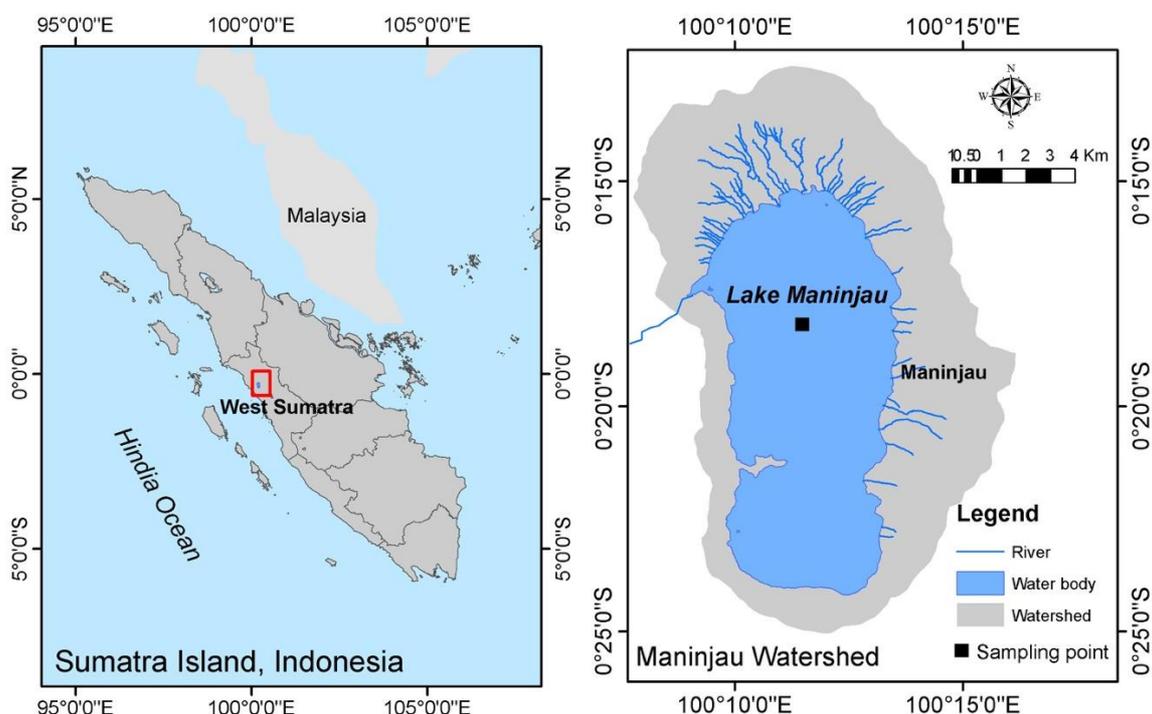


Figure 2. Location of Lake Maninjau

2.1 Laboratory analysis

The sediment sample was sliced with thickness 2cm then be dried with temperature 60°C for 3 days. Weight of dry sample as many as 5 – 15 gr used for the chemical reaction. The method used chemical such as KOH, HF, HCl, and ZnCl₂. The acetolysis reaction conducted as the last reaction [11] with Swirling as modification method [12]. The residue from the chemical process then placed on the preparation slide. The remaining samples were used for dating ²¹⁰Pb which was carried out in National Nuclear Energy Agency of Indonesia (BATAN).

2.2 Pollen and spore description

Observation of pollen and spore were made based on sediment layers that have been through the chemical process completely. A microscope Olympus CX23 with 1000x magnification was used for the description. Total number of pollen and spore from a slide must be at least 200 individuals to get high resolution. If it less than 200 individuals, preparation would be repeated until it gets 200 individuals in a slide. Grouping of taxa plants into groups basis of habitus and vegetation that is Arboreal Pollen (AP) and Non-Arboreal Pollen (NAP) in the form of a percentage. The description guidelines used Erdtman [13], Huang [14], Hesse [15], Moore and Webb [16] and Traverse [17].

3. Results and Discussion

3.1 Radioactive dating

The withdrawal of the remaining sediment samples for each layer which carried out absolute age were using radioactive ²¹⁰Pb. The analysis shows that the oldest figure is 150 years. The absolute age of each 6 cm layer per core sample also founded in other results (table 1). The withdrawal results were considered as sediment age so that it can facilitate the validation of climate change data using pollen.

Table 1. ^{210}Pb radioactive dating in Lake Maninjau

	Depth (cm)	^{210}Pb Activity (Bq/kg)	Years	Date	Mass flux (kg/m ² .y)	Mass flux (gr/cm ² .y)
DM7-1	0-6	88.24	10	2008	1.5	0.15
DM7-2	6-12	177.19	38	1980	0.36	0.04
DM7-3	12-20	74.8	-	-	-	-
DM7-4	20-27	23.34	150	1868	-	-

3.2 Climate reconstruction

Climate change observation was focused on any significant changes that happen in each occurrence of pollen individuals over the change in the AP/NAP percentage that are striking or dominate a climate-forming plant in the existing sediment samples stratum. Mangrove identifier taxa found that rarely occurs in the region of lake specially *Acrosticum aureum* and *Acrosticum danadefolium*. Both of mangrove species that commonly grows in a variety of condition growing and therefore cannot be used as a reference in the study because the pore can appear in lowland forest and montane forest. In this study, the reconstruction of Lake Maninjau watershed conditions can be seen from the AP/NAP percentage (table 2).

The analysis shows the zoning of climate change over the past 150 years. Reconstruction of habitat and climate conditions is shown below:

Zone 52 – 40 cm

First observation performed on sediments of -52 cm depth from the top of the sediment. The percentage of NAP is 53.2%. the vegetation plant was dominated by *Panicum rapens* and *Ipomea pes-caprae* that lived in the swamp while *Typha angustifolia* and *Eragrostis ellioti* lived in wetland. It showed that, the formation of the sediment, the face of water lake is higher so the area was inundated (litoral) wider with overgrown by identifier plants wetland and swamp area. The composition of pollen indicates that forest formed is an open forest with hot climate.

Zone 40 – 34 cm

The change in percentage was noticeable at a depth of -40 cm from the top of the sediment. The appearance of AP is 63.6% which is dominated by high-level plants such as *Sapindaceae* and *Artocarpus communis* which lived in humid climate habitats. both of these plant habitus indicate a change in climate from dry to humid conditions and then cold climatic conditions in the past.

Zone 34 – 32 cm

At the depth of -34 cm from the top of sediment, found the percentage of vegetation that dominates is NAP up to 68%. The vegetation of plants that grow is *Pilea (Moraceae)*, *Poaceae*, *Typha angustifolia*, and *Gramineae* (figure 3b.). That plant is a dry climate identifier with wetland as its habitat. The plants as the identifier of humid climate change into a dry climate.

Zone 32 – 26 cm

At the depth of -32 cm from the top of sediment, the percentage of vegetation plants are dominated with AP up to 61.7%. the plants are *Nenga (Palmae)*, *Lugopollis sp. (Aglaia type)* (figure 3j.) and *Palmaepollenites kutchensis* (figure 3i.) as plants of the tropical forest as the habitus. It was indicated that the climate was changed into the humid climate.

Zone 26 – 20 cm

There is no significant change at depth -26 cm from the top of sediment, vegetation dominate by NAP vegetation with the percentage of 80.6%. This is directly proportional to percentage of non-arboreal

vegetation that lived a lot in littoral area of the lake i.e. *Psilotum sp.*, *Poaceae* (figure 3c.), *Dicranopteris linearis*, and *Pilea (Moraceae)*. This layer is founded layer of a tuff which was estimated as the tuff product of Mount Krakatau that erupted in 1886. This result is reinforced by the results of dating observation by Pb_{210} which shows that this layer has an age range of 1865, also affected by the eruption of Mount Krakatau which was exposed to Lake Maninjau.

Zone 20 – 12 cm

At the depth of -20 cm from the top of sediments, the percentage of vegetation AP around 50%, with dominance vegetation by *Pometia. Pometia* (figure 3j.) is an identifier plant that identifier low mountain rain forest 1000 – 1200 mdpl. Another plant vegetations grown are *Typha latifolia*, *Poaceae*, *Osmunda regalis*, *Sapindaceae* (figure 3d.) and *Palmaepollenites kutchensis*. Based on the presence of vegetation that characterizes low mountain rainforests, dry climate changes become more humid with the presence of vegetation marking low mountain rainforests.

Zone 12 – 2 cm

At the depth -12 cm from the top of sediment, the vegetation of NAP dominate up to 60%. The dominate plant vegetations are *Cyclophorus sp.* (figure 3a.), *Psilotum sp.*, *Eragrostis elliotti*, and *Solonum americium*. Based on the result of the percentage AP/NAP, it can be concluded there is a change in humid climate become drier. This change occurred about 40 years ago based on the result of dating observation used ^{210}Pb .

Zone 2 – 0 cm

At the depth of -2 cm from the top of sediment based on analysis of pollen, vegetation grown dominance by AP up to 60%. The presence of more diverse vegetation and it is appearance only at this layer like *Timonius sp* (figure 3e.). And *Elyteranthe*. The productive plant is more dominate, like the plant from *Aranceae* family that lived in low mountain rainforest. The climate at Lake Maninjau showed that humid climate around 22 – 23°C.

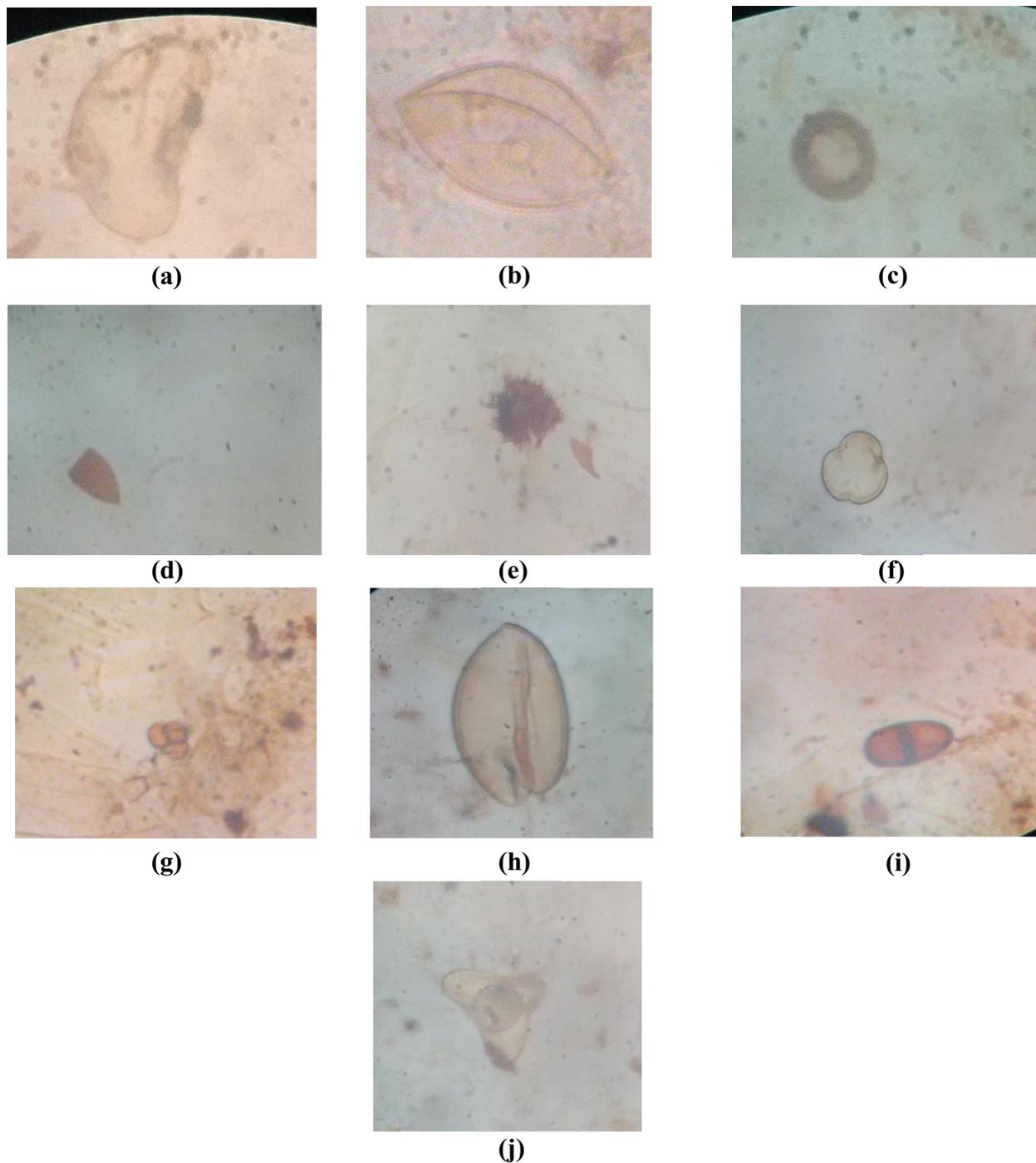


Figure 3. Photomicrographs of pollen from Lake Maninjau: (a) *Cyclophorus sp.*; (b) *Gramineae*; (c) *Poaceae*; (d) *Sapindaceae*; (e) *Timonius sp.*; (f) *Rubiaceae*; (g) *Typha latifolia*; (h) *Palmaepollenites kuchensis*; (i) *Lugopollis sp.*; (j) *Pometia sp.*

Table 2. Non-Arboreal Pollen (NAP) graphic

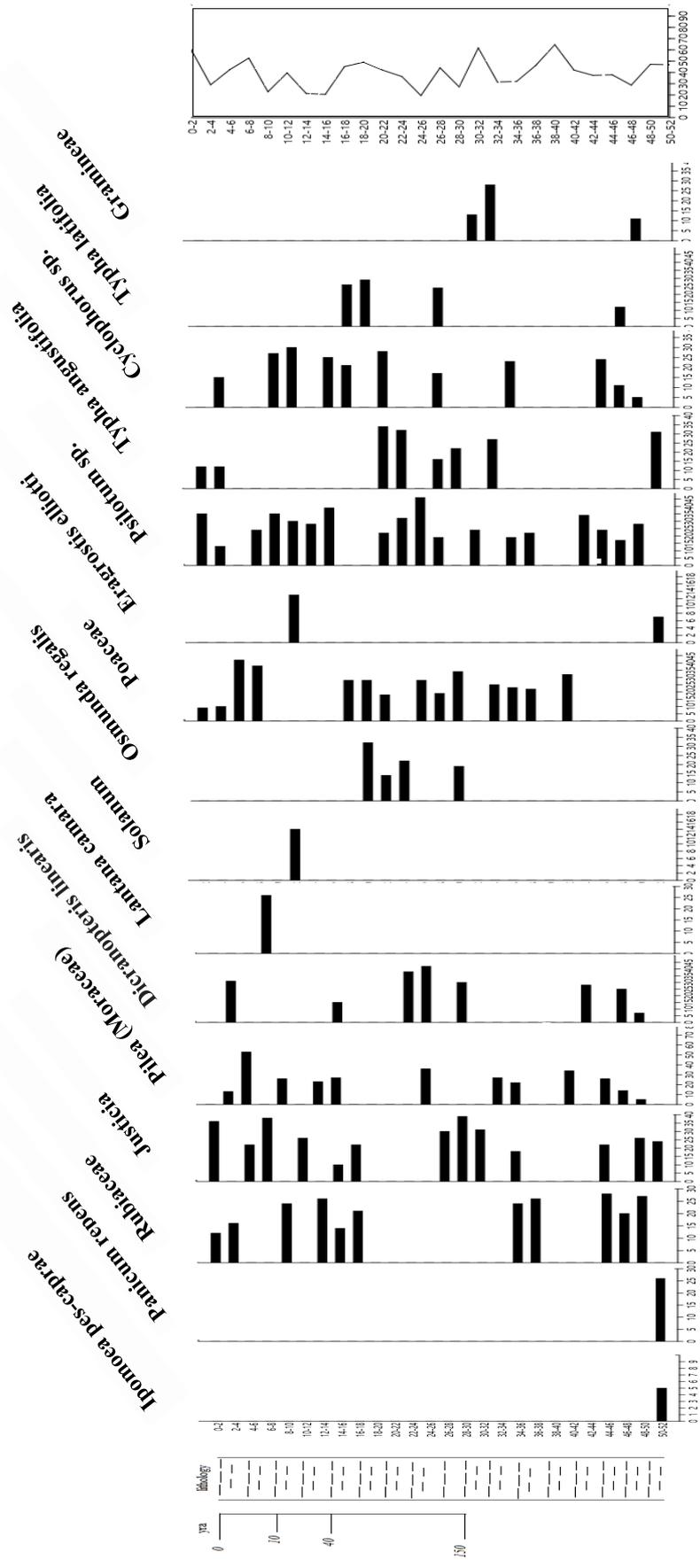
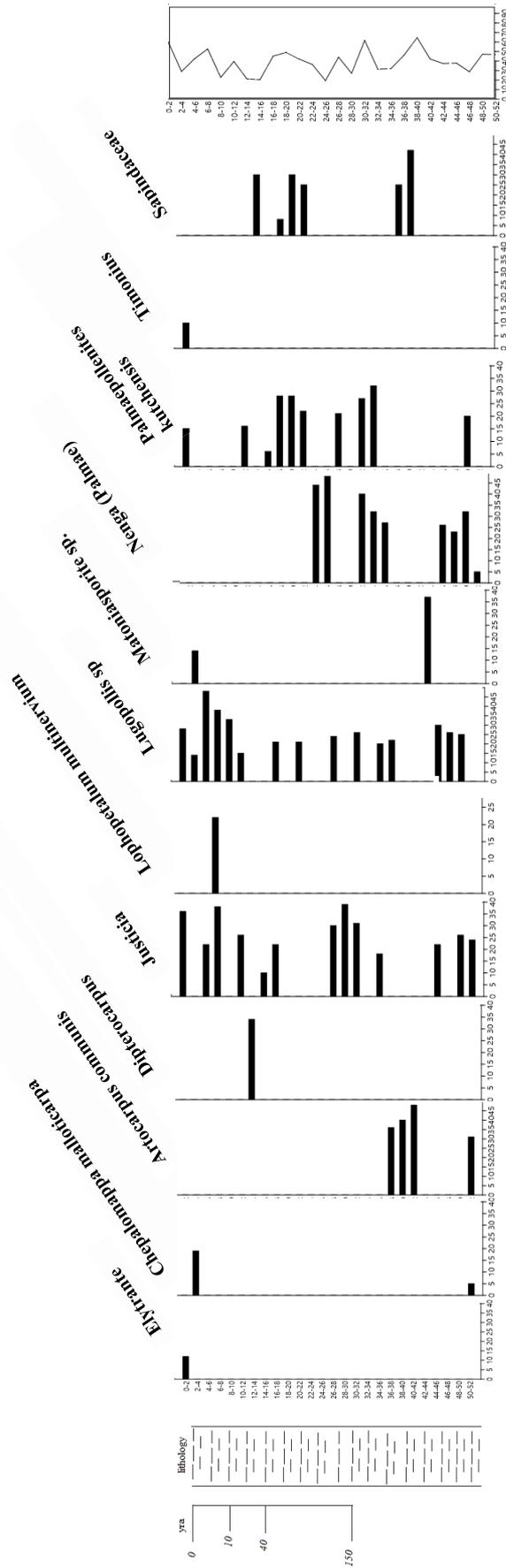


Table 3. Arboreal Pollen (AP) graphic



4. Conclusions

The abundance of pollen as a proxy in this research is dominated by pollen derived from around the lake and small part of pollen comes from out of the area around the lake. It occurs due to the transport of sediment that can be through along with the wind or water supply for the lake. Climate change views based on the classification of vegetation pollen AP and NAP indicates not so much climate change is happening. There is no drastic climate change for over 150 years because climate around the lake was a warm dry until humid. The changes of land use in the past caused by water surface of the lake was higher than waterlogged of littoral region, showed by the grown plant from wetland until swamp habitats such as *Panicum repens*, *Typha angustifolia*, *Typha latifolia*, *Eragrostis elliotti*, *Ipomea pes-caprae* and *Gramineae*. At the present day, climate in the region of lake is dominated with humid climate. It is shown by the percentage of Arboreal plants which were dominated by the productive plants i.e *Pometia sp.*, *Sapindaceae*, *Rubiaceae*, and *Nenga (Palmae)* as identifier of rainforest. The changes were observed by any variable to reconstruction of Lake Maninjau generally agreed between used pollen as the proxy with result of study past environments by clay minerals as the proxy.

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