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Palynological Characteristics of Iabang Lake Sediments

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Abstract: *This* paper presents a pollen and spore-based record from lake sediment in Central Highlands of Vietnam, spanning the last 22.5 cal ka BP. The analysis of spores and pollen derived from a sediment core drilled to a depth of 17.7m in Iabang Lake (Dak Doa District, Gia Lai Province) allowed for the reconstruction of paleoclimate variability over this period. The climate conditions in the Iabang Lake area have changed from temperate to subtropical and then to tropical conditions. Our new findings are consistent with other regional paleoclimate archives. The record of spores and pollen in the lake sediments also indicates a dry and cold interval interspersed with subtropical phases, occurring between approximately 17.1 and 16.1 cal ka BP, which corresponds to the Heinrich 1 event.

Keywords: pollen, spore, palynology, lake sediments, Iabang Lake, paleoclimate.

1. Introduction

Paleoclimate reconstruction using lake sediments is a critical field of study that provides insights into historical climate changes over thousands to millions of years. Lakes serve as natural archives, preserving layers of sediment that accumulate over time, which contain valuable information such as pollen, spores, and organic matter. By analyzing these sediments, researchers can infer past environmental conditions, including temperature, precipitation patterns, and the types of vegetation present [1-19].

Globally, numerous studies have utilized lake sediment analysis to reconstruct paleoclimate conditions [1-20]. Research in North America has revealed shifts from glacial to interglacial periods through detailed

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stratigraphic analysis [11, 17]. Studies in Europe and Asia have identified periods of significant climate events, such as the Little Ice Age and Medieval Warm Period, by examining diatom and foraminifera records [5-7, 13].

In tropical regions, lake sediments have uncovered evidence of past monsoonal patterns and their impact on local ecosystems [1-2, 9]. Moreover, advancements in analytical techniques, such as high-resolution dating methods and isotopic analysis, have enhanced the accuracy of paleoclimate reconstructions. These findings are essential not only for understanding past climates but also for informing predictions about future climate scenarios in the context of ongoing global changes.

Pollen and spores produced by plants preserved in lake sediment are an essential proxy for paleoclimate reconstruction. By analyzing the types and abundance of these microfossils, researchers can infer changes in temperature, precipitation, and ecosystem dynamics over time [1]. This method has been widely applied in various regions worldwide. In temperate zones, studies have identified transitions between glacial and interglacial periods by examining shifts in plant communities, as reflected in pollen assemblages [17]. In tropical areas, such as Southeast Asia and the Amazon Basin, spore and pollen analyses have revealed responses of ecosystems to climatic fluctuations, including monsoonal changes and periods of drought [4].

Natural lakes in the Central Highlands (Gia Lai, Dak Lak provinces,...) are ideal sedimentary basins for regional paleoclimate restoration through stratigraphic methods, including spore-pollen analysis. However, research on pollen and spore composition in lake sediments is still limited. Research on lake sediments in the Central Highlands has just focused on paleoenvironmental reconstruction [21]-[24]. Paleoclimate condition of the Central Highlands was interpreted for the last 1250 years BP using geochemical proxies [25].

2. Study Area

Ia Bang Lake, located in Gia Lai Province, Vietnam, lies approximately 30 kilometers southwest of Pleiku City (Fig. 1). The lake covers a natural surface area of about 32 hectares. The following section describes the geological, geographical, and climatic conditions that influence the vegetation characteristics of the study area.

2.1. Geological and Geographical Characteristics

Iabang Lake occupies a volcanic depression within the Pleiku Plateau of Gia Lai Province (Fig. 1). The Pleiku Plateau forms part of one of the most extensive Cenozoic volcanic provinces in Vietnam, developed in response to regional tectonic activity associated with the collision between the Indian and Eurasian plates during the Cenozoic era [26]. This tectonic interaction triggered widespread pull-apart rifting, faulting, and basaltic volcanism across Mainland Southeast Asia, including the Central Highlands of Vietnam.

Volcanic activity in this region began approximately 17 Ma and continued intermittently from the Neogene into the Quaternary, ceasing around 0.2 Ma. The eruptions produced thick sequences of basaltic lava that now form several extensive volcanic plateaus, most prominently the Pleiku Plateau in Gia Lai Province and the Buôn Ma Thuột Plateau in Đắk Lắk Province (Fig. 1). Covering more than 4,000 km^2, the Pleiku volcanic complex represents one of the largest Cenozoic basaltic fields in Vietnam. Its evolution occurred in two principal eruptive phases: an early shield-building stage during the Miocene–Pliocene (6.5–3.4 Ma), which generated a basaltic edifice up to 150 m thick, and a later phase during the Pleistocene (2.4–0.2 Ma) characterized by thinner, late-stage lava flows.

Within this volcanic landscape, numerous explosion craters and maars formed more than 200 ka ago, creating enclosed depressions that now host several crater lakes, including Iabang Lake [26].

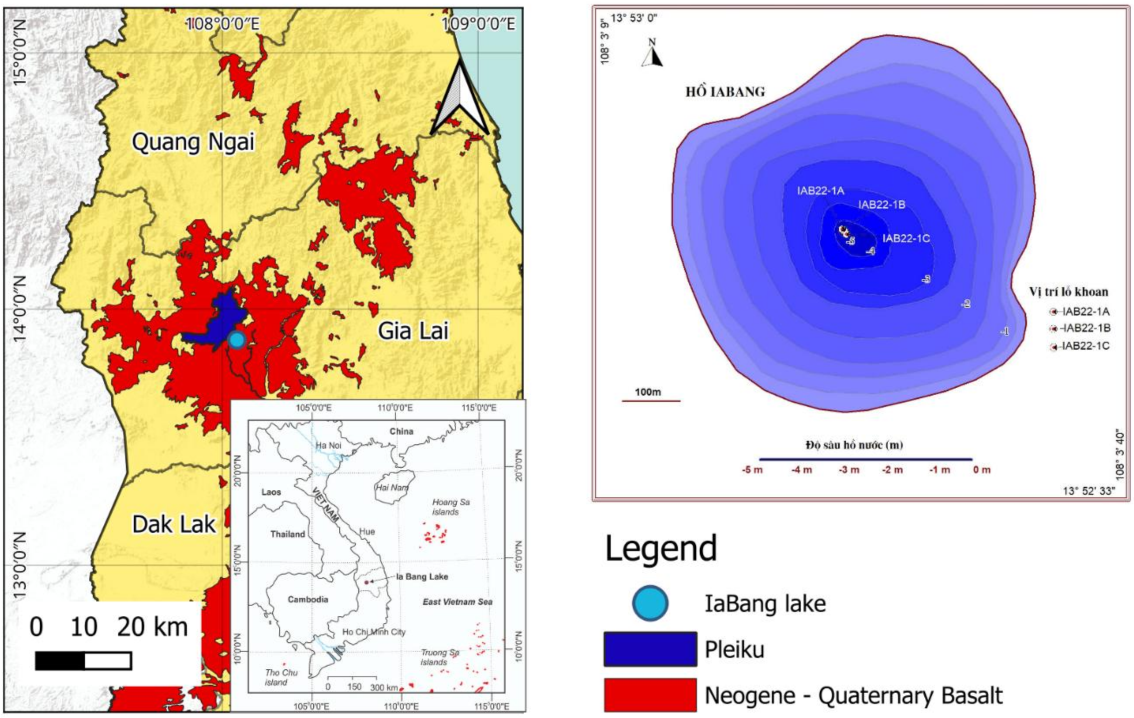

Figure 1. Location of Iabang Lake.

2.2. Climate Conditions

A tropical highland climate, characterized by distinct wet and dry seasons, prevails around Iabang Lake in Gia Lai Province. The region experiences mild temperatures throughout the year, averaging between 18°C and 25°C. The rainy season typically occurs from May to October, bringing heavy rainfall that nourishes the lush vegetation and fills the lake. In contrast, the dry season lasts from November to April, which is characterized by cooler temperatures and less humidity [27]. This pleasant climate supports a diverse array of flora and fauna, making Iabang Lake an attractive destination for visitors seeking a natural retreat.

2.3. Vegetation

Iabang Lake is surrounded by rice fields and pine forests (Fig.2). The pine forest is dominated by *Pinus kesiya*. The extensive pine forests create the distinctive landscape of the Central Highlands, characterized by tall, straight trees with broad canopies and high adaptability to dry climate conditions. In lower areas with a pronounced dry season, deciduous dipterocarp forests become more prevalent, featuring species such as *Dipterocarpus*, *Lagerstroemia*, and *Dalbergia* [28], [29].

Figure 2. Surrounding area of the Ia Bang Lake.

3. Materials and Methods

3.1. Materials

Fifty-three sediment samples were subsampled from an 18 m piston-cored sediment core in Ia Bang Lake, Gia Lai. Characteristics of each sediment interval are briefly described in Table 1. The sediments were processed using the procedure described by Fægri and Iversen [30]. In this study, we used potassium hydroxide to remove humic substances and organic acids, hydrochloric acid and hydrofluoric acid were used to remove carbonates and silicates. An acetolysis mixture was used to remove cellulose fibers from the pollen surface and within the residue, clarifying the pollen surface structure and increasing the pollen concentration in the sample.

Table 1. Sediment characteristics from the core

Depth (cm)	Sample No.	Sample depth (cm)	Sediment characteristics
15 – 130	IAB22 – 1C – 1 – 4D/E	15	Dark clay, very smooth when scratched, with alterations of slightly lighter and darker parts in the range of 5 cm, fine lamination in the range of a few mm (mostly lost in the current condition). Two slightly darker laminations at 100 cm.
	IAB22 – 1C – 1 – 18D/E	71	
	IAB22 – 1C – 2 – 4D/E	123	
	IAB22 – 1C – 1 – 32D/E	127	
130 – 177	IAB22 – 1C – 2 – 14D/E	163	Transition zone/ boundary, sediments are slightly stiffer when scratched, gradual color change with depth (color becomes lighter and yellowish brown), light lamination at 165 cm.
177 – 280	IAB22 – 1C – 2 – 22D/C	195	Gradual boundary from dark yellowish brown to dark gray, darker in the lower part of the unit, with clear mm-scale laminations.
	IAB22 – 1C – 3 – 4D/E	228	
	IAB22 – 1C – 3 – 14D/E	268	
280 – 315	IAB22 – 1C – 3 – 22D/E	300	Black and distinct boundary, homogenous appearance, high organic content.
315 – 385	IAB22 – 1C – 4 – 4D/E	333	Spotted/ sprinkled with mm-sized particles and large cm-sized, organic clasts, very transitional towards the end of the unit, generally disturbed appearance.
	IAB22 – 1C – 4 – 14D/E	373	
385 – 418	IAB22 – 1C – 4 – 22D/E	405	Yellowish and brighter, less visible laminations.
418 – 490	IAB22 – 1C – 5 – 4D/E	430	Stronger, clearly visible laminations, alternations of brighter and darker layers.
	IAB22 – 1C – 5 – 14D/E	470	
490 – 530	IAB22 – 1C – 5 – 22D/E	502	Only weak visible laminations, uniform color across the unit.
	IAB22 – 1C – 6 – 4D/E	530	
530 – 565	IAB22 – 1C – 6 – 14D/E	570	Stronger visible laminations, darker coloration.
565 – 600			Similar to unit 4, spotted/ marbled appearance, colorful layers in cm-range from 595 – 600.
600 – 710	IAB22 – 1C – 6 – 22D/E	602	Color becomes darker downwards, lighter layer from 630 – 635.
	IAB22 – 1C – 7 – 4D/E	629	
	IAB22 – 1C – 7 – 14D/E	669	
	IAB22 – 1C – 7 – 24D/E	709	
710 – 800	IAB22 – 1C – 8 – 4D/E	734	Color changed downward from dark brown/dark yellowing brown to slightly darker and more silty, organic remains, charcoal found at 743 cm depth, and a brighter lens found at 780 cm depth.
	IAB22 – 1C – 8 – 14D/E	774	

800 – 940	IAB22 – 1C – 8 – 22D/E	806	Color altered from lighter to darker clayey, with visible organic matter at 855 cm depth.
	IAB22 – 1C – 9 – 4D/E	832	
	IAB22 – 1C – 9 – 14D/E	872	
	IAB22 – 1C – 9 – 24D/E	912	
	IAB22 – 1C – 10 – 4D/E	932	
940 – 1189	IAB22 – 1C – 10 – 14D/E	972	Homogeneous, dark color, continuously darker with no variation.
	IAB22 – 1C – 10 – 22D/E	1004	
	IAB22 – 1C – 11 – 4D/E	1028	
	IAB22 – 1C – 11 – 14D/E	1068	
	IAB22 – 1C – 11 – 22D/E	1104	
	IAB22 – 1C – 12 – 4D/E	1135	
	IAB22 – 1C – 12 – 14D/E	1175	
1190 – 1268	IAB22 – 1C – 13 – 4D/E	1194	Lighter layer.
	IAB22 – 1C – 13 – 14D/E	1234	
1268 – 1320	IAB22 – 1C – 14 – 4D/E	1295	Darker layer.
1320 – 1420	IAB22 – 1C – 14 – 14D/E	1335	Gradual change from top to bottom.
	IAB22 – 1C – 14 – 24D/E	1375	
	IAB22 – 1C – 15 – 4D/E	1394	
1420 – 1689	IAB22 – 1C – 15 – 14D/E	1430	Homogeneous with a fragment of organic matter across the unit. Increasing silt content toward the bottom.
	IAB22 – 1C – 15 – 24D/E	1470	
	IAB22 – 1C – 16 – 4D/E	1489	
	IAB22 – 1C – 16 – 14D/E	1529	
	IAB22 – 1C – 16 – 24D/E	1569	
	IAB22 – 1C – 17 – 4D/E	1589	
	IAB22 – 1C – 17 – 14D/E	1629	
	IAB22 – 1C – 17 – 24D/E	1669	
1689 – 1730	IAB22 – 1C – 18 – 4D/E	1690	Dominant by clay, strong color change layer 3 – 5 cm thickness between lighter and darker, very dark grayish brown, and very dark brown
1730 – 1763	IAB22 – 1C – 18 – 14D/E	1730	Still clay dominated, but more homogenous
1763 – 1797	IAB22 – 1C – 18 – 26D/E	1778	More silty clay

3.2. Methods

Pollen and spores were counted and identified under an optical microscope, primarily at 400x magnification, while smaller pollen grains were identified under a 1000x magnification microscope (using oil immersion). Identification of spore and pollen taxa was based on modern pollen atlases from China [31], [32] and modern samples from Vietnam, collected by Nguyen Thuy Duong in 2004.

To determine the absolute age of the cores, two samples were collected from the top and bottom of the core, at depths of 0.17 m and 17.70m, respectively. ^{14}C dating was performed using an accelerator mass spectrometry (AMS) device. A calibration procedure using CALIB rev 8.1.0 was applied. The ages are expressed as cal. yr BP.

A minimum of 150 spore and pollen grains were counted in each sample to calculate the percentage of spore and pollen types in the sample. The C2 software was used to construct pollen diagrams showing the percentage changes in spore and pollen types with depth. Spore and pollen types were grouped into ecological categories to interpret paleoclimatic conditions.

4. Pollen and Spore Characteristics and Implications for Paleoclimate Variability

4.1. Radiocarbon Dating

In determining the absolute age of a sample based on the results from CALIB rev. 8.1.0, multiple possible calibrated age ranges are obtained, each associated with a corresponding possibility (Table 2). The final estimated age is calculated as the weighted sum of the mean ages of all possible ranges, where each mean age is multiplied by its respective possibility. As a result, the ^{14}C-calibrated date at a depth of 17.70m was estimated to be 22.4 ka BP. The calibrated ^{14}C date calculated for the sample collected at a depth of 0.17 m is approximately 131 years BP. With only two ^{14}C dating results, the sedimentation rate of the lake was calculated to be 0.072 cm/year. This data is quite consistent with the sedimentation rate (~0.085 cm yr^{-1}) inferred by Nguyen-Van et al., [24] from preliminary ^{14}C age estimates of radiocarbon-dated samples obtained from this core.

4.2. Pollen and Spore Characteristics

Seventy-six types of spores and pollen belonging to 50 families were identified in the sediment core from Iabang Lake. Typical pollen were divided into ecological groups (Table 2, Figs. 3 and 4). Based on spore and pollen characteristics, the sediment core from Iabang Lake is divided into seven zones. Descriptions of the seven zones are as follows:

Zone Ib1 (17.78-13.9 m depth) is characterized by the abundance of pollen and spores, with a dominance of subtropical and temperate pollen from the families Pinaceae, Fagaceae, and grass pollen from Gramineae gen indet. Tropical pollen types are rarely found in this zone. Additionally, other temperate pollen types such as *Picea* sp., *Carpinus* sp., *Corylus* sp., and *Abies* sp. are also present in the sediment of this zone. According to the sedimentation rate, the Ib1 sediment was formed in the time range from 22.5 to 17.1 cal kyr BP.

Table 2. ^{14}C dating result

Sample No.	Lab-ID	Depth	^{14}C age BP (uncalibrated)	Calibrated ^{14}Cage (BP)	
				2σ range	Possibility (%)
IAB22-1B-2-90	29843	172	123 ±50	6 – 153	62.2
				181 - 279	35.5
				171 - 180	2.3
IAB22-1C-18-85	29359	1770	18410 ±230	21860 - 22923	100

Zone Ib2 (13.9-13.15 m depth) is characterized by the poverty of pollen and spores. Pollen types found in this zone include Gramineae gen indet and *Artemisia* sp., *Pinus* sp., *Quercus* sp., *Castanopsis* sp., and Moraceae gen indet. According to the sedimentation rate, the Ib2 sediment was formed in the time range from 17.1 to 16.1 cal kyr BP.

Zone Ib3 (13.15-10.6 m depth) is characterized by the abundance of pollen and spores, with a dominance of pollen from the family Fagaceae, *Pinus* sp., and the presence of temperate pollen types such as *Picea* sp., *Tsuga* sp., *Larix* sp., and *Abies* sp. Herb pollen from the family Gramineae shows a low ratio in this zone. Shrub pollen types are regularly found in this zone. According to the sedimentation rate, the Ib3 sediment was formed in the time range from 16.1 to 12.5 cal kyr BP.

Zone Ib4 (10.16-8.16 m depth) is characterized by the abundance of Gramineae gen indet and a lower ratio of *Pinus* sp. and

Quercus sp. pollen types. *Castanopsis* sp. shows higher values in this zone. According to the sedimentation rate, the Ib2 sediment was formed in the time range from 12.5 to 9.2 cal kyr BP.

Zone Ib5 (8.16-6.36 m depth) is characterized by a lower concentration of pollen and spores, with a dominance of pollen from the family Moraceae. Pollen types from the Fagaceae and Gramineae families show a lower value in this zone. Tropical spores and pollen types show more diversity in this zone than in the previous ones. According to the sedimentation rate, the Ib2 sediment was formed in the time range from 9.2 to 6.7 cal kyr BP.

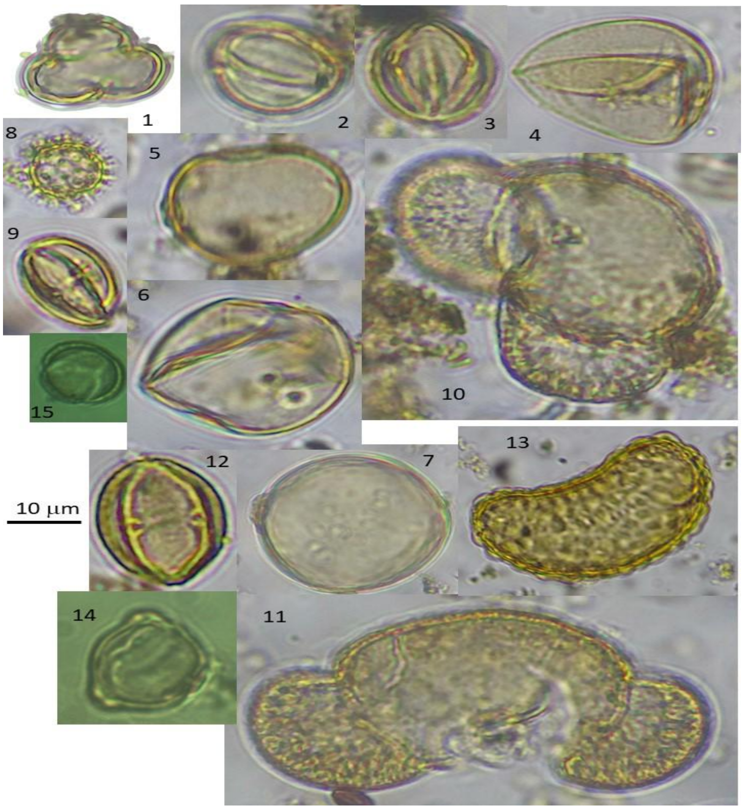

Figure 3. Some typical pollen types.
1-3: *Quercus* sp.; 4-7: Gramineae gen. indet.;
8: Compositae gen. indet.; 9: Castanopsis sp.;
10. *Pinus* sp., 11. *Keteleria* sp., 12. *Phyllanthus* sp., 13. *Polypodium* sp., 14. *Carpinus* sp.,
15. *Artemisia* sp.,

Zone Ib6 (6.36-5.16 m depth) is characterized by the abundance of Gramineae gen. indet., Quercus sp., and Cyclobalanopsis sp. *Pinus* sp. shows a relatively high value in this zone. According to the sedimentation rate, the Ib2 sediment was formed in the time range from 6.7 to 5.0 cal kyr BP.

Zone Ib7 (5.16-0.15 m depth) is characterized by the abundance of Gramineae gen indet and the decrease of Pinus sp., and *Quercus* sp. The Zone Ib7 can be divided into three subzones.

Subzone Ib7/1 (5.16-3.89 m depth) is characterized by the poverty of pollen and spores, which are dominated by pollen from the Fagaceae and Gramineae families. A large amount of charcoal was found in the sediment at a depth of 4.30m, despite the sediments having been processed with strong acid. According to the sedimentation rate, the subzone Ib7/1 sediment was formed in the time range from 5.0 to 3.2 cal kyr BP.

Subzone Ib7/2 (3.89-2.12 m depth) and Subzone IB7 (2.12-0.15 m depth) are separated by a decrease in Pinus sp. and Quercus sp. Both pollen types show the lowest values in the subzone IB7/3. According to the sedimentation rate, the subzone Ib7/2 sediment was formed in the time range from 3.2 to 0.8 cal kyr BP, and subzone IB7/3 was formed in the time range from 0.8 to the present.

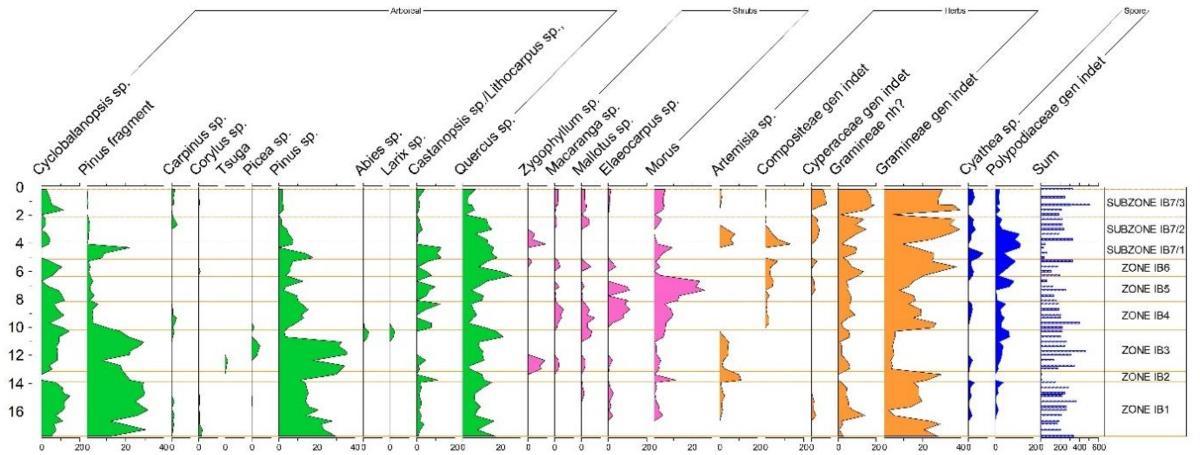

Figure 4. Pollen diagram of selected taxa.

4.3. Paleoclimate Implications

The dominance of Pinaceae and Fagaceae, along with the low diversity of tropical pollen in Zone Ib1 (22.5-17.1 cal kyr BP), indicates subtropical conditions. The presence of temperate pollen such as *Abies* sp. may suggest more temperate conditions. The ^{14}C dating at 17.78 m indicates that a temperate climate prevailed around 22.5 ka BP, characterized by the dominance of mixed conifer–broadleaf forest. The dominance of gymnosperm and herb pollen indicates a dry environment for this period. This new findings are in line with the conclusions of the other area in Mainland Southeast Asia [33]. The presence of mixed conifer–broadleaf forest inferred from the pollen assemblages of zone Ib1 also supports the interpretation proposed by Hamilton et al., [34] that forest mosaics, rather than continuous savanna corridors, dominated Mainland Southeast Asia during the Last Glacial Maximum.

The poverty of pollen in zone Ib2 (about 17.1 cal kyr BP to 16.1 cal kyr BP) and the pollen composition of this zone indicate a cold and dry climate making the sedimentary environment unfavorable for the deposition and preservation of spores and pollen. This result is consistent with the Heindrich event 1 (H1) [35] and the evidence of H1 in Towuti Lake (Sulawesi, Indonesia) [36].

Temperate to subtropical conditions may have prevailed during the formation of zone Ib3 (approximately 16.1 cal kyr BP to 12.5 cal kyr BP), characterized by higher precipitation, which facilitated the accumulation of pollen and spore deposits in the lake sediments.

From the onset of Zone Ib4 (ca. 12.5-9.2 cal kyr BP), the climate conditions within the study area shifted to tropical conditions, triggering the strong development of subtropical and tropical vegetation and a decrease in the abundance of Pinus sp. Although the timeline presented in this paper may differ slightly from other research due to the limitations of ^{14}C dating, our results are relatively consistent with the data published by Đào-Trung et al., [23] that demonstrated an increase in temperature at about 11.7 cal kyr BP in the Central Highlands, Vietnam. An intensification of the Australian–Indonesian monsoon rainfall was also recorded in a stalagmite collected in Liang Luar cave (Flores, Indonesia) [37].

An indication of strengthened humid tropical conditions is clearly evident in zones Ib5 (approximately 6.7-5.0 cal kyr BP) and Ib6 (approximately 5.0 to 3.2 cal kyr BP), as indicated by a decrease in the frequency of Pinus sp. and *Quercus* sp. It is also suggested that the mid-Holocene humid tropical climate occurred in various areas in Southeast Asia [33], [36]-[39].

Table 3. Ecological groups of typical pollen types

Tropical	Sub-tropical	Temperate
Elaeocarpus sp.,	Castanae sp.,	*Abies* sp.,
Artemisia sp.,	Cyclobalanopsis sp.,	Betula sp.,
Aralia sp.,	Dacrydium sp.,	Carpinus sp.,
Brousenia sp.,	*Larix* sp.,	Corylus sp.,
Euphorbia sp.,	Lithocarpus sp.,	Ephedra sp.,
Helwingia sp.,	Myrica sp.,	*Picea* sp.,
Ilex sp.,	Osmanthus sp.,	Keteleria sp.,
Macaranga sp.,	*Pinus* sp.,	
Magnolia sp.,	Platycarya sp.,	
Mallotus sp.,	Pterocarya sp.,	
Phyllanthus sp.,	Quercus sp.,	
Podocarpus sp.,		
Rhamnus sp.,		
Salix sp.,		
Typhar sp.,		
Zygophyllum sp.,		

The sediment formation corresponding to zone Ib7/1 (ca. 3.2–0.8 cal. ka BP) may reflect a period characterized by a warmer and drier climate and/or increased anthropogenic influence. Two factors may have driven deforestation, which in turn led to reduced pollen deposition and production of charcoal in the lake sediments. The weaker East Asia summer monsoon indicated for a drought period from 0.9 to 0.6 cal kyr BP was also recorded from Ea Tyn Lake, the Central Highlands of Việt Nam [25].

The climate conditions for the formation of sediments in the Ib7/2 and Ib7/3 transition zones transitioned to humid tropical conditions, characterized by the abundance of pollen and spores in the sediments and a decrease in temperate pollen.

5. Conclusion

The results of pollen and spore analysis from the sediment core taken from Iabang Lake, Dak Doa District, Gia Lai Province, allowed us to reconstruct paleoclimate variability over the past 22.5 cal ka BP. The paleoclimate trend in the Iabang Lake area has evolved from temperate to subtropical and then to tropical conditions. The record of spores and pollen in the lake sediments also indicates a period of dry and cold conditions interspersed with a subtropical climate at approximately 17.1 to 16.1 cal kyr BP. The scarcity of pollen and spores in the sediment at depths of 4.30-4.02 m may indicate an arid, hot climate at approximately 3.2 to 0.8 cal kyr BP, interspersed with humid tropical conditions, but may also be a sign of impoverishment due to increased erosion caused by human activity.

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