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Paleoecological analysis of the sediments of Lake Mucubaji, Venezuelan Andes

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Abstract. Pollen and spore analysis of lake sediments at 3540 m elevation, in the paramo belt, has shown that the vegetation has not changed during the last 8300 years. The Mucubaji valley was covered by paramo vegetation, similar to the present, but with less 'Espeletias' (Compositae). *Podocarpus* pollen from the forest at lower elevation was more abundant in the past, and declined during the last few centuries, suggesting the destruction of the trees by humans. There was an increase in the pollen concentration of paramo pollen types between *c.* 5400 and 6075±290 years BP, indicating a denser vegetation during this interval, probably due to an increase in humidity in the valley. The absence of pollen deposition at depths up to 2.40 m in the last two millennia suggests that the water level of the lake decreased from 2235±380 years BP, until the present, when an artificial dam was built.

When compared to other sites in the same mountains, Lake Mucubaji sediments show small changes in the pollen assemblages during the Holocene. The attenuated signals must be due to the fact that the site is located in the core of the paramo belt, away from the ecotones of superparamo and the transition zone to forest.

Key words. Palynological analysis, lake sediments, Venezuelan Mountains, Holocene, Andean paleoecology.

INTRODUCTION

Studies of glacial geology of the Venezuelan Andes have shown that the Páramo de Mucubaji (3550–3600 m) was covered by glacial ice during the Late Pleistocene (Mérida) glaciation. A deep glacial valley was eroded and within the valley four end moraines indicate that the retreat of the glacier was in steps (Fig. 1). Terraces in this valley were formed as a result of normal faulting along an active fault belonging to the Boconó Fault zone (Schubert, 1970; Giegengack & Grauch, 1975; Schubert & Henneberg, 1975).

Palynological evidence from one of these terraces (Salgado-Labouriau, Schubert & Valastro, 1977) has shown that the glaciers had retreated from the valley by 12,650±130 radiocarbon yr BP. Superpáramo vegetation, similar to that found at present in elevations above 3600 m, but poorer in species, covered the site at the time (Mucubaji cold phase). From 12,250 to 11,960 yr BP, a warm, short interval took place (Mucubaji warm phase) during which tree line increased in elevation by 550 – 850 m, to an elevation similar to that of present. During this warm phase vegetation was abundant. Both phases were detected in the Colombian Andes: the 'El Abras' Stadial (van Geel & van der Hammen, 1973) and the 'Guantiva' interstadial (Gonzales, van der Hammen & Flint, 1965). The cold phase was also detected in Peru (Mercer & Palacios, 1977) and in the southern Andes (Markgraf & Bradbury, 1982). Shortly after 11,960 ± 100 yr BP the Mucubaji valley returned to superpáramo conditions and a second cold phase began (Miranda cold and humid phase). The section ends during this phase (Salgado-Labouriau *et al.*, 1977).

Pollen analysis of a terrace in the Páramo de Miranda, within a glacial cirque at ~3920 m, in the present periglacial belt, gives an almost continuous record from more than 11,470 ± 170 yr BP to the present (Salgado-Labouriau *et al.*, 1988). Two cold phases were detected; the first phase (Miranda cold phase) began prior to 11,500 and lasted until 11,120 yr BP (probably corresponding to deglaciation of the glacial cirque) and is considered to be coeval with the second Mucubaji cold phase. It indicates, as one might expect, that deglaciation at this higher elevation occurred later than at 3600 m.

Another cold phase took place from 6000 to 5250 yr BP at approximately the same time as the La Culata cold phase (Salgado-Labouriau & Schubert, 1976). Around the same time in Colombia (van der Hammen, 1974) and in Chile (Heusser, 1972; Heusser & Streeter, 1980) there was also a temperature depression. From 8350 yr BP onwards new pollen types were increasingly incorporated in the sediments, as vegetation in the Páramo de Miranda was becoming progressively richer in species.

Analysis of samples from three páramos, La Culata, Miranda and Piedras Blancas (all in the Mérida Andes)

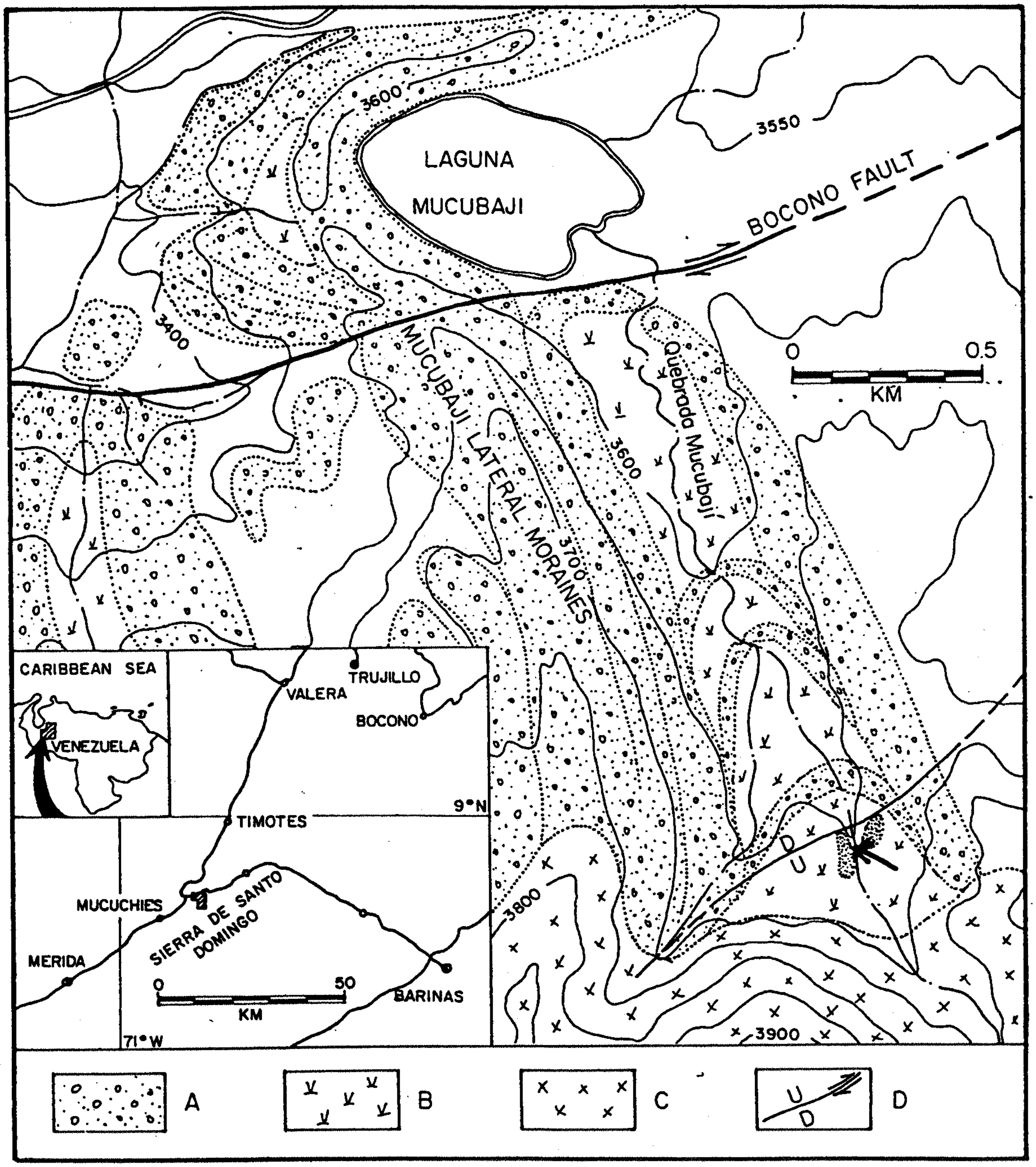

FIG. 1. Geological map of the Mucubaji glacial valley, Venezuelan Andes, showing location of Lake Mucubaji (laguna Mucubaji). A, morainal till; B, bog; C, igneous-metamorphic basement rock; D, fault showing relative movement (U=up; D=down). Elevation in metres above sea level. Arrow indicates a fluvio-glacial terrace previously studied. After Salgado-Labouriau *et al.* (1977).

indicated small climatic oscillations during the Holocene. Among these was a warm phase from 3000 to 2500 ± 70 yr BP, clearly shown in sediments from Miranda and La Culata, that probably represented a short interval with temperatures of about 1.2°C above the modern average temperature for the sites. In the last centuries there was a temperature depression, well represented at the Páramo de Piedras Blancas at 4080 m elevation (Rull *et al.*, 1987) which was coeval with the 'Little Ice Age'.

These palynological analysis were of sediments located at the modern boundary between superpáramo and páramo proper, where a small change in climate would result in a change of the vegetation belt, and hence, in the composition of vegetation in the site. An analysis of Holocene sediments from the páramo proper was needed. The present article gives new information for the Páramo de Mucubaji using lake sediments from the period following the establishment of vegetation.

FIG. 2. Lake Mucubaji, looking towards the northwest showing the terminal moraine which dams the lake (in the background).

THE SITE

The Mucubaji lake (8°47'N and 70°49'W) was formed behind the last end moraine of the Mucubaji glacial valley (Figs 1 and 2). It is a small, exorheic lake fed by a creek ('Quebrada de Mucubaji') that contributes 83 – 95% of its water, and another creek, with the same name, that flows from it. Its water level was increased in 1946 by an artificial dam. In 1967 Weibezahn *et al.* (1970) studied the lake and showed that there is a difference of about 1 m in the water level between the maximum of the rainy season and the minimum of the dry period (November – March). Their bathymetric studies were done during the rainy season when the water level was at 3540 m elevation and the lake depth was slightly over 15.50 m (Fig. 3). Preliminary results on the water characteristics are given elsewhere (Bradley *et al.*, 1985). The mean ionic concentration (ppm) and total dissolved solids are given in Weingarten *et al.* (1990).

SAMPLE DESCRIPTION AND METHOD OF ANALYSIS

It was not possible to obtain long cores from the deepest part of the lake because Mucubaji was too deep to anchor the boat in its centre, and our records from the subbottom profiling using a Raytheon acoustic profiler showed that the sediment thickness in the centre was not much greater than the site that was eventually cored.

Two long cores have been recovered from the lake sediment under 2.40 m of water with a Livingstone sampler (Fig. 3). Core A was used for the palynological studies and core B for the geochemical analysis (Weingarten, 1988). In addition, several short cores were taken with a Davis-Doyle sampler in the deepest part of the lake (15.80 m). From these, two short cores were selected for palynological and geochemical analysis. Here we report on the palynological studies.

Samples for pollen and spore analysis were taken in the laboratory at about 10 cm interval. The long core samples (198 cm in three sections) were numbered from MUL-1 to MUL-25 starting at 3 cm below the top of each section. It was sub-sampled between 130 and 140 cm from the top (samples MUL-15 to -18) where there was a marked change in the sediments. The short core, in one section of 50 cm, was numbered from MUL-26 to -31.

Samples were processed by standard methods described previously (Salgado-Labouriau *et al.*, 1977) and stored in silicone oil. Pollen of *Kochia scoparia* Schrad. was added, prior to the chemical treatment as an internal standard marker for the absolute value estimation (grains/cm^3, Salgado-Labouriau & Rull, 1986).

The percentage values include the sum of all the pollen grains. Spores and algal remains were calculated relative to the pollen sum. The paleoecological interpretation was based on a comparison with soil surface samples (SD-20, -47, -53) of peat bogs along the Mucubaji valley (Salgado-Labouriau, 1979), and from other sites in the adjacent mountains (Salgado-Labouriau, 1979; Salgado-Labouriau *et al.*, 1988). Sample SD-20 is taken from the peat bog close to the lake border; SD-47 is from a peat bog opposite

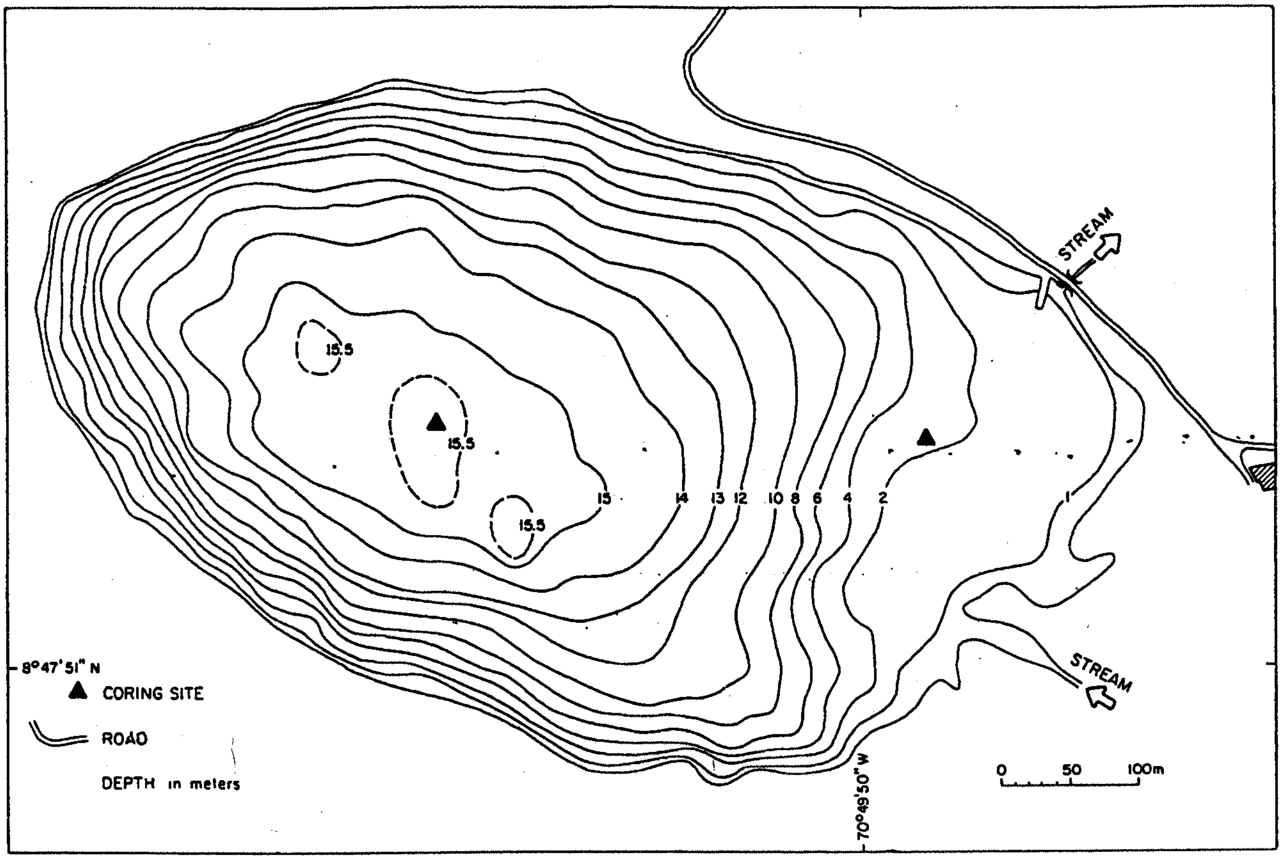

FIG. 3. Lake Mucubaji, adapted from Weibezahn *et al.* (1970).

TABLE 1. Radiocarbon dates from Lake Mucubaji sediments. The palynological analysis was done on cores A.

Sample no.	Laboratory no.	Depth (cm)	Date (yr BP)		Sedimentation rate	
					cm yr 10^3	yr cm^{-1}
Core A						
LMU1-LMU2	GX-13218	6.5–9.0	2235	380		
					26.2	38.2
LMU8-LMU9	GX-13219	71-76	4745	275		
					39.8	25.1
LMU14-LMU15	GX-113220	124-129	6075	290		
					29.0	35.5
Core B	GX-9987	185-197	8300	255		
Short core B	GX-10800	79-84	1555	245	53.2	18.8

to the Mucubaji terrace (see arrow in Fig. 1) previously analysed (Salgado-Labouriau *et al.*, 1977); SD-53 is from the margin of the Mucubaji creek. Their percentage values have been recalculated to include all the pollen grains in order to compare with the lake sample data. The results for the modern pollen deposition at Mucubaji are given at the top of Fig. 5.

An internal standard marker was not used in the earlier studies of modern deposition and absolute values were calculated by another method (as number of grains per milligram of sediment) which is not strictly comparable with the present calculation (grains/cm^3). Therefore, these absolute values are not used here in the diagrams, although an approximation can be calculated and the results can be used in the interpretation.

Radiocarbon dates are given in Table 1. The age of the base the long core was estimated at about 8300 yr BP by comparison with the other long core (B) taken a few metres from it, at the same water depth. That core yielded the age of 8300 ± 250 yr BP (GX-9987) at 185–197 cm depth.

TABLE 2. Description of Lake Mucubaji long core taken under 2.40 m of water, with a Livingstone sampler.

Depth (cm)	Description
0–1	Loose, light brown
1–3	Dark olive, more cohesive
3–10	Light brown changing to black with depth; increasingly cohesive
10–31	Top 1 cm brighter, remaining portion brown to black; streaks of Fe-oxides (?) at 24 cm and some rootlets
31–37	Gradual change to grayish dark
37–38	Very dark layer
38–42	Brighter
42–48	Bright olive
48–58	Increasingly greyish; some rootlets
58–59	A prominent black-brown layer
59–65	Gradual change from olive to grey (63 cm)
65–76	Dark grey with increasing amount of roots decreasing cohesiveness
76–84	Black layer at the top (1 cm) changing sharply to olive-light brown
84–93	Dark brown to black
93–101	Mottled, dark brown to brown-black rich organic layer at 98–99 cm
101–104	Grey, clay rich layer
104–132	Sharp change to dark-brown-black; abundance of plant stems and rootlets; mica-rich at 114 cm
132–136	Dark brown with streaks of olive
136–148	A pocket of olive colour material showing concentric bands organic-rich, within light to dark brown material
148–174	Dark-brown with abundant mica flakes
174–177	Dark grey
177–179	Black
179–192	Olive-grey-green, clayey and dryer
192–197	Black

DESCRIPTION OF THE CORES

The description of the long core is given in Table 2. The sediments contain gypta with clay and the geochemical analysis on a duplicate core (unpublished data) show that the total organic matter varies between 8 and 12 weight per cent in the upper part of the core, from *c.* 2200 to *c.* 4500 BP, as determined by loss-on-ignition at 450°C. There is a sharp increase in total organic matter at about 75 cm depth (4700 BP) and from there to the bottom of the core the organic contents are higher. Maximum occurs at a depth of 90 cm (about 5100 BP). Organic bound iron is the dominant form, comprising some 70–90% of the total extractable iron. Clay minerals are chlorite, mixed layer illite-chlorite (ML), illite and kaolinite. Some slight variations in the relative clay-mineral abundance occur down the core. Of particular interest is the great amount of chlorite between 75 and 100 cm (about 4600–5500 BP) and an increase abundance of illite below this depth. Kaolinite and ML are relatively abundant throughout the core.

The short core sediments contain an average of 36.6 weight per cent of organic matter; 71.6% or organic bound iron of the total extractable clay mineral representing 52% weight per cent. Additional geochemical data in the short core is found in Weingarten *et al.* (1990).

ANALYSIS OF THE PALYNOLOGICAL DATA

Results from the long and the short cores are depicted in Figs 4 – 7.

Long core (shallow water core)

The percentage diagram (Fig. 5) does not show marked differences in the relative values of the pollen types indicating that the composition of the vegetation has not changed during the whole interval of sedimentation. Nevertheless, the increase of Compositae and the decrease of *Podocarpus* L'Hérit. ex. Pers. pollen towards modern time, although small, supports the results from other sites (Salgado-Labouriau, 1976; Rull *et al.*, 1987). *Podocarpus* pollen oscillates between 4% and 20% up to *c.* 2200 BP., and decreases to 2% to zero after 1550 BP and to 1–3% of the total pollen in the modern deposition (Fig. 5). Compositae pollen oscillates between 4% and 20% before 2200, between 10% and 20% after 1550 BP and increases to 30–38% of the total pollen in the modern deposition.

Modern deposition in the peat bogs of the Mucubaji valley (top of Fig. 5) shows some differences in composition of the pollen assemblages in relation to the older lake sediments. This difference is mainly observed in the higher values of Compositae, 'aquatic plants' and 'other paramo herbs' in the peat bogs compared to the lake sediments. *Isoetes* L. microspores are very abundant in SD-53 probable because it is a creek sample. The other elements are within the values of the three uppermost levels of the lake. This is probably due to differences in the deposits because the peat plants contributed more pollen to the bog than to the lake.

The large amount of Compositae pollen today and in the last few centuries probably indicates a recent increase in abundance of the plants, mainly *Espeletia* Mutis, in the valley. Today *E. schultzii* Wedd. is the dominant plant in the moraines that form the valley.

Long-distance transported pollen from the cloud forest was relatively more abundant in the past with a marked maximum between levels MUL-8 and -11 (*c.* 4700 – 5100 BP) suggesting an altitudinal increase in the forest limits. It is below present time values at levels -23 to -25 (*c.* 8000 – 8300 BP)

The abundance of pollen (Fig. 4) oscillates with values between *c.* 20,000 and *c.* 80,000 grains/cm^3 through most of the core. It reaches a maximum in the interval of *c.* 5400 to 6075 ± 290 years BP (samples -12 to -15) of *c.* 120,000 to *c.* 135,000 grains. This increase is mainly due to Gramineae and Compositae, indicating a denser vegetation in the valley (Fig. 6). During this interval the aquatic plants (Cyperaceae, Onagraceae, *Rhizocephalum* Wedd. and *Potamogeton* L.) also increase, suggesting higher soil humidity in the valley and perhaps a rise in the lake level.

Isoetes microspores are very abundant throughout the section, always above 60,000 grains/cm^3 (Figs 4 and 7). The great quantity of this submerged fern shows that a lake has existed throughout the period of record.

Other spores, although present, are not as abundant as the pollen (Fig. 4), but the paramo pteridophytes (*Lycopodium*

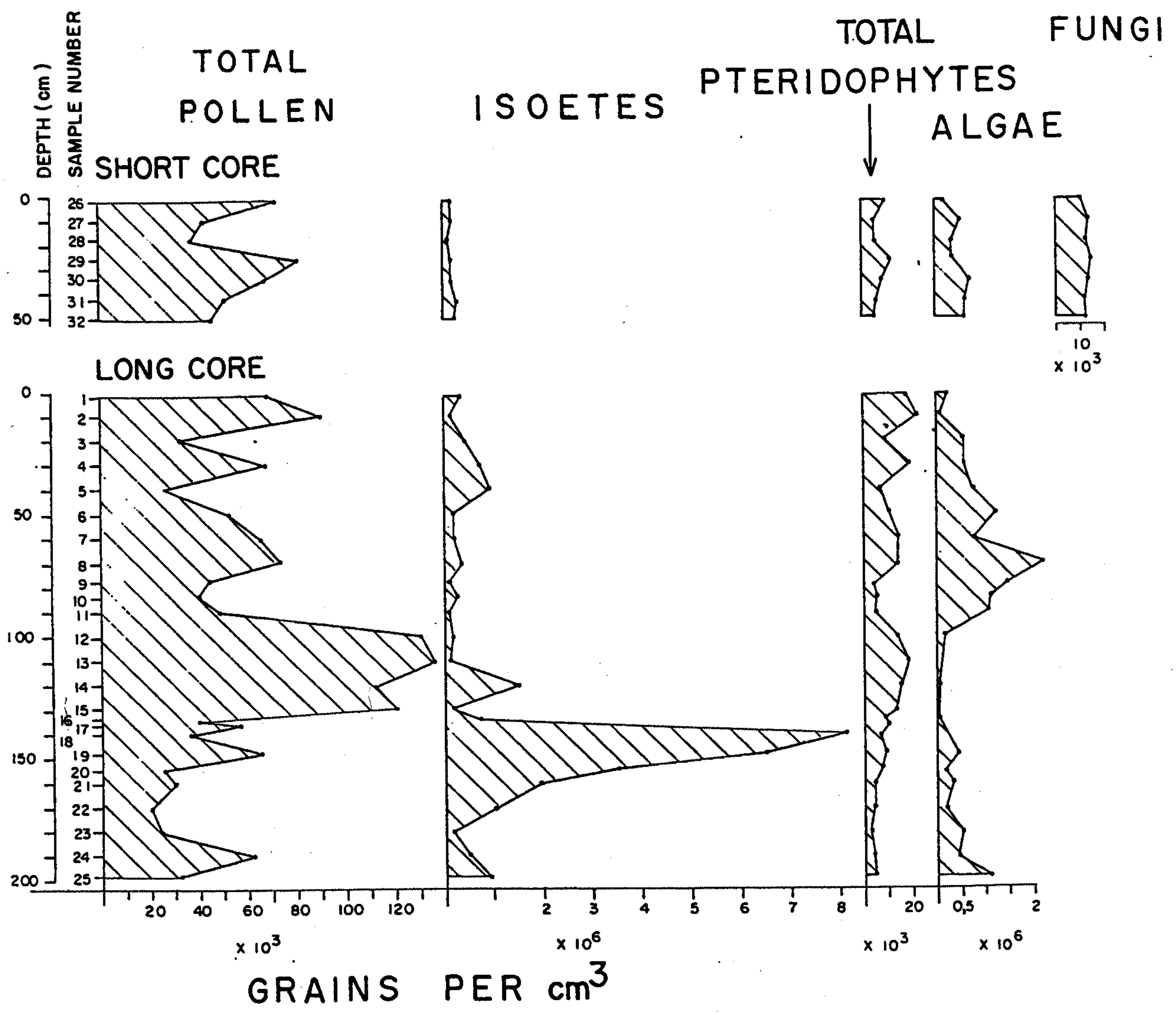

FIG. 4. Abundance of palynomorphs (absolute values) in two Mucubaji sections. Total pteridophyte spores excludes *Isoetes* spores.

L. and *Jamesonia* Hook & Grev.) as well as the long-distance spores of forest ferns (Cyatheaceae) are well represented throughout the core and at values similar to those of the present.

Planktonic algal remains are present throughout the core, supporting the interpretation of a lake during the whole interval. They are more abundant between samples MUL-3 and -11 (*c.* 2700 – 5100 BP). From level -11 to -6 changes in their assemblage with dominance of the algae *Botryococcus* Kuetz and *Pediastrum* Meyer, suggest a change in the lake flora.

Fungal remains were not counted in this core because when it was opened in the laboratory it was contaminated with modern fungi. This has not happened in the short core, thus fungi were counted.

Shortly after 2235 BP (Table 1) sedimentation creased at the site, and remained as so until the present when in 1946 the lake water was raised by an artificial dam (Fig. 3).

Short core

It presents the same general fluctuations in pollen and pteridophyte spores as the upper part of the long core (level MUL-11 upwards). *Isoetes* spores are abundant. Because the core was taken under 15.80 m of water, their presence up to 3 cm below the water/sediment interface together with the abundant assemblage of planktonic algal (*Botrycoccus* Kuetz, *Pediastrum* Meyer, *Scenedesmus* Meyer, etc., Fig. 7), support the interpretation that the lake existed. Nevertheless, it was smaller and probably shallower during the last 2200 years than at present. There is not enough light to support the growth of *Isoetes* in such water depths. This fern does not grow in the northern Andes at depth higher than 3 m. Another interpretation of the presence of *Isoetes* microspores in the centre of the lake is that they have been taken by the creek or by currents from the littoral zones. The present study cannot distinguish between the two interpretations. Nevertheless, the absence of sediments

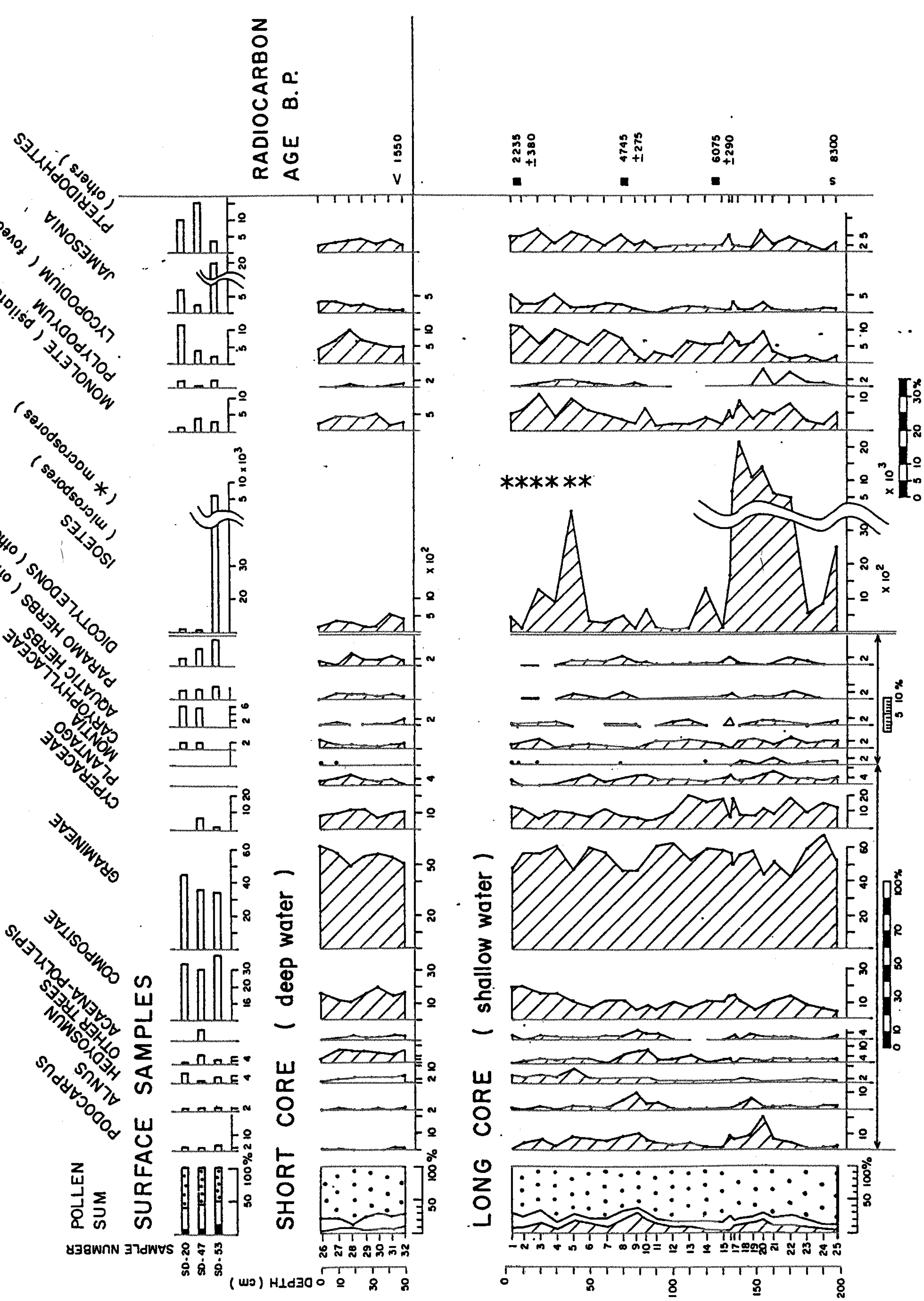

FIG. 5. Lake Mucubaji: percentage diagram of pollen and pteridophyte spores. Modern surface samples are at the top, followed by the short core from the deepest part of the lake; at the base is the analysis of the long core close to the lake margin. Percentages of all the palynomorphs are calculated in relation to the sum of all the pollen grains found in each level.

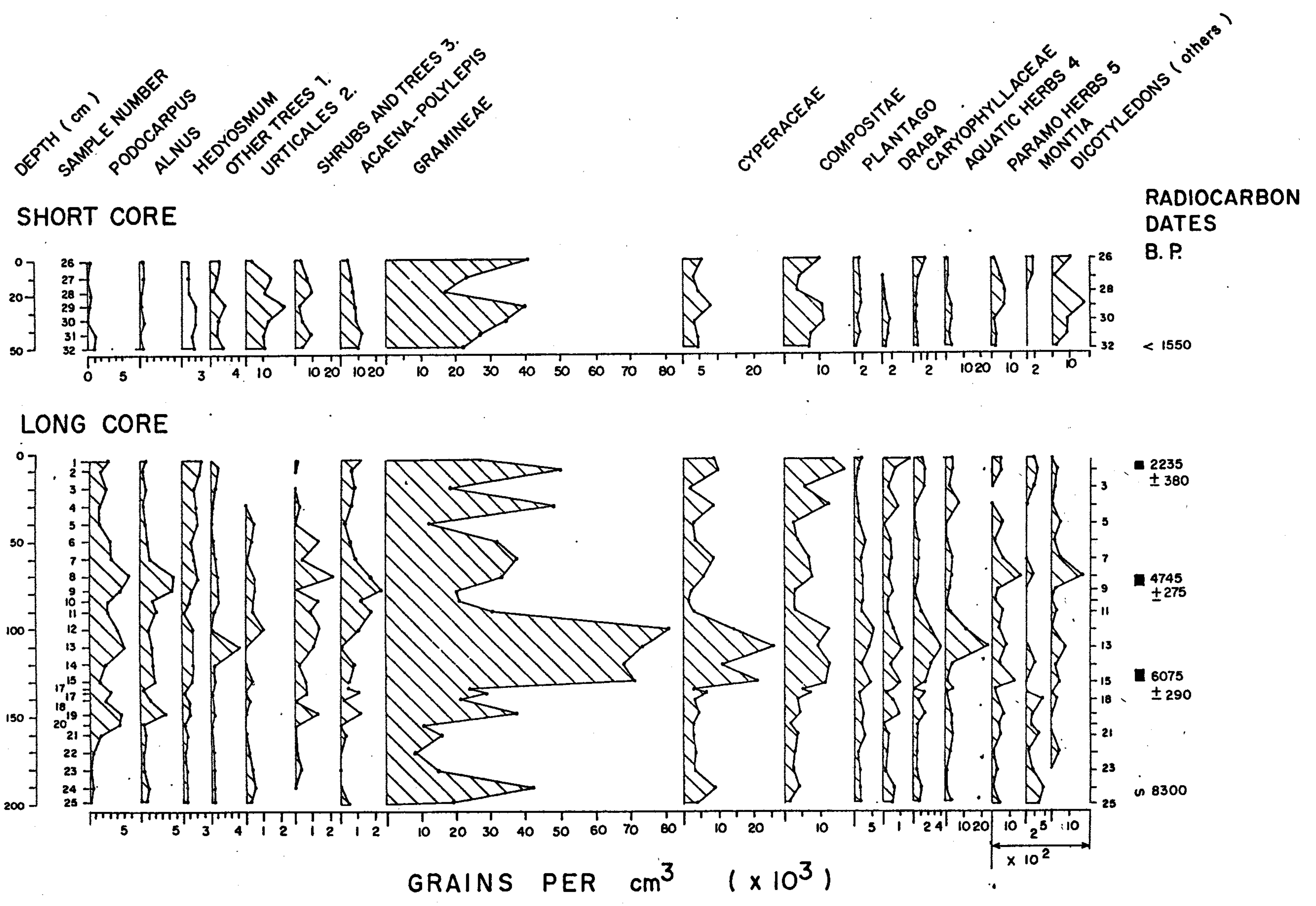

FIG. 6. Lake Mucubaji: concentration diagram of pollen of the two cores (see explanations in Fig. 5). The numbers after pollen types represent the sum of grains of: 1, *Myrica*, *Juglans*, *Vallea* and *Weinmania*; 2, all the 3.4-porate grains of the Urticales; 3, *Escalonia*, *Dodonaea* and Umbelliferae; 4, *Potamogeton*, *Rhizocephalum* and Oenotheraceae; 5, *Valeriana*, *Geranium*, *Gentiana* and *Hypericum*.

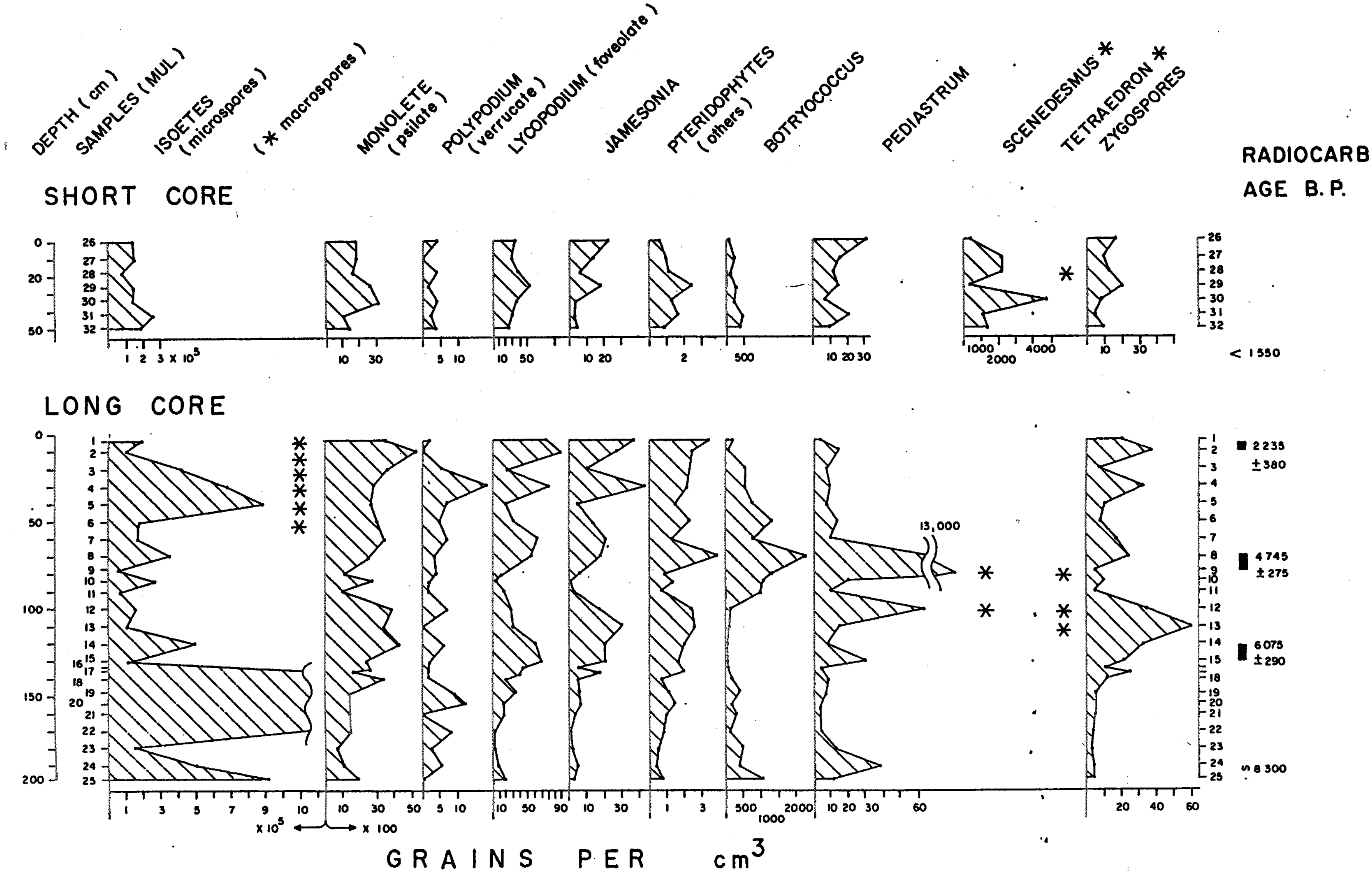

FIG. 7. Lake Mucubaji: concentration diagram of pteridophyte spores and algal remains (see Fig. 5 for explanations).

younger than 2235 yr BP in the shallow water of the modern lake (long core site) and the raise of the water level by a dam (Fig. 3) corroborate to the hypothesis of a smaller and shallower lake. The lake probably had shrunk after that time and had not covered the parts today under 2.40 m of water.

CONCLUSIONS

Analysis of pollen and spores in the sediments of Lake Mucubaji shows that the composition of the vegetation has been very similar to the present day since the beginning of sedimentation. Therefore, during the last 8300 years the Mucubaji valley was a paramo with the same plants as today, but with fewer Espeletias than at present. The same results were found at LaCulata (3600 m elevation), on another ridge (Salgado-Labouriau & Schubert, 1976). Lake Mucubaji has existed throughout the interval but has shrunk to a much smaller and shallower lake after about 2235 BP.

Though ecological conditions in the Paramo de Mucubaji have always been that of a paramo, small oscillations in climate, without significant changes in vegetation characteristics, have occurred. The increase of pollen input at levels -12 to -15, dated between 5400 (interpolated age) and 6075 ± 290 yr BP, indicates a denser vegetation during this time. This corresponds to the beginning of Miranda Phase III (interpolated age of 5470 yr BP) where aquatic plants, mainly *Rhizocephalum* and *Isoetes*, were abundant (Salgado-Labouriau *et al.*, 1988). Mucubaji and Miranda results indicate that this time interval, although having a gradual increase in temperature, seems to represent much more an increase in humidity.

The deep water core is much younger than the shallow water core, and the dates do not overlap (Figs 5 – 7). Therefore the interval from 2000 to 1500 yr BP is not represented here and the climatic oscillation towards a climate warmer than at present could not be detected.

At present Lake Mucubaji is located in the paramo proper belt, far from the tree line and from the limit between superparamo and paramo proper. The results presented here show that this location has not changed during the last 8300 years. The geochemical studies of the lake sediments (Weingarten, 1988; Weingarten *et al.*, 1990)) support this conclusions. The sediments show a typical lacustrine environment of the montane cold climate belt without significant changes throughout the record. This probably explains why the signals for small climatic oscillations were attenuated there, whereas at Miranda and Piedras Blancas, located in the lowest part of the superparmo, they were clearly shown. The same applies to La Culata, today at the upper limit of the paramo proper. In those three sites climatic oscillations changed the vegetation composition during the Holocene back and forward from paramo to superparamo, thus reflecting in the deposited pollen assemblages. At Mucubaji the small changes in the montane climate would still keep the lake within the paramo proper belt.

Lake Mucubaji sediments support the results from other sites that show a decline of *Podocarpus* pollen and an increase in Compositae pollen in the last centuries. Together with La Culata it shows that the vegetation in the paramo proper has had the same elements as at present since 7500 ± 8000 yr BP. By contrast, in the superparamo at about 4000 m elevation, the establishment of the modern vegetation started gradually and the composition of the pollen assemblages has been the same as today only since about 3000 BP (Salgado-Labouriau *et al.*, 1988).

Some shallow water lakes in North America are shown to have mixing and redeposition of pollen, mainly in spring and fall (Davis & Brubaker, 1973; Davis, Moeller & Ford, 1984). The pattern of differential deposition of these lakes cannot be applied to lake Mucubaji located in the equatorial zone (8°47'N) where there is no four-seasons cycle and temperature is stable throughout the year (Salgado-Labouriau, 1979). Nevertheless, some pollen grains and spores probably are taken to the lake basin by the Mucubaji Creek and by run off from rain; mixing and redeposition may occur. How much these factors affect the distribution of pollen and spores in the sediments of the northern Andes glacial lakes is still an open question.

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