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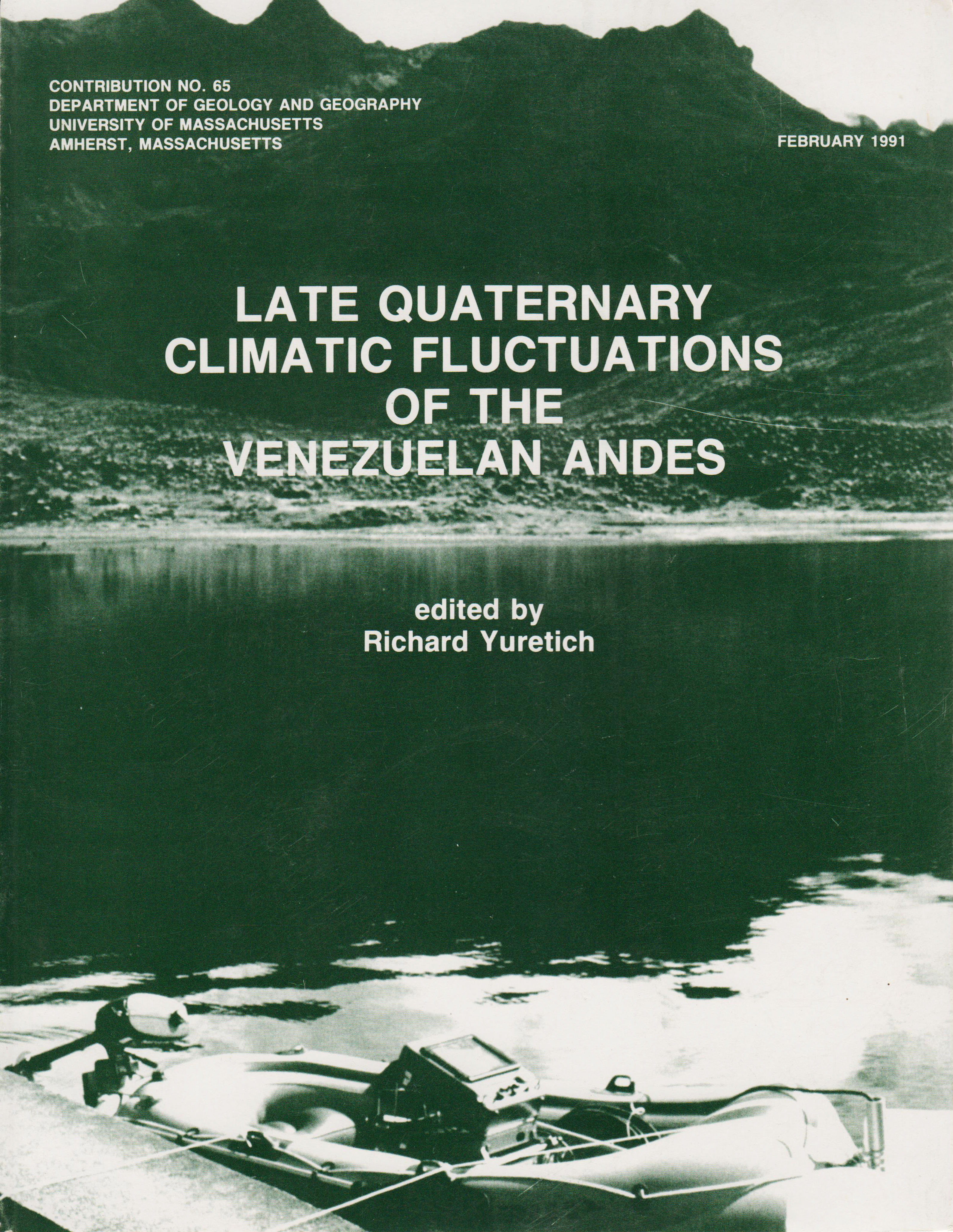
LATE QUATERNARY CLIMATIC FLUCTUATIONS OF THE VENEZUELAN ANDES

edited by
Richard Yuretich



LATE QUATERNARY CLIMATIC FLUCTUATIONS OF THE VENEZUELAN ANDES

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TABLE OF CONTENTS

PREFACE

The pages following summarize the major findings of a research project funded jointly by the National Science Foundation and the Consejo Nacional de Investigaciones Cientificas y Tecnologicas (CONICIT) of the Republic of Venezuela. Our principal goals were to evaluate the relationship between climatic conditions and sediment characteristics in a series of lake basins along an altitudinal transect through the Venezuelan Andes, and then use these data to evaluate paleoenvironmental changes in long cores collected from the lake basins. NSF funded the expenses of the U.S. investigators, the laboratory analyses of the sedimentary geochemistry and the gathering of new climate data from the Venezuelan Andes. The primary responsibility of the CONICIT grant (SI-1359) was to support the palynological analyses of Dr. Maria-Lea Salgado-Labouriau (then at IVIC -- Instituto Venezolano de Investigaciones Cientificas, Caracas) and to provide additional resources for the field work.

Our objectives were ambitious, and, in spite of the difficulties of the field work, the disappointments in our data collection and the inevitable missed opportunities, we achieved our major goals of 1) documenting the connections between contemporary climatic conditions and sediment geochemistry, and 2) revealing new information concerning the Late Quaternary environmental changes in this underexplored region of the world.

Naturally, our progress was helped along at critical junctures by many people. Most important is Dr. Carlos Schubert of IVIC whose initial interest helped get the project underway. In addition we extend our thanks to all those who helped us conduct the field work, among them: Professor Rigoberto Andressen of the Universidad de Los Andes in Merida; Mr. Hugo Arnal of INPARQUES, Merida and Major Luis Erraza of the Fuerza Aerea Venezolana. Most of the diagrams in this report were expertly drafted by Marie Litterer, Technical Illustrator, Dept. of Geology & Geography, University of Massachusetts.

Much of the text of the technical report is based upon the Ph.D. dissertation of Baruch Weingarten, and the reader is referred to this document for additional information.

Dissertation Completed:

Weingarten, Baruch, 1988: "Geochemical and Clay-Mineral Characteristics of Lake Sediments from the Venezuelan Andes: Modern Climatic Relations and Paleoclimatic Interpretation"; Unpublished Ph.D. Dissertation, University of Massachusetts, Amherst, 217 p.

Publications resulting from this project (excluding abstracts):

Bradley, R.S., Yuretich, R.F., Salgado-Labouriau, M., and Weingarten, B., 1985, Late Quaternary paleoenvironmental reconstruction using lake sediments from the Venezuelan Andes: preliminary results; Zeitschrift fur Gletscherkunde und Gläzialgeologie, v.21, p.97-106.

Weingarten, B., Yuretich, R., Bradley, R. and Salgado-Labouriau, M.L., 1990, Environmentally controlled variations in clay mineral assemblages from lake sediments in the Venezuelan Andes; **in** Farmer, V.C and Tardy, Y. (eds.) **Proceedings of the 9th International Clay Conference**, Strasbourg, France (in press).

Weingarten, B., Yuretich, R., Bradley, R. and M. Salgado-Labouriau, 1990, Sedimentary characteristics of an altitudinal sequence of lakes in the Venezuelan Andes: principal data and climatic implications; Jour. of South American Earth Sciences, v. 3, p. 113-124..

Salgado-Laboriau, M.L., Bradley, R.S., Yuretich, R. and Weingarten, B., 199_, Paleoecological analysis of the sediments of Lake Mucubaji, Venezuelan Andes: Journal of Biogeography (provisionally accepted)

ABSTRACT

Lake sediments from the Central Andes of Venezuela were studied in order to relate their chemical composition and clay mineralogy to depositional conditions. The lakes are located at elevations ranging from 1,100 to 3,700 m. This altitudinal range encompasses four climatic belts: Tierra Caliente, Tierra Templada, Tierra Fria and Tierra Helada, each with distinctive temperature and vegetational regimes. A total of nine lake basins were the primary focus of this study: four in the Tierra Helada, four in the Tierra Templada and one lake in the Tierra Caliente.

Organic matter, extractable iron and manganese, and carbonate content were the principal geochemical characteristics studied. Carbonate is absent from all lakes except in the arid Tierra Caliente. Organic matter is at a maximum in the warm, wet Tierra Templada lakes. The distribution of extractable iron is also altitudinally related. Organically bound iron dominates the sediments in the Tierra Helada lakes and amorphous iron is most abundant in Tierra Templada lakes. About equal amounts of amorphous and crystalline iron occur in the sediments of the Tierra Caliente lake. Climatic differences are believed to be the principal controlling factor.

X-ray diffraction analysis demonstrates that clay minerals also change with elevation. In the high elevation lakes (Tierra Helada), illite and chlorite are the most abundant clay minerals. In the Tierra Templada lakes, modern sediments are either X-ray amorphous or dominated by kaolinite and gibbsite. Bedrock differences can control the variability from lake to lake, but the main control is once again climate. Changes in illite crystallinity with elevation also support this conclusion.

Late Pleistocene (17,000 to 10,000 years B.P.) clay-mineral assemblages in a long core from Lake Los Lirios in the Tierra templada are similar to modern clay assemblages in the Tierra Helada lakes. This suggests a colder climate at lower elevations during the late Pleistocene. Altitudinal patterns in the abundance of organic matter and the distribution of extractable iron also support this climate change. Available pollen data from Venezuela and the northern Andes are in agreement with the results from this study.

PALEOCLIMATOLOGY, LAKE SEDIMENTS AND THE VENEZUELAN ANDES

Baruch Weingarten, Richard Yuretich, Raymond Bradley
and Maria-Lea Salgado-Labouriau

Introduction

Lake sediments preserve a high quality record of pollen and aquatic fauna which can serve as guides to environmental conditions that prevailed during their deposition. In addition, recent studies indicate the existence of a sensitive response of both clay minerals and chemical properties of lacustrine sediments to climatically-induced environmental changes (Dean and Gorham, 1976; Kelts, 1978; Lewis and Weibezahn, 1981; Yuretich, 1982). Quaternary paleoclimatic and paleoenvironmental variations over tropical continental areas have been established primarily using pollen data and records of lake level fluctuations (Colinvaux, 1972; van der Hammen, 1974; Salgado-Labouriau and Schubert, 1976; Street and Grove, 1979). The present study explores the value of mineralogy and geochemistry in providing information about both current and Late Quaternary climatic conditions in the Venezuelan Andes.

The underlying premise of this study is that clay minerals and geochemical characteristics of lake sediments are sensitive to climatic changes. The present study has three principal objectives. First, to establish, by appropriate analytical methods, the characteristics of selected sedimentological, mineralogical and geochemical properties of surface sediments in several lakes spanning various altitudinal climatic zones in the Venezuelan Andes. Secondly, once these characteristics are established, to evaluate the relationships between the lake sediments and prevailing climates, i.e. the "climatic signature". Thirdly, in a similar manner, after individual characteristics of each lake basin have been identified, to evaluate the characteristics of long sediment cores from high and mid-elevation lakes. These will provide records of variations of the different mineralogical and geochemical characteristics as a function of time, from which changes in climate during the late Quaternary may be interpreted. Comparison with other proxy-climate data, specifically pollen assemblages, can be used to evaluate the fidelity of the sedimentological data and to establish regional correlations.

Clays and Paleoclimate

Paleoclimatic interpretations of clay minerals presuppose that the clays are detrital and did not experience diagenetic alterations (Singer, 1980). Clay minerals in lacustrine sediments are inherited from the surrounding drainage basin after developing in situ by subaerial weathering of primary minerals (Jones and Bowser, 1978). Thus, they reflect the climate-controlled processes of soil formation within the watershed and, once transported to a lake basin, they often preserve a climatically-induced signal (Singer, 1984). This fingerprint can be of quantitative or qualitative significance. For example, clays from the smectite group often indicate "moderate" amounts of weathering (Loughnan, 1969; Barshad, 1966), and the total quantity of clay minerals present can be indicative of the degree of "dryness" or "wetness" of climate, as suggested in a study of sediments from Lake Valencia in Venezuela (Bradbury et al. 1981).

Although climate is the most influential factor in chemical weathering, and therefore in clay mineral formation, the role of topography and other factors such as bedrock characteristics are also important (Loughnan, 1969). Rocks in high relief topographic settings will usually experience a much greater mechanical disintegration than chemical breakdown. This will result in the presence of limited amounts of secondary products, i.e. clay minerals. Variations in source-rock mineralogy will also control the types of clay minerals forming in a soil profile. In an ideal study of climatic controls on sediment characteristics, both topographic and geologic influences should be similar.

Authigenic Minerals and Iron Content

The amount and type of authigenic minerals in lake sediments have often been used as indicators of paleochemistry and by inference, paleoclimate. For example, studies by Lewis and Weibezahn (1981) of carbonate sedimentation in Lake Valencia, Venezuela, suggest that during relatively moist periods, $CaCO_3$ content was high, and low-Mg calcite prevailed. As salinity increased during arid climatic episodes, $CaCO_3$ deposition decreased and carbonates became enriched in Mg.

Another chemical variable of potential climatic significance is the iron content of lake sediments. Iron is transported to lake basins by three general mechanisms: a) true solution; b) organo-iron complexes; and c) oxyhydroxide sols (Stumm and Morgan, 1981; Crerar et al. 1972). The first process is negligible under most natural settings and the distribution of Fe between the two other phases will depend upon the weathering conditions and vegetative cover. Iron oxyhydroxides are the dominant forms in cold-temperate climatic conditions, as in the glacial lakes of North America (Burns and Nriagu, 1976). Lewis and Weibezahn (1981) noticed a general coincidence of high sedimentary Fe with high organic carbon content in Lake Valencia. They interpreted such episodes as transitional between arid climates (high clastic loading) and moist periods (high carbonate content).

In general, changes in sediment characteristics can reflect differences in climate and enable diagnostic signals to be identified from different climatic zones, as has been done with changes in pollen deposition (Salgado-Labouriau, 1979; Andrews et al. 1982). These signals, or "climatic signatures", in the sediment can then be used as keys to interpret the sedimentary record preserved in long sediment cores raised from lakes using the assumption that sediment composition, as well as pollen deposition, would have changed in concert with climate.

The Venezuelan Andes

The Venezuelan Andes are an elongated mountain chain which extends for over 400 km across northwestern Venezuela in a SW-NE direction (Fig. 1). The central part of the Venezuelan Andes, also called the Sierra Nevada de Merida, reaches elevations of up to 5000 m (Pico Bolivar, 5008 m a.s.l.). Above 4700 m, which is the present day snow line, the prevailing climate of the Sierra Nevada supports several small glaciers, confined to the highest peaks, although these have been receding rapidly in recent years (Schubert, 1984).

Uplift of the Venezuelan Andes began in the Late Tertiary, and continues today (Giegengack, 1984). In general, the Andes consist of two east-west trending parallel subranges, separated by a central valley marked by pull-apart basins and strike-slip faults (Schubert, 1982; Giegengack, 1984). In the study area, the Chama and Mocoties Rivers flow in the central valley. They originate at opposite ends of the range and meet in the area of Estanquez where they unite and flow in a NW direction into the Maracaibo Basin (Fig. 1).

Geology

The regional geologic history of the Venezuelan Andes is discussed by several authors, most notably by Shagam (1972b). Three rock formations crop out in the study area; the Precambrian (?) Sierra Nevada, the Paleozoic Mucuchachí and the Mesozoic La Quinta Formation (Fig. 2).

Metamorphosed and complexly deformed schists, gneisses and amphibolites are the principal rock types in the Sierra Nevada Formation. Muscovite-quartz-feldspar schist is the dominant rock type (Kovisars, 1971), however, mineralogical variations are frequent, and biotite often occurs as a common mica. A micaceous-quartz-feldspar gneiss is the second most common rock type in this formation, with biotite as the predominant mica.

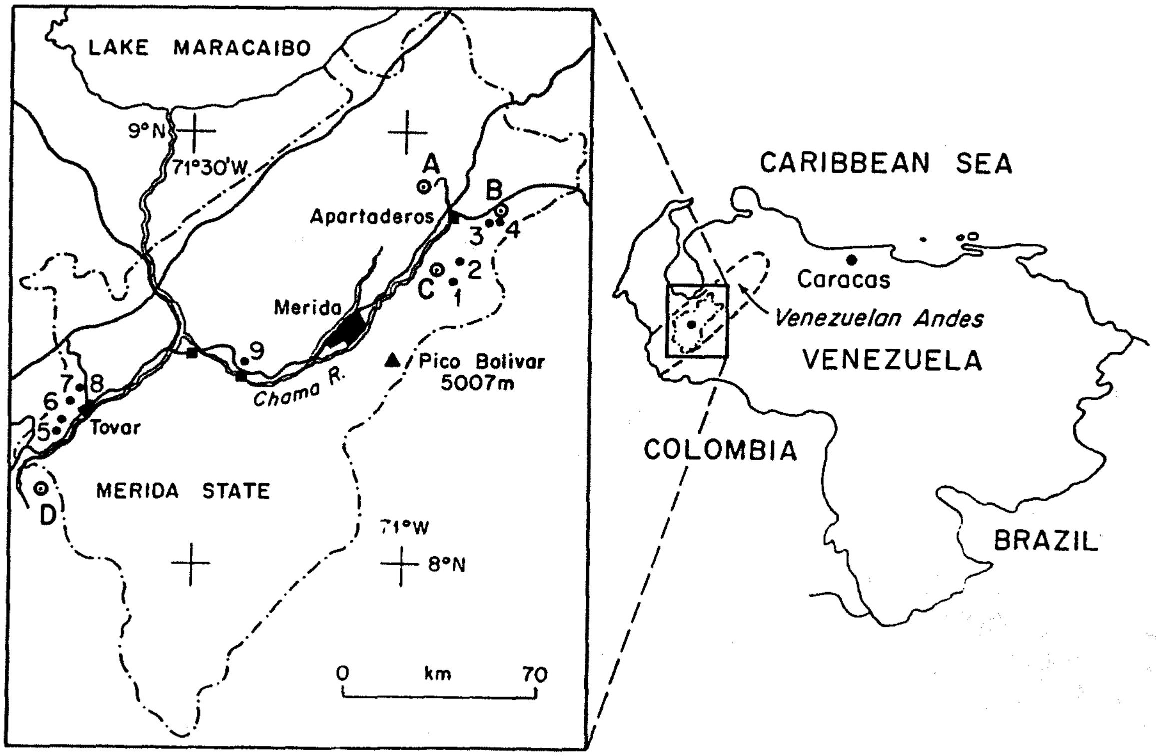

Figure 1. Index map of the study area. Numbers show locations of primary lakes : 1 = Saisay; 2 = Montón; 3 = Mucubají; 4 = Negra (Apartaderos); 5 = Blanca; 6 = Negra (Mariño); 7 = Los Lirios; 8 = Brava; 9 = Urao. Letters show locations of secondary lakes: A = Las Verdes; B = La Canoa/Victoria; C = Misteque; D = El Cienegón.

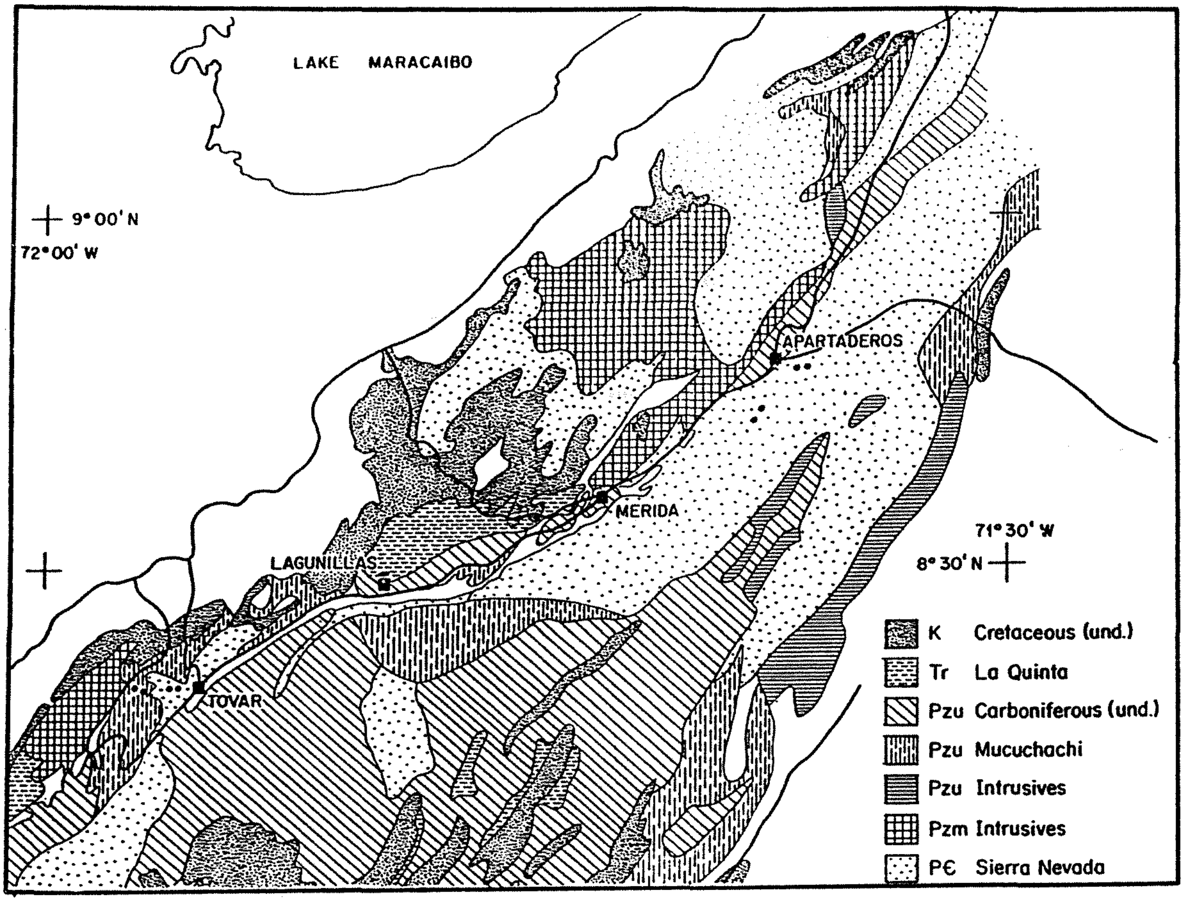

Figure 2. Geologic map of the study area. Locations of the primary lakes are shown in black.

Plagioclase-hornblende amphibolites constitute the third rock type. Locally these rocks are intruded by granites (Shagam, 1972a).

The Mucuchachí Formation consists of metamorphosed marine deposits of Late Paleozoic age and its lithology is dominated by a laminated slate with subordinate sandstone (Shagam, 1972b). According to studies by Arnold and Smith (Compania Shell de Venezuela and Creole Petroleum Corporation, 1964) the slates are carbonaceous and, in part, phyllitic. Pyrite is a common mineral replacing most of the preserved fossils. In thin sections, the sandstone displays a dark matrix (25%-35% by volume) which appears to be composed of muscovite, chlorite, quartz grains and highly altered microcline and plagioclase (?) (Shagam, 1966). The sandstone is a litharenite: quartz 60-80%, plagioclase 20% and rock fragments 20% (Shagam, 1966). The rock fragments are commonly siliceous schists, meta-cherts and slate fragments. The accessory minerals (approx. 5%) are pyrite, magnetite and leucoxene.

The La Quinta Formation consists of sedimentary rocks of Jurassic age (Hargraves and Shagam, 1969). Rocks in this formation are predominantly red-colored sandstone and conglomerate, massively bedded. Thin sections of selected specimens show a poorly sorted texture with clastic grains of quartz (50-70%) and subsidiary microcline, plagioclase (1-10%), mica (muscovite 5-7%), chlorite and rock fragments (3-10%), all embedded in a red-stained clayey matrix which is locally calcareous. Many specimens show silica overgrowths on quartz grains. Opaque oxides are present as detrital grains, as matrix elements, void fillings and alteration products. Hematite is the main constituent of clastic opaque grains and iron oxide coating on clastic grains (Shagam, 1966; Hargraves and Shagam, 1969). Table 1 lists the minerals present and the average mineralogical composition (by volume) of each of the three formations.

Table 1. Comparison of mineral assemblages and mineral abundance in the three rock formations that underlie the lake basins in this study. (Modified from Shagam, 1966; Hargraves and Shagam, 1969; Kovisars,1971).

		Rock Formations	
Minerals	*Sierra Nevada*	*Mucuchachi*	*La Quinta*
Quartz	35%	60%	65%
Plagioclase	40%	15%	10%
Microcline	15%	5%	5%
Muscovite	1%	5%	7%
Biotite	6%	---	---
Chlorite	---	5%	3%
Rock fragments	---	10%	10%
Calcite	---	---	*

* Locally abundant, up to 40%.

The geomorphology of the Andes is primarily a function of an ongoing vertical uplift of ~6 cm/100 years (Shagam, 1972b) together with adjustments along strike-slip faults (Schubert and Sifontes, 1970; Giegengack and Grauch, 1972a). This tectonic topography has been altered by periods of intense weathering and erosion as illustrated by a remnant paleoxisol (Weingarten, 1977). Finally, periods of glacial and related periglacial activity during the Quaternary have given the landscape a final modification (Tricart and Michel, 1965; Tricart and Milles-Lacroix, 1962; Schubert, 1976, 1977).

Climatic Setting

Walter (1977) studied the climate of the Venezuelan Andes and defined four major altitudinal zones based on temperature (Fig. 3). The Tierra Helada is an altitudinal zone above 3,200 m with mean annual temperature of $<8^{o}C$. The upper limit of the Tierra Helada reaches the elevation of Pico Bolivar (5,008 m. a.s.l.) and mean annual temperature of $-1.5^{o}C$. The Tierra Helada is further subdivided into five zones based upon vegetation (Lauer, 1979). The lower three sub-zones (Subparamo, Paramo and Superparamo) are the most significant sources of palynological evidence indicating past climatic fluctuations in the Venezuelan Andes.

The Tierra Fria extends altitudinally between 3,200 and 2,400 m a.s.l. with mean annual temperatures ranging from $8^{o}C$ to approximately $13^{o}C$. The Tierra Templada comprises elevations between 2,400 and 1,100-1,000 m. The mean annual temperature in the Tierra Templada ranges from 13^{o} to $21^{o}C$. Below an elevation of 1,000 m and down to sea level, the warmest climatic zone, the Tierra Caliente has a mean annual temperature reaching $25^{o}C$.

Lakes and Lake Basins

The lakes in the Venezuelan Andes can be divided into three groups. "High Elevation Lakes" (lakes above 3,200 m) lie within the Tierra Helada climatic belt and the paramo-subparamo vegetation zones. The greatest abundance of lake basins is found in this zone, which is a function of past glacial activity in the Venezuelan Andes. Four lakes were chosen as primary sites for this study: Negra(A), Mucubají, Saisay and Montón. Except for Mucubají, which is a moraine-dammed lake, the other three are cirque basins.

The "Intermediate Elevation Lakes" are closely spaced in the Paramo de Mariño area, northwest of Tovar (Fig. 1). Lakes Brava and Los Lirios straddle the limit between

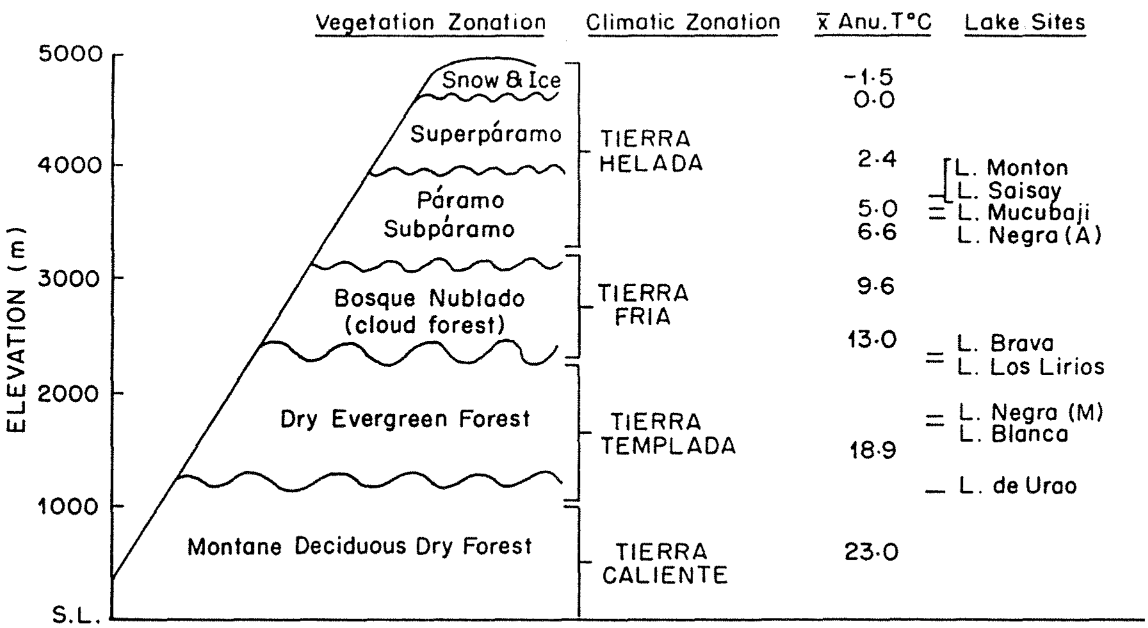

Figure 3. Schematic altitudinal cross-section through the Venezuelan Andes displaying altitudinal distribution of lakes in relation to climatic and vegetation zones. (Modified from Bradley et al., 1985)

the Tierra Fria and Tierra Templada altitudinal climatic belts and the transition from Bosque Nublado (cloud forest) to Dry Evergreen Forest vegetation zones (see Fig. 3).

The morphology of this area is a "karst-like" topography of low hills and depressions, some of which are presently occupied by lakes. Although the formative processes for this landscape are still unclear, the disrupted drainage explains the clustering of the "Intermediate Elevation Lakes" in the Paramo de Mariño area.

The lowest lake, Lago de Urao, is located at the upper limit of the Tierra Caliente climatic zone. This is the only lake known at this elevation (1,000 m). The basin is an asymmetrical graben, and the ponded water is most likely a result of the blocking of drainage to the Chama River by a north-facing, uplifted fault scarp.

Geology of Lake Basins

Bedrock geology is not entirely similar in the basins studied (see Fig. 2). This complicates the climatic interpretation of sedimentary mineralogy and geochemistry because of the difficulty in separating the climatic signal from the control that bedrock imposes on the resulting sedimentary characteristics. Thus, to isolate the climatic signal, this contribution has to be estimated and accounted separately for each different group of rocks.

Lithologically, the nine lake basins can be divided into three groups. Drainage basins of the Lakes Montón, Saisay, Mucubají, Negra(A), Negra(M) and Blanca are underlain by the Sierra Nevada Formation. The influences of climate upon sediments can be most easily ascertained by comparisons within this group. Phyllites of the Mucuchachí Formation crop out in the basins of Lakes Brava and Lirios. The influence of bedrock geology on the sediments of these lakes can be most easily determined by comparison with the other Tierra Templada lakes, Negra(M) and Blanca. The redbeds of the La Quinta Formation dominate the drainage basin of Lake Urao, and the lack of comparable basins at other altitudes make the climatic interpretation of the sediments in this lake the most uncertain. However, the prevailing arid climate at this elevation imparts some strong environmental signals onto the lake water chemistry and hydrology, and this tends to overpower the geological influences.

MODERN ENVIRONMENTAL CHARACTERISTICS OF THE LAKES

Baruch Weingarten, Richard Yuretich, Raymond Bradley
and Maria-Lea Salgado-Labouriau

The Trans-Andean Highway is the principal road within the Venezuelan Andes. Between the villages of Tovar and Apartaderos, this road follows the course of the Rivers Mocoties and Chama. In the area of Apartaderos, the road bifurcates, allowing access to the Panamerican Highway north of the Andes and to the Llanos Highway south of this mountain range. The access to all the principal lakes in the study area originates from this route (see Fig. 1).

The easiest access is to Lake Urao. The lake is located in the NW corner of the village of Lagunillas which has a good paved road from the Transandean Highway. Relatively good access exists to all four lakes in the Paramo de Mariño area, although the road is paved only to Laguna Blanca. From this lake to the other three lakes (Negra (M), Lirios, Brava), the quality of the dirt road diminishes with distance and increasing elevation but all three lakes can be reached by a four-wheel-drive vehicle. Lake Mucubají is a short distance from the Llanos branch of the Transandean Highway. The other three lakes, Negra (A), Saisay and Montón, are ultimately reached only on foot. Pack animals are necessary to carry heavy equipment to these lakes.

Field Procedures

The principal field season lasted from September 1983 through March of 1984. During this time period, 36 short cores and 5 long sediment-cores were retrieved from 9 lakes. Water samples were also collected from the same lakes. In addition, samples from a wider array of lakes, together with representative soil samples, were collected in February and March, 1985.

Field procedures included bathymetric surveys, measurements of water temperature, salinity, dissolved oxygen, electrical conductivity and pH in addition to sediment coring. Water depth values were recorded routinely using a heavy metal plate (approx. 15x15 cm and 0.5 kg) attached to a scaled rope. One series of soundings was taken along the long axis of each lake and supplemental traverses perpendicular to this direction were also obtained. In addition, depth and sub-bottom profiles of Lakes Mucubají, Brava, Blanca and Urao were acquired in December, 1983 using a Raytheon acoustic profiler.

Water temperature, salinity and electrical conductivity were measured with a Y.S.I. Model 33 S-C-T meter. Cable length limited measurements to the top 15 m of the water column. Dissolved oxygen and temperature readings were recorded using a Y.S.I. Model 51B dissolved oxygen meter. A portable digital pH meter measured pH. Water samples from the surface, middle and near the bottom of the lakes were obtained using a Kemmerer bottle. In Lakes Saisay and Urao, four water samples from equally spaced depths were collected.

Sediment sampling was accomplished in two stages. Four short sediment-cores (0.56-1.12 m in length) were recovered from each of the nine lakes using a Davis-Doyle corer; these cores were taken from the deepest part of the lake basins. During the second coring stage, long cores were retrieved using a Livingstone piston corer. Two long cores were recovered from each of the Lakes Mucubají and Urao (respective elevations 3,540 and 1,100 m), and one from Lake Lirios (2,300 m a.s.l.).

During the field effort of February and March, 1985, five additional lake basins were investigated on a reconnaissance basis. Twenty surface sediment samples were recovered from additional lakes using the Eckman Dredge Sampler. Fifteen additional surface water samples and 22 soil samples were also collected. Complete field data are given in Appendix A.

Laboratory Procedures

All water samples were analyzed for major cations (Ca^{++}, Mg^{++}, Na^{+}, K^{+}) anions (NO_3^-, $SO_4^=$, Cl^-) and silica (SiO_2). Cation concentrations were determined by atomic absorption using an IL AA/AE 357 Spectrophotometer. The anions NO_3^- and $SO_4^=$ were analyzed on a WESCAN Model 1A ion chromatograph. Electrode techniques were used to determine Cl^- concentrations, and silica concentrations were measured by the heteropoly-blue method (Greenberg et al., 1980) and a Bausch & Lomb, Spectronic 20 Spectrophotometer. Alkalinity was measured by potentiometric titration to an end point of pH = 4.5.

A total of 127 sub-samples were taken from the short sediment-cores; the interval for sub-sampling was dependent upon the stratigraphy in each core with a minimum of 10 samples (Lake Blanca) and a maximum of 23 samples (Lake Negra-M). A sample from the bottom section of each core was submitted for ^{14}C dating.

All samples were analyzed for organic matter content by loss on ignition (Bengtsson and Enell, 1986), and carbonate values were calculated using weight loss after consecutive heating to 450° and 1000°C (Dean, 1974).

A major analytical procedure was the quantitative determination of organic, amorphous and crystalline phases of Fe- and Mn-sesquioxides. Commonly, three subsamples from each sample are used, one for each iron phase analysis. In this study, the analyses were done on one sub-sample because only small amounts of sample were available. This also avoids the common problem of obtaining values of over 100% in total iron after recalculating the values to weight percent. The pyrophosphate method was employed first to extract the organically bound iron (McKeague, 1968), followed by the oxalate-extractable amorphous iron (McKeague and Day, 1966) and culminating with the dithionite-citrate-bicarbonate (D.C.B.) method (Mehra and Jackson, 1960) for crystalline iron oxides. The degree of selectivity of each method was summarized by Bascomb (1968) and is shown in Fig.4.

Clay minerals were determined qualitatively and semi-quantitatively. A detailed description of the methods used for their identification and quantitative estimations is given in Appendix B. The primary qualitative analysis of the clay minerals was performed on the <2 μm size fraction of untreated sediment samples which were analyzed on a Siemens X-ray diffractometer from 2^{o} to 35^{o} 2θ using Cu Kα radiation with a Ni filter.

Since diffraction patterns were very similar within each core, only every fourth sub-sample (on the average) was treated further by glycolation and heating in order to differentiate expandable clay minerals from chlorite and kaolinite. A few samples were analyzed for the presence of vermiculite. In the two long cores examined (one from Lake Mucubají and the other from Los Lirios), every fifth sample was subjected to these additional treatments.

The Lake Basins

The morphometric and bathymetric characteristics of the principal lake basins are summarized in Table 2. The lake surface and watershed areas were calculated from aerial photographs (scale 1:30000, 1958); some corrections for scale caused by differences in basin elevations were made, but the results could differ by as much as 40% from the true values compared with data given by Weibezahn et al. (1970) for Lakes Mucubají and Negra(A).

All Tierra Helada lakes have a similar ratio of watershed surface-area to lake surface-area. However, the Lake Mucubají drainage basin is 3 to 4 times larger than the other three drainage basins. This may be due to its origin as a moraine-dammed lake, whereas the three others are glacial cirque basins. The lake basins in the Paramo de Mariño exhibit a greater morphometric variability, which may be attributable to their different formational processes. The Lake Urao basin is formed in the tectonically active

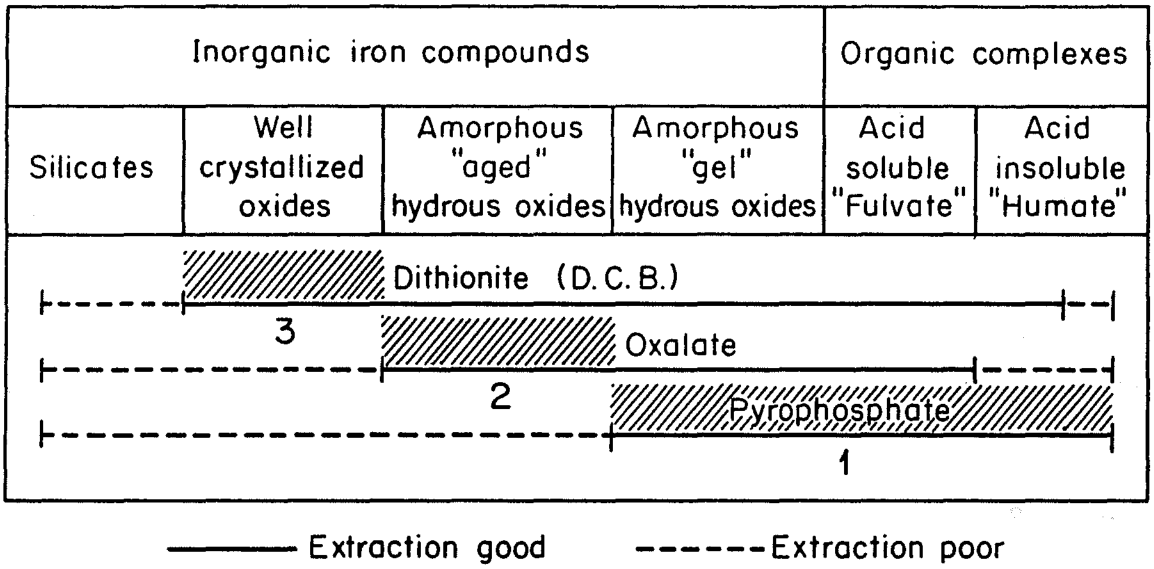

Figure 4. Selective extractions of iron oxyhydroxides. Numbers under the hashed lines indicate the order of extractions followed in this study and the principal type of iron in each extracted phase. Modified from Bascomb (1968).

Bocono fault zone. Figure 5 shows the morphology and topography of several typical lake basins.

Lake Water Composition

Results of analyses of the lake waters are given in Table 3. The small numbers of samples from each lake limits their utility for identifying trends within the water column. Although the charge balance is poor, reproducibility was achieved with <2% error.

Except for the relatively high ionic concentration in the bottom waters of Lakes Lirios and Montón, the different ionic species are uniform throughout the water column of each individual lake. The elevated values in Lirios and Montón may result from an interaction between the lake water and the underlying sediments.

Table 2. Physical characteristics of the primary lake basins. Areas are estimated from measurements made on aerial photographs.

Lake	Elevation (m a.s.l.)	Max. depth (m)	Area drained (ha)	Lake area (ha)	D/L*
Montón	3700	38.1	387.9	20.8	18.6
Saisay	3700	43.5	713.3	23.1	30.9
Mucubají	3540	15.7	1279.7	43.4	29.5
Negra(A)	3460	24.0	330.4	19.1	17.3
Brava	2380	14.6	516.2	38.5	13.4
Lirios	2300	8.7	323.5	20.2	16.0
Negra(M)	1700	3.9	213.7	10.4	20.5
Blanca	1620	4.8	274.2	22.0	12.5
Urao	1100	2.2	1057.0	13.0	81.3

* *Ratio of "Area drained" to "Lake area."*

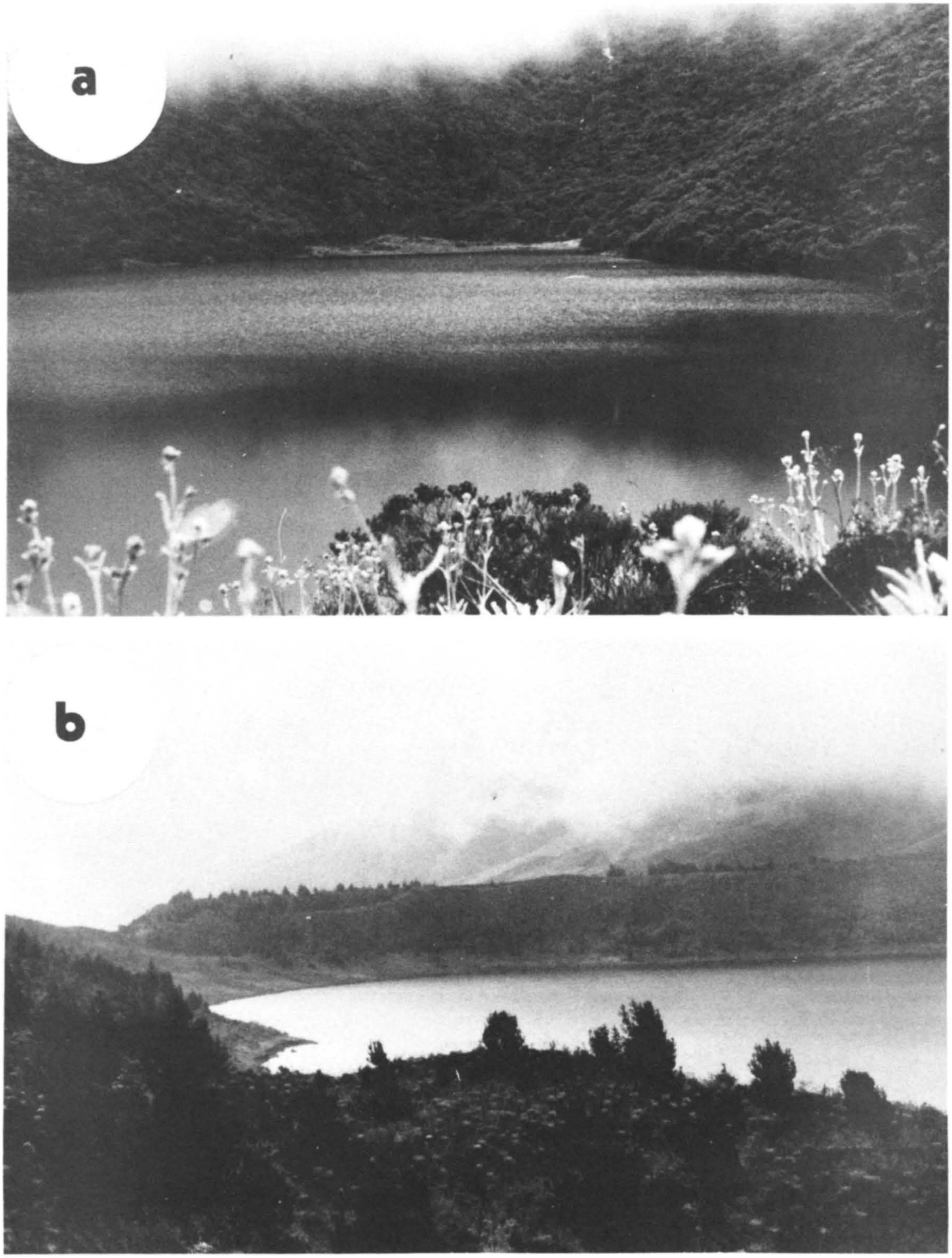

Figure 5. Representative lake basins. Tierra Helada: a) Laguna Negra (Apartaderos) shows typical cirque-basin morphology; b) Laguna Mucubají has a moraine dam.

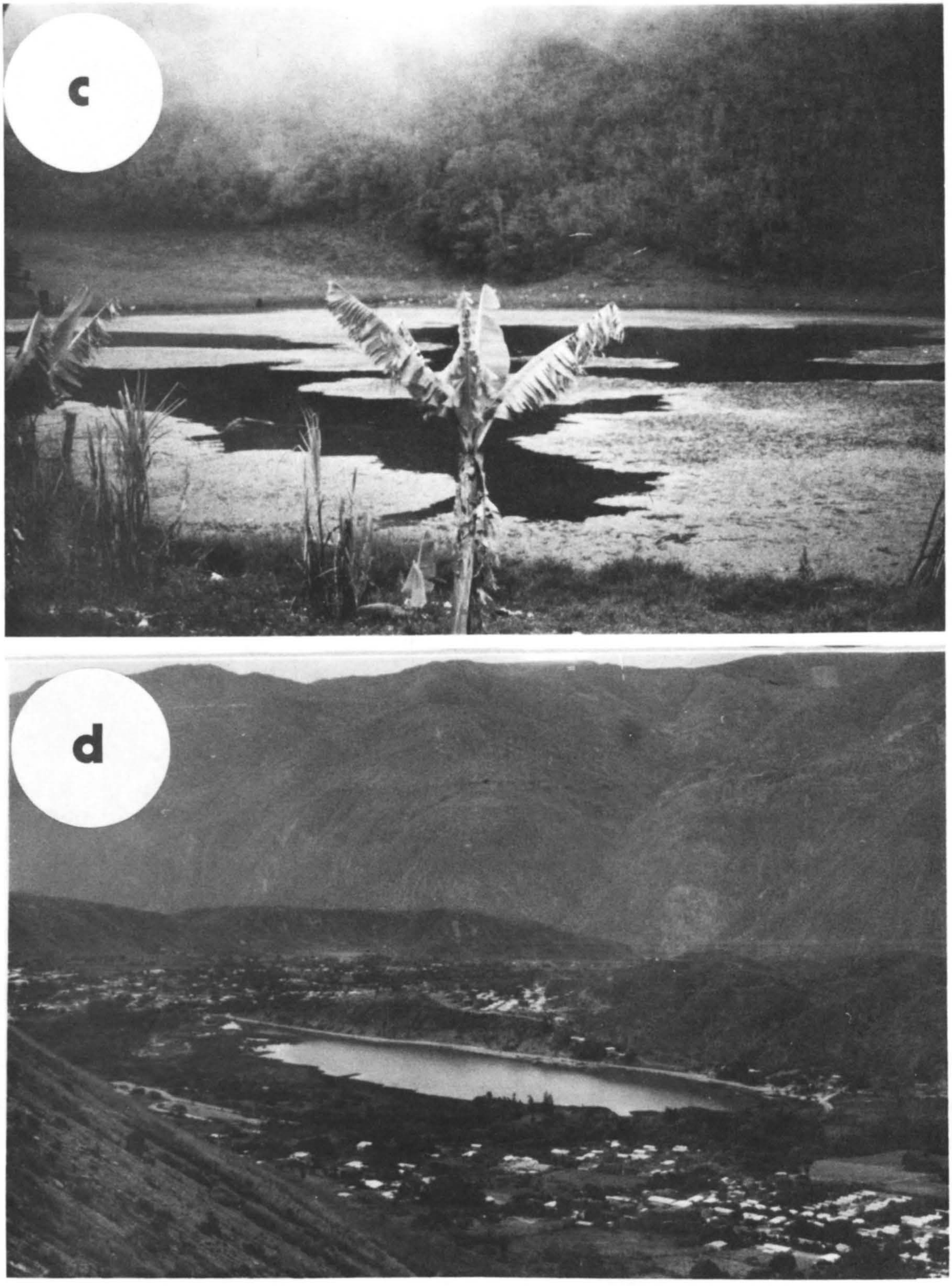

Figure 5 (continued). Tierra Templada: c) Laguna Negra (Mariño); Tierra Caliente: d) Lago de Urao with fault-line scarp at southern margin

Mean total ionic concentrations for the four lakes in the Tierra Helada climatic zone show very low and similar values, averaging 10.8 ppm (Table 3). These compositions reflect the low rates of chemical weathering and the gneissic basement rocks in the basins. Small differences exist in the cation and sulfate concentrations, perhaps related to minor differences in bedrock composition and microclimate.

Table 3. Mean chemical composition of the water in the primary lakes. Note the general similarities among lakes in the different altitudinal-climatic zones. Additional data are in Appendix A.

Zone	Date	Lake	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SiO_2	Cl^{-}	$SO_4^{=}$	TDS	pH
	10/13/83	Montón	0.86	0.16	0.56	0.18	4.71	0.96	1.11	10.45	6.5
Tierra	11/11/83	Saisay	0.61	0.13	0.55	0.19	2.61	0.86	1.22	9.35	6.3
Helada	10/83	Mucubaji	0.57	0.22	0.74	0.34	4.75	0.89	1.92	11.59	6.8
	10/8/83	Negra(A)	0.85	0.24	0.81	0.35	5.02	0.82	1.62	11.75	7.0
	10/18/83	Brava	1.79	1.23	3.94	2.80	13.42	1.39	4.07	43.18	7.0
Tierra	10/10/83	Lirios	1.76	1.51	4.37	5.10	1.50	3.62	8.39	45.60	7.0
Templada	10/20/83	Negra(M)	1.38	0.66	1.02	1.16	3.00	0.98	0.00	19.95	7.3
	10/21/83	Blanca	3.85	2.07	5.25	6.60	17.98	3.95	0.00	78.59	7.7
Tierra Caliente	9/2/83	Urao	4.39	3.35	424.	20.0	37.24	92.8	14.84	~1400.	10.0

Lakes Brava, Lirios, Negra(M) and Blanca are all in the Tierra Templada climatic zone, and they contain higher total dissolved solids than the Tierra Helada lakes. However, the water chemistry is more variable within this group, owing to three principal factors: the different bedrock underlying the drainage basins (Mucuchachí phyllites in Brava and Lirios basins vs. the gneissic Sierra Nevada Fm. in Negra(M) and Blanca); differences in the hydrology of these lakes, which is largely a function of groundwater flow; and a variable anthropogenic disturbance of the watersheds.

The composition of Lake Urao reflects its status as a closed-basin, evaporative lake. The precipitation of Ca-rich evaporite minerals (such as gaylussite) regulate the hydrochemistry of this lake.

Lake Sediments

Results of mineralogical and geochemical analyses are listed in Appendix C. In order to compare the results equally among all the lake basins, averages of each component are computed from the last 1,000 years of record as determined from ^{14}C dating of the cores.

Organic Matter

Organic matter in the recent sediments reflect the different locations of the lake basins. The Tierra Helada lake basins cluster around a mean of 37 to 45 weight percent (wt.%) organic matter (Table 4). In the middle climatic zone, Tierra Templada, there is a noticeable difference between the two upper and two lower basins. This difference may be related to limnological characteristics of the lakes. Lake Urao stands by itself with the lowest organic matter content.

The relationship between organic matter content and elevation is not simple (Fig. 6). A linear increase might be expected with decreasing elevations since increasingly warmer and wetter climates are characterized by denser vegetation and consequently a higher input of organic matter into the basin. However, this is not the case here. Some altitudinal "trends" may be inferred, with a reversal at >2,400 m, (Fig. 6) but the data are too sparse to be certain. More likely, the clustering may be caused by limnological

Table 4. Average organic matter content in the recent sediments (~1000 years) of the primary lakes, as determined by loss-on-ignition at 450°C. Additional data are in Appendix C.

			O. M. (wt.%)			
	Elev. (m)	*Depth (m)*	*Max.*	*Min.*	*N*	*Mean*
Montón	3,700	0.56	41.9	36.8	8	38.9
Saisay	3,700	0.54	47.3	43.1	6	45.2
Mucubají	3,540	0.56	38.2	33.0	8	36.6
Negra (A)	3,460	0.32	40.3	30.4	6	38.0
Brava	2,380	0.50	74.5	72.4	5	73.1
Lirios	2,300	0.15	79.1	77.9	3	78.4
Negra (M)	1,700	0.89	58.0	20.4	19	42.7
Blanca	1,620	0.50	59.0	33.1	9	50.6
Urao	1,100	0.45	17.6	7.0	9	13.3

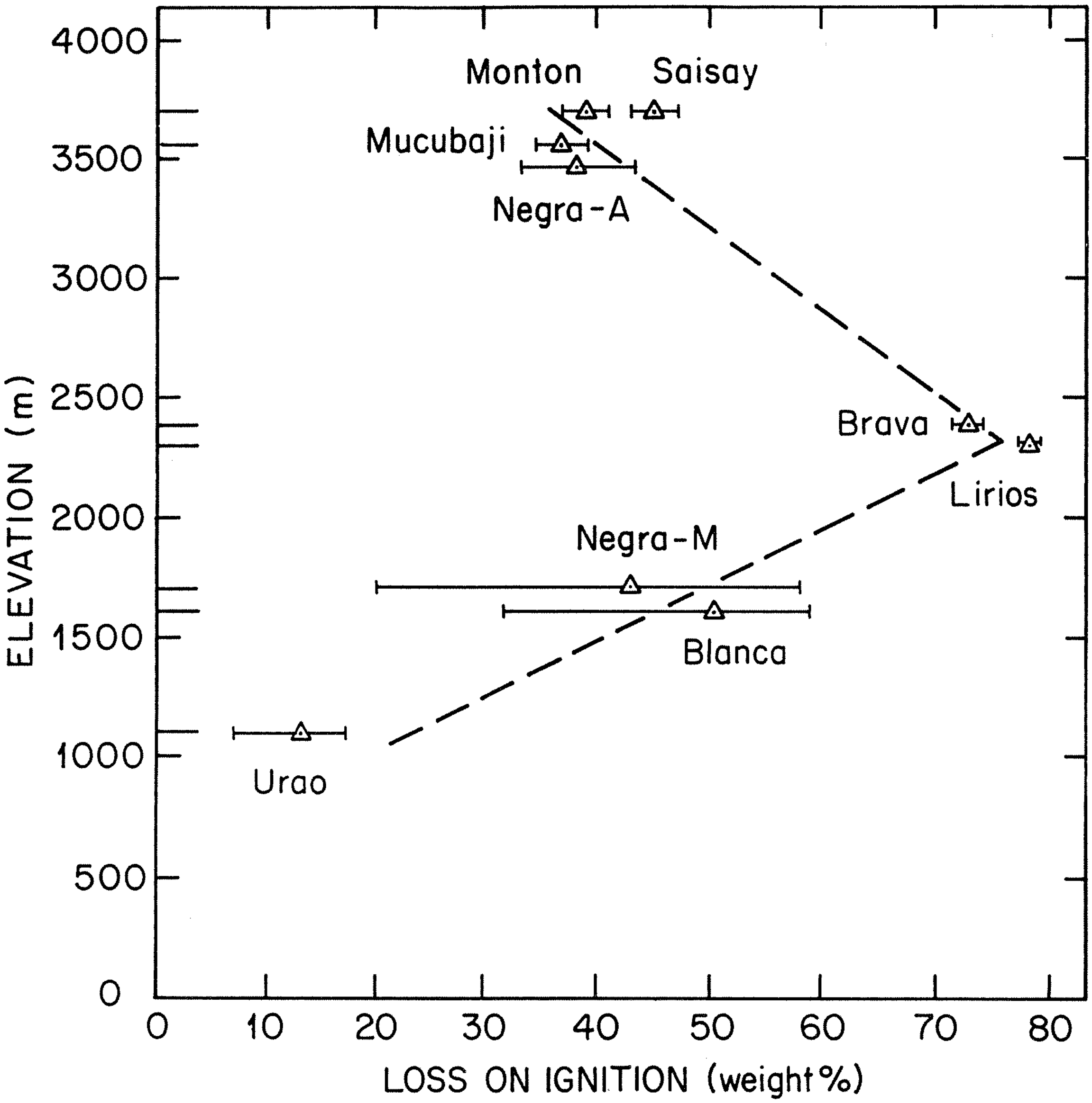

Figure 6. Organic matter abundance in lake sediments as a function of elevation.

(Triangle = mean, Line bar = range.)

processes within the lakes themselves. Dissolved oxygen in the lake water-column is a useful indicator of these processes. In the Tierra Helada lakes, the water is close to saturation down its total depth (Appendix A). In contrast, the lakes in Paramo de Mariño (except for Lake Blanca) show a noticeable decrease in dissolved oxygen with depth and a corresponding increase in electrical conductivity. Conductivity is a measure of dissolved solids and nutrients (Wetzel, 1975), and high organic matter may be a function of high productivity and preservation, particularly in lakes Brava and Lirios.

Sedimentation rates can also have a pronounced effect on organic matter content. Basins with a higher detrital flux will have a proportionately lower organic content. Sedimentation rates in the Venezuelan lakes, as determined from ^{14}C dates show some variability (Table 5; Fig. 7). Lake Los Lirios has the lowest sedimentation rate, which probably reflects its high organic matter content. Laguna Brava has a higher sedimentation rate, but the presence of abundant diatoms in the sediments may contribute to the high rates (Muñoz, 1970).

Carbonates

Table 6 shows carbonate content calculated from loss on ignition @ 1000°C (Dean, 1974). Values up to ~5% may come from loss of structural water in clay minerals. Consequently, only Lago de Urao has a significant amount of $CaCO_3$. Carbonate minerals were also not detected in the subsequent X-ray analyses.

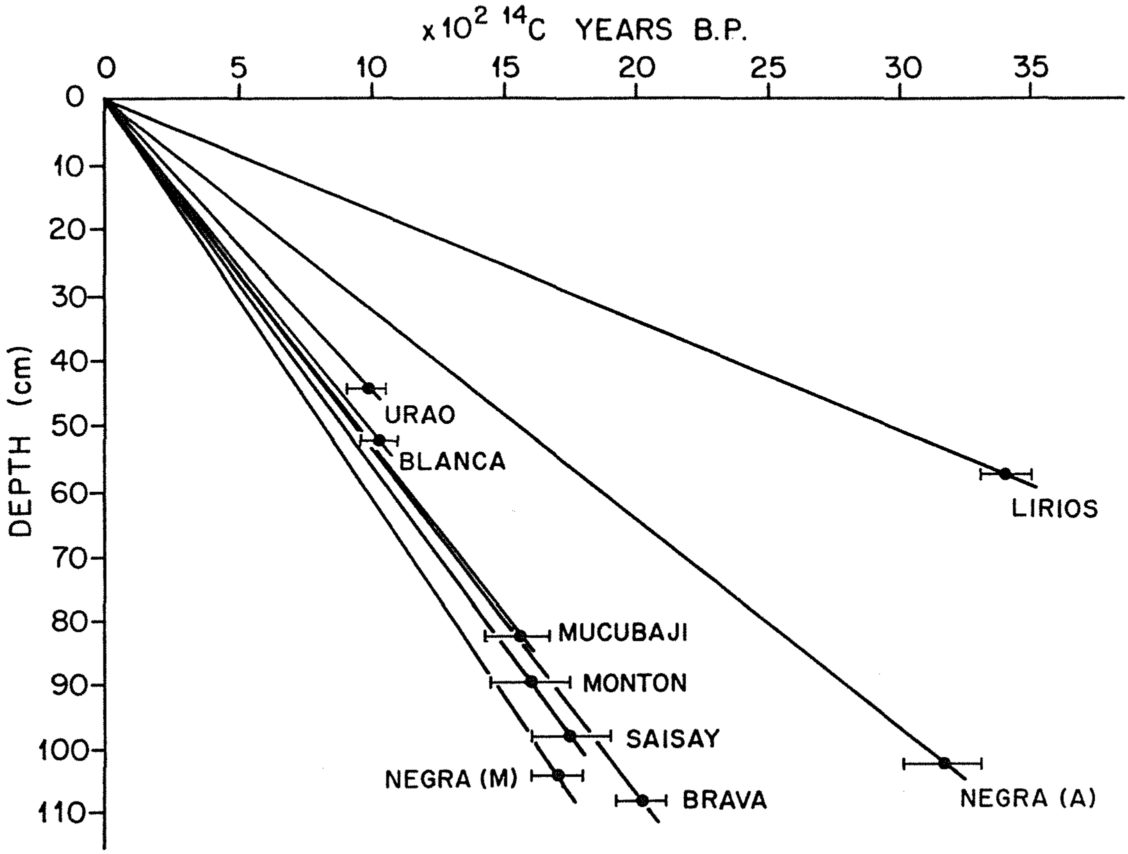

Figure 7. Sedimentation rates in the nine lake basins.

Table 5. Radiocarbon dates and sedimentation rates for the various lakes.

Lake	Depth (m)	^{14}C Years	$\delta^{13}C_{PDB}$	Sed. Rate
Montón	0.89	1,595 +/-275	-25.9%	~.06 cm/year
Saisay	0.98	1,745 +/-300	-26.5%	~.06 cm/year
Mucubají	0.82	1,550 +/-245	-26.7%	~.05 cm/year
Negra (A)	1.01	3,165 +/-330	-27.3%	~.03 cm/year
Brava	1.08	2,010 +/-180	-29.0%	~.05 cm/year
Lirios	0.57	3,395 +/-195	-33.3%	~.02 cm/year
Negra (M)	1.04	1,675 +/-190	-30.9%	~.06 cm/year
Blanca	0.52	1,035 +/-170	-27.8%	~.05 cm/year
Urao	0.44	990 +/-170	-21.5%	~.04 cm/year

Iron and Manganese

The three extractable forms of iron oxyhydroxides (crystalline, amorphous and organically bound) in the upper sediments show substantial variations among the lakes (Table 7), but there is a distinct clustering according to altitudinal-climatic zones (Fig. 8). Lake Urao sediments have about equal abundances of amorphous (oxalate-extractable) and crystalline (dithionite-extractable) iron which are higher than organic Fe (pyrophosphate extractable) by a factor of ~2 (see Table 7). Lakes in the Tierra Templada climatic zone show a greater diversity in the distribution of iron. Lakes Blanca and Negra (M) have higher relative proportions of amorphous Fe and crystalline

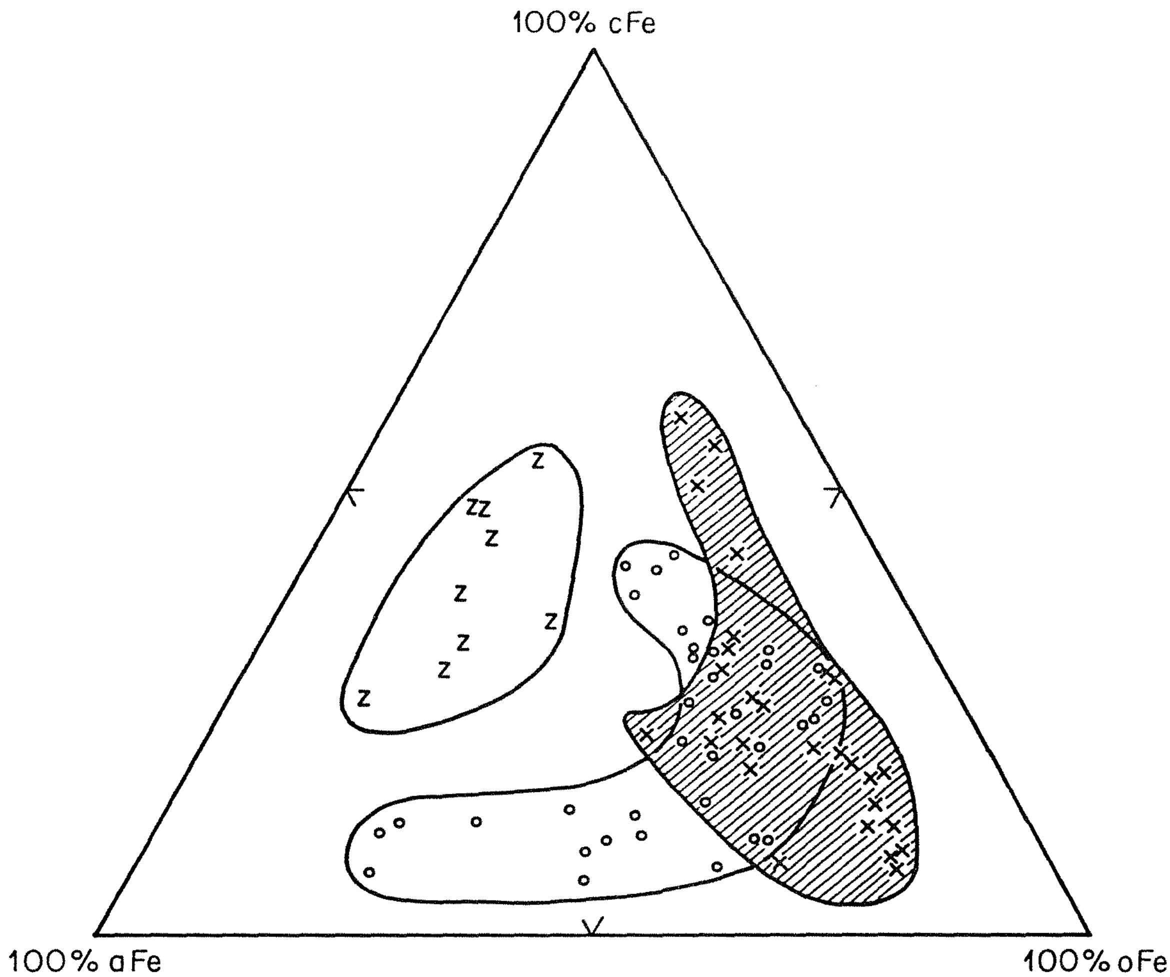

Figure 8. Relative abundances (%) of the three types of extractable iron in Venezuelan lake sediments. Amorphous iron = aFe; crystalline iron = cFe; organic iron = oFe. X = high-elevation lakes; O = mid-elevation lakes; Z = Lake Urao.

Table 6. Average calcium carbonate content in the recent sediments (~1000 years) in the primary lakes.

Lake	*N*	*x CaCO$_3$*	σ
Montón	8	2.97	0.59
Saisay	6	3.33	0.60
Mucubají	8	3.28	0.82
Negra (A)	6	3.85	1.84
Brava	5	1.62	0.87
Lirios	3	1.06	1.05
Negra (M)	19	2.36	0.61
Blanca	9	2.30	0.61
Urao	9	28.80	13.17

Fe than Lakes Lirios and Brava. The relative abundance of organic Fe is lower in these lakes than in Lake Urao, especially in Lake Brava.

In the four lake basins of the Tierra Helada climatic zone, the relative abundance of the different forms of extractable iron is much less varied (Fig. 8). Except for Lake Negra(A), organic Fe is the principal iron form. Crystalline and amorphous forms occur in subequal proportions (Table 7).

In general, these lake sediments have a lower proportion of their Fe in amorphous form and more as crystalline Fe than those in the Tierra Templada. The distribution of the iron in sediments of Lakes Negra (M) and Blanca resembles sediments of the Tierra Helada. This may be a function of similar bedrock (Sierra Nevada Formation) in the two areas.

Table 7. Relative abundance (in wt. %) of the three types of extractable iron in the recent lake sediments.

Zone	Lake	N	oFe	aFe	cFe
	Montón	8	52.9	25.6	21.5
Tierra	Saisay	6	60.8	16.2	23.0
Helada	Mucubají	8	71.6	15.3	13.1
	Negra (A)	6	38.6	14.6	46.8
	Brava	5	29.1	59.5	11.4
Tierra	Lirios	3	45.9	45.1	9.0
Templada	Negra (M)	19	48.5	21.4	30.1
	Blanca	9	56.4	28.3	15.4
T. Caliente	Urao	9	18.4	40.5	41.1

The distribution of manganese in the lake sediments has a twofold significance: it once again groups the lake basins altitudinally and may also be an indicator of the intensity of chemical reduction in the environment. The differential fluctuation of manganese and iron concentrations can be used to estimate the relative intensity of post-depositional oxidation-reduction processes. In modern soils, the Fe/Mn ratio is approximately 10:1 (Brady, 1974); since manganese is much more susceptible to chemical reduction than iron, an Fe/Mn ratio value higher than 10 suggests an intensified reduction and loss of manganese. Using these criteria, strongly reducing conditions obtain at the bottom of Lakes Lirios and Brava (Table 8), a conclusion supported by the very low dissolved oxygen in the deep water of these lakes (Appendix A).

Table 8. Calculated means for total concentrations (wt.%) of iron and manganese in recent sediments of the primary lakes and the resulting Total Fe/Total Mn ratio.

Lake	N	Mean TMn	σ	Mean TFe	σ	TFe/TMn
		10^{-2} wt.%		10^{-2} wt.%		
Montón	8	9.32	2.17	118.49	25.87	12.71
Saisay	6	6.70	0.86	91.91	14.09	13.72
Mucubají	8	8.92	0.85	257.18	25.47	28.83
Negra (A)	6	2.95	0.55	58.07	20.63	19.68
Brava	5	0.71	0.24	87.11	23.64	122.69
Lirios	3	0.61	0.16	263.11	60.88	431.33
Negra (M)	19	2.62	1.19	45.33	18.89	17.30
Blanca	9	3.41	1.11	41.43	12.31	12.15
Urao	9	9.85	2.35	86.90	19.69	8.82

Clay Minerals

X-ray diffraction analysis of the clay fraction (<2 μm) reveals the presence of four clay minerals: chlorite, a mixed-layer clay, illite and kaolinite (Table 9). In addition, gibbsite and gypsum or brushite were identified in the clay fraction of certain lakes.

Table 9. Mean relative abundance (%) values of clay minerals and gibbsite in the recent sediments of the lakes, as determined from the area under the 001 peak.

Lake	Chlorite	M.-L.	Illite	Kaol.	Gibbsite
Montón	18.7	8.2	26.1	47.1	----
Saisay	12.3	6.4	45.7	35.6	----
Mucubají	15.4	8.4	52.0	24.2	----
Negra-A	4.4	---	71.5	24.1	----
Brava	----	---	----	tr.	tr.
		(Mostly X-ray amorphous)			
Lirios	----	---	----	tr.	tr.
Negra-M	2.7	---	2.4	76.2	18.7
Blanca	1.2	---	2.6	88.6	7.6
Urao	2.9	---	83.1	14.0	----

Several samples showed a major diffraction peak at 14Å, which is shared by chlorite, smectite and vermiculite. Chlorite, in contrast to the other two clay minerals, does not possess interlayered hydrated cations and therefore it does not expand when treated with ethylene glycol. However, some varieties of vermiculite will also not expand. Additional treatments are therefore necessary in order to establish the existence of each of these three mineral phases. This was done by saturating the clay sample with potassium and heating it to 300^{o}C. Upon this treatment, a partial collapse of the vermiculite structure takes place, and the 14Å peak shifts to a 10Å position. Since no changes in the peaks were observed, it was assumed that vermiculite is absent.

By heating the sample to 550°C, the 14Å peak of smectite and vermiculite will collapse to 10Å. In some of the samples, the 14Å peak persisted but showed a substantial contraction when compared with its pretreatment intensities. Barnhisel (1977) mentions several studies where similar responses were reported. It has been suggested (Brindley and Brown, 1980) that these responses (lack of swelling upon glycolation and the collapse of the 14Å peak to a 10Å position) indicate the presence of a degraded Mg-rich chlorite.

Illite is a fine-grained muscovite with some substitution in the octahedral layer, less Al^{+3} in the tetrahedral layer and thus less K^{+} in the interlayer (Berner, 1971). The most intense basal reflections of illite (and 1M muscovite) are (001) and (003) with respective d-spacings of 10Å and 3.33Å, and these were used to identify this clay mineral in the lake sediments.

A mixed-layer clay mineral layer clay mineral phase was recognized by diffraction peaks between 11Å and 12Å, suggesting the presence of an illitic (10Å) component and a 14Å component. The lack of swelling upon glycolation shows that no expandable clay is present, and the most likely composition is therefore an illite-chlorite. Malagon (1982) identified interlayered illite-chlorite as the most abundant mixed-layer clay in soils from the Mucubají area. It is very likely therefore, that the sediments in these lake basins will contain a similar mixed-layer clay.

The kaolinite structure consists of one octahedral and one tetrahedral layer with little ionic substitution. Kaolinite has two major X-ray diffraction peaks of 7Å (001) and 3.5Å (002), which collapse when the sample is heated to 550^{o}C. A complication arises when chlorite is present because the 002 and 004 reflections of chlorite are similar. Furthermore, iron-rich chlorite will also lose the 7Å (002) reflection upon heating to

550°C (Brindley and Brown, 1980). To distinguish between these two clay minerals, the sample is treated with 1M HCl (Carroll, 1970). The hydrochloric acid destroys the chlorite crystal structure, so any remaining 7Å reflection belongs to kaolinite.

Gibbsite was identified on the basis of three X-ray diffraction peaks of 4.85 (002), 4.36 (110) and 4.32Å (200). However, when the basal (002) reflection was of low intensity the other two were usually undetectable.

Clay minerals in the sediments of the Tierra Helada lakes show similar patterns of abundance and distribution. Vertical profiles of clay minerals in the cores from lakes Montón and Saisay exhibit greater variability than those from Mucubají and Negra-A (Fig. 9). In the Tierra Templada lakes, two extremely different results were obtained. Lakes Brava and Los Lirios contain largely X-ray amorphous material (only traces of gibbsite and kaolinite were detected), whereas in the lower-elevation lakes Negra-M and Blanca, the mineral assemblages consist primarily of kaolinite and gibbsite (Table 9; Fig. 10). The clay minerals in Lake Urao consist of illite and kaolinite (Fig. 11). In general, there appears to be a consistent grouping of clay mineral assemblages according to altitudinal differences among the lakes, and perhaps this is related to the climate at these elevations (Lauer, 1979).

An apparent association between climate and clay minerals was initially recognized in deep-sea sediments of the Atlantic Ocean (Biscaye, 1965; Jacob, 1970). Latitudinal belts of clay minerals coincided reasonably well with known global climatic zones, although some bedrock influences could also be discerned. In general, the deposited clays reflect the weathering environment in the continental source area (Singer, 1984), and early diagenesis in sea water is minimal. An analogous relationship between weathering conditions and deposited clays might also be extended to altitudinal climate zones as observed in the Venezuelan Andes.

The prevalence of illite and chlorite in the highest-elevation lakes agrees with similar findings in Antarctic soils and sediments (Bockheim, 1982). High abundances of

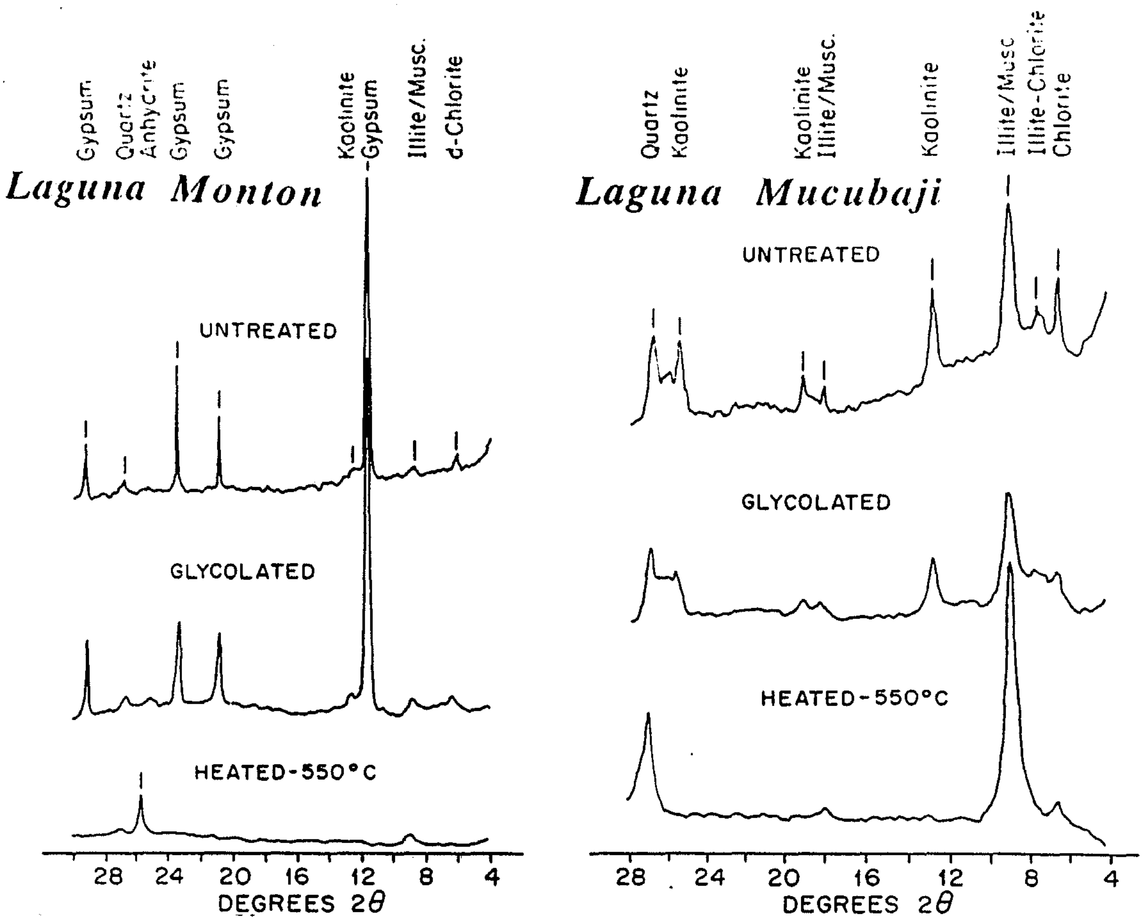

Figure 9. Comparison of X-ray diffraction patterns for two of the Tierra Helada lakes, Montón and Mucubají.

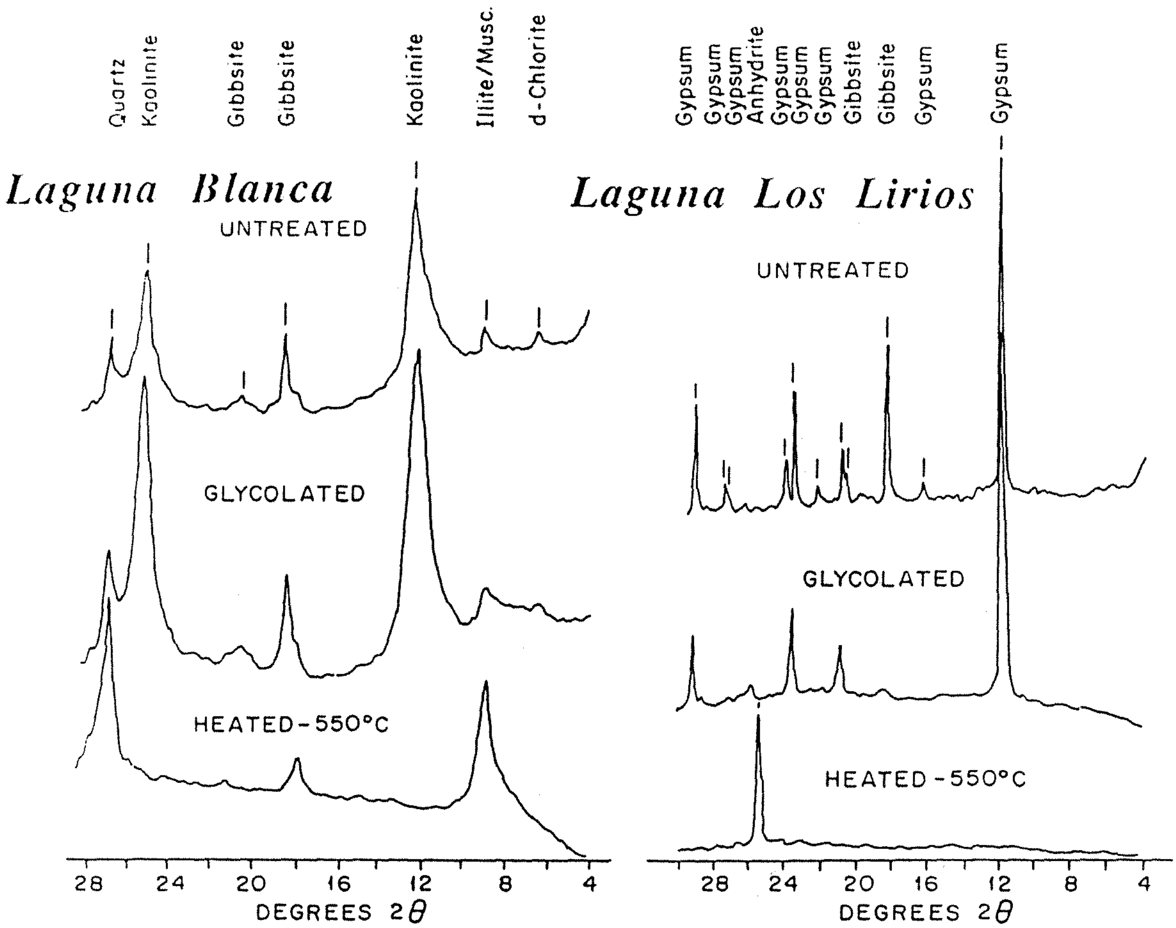

Figure 10. X-ray diffraction patterns from Tierra Templada lakes Blanca and Los Lirios.

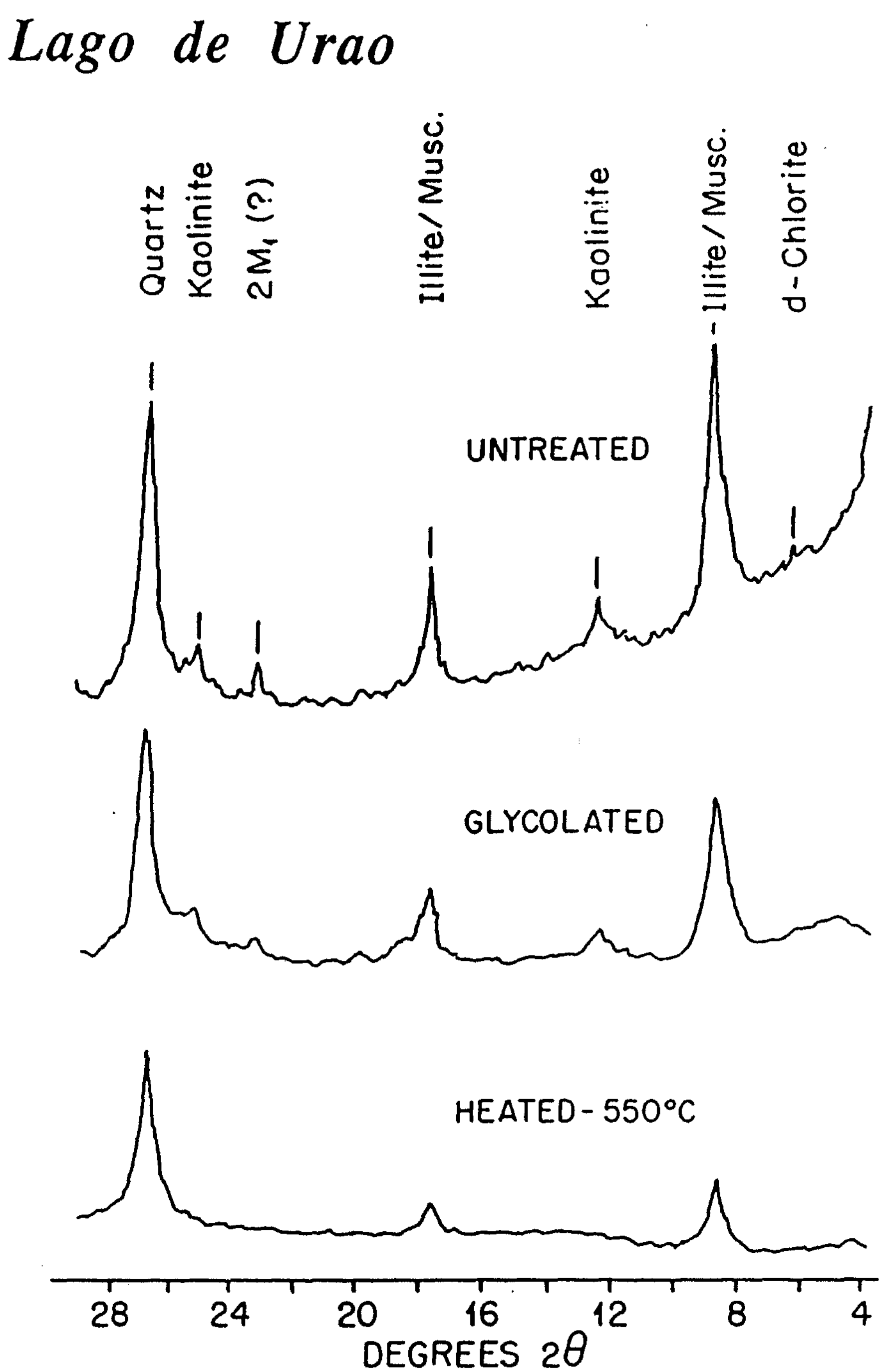

Figure 11. X-ray diffractogram of sediments in Lake Urao, located in the Tierra Caliente.

illite and chlorite in Antarctica were interpreted as indicating weak weathering intensities, typical for cold climatic conditions dominated by mechanical weathering. For these minerals to be very abundant, hydrolysis should be minimal, since this process is responsible for the degradation of illite and chlorite (Birkeland, 1984).

Degraded chlorite was identified in the sediments of the two lower lake basins of the Tierra Helada climatic zone, Mucubají and Negra-A (Fig. 9). The greater abundance of d-chlorite may indicate some increase in weathering intensity at these slightly lower elevations (Barshad, 1966).

The presence of kaolinite in the clay assemblages of these high-elevation lake basins seems out of place, since kaolinite normally forms under warm, wet conditions accompanied by a high leaching rate (Singer, 1985). Malagon (1982) interpreted kaolinite in some soils around Lake Mucubají as a relict of an older paleosol. Weingarten (1977) also found such paleo-oxisols in other parts of the Venezuelan Andes. Thus, kaolinite may not be forming in the present Tierra Helada environment, and its presence in the sediments reflects an anomalous environmental signal.

In the two higher-elevation lakes of the Tierra Templada climatic zone (Brava and Los Lirios), the clay-size fraction contains mostly amorphous material, except for prominent diffraction peaks of gypsum or brushite (Fig. 10). The nature of the amorphous material is unknown, although it is presumably organic in origin. It proved resistant to peroxide oxidation. The source of the gypsum is not known. One possibility is that sulfide minerals in the Mucuchachí Formation are oxidizing to gypsum in the soil, and these are subsequently transported to the lake. If this mineral is brushite ($CaHPO_4$), it is most likely related to the high organic productivity in these lake basins.

Chemical analyses of the lake waters show elevated silica concentrations (up to 14 ppm) in lakes Brava and Los Lirios (Table 3), suggesting a high rate of silicate weathering in the surrounding drainage basin. The source of the amorphous organic material may be from diatoms, which should also thrive in the high-silica environment.

Although modern diatoms have not yet been recovered from the lake, the presence of diatomaceous earth in the drainage basin supports their presence (Varga Molner, 1970).

Kaolinite and gibbsite dominate the clay mineral assemblages in the two lower Tierra Templada lakes (Negra-M and Blanca). The presence of these minerals reflects the warm temperatures and high humidity at these elevations, which would result in enhanced leaching, intense hydrolysis and deep chemical weathering. The chlorite in these lake sediments is a poorly crystalline, degraded variety, in contrast to the type found at higher elevations. This also fits the climatic conditions at these altitudes, where chlorite undergoes more rapid breakdown.

The clay-mineral assemblage of Lake Urao, in the Tierra Caliente climatic zone, contains illite as the dominant clay (Fig. 11). Although the climate here is warm, the accompanying aridity would limit weathering. Furthermore, the surrounding sedimentary rocks in the basin (La Quinta) may contribute detrital illite to the basin. Finally, Lake Urao is an alkaline, saline water body (pH = 10; TDS = 1400 ppm), and such conditions can favor the preservation of illite (Yuretich and Cerling, 1983).

Since illite is a recognizable component of all the lake groups, measurements of illite crystallinity were undertaken to see if it varied in an regular or systematic fashion. Illite crystallinity was determined by measuring the width of the glycolated illite (001) peak at half its height (the "Kubler Index") and dividing this by the peak height to normalize for intensity differences among the various diffractograms. The results show that illite is 3 to 4 orders of magnitude more crystalline in the Tierra Helada lake sediments than in those from the Tierra Templada (Table 10).

The high illite crystallinity in Lake Urao suggests that hydrolysis is less intense here than in the Tierra Helada lakes, and this agrees with the previous clay-mineral data. Because rainfall in the Urao area is intense but sparse and of short duration, only poorly weathered detrital material from the shattered La Quinta Formation reaches the lake.

Table 10. Illite crystallinity calculated by dividing the width of the illite (001) diffraction peak at half height by its height.

Lake	*Illite crystallinity*
Montón	0.12
Saisay	0.15
Mucubají	0.11
Negra-A	0.11
Negra-M	0.21
Blanca	0.30
Urao	0.04

The elevated alkalinity of Lake Urao may also contribute to the high illite crystallinity. Similar environments have been found to promote the formation of illite, since the high concentration of K^+ in the water may fully saturate the exchange sites in the illite structure (Singer and Stoffers, 1980).

Supplemental Studies

In order to ensure that the patterns observed in the primary lakes were typical of those found throughout the region, a short reconnaissance of five other lake basins was carried out. All of these lakes are in the Tierra Helada zone, with Lagunas Las Verdes (4,300m a.s.l.), Laguna El Misteque (3,750 m), Laguna La Canoa (3,500 m) and Laguna Victoria (3,250 m) located in the eastern part of the study area near Apartaderos (Fig. 1). Only one additional lake was investigated in the western end, in the Paramo de Batallon, southwest of Tovar: Laguna El Cienegón (3,250 m). This seemingly "biased" preference for high-elevation lakes is actually a reasonable reflection of reality, since the overwhelming majority of lake basins in the Venezuelan Andes occurs at high elevations (Fig. 12). Although the data from these lakes have not been subjected to the same rigorous inspection as that from the principal lakes, the general patterns discovered in the original nine lakes are reproduced. The complete analytical information is given in Appendix C.

Summary

The sediments in the lakes of the Venezuelan Andes form compositional groups which reflect the environmental conditions in their altitudinal-climatic zones. The high-elevation Tierra Helada is characterized by low temperatures and an excess of precipitation over evaporation. The resultant cold and wet environments sustain strong physical weathering conditions which are reflected in the abundance of organically bound iron and a high amorphous/crystalline iron ratio. Clay minerals in the sediments are principally illite and chlorite. In the intermediate elevations, the Tierra Templada, the relative proportion of amorphous iron is greatest. This may be partially caused by an increase in the intensity of chemical weathering, specifically hydrolysis. These conditions also support a greater abundance of kaolinite, lesser amounts of illite and mixed-layer clay, as well as a proportional increase of degraded chlorite. Some kaolinite is inherited from pre-existing paleosols.

Precipitation at these altitudes is very high, as is the amount of organic matter available for decay from the surrounding terrestrial vegetation. Productivity in the Tierra

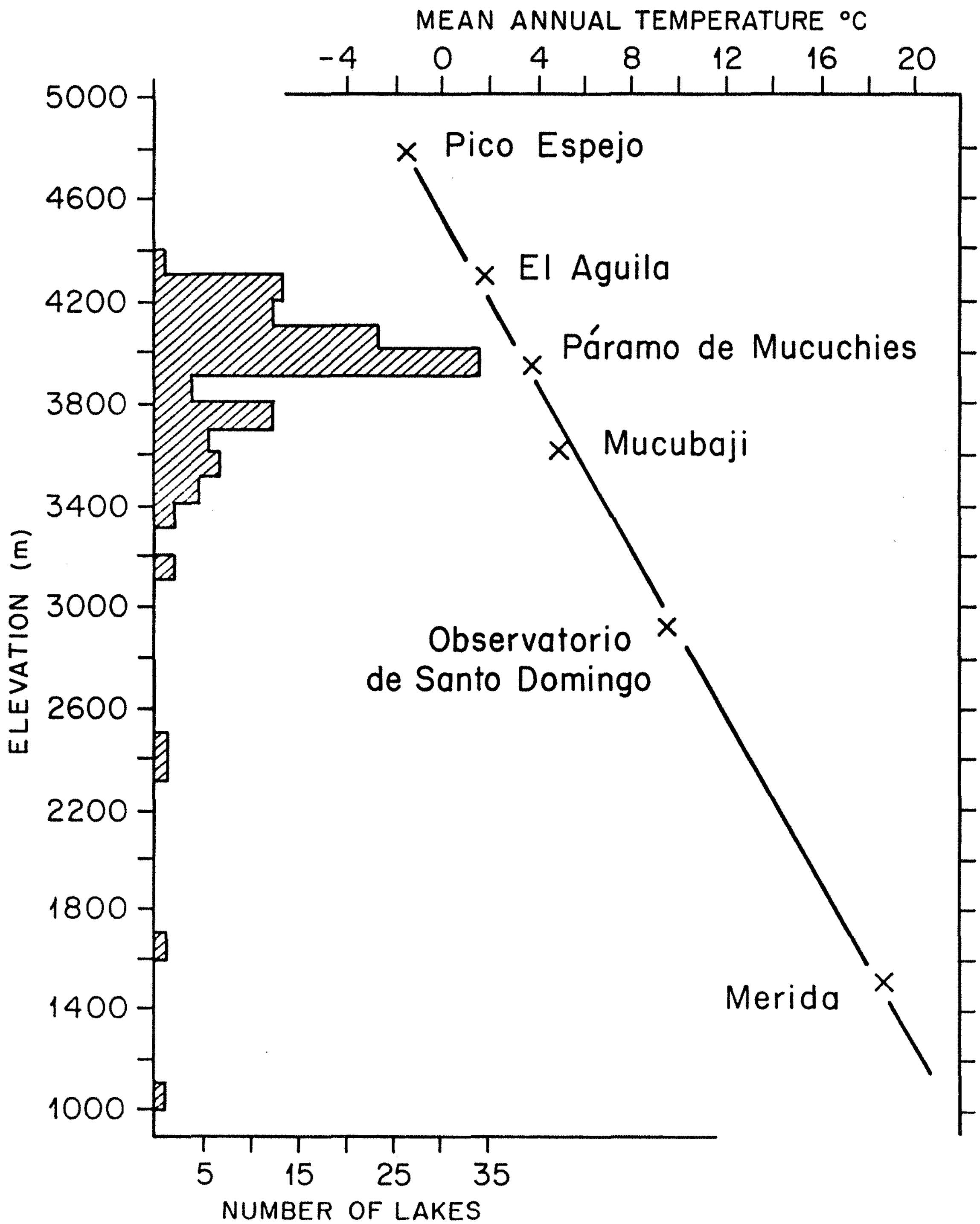

Figure 12. Distribution of lakes in the Venezuelan Andes shows a high concentration in the cooler climatic zones. Temperature data from stations indicated.

Templada lakes is evidently high, and the possible development of an anoxic hypolimnion promotes the preservation of organic matter in the sediments.

Finally, the aridity of the Tierra Caliente (Lago de Urao) may reduce the hydrolysis of minerals, promoting the formation of more crystalline iron sesquioxides. Some of these many be hydrolyzed to amorphous iron in the alkaline lake waters, giving rise to an equal importance of crystalline and amorphous iron. The importance of illite in these lake sediments can be related both to the detrital influx and the high alkalinity of the lake.

Although other factors, most notably bedrock mineralogy, will have an influence on sediment composition, the distinctive geochemical signatures in the three altitudinal zones point toward an overriding climatic influence.

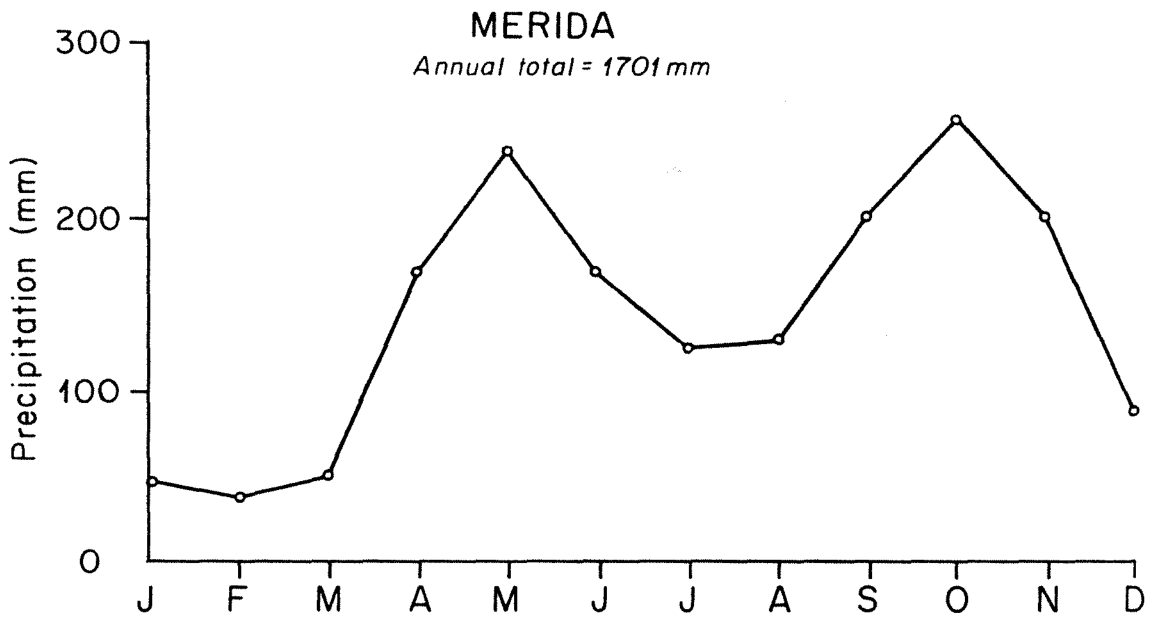

Figure 13. Monthly precipitation recorded at Merida.

STUDIES OF MODERN CLIMATE

Raymond Bradley, Richard Yuretich and Baruch Weingarten

Climate of the Field Area

On a large scale, the climate of the Mérida Andes is controlled by seasonal changes in the equatorial trough, which are linked to the seasonal change in solar declination. The sun passes overhead at Mérida on April 11th and September 1st; precipitation from convective storm systems increases at these times and during the subsequent two months, producing a pronounced biannual precipitation regime (Figure 13). Maximum rainfall occurs throughout the region in May and October (Figure 14); only in the higher elevations in the northeast of the field area, close to the continental divide, is there an annual harmonic in the rainfall regime, with maximum amounts in the month of June (e.g. Figure 15a). This may be related to the movement of moist air across the divide from the Llanos to the east and the development of (fairly localized) cloud systems over the higher peaks around the headwaters of the Chama river valley. It is this seasonal change in precipitation and associated cloudiness that dominates the climate of the region and defines the seasons. The *verano* is the wet season, April to mid-November; the *invierno* is the dry season, mid-November to March. In Mérida, over 85% of annual precipitation falls during the *verano*. Regional airflow has an easterly component throughout the year, being slightly stronger with a more southeasterly provenance during the *verano*, and somewhat weaker with a more northeasterly provenance during the *invierno* (Snow, 1976).

Monthly mean temperatures vary very little during the year. Mérida, for example, has an annual range of only 1.5°C. However, in common with other tropical mountain regions, seasonal changes in temperature are mainly manifested by an increase in diurnal range during the dry season *(invierno)*. This results from high solar radiation receipts during the day and large radiative losses at night. The effect increases with elevation so that in the highest parts

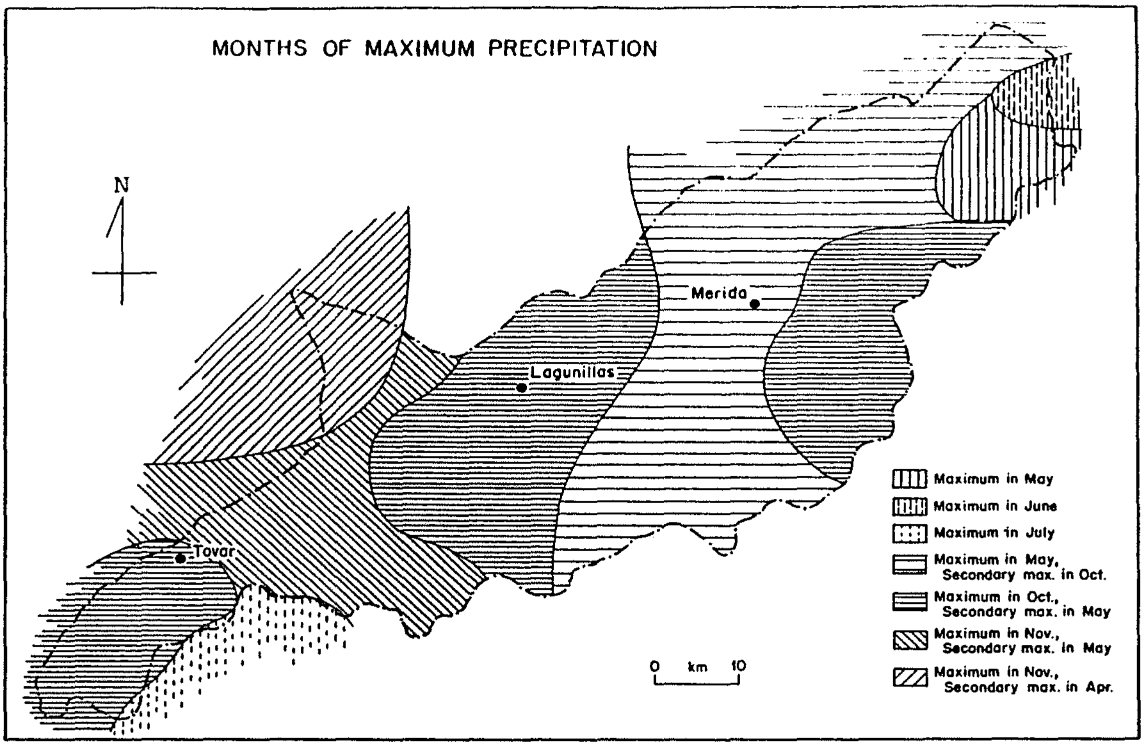

Figure 14. Regional patterns in time of maximum precipitation, Venezuelan Andes.

(from Andressen and Ponte, 1973)

of the region daily maximum and minimum temperature may differ by more than 20°C at this time of year, and minimum temperatures may fall well below 0°C. Walter and Medina (1969) note that in 1967 at Mucubají (~3600m) the maximum and minimum *for the year* were recorded within a period of 48 hours (+14°C to -7.5°C)! During the *invierno*, diurnal cycling across the 0°C threshold may be an important factor in mechanical weathering processes and, in fact, periglacial phenomena at elevations above ~4500m have been described (Schubert, 1979; 1980; Perez, 1984).

An important factor in the hydrology of lakes in the region is the precipitation-evaporation relationship (P-E) both in absolute terms over the year and in terms of seasonal variations. Figure 15(a and b) shows monthly mean precipitation totals and monthly pan evaporation (in mm) for two stations close to the most important lake coring sites in the study area. Pan evaporation is not an equivalent measure of actual lacustrine evaporation but it is the only relevant long-term parameter measured in the region (indeed, the area is fairly well endowed with such data which are generally not available in most mountain regions). Empirical estimates suggest that lacustrine evaporation is generally lower than pan estimates, by a factor of 0.7 ($^{+}/_{-}$0.2) (Morton, 1967). The precise factor depends on many variables, including lake size and bathymetry, mean wind speed, and topographic factors affecting airflow and solar radiation receipts. Nevertheless, the pan data provide some useful information for our study. At both Tovar and Mucubají, total annual precipitation is slightly greater than pan evaporation. This suggests, for the real lake environment, a positive value of P minus E for the entire year. However, the strong seasonal precipitation cycle (unimodal at Mucubají, bimodal at Tovar) together with the associated seasonal changes in cloudiness and solar radiation receipts, results in a period of the year when E exceeds P (November - December to March - April). This may result in some seasonal concentration of dissolved solids in lake waters, particularly in the lakes of the Tierra Templada, above Tovar. No surface waters currently flow from these lakes, although it is likely that they have a throughflow of groundwater, and lake levels will reflect the regional groundwater table.

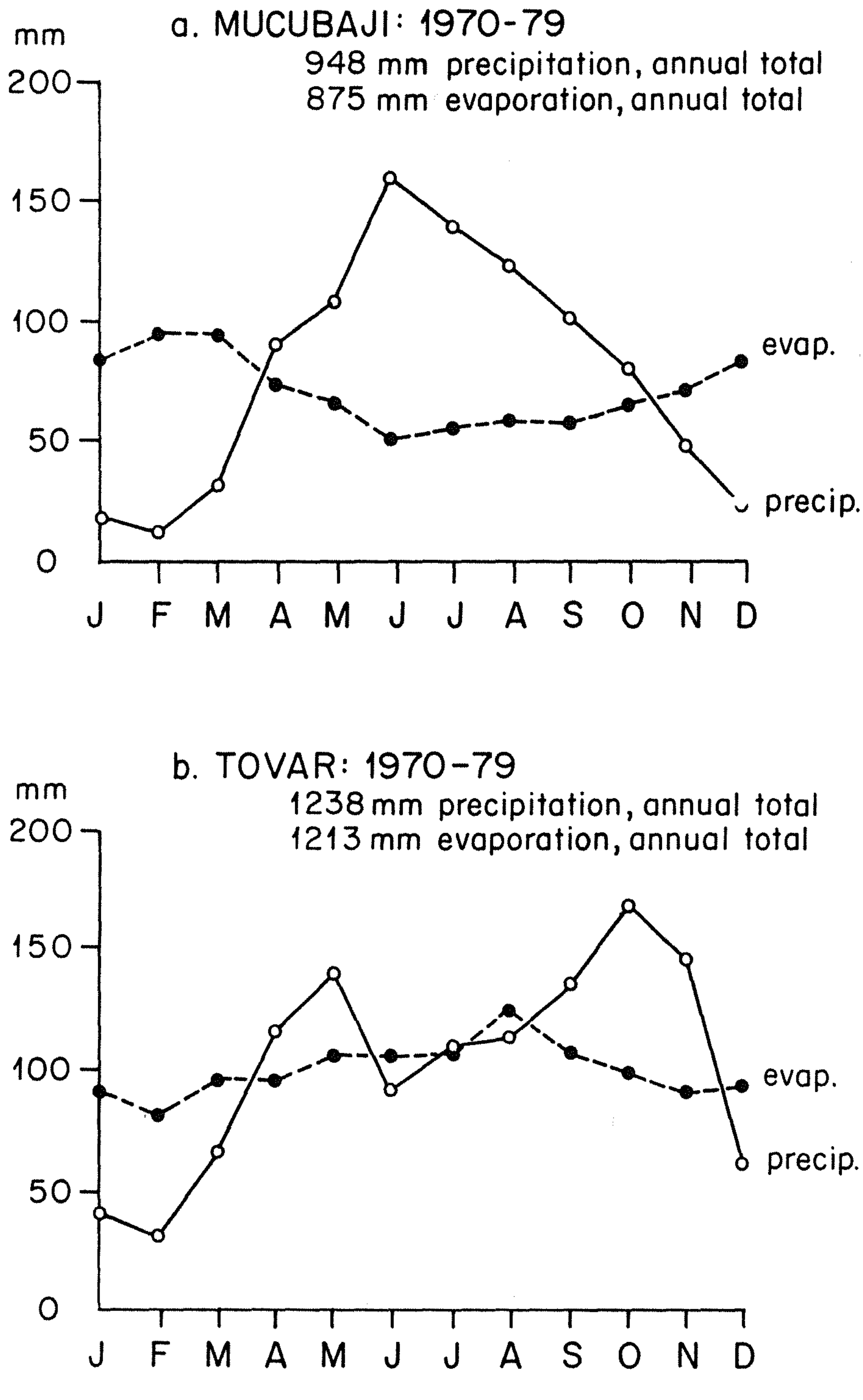

Figure 15. Annual trends in precipitation and evaporation at two stations in the Merida Andes.

There is geomorphological evidence that these lakes have overflowed in the past. Currently, withdrawal of water for agricultural use maintains a negative water balance for the lake. It is not known how long this condition has prevailed but it seems probable that even without this interference, the lake would not overflow and that P minus E $\cong 0$ on an annual basis.

Further discussion of climatic conditions in the region can be found in Nieto and Arroyo (1968) Gonzales (1971) Andressen and Ponte (1973) Azocar and Monasterio (1979; 1980a,b) Lauer (1979) Monasterio (1979) and Monasterio and Reyes (1980). However, in most of these studies, the emphasis is on climatic conditions in the higher elevations of the region.

Precipitation in relation to elevation

Figure 16 shows all the long-term annual precipitation data in the study area plotted with respect to station elevation, based on a common period of observation (1970-79). Although there is considerable scatter in these data, highest precipitation amounts are recorded at around 2400 $^{+}/_{-}100$ m. This may be associated with the mean elevation of the cloud base in the region, though no observational record exists to be certain.

Regression analysis of monthly and seasonal precipitation data reveals that, when all data are considered, each month shows a decrease in precipitation with altitude, although this is only statistically significant in the month of September. When the data are broken down into two subsets of stations above and below 2500m, the lower elevation stations are positively related to precipitation (although this is only statistically significant in March and April). However, at higher elevations the relationship is generally negative (except in June-August). Such patterns provide weak support for the hypothesis that precipitation generally increases with elevation at low levels (up to ~2500m) and decreases above ~2500m; further study of this is warranted. Data should be stratified by slope orientation and relationship to principal topographic divides. It would also be useful to look at individual synoptic events on

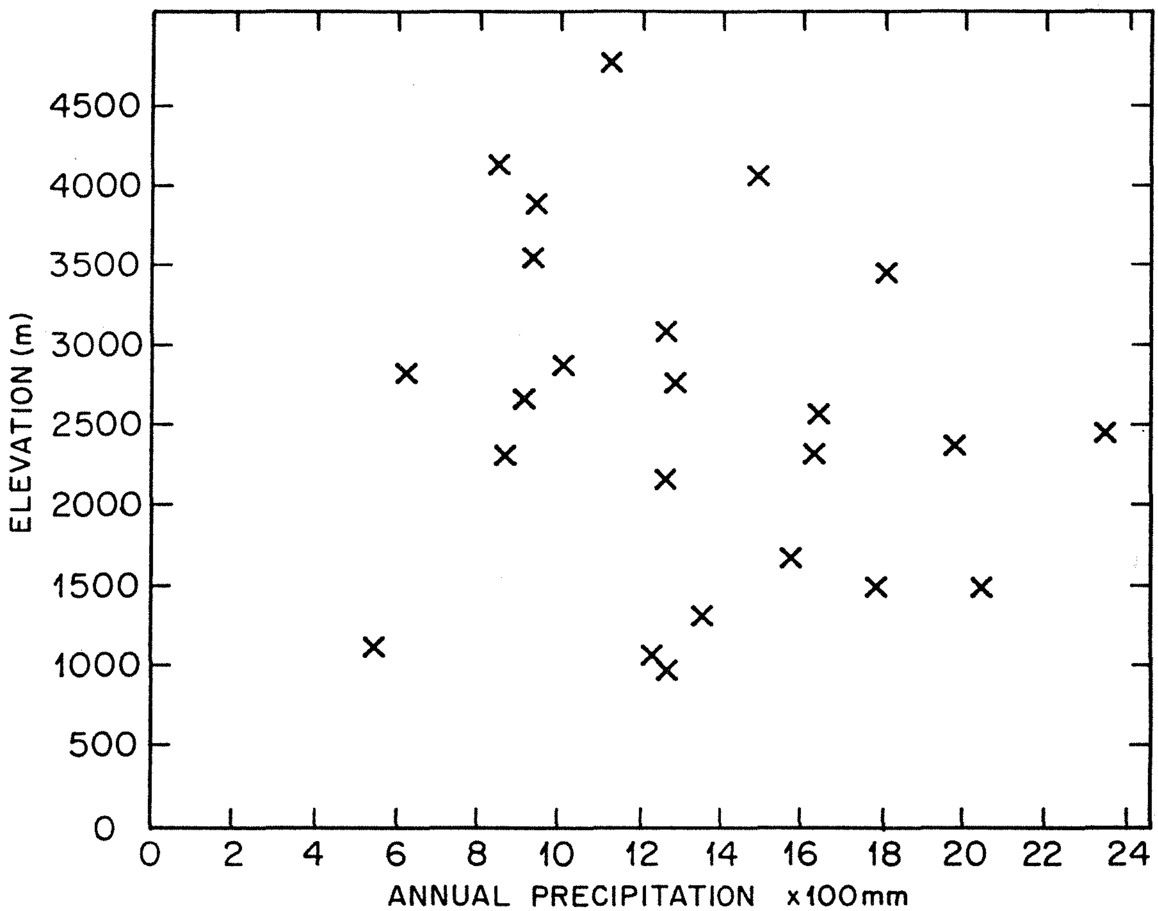

Figure 16. Relationship between precipitation and elevation in the Venezuelan Andes.

a regional basis, so that the resultant precipitation could be examined in relation to regional airflow patterns .

Temperature in relation to elevation

Temperature is closely related to altitude. Figure 12 also shows mean annual temperature in the region with respect to station elevation. A very strong correlation is seen, with temperature decreasing ~0.63°C $100m^{-1}$. Mean annual temperatures are estimated to be below 0°C above ~4500m, which is 100-200m below the elevation of the permanent snow line in the region at present. Andressen and Ponte(1973) have prepared a map of thermal zones in the region based on an estimate of annual temperature at different elevations, utilizing this strong relationship between temperature and altitude (Figure 17).

It is common to refer to bioclimatic zones in the mountain region, based on a vegetation-climate zonation scheme. As previously mentioned, four zones are commonly recognized: *Tierra Caliente, Tierra Templada, Tierra Fria* and *Tierra Helada* (Figure 3). Lauer (1979) also recognizes a fifth zone, the *Tierra Nevada* for the region above snowline (~4700m in the study area). Although no precise definitions exist for these zones, in the region of the Mérida Andes, only the area around Lagunillas can be considered to fall in the *Tierra Caliente* zone with mean annual temperatures exceeding 22°C. The *Tierra Templada,* associated with the lower tropical montane forest, extends to ~2200m, above which the cloud forest (*bosque nublado*) or upper montane forest is found in the *Tierra Fria.* In the higher elevations of this zone, the montane forest gives way to *páramo* vegetation, though the main *páramo* zone is found above ~3200m in the *Tierra Helada.* Of course, there are variations in this simple scheme from one part of the region to another, particularly in relation to the distribution of precipitation (Figure 18). Arboreal species are found at higher elevations in the more humid regions of the mountains (Monasterio, 1979).

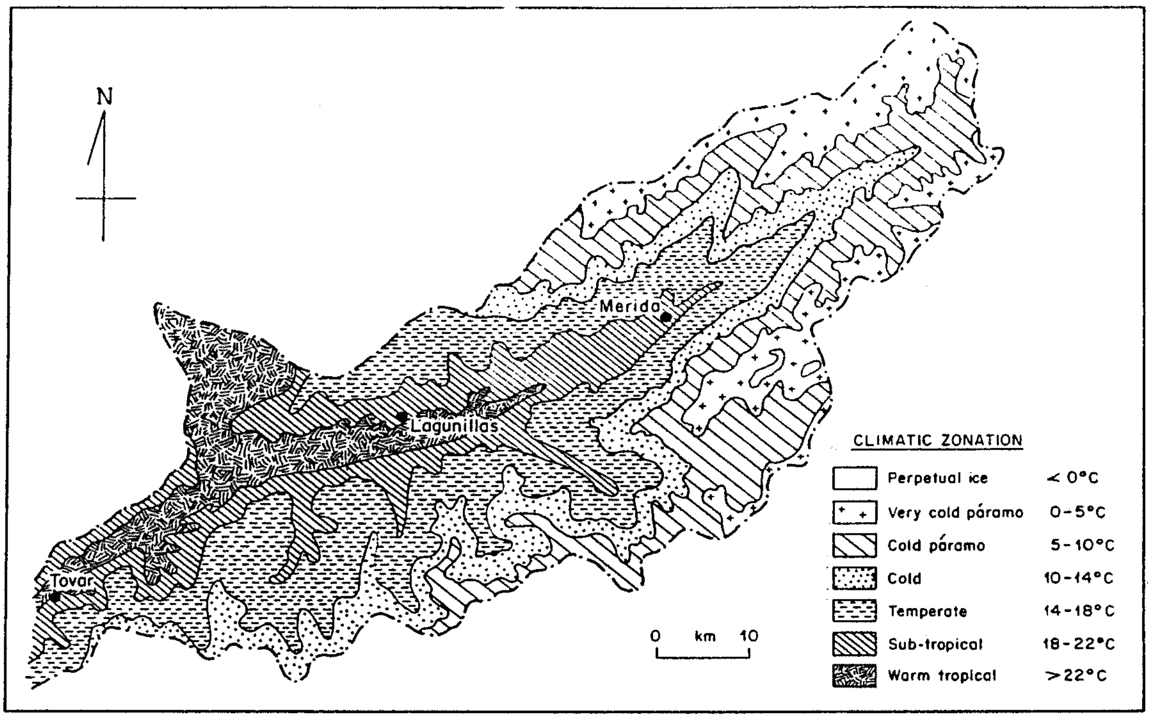

Figure 17. Regional geographic distribution of altitudinal climatic zones.

(from Andressen and Ponte, 1973)

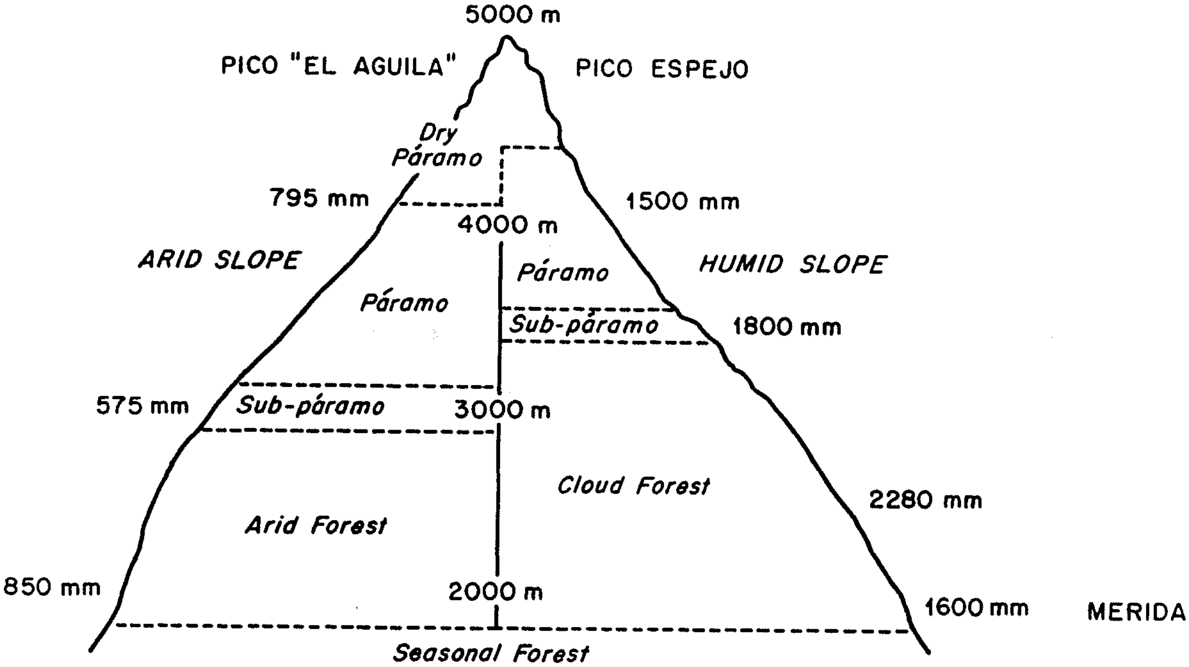

Figure 18. Precipitation and vegetation differences found on humid (north-facing) versus arid (southfacing) slopes in the Venezuelan Andes.

(after Monasterio and Reyes, 1980)

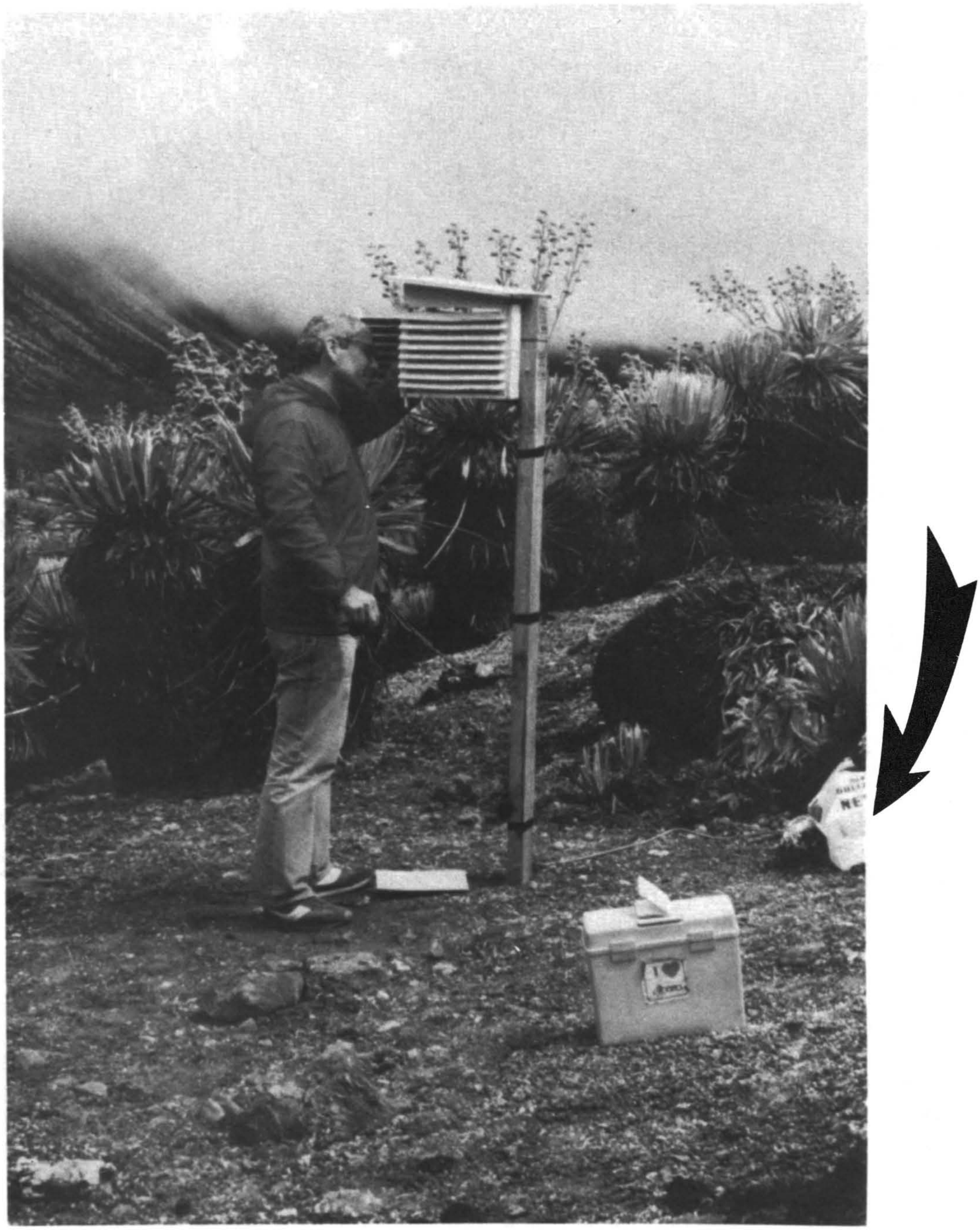

Figure 19. Weather station in the Páramo de Piedras Blancas. Baruch Weingarten checks air temperature and relative humidity sensors; micrologger is in box at right of photo (arrow).

Table 11. Short-term meteorological stations operated in Venezuelan Andes with high-frequency sampling.

Station	Elevation (m)	Sampling Interval	Period of Record	Parameters Measured
Páramo de Piedras Blancas	4200	3 hours	Sept.1983-Feb. 1985 (May -Sept. 1984 missing)	150 cm temp. and relative humidity, -5cm & -20cm soil temp., soil moisture (-10cm), wind speed, precipitation
Loma Redonda	4200	1 hour	May 14, 1984 to Feb. 1985 (missing in places)	net radiation, incoming longwave & shortwave radiation, reflected shortwave radiation
Laguna los Lirios	3300	2 hours	Sept. 1983 -Feb. 1985	150 cm temp. and relative humidity, -5 cm soil temp., wind speed, pprecipitation
Lagunillas (Lago de Urao)	1100	2 hours	Sept. 15, 1982 to July 28, 1984	150 cm temp. and relative humidity, -5cm & -20cm soil temp., -10 cm soil moisture, wind speed, precipitation

Automatic Weather Stations

In order to provide additional climatic data to supplement those available from various state and government agencies, a number of automatic weather stations were established close to the lakes being studied. Each station consisted of a screened temperature and humidity sensor, automatic rain gauge, anemometer and ground temperature sensors at 5 and/or 20cm depths. Soil moisture blocks were also buried at depths of 10 or 20cm. All sensors at each site were connected to a Campbell Scientific CR21 micrologger which was programmed to record data at pre-set time intervals (generally 2 or 3 hours) and to provide daily data summaries. Table 11 summarizes the data collection program. Figure 19 shows the weather station site in the Páramo de Piedras Blancas.

Although a great deal of data was collected, there were innumerable problems with the system employed. Data were logged onto magnetic types but frequent break-down of the tape recorders often resulted in months of data being lost. Stations could not be serviced regularly, due to logistical problems, and so months often went by before the tapes could be recovered and sent to the U.S. for analysis. When errors were detected, further delays often occurred before steps could be taken on-site to correct the problems. Consequently, the data set has a large number of gaps and numerous incorrect values which has made data analysis an extremely time-consuming process. Clearly, any subsequent attempts to record data in remote sites requires a dedicated field support program with frequent site visits, periodic sensor calibration and initial data analysis at a local site. Improvements in data logging technology (specifically, solid state recording media) have eliminated many of the problems that we faced in using mechanical devices; consequently many valuable studies could now be carried out with much greater prospects for success.

Despite the fact that the automatic weather stations we established (in collaboration with R. Andressen, Universidad de Los Andes) operated intermittently over a number of years, we never obtained a continuous annual record which would have enabled us to place the climate of the sites into a longer term perspective (i.e. in relation to other permanent meteorological station records). Thus, our primary objective was not achieved. However, the observations that were made do provide an interesting data set for remote parts of the mountain region where very few meteorological measurements have hitherto been made.

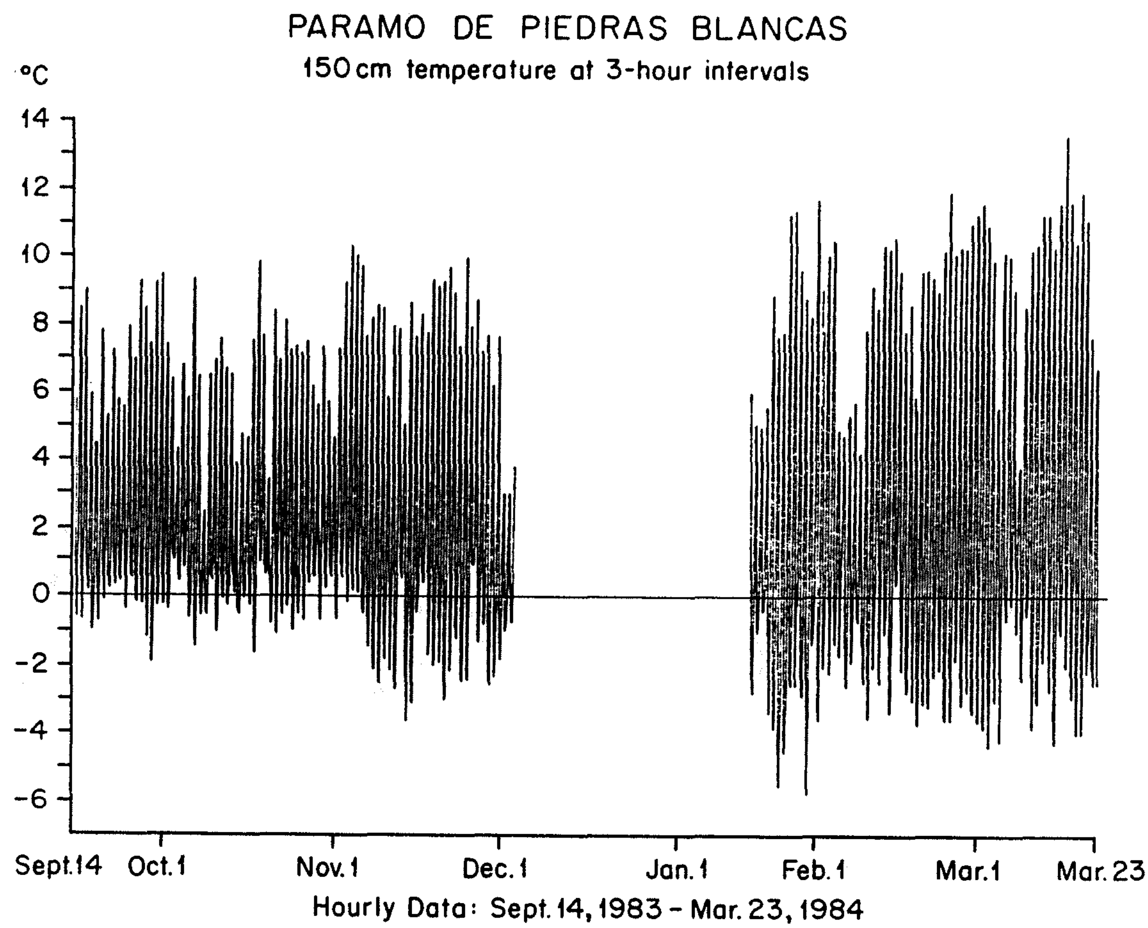

Figure 20. Air temperature recorded by the automatic weather station at Páramo de Piedras Blancas.

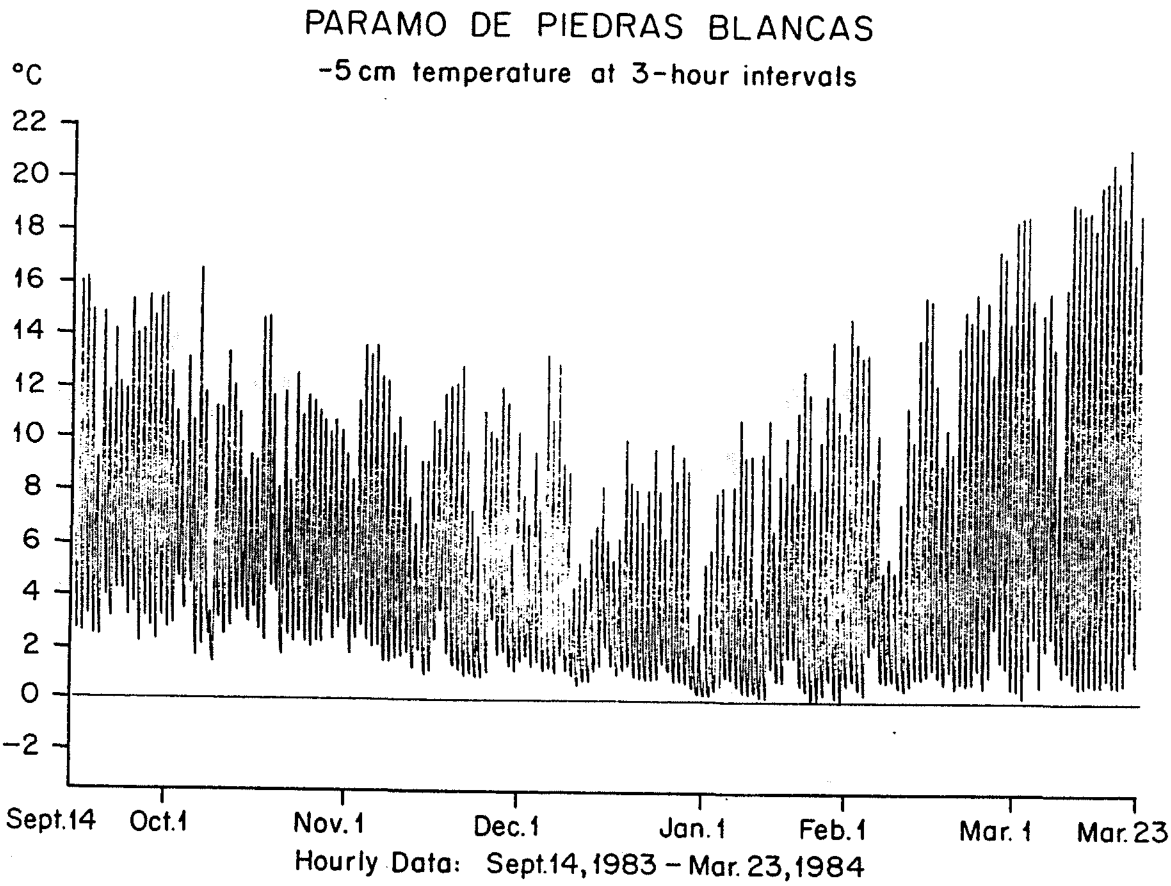

Figure 21. Soil temperature (5 cm below the ground surface) recorded by the automatic weather station at Páramo de Piedras Blancas.

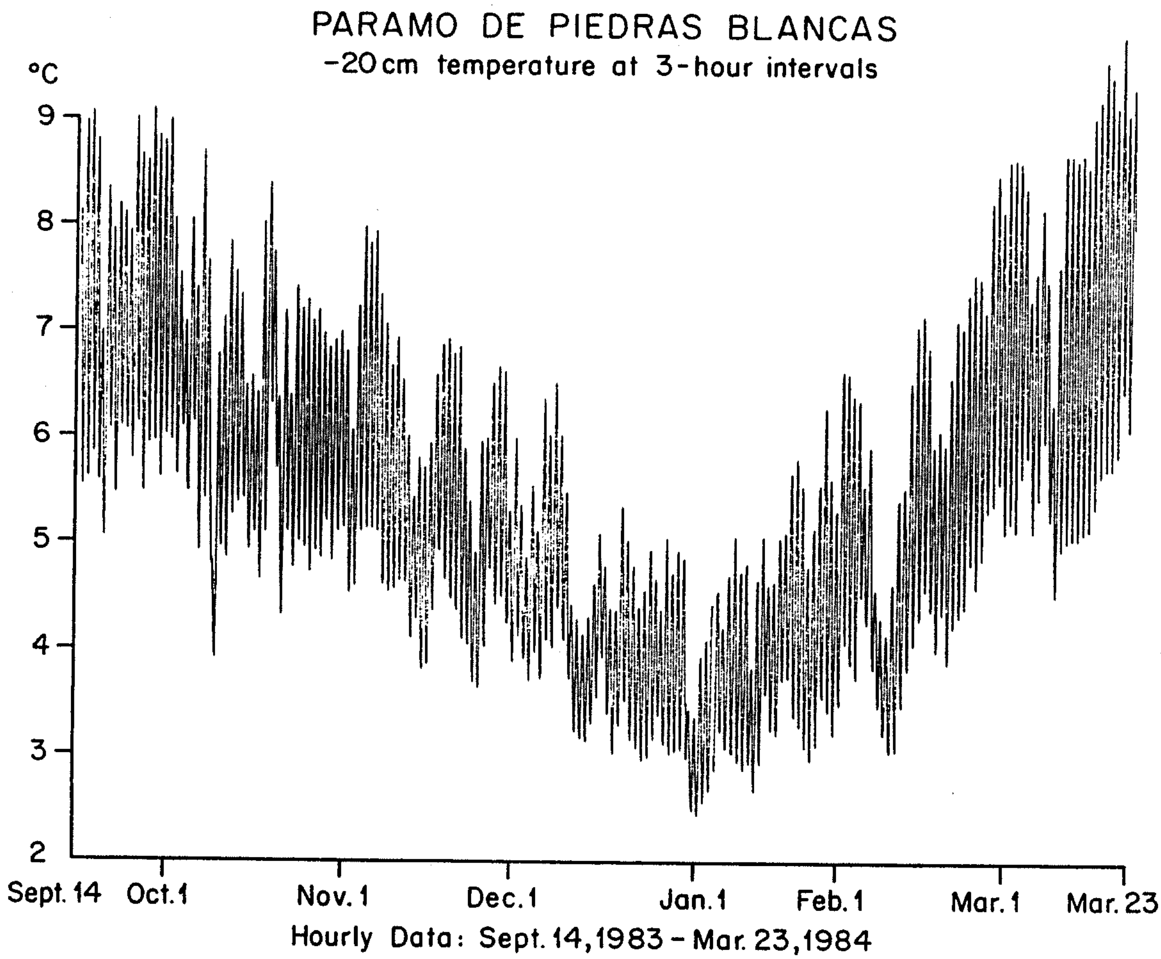

Figure 22. Soil temperature (20 cm below the ground surface) recorded by the automatic weather station at Páramo de Piedras Blancas.

Figures 20 to 22 show some examples of the data recorded every 3 hours at the 4200m meteorological station in the Páramo de Piedras Blancas over a 6 month period from September 14, 1983 to March 23, 1984 (i.e. primarily during the *invierno*). Of particular interest is the frequency with which air temperature at ~150cm cycled back and forth across the freezing point (Figure 20). Despite the period of missing data, it is clear that this was an almost daily occurrence at this elevation during the observational period. Minimum temperature for the period was ~-6°C and the maximum ~14°C. Daily air temperature minima were most commonly recorded between 6 and 7 a.m and daily maxima between 1300 and 1400 hours (local time). The diurnal range of temperature increased from ~9°C in September to ~15°C by March.

Just below the surface, at -5cm, the diurnal range also increased, from ~13 °C to ~20°C over the same period (Figure 21). However, there were no occurrences of temperature below 0°C at this depth though minima were commonly within 0.5°C of the freezing point. It seems very probable that there were frequent night-time frosts at the ground surface during this period. Maximum temperatures of ~20°C (resulting from high radiation receipts under clear skies) were recorded at -5cm. At -20cm, the daily range was 2-4°C (note scale change on figures) and temperatures never dropped below 2.5°C, nor rose above 10°C (Figure 22). 169mm of rainfall was recorded (by tipping-bucket rain-gauge) during the 6 month interval; half of this fell within the first month (i.e. from mid-September to mid-October).

Figures 23 and 24 show a similar period of record from ~2300m at Laguna Los Lirios, in the mountains above Tovar. Air temperatures at 150cm ranged from a daily minimum for the period of ~7°C to a daily maximum of ~26°C and precipitation totalled ~237mm (Figure 23). One third of the precipitation fell during the month of October, 1983. Mean daily wind speeds were generally <1m sec^{-1}, though daily maxima above 8m sec^{-1} were recorded frequently, generally during the development of convective (up-slope) conditions in the late afternoons (Figure 24). Further work on cleaning up the remaining records (Table 11) is planned for the future as resources become available.

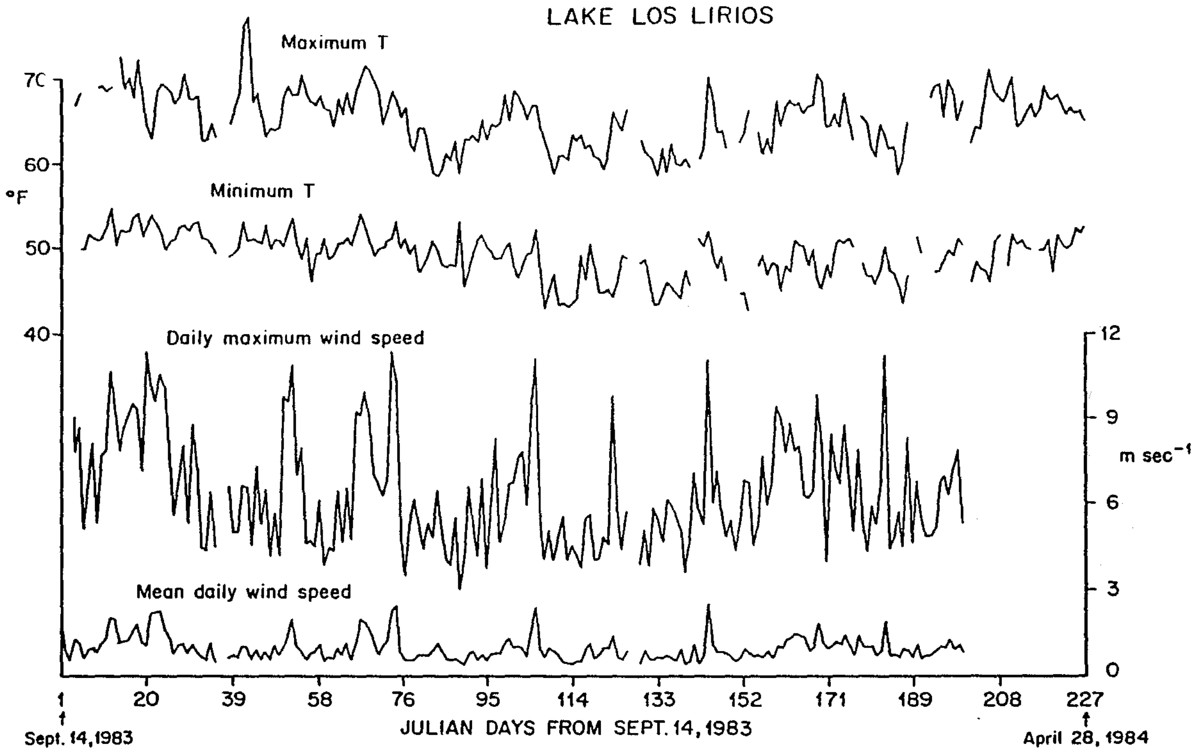

Figure 23. Air temperature and wind speed recorded by the automatic weather station at Laguna Los Lirios.

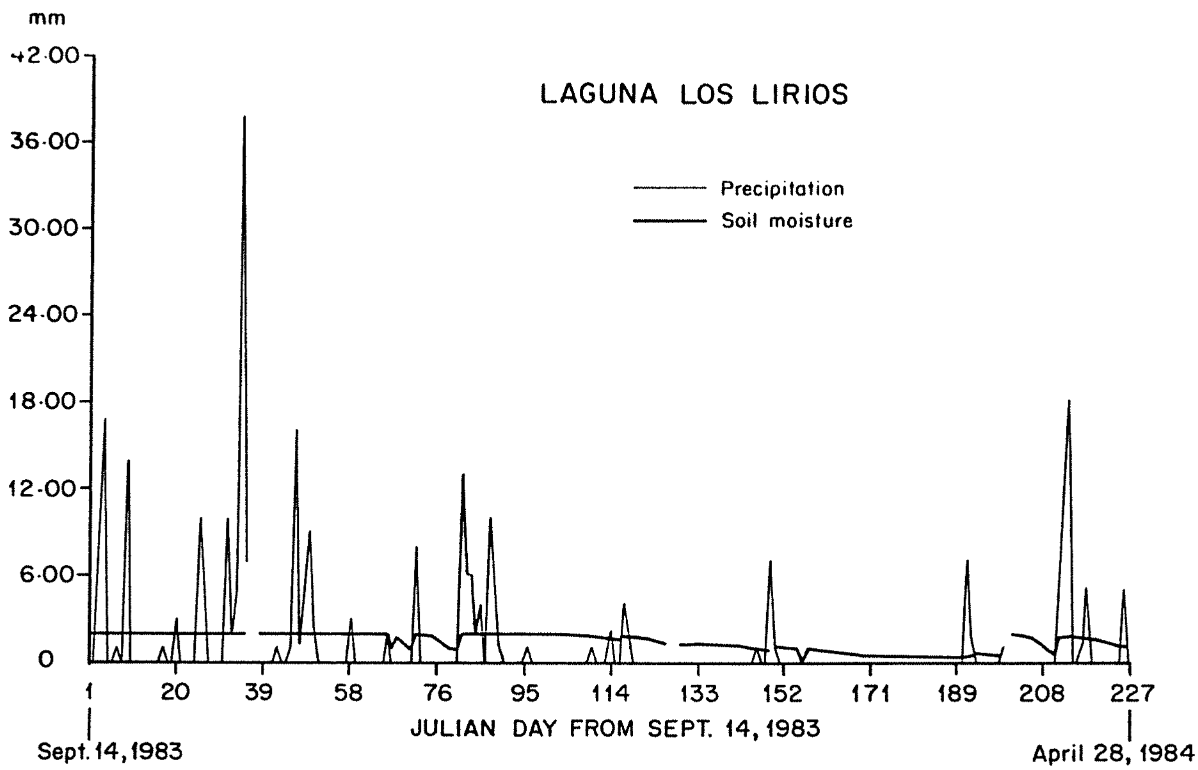

Figure 24. Precipitation and soil moisture recorded by the automatic weather station at Laguna Los Lirios.

LATE QUATERNARY ENVIRONMENTAL HISTORY OF THE VENEZUELAN ANDES

Baruch Weingarten, Maria-Lea Salgado-Labouriau, Richard Yuretich
and Raymond Bradley

Long cores were recovered from three lakes: Mucabají in the *Tierra Helada* zone, Los Lirios in the *Tierra Templada* and Urao in the *Tierra Caliente* (Figure 1). Since the Tierra Templada and Tierra Helada zones have shown the greatest environmental fluctuations, as deduced from geomorphologic observations, detailed geochemical and clay mineral analyses were conducted only on the cores from Los Lirios and Mucabají. These cores were analyzed in a manner similar to the surface sediments to see how the sedimentation patterns in the various altitudinal-climatic zones have varied over time. Descriptions of all cores are given in Appendix D.

Lake Mucabají

The long sediment-core from Lake Mucabají (elevation 3,540 m a.s.l.) is 1.97 m in length. The sediment-core was analyzed in a similar fashion to all other lake sediment-cores (see Appendix C). Three segments were ^{14}C dated, yielding ages ranging from 2,195 +/-195 @ 8 cm to 8,300 +/-255 years B.P. (GX-9987) at a depth of 1.91 m (Table 11). Dates on a duplicate core raised adjacent to the first which was used for pollen analyses gave comparable results; the anomalous ^{14}C date at 79 cm in the first core indicates contamination and the value was discarded.

Geochemical Data

The upper portion of the core, corresponding to the period from ca. 2,000 to 4,500 B.P., has an organic content varying between 8 and 12% (Fig. 25). There is a sharp increase in total organic matter at ~75 cm depth (4,700 B.P.), and from here to the bottom of the core the total organics are higher. Maximum organic content of 32% occurs at a depth of 90 cm (about 5,100 B.P.), which is followed by a general decrease in organic

Table 11. Radiocarbon dates from the Laguna Mucabají long core. Geochemical analyses were done on core B; palynological analyses on core A.

Laboratory Number	*Depth (cm)*	*Date (years B.P.)*
CORE A		
GX-13218	6.5-9.0	2235 +/- 380
GX-13219	71-76	4745 +/- 275
GX-13220	124-129	6075 +/- 290
CORE B		
GX-13331	8	2195 +/- 195
GX-13332	79	[1885 +/- 255]*
GX-9987	191	8300 +/- 255

**Contaminated sample; not used for chronology.*

matter with depth.

Organically bound iron is the dominant form, comprising some 70 to 90% of the total extractable iron (Fig. 26). The total iron shows a gradual decrease with depth from the top of the core, which is terminated by a sharp "spike" of extractable iron at a depth of 78 to 81 cm (about 4,900 B.P.). Interestingly, this iron increase has large components of amorphous and crystalline iron contributing to it (Fig. 26). Below this horizon, the previous ratio of organic iron to total iron is re-established, although there is a gradual

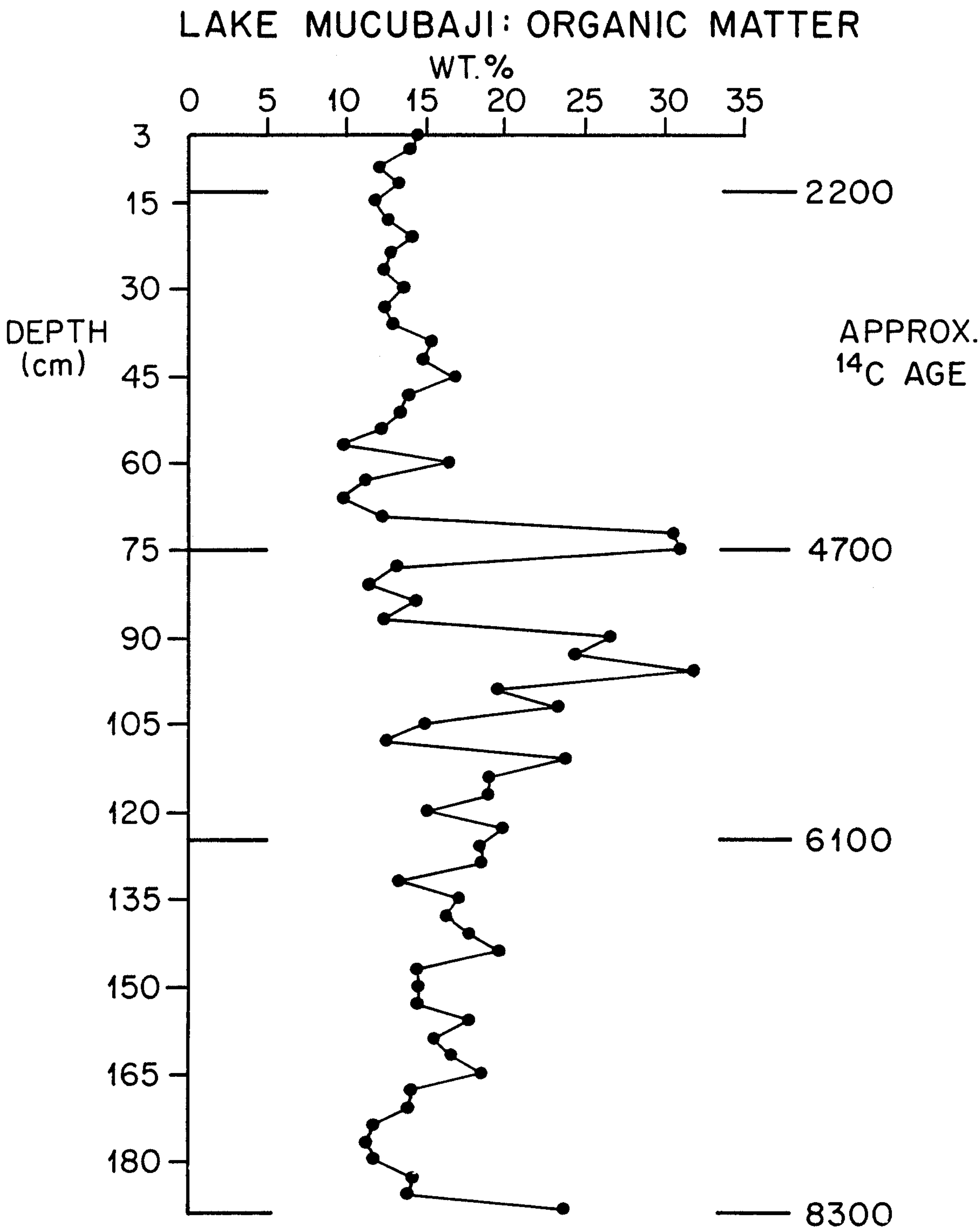

Figure 25. Distribution of organic matter in the long core recovered from Lake Mucabají.

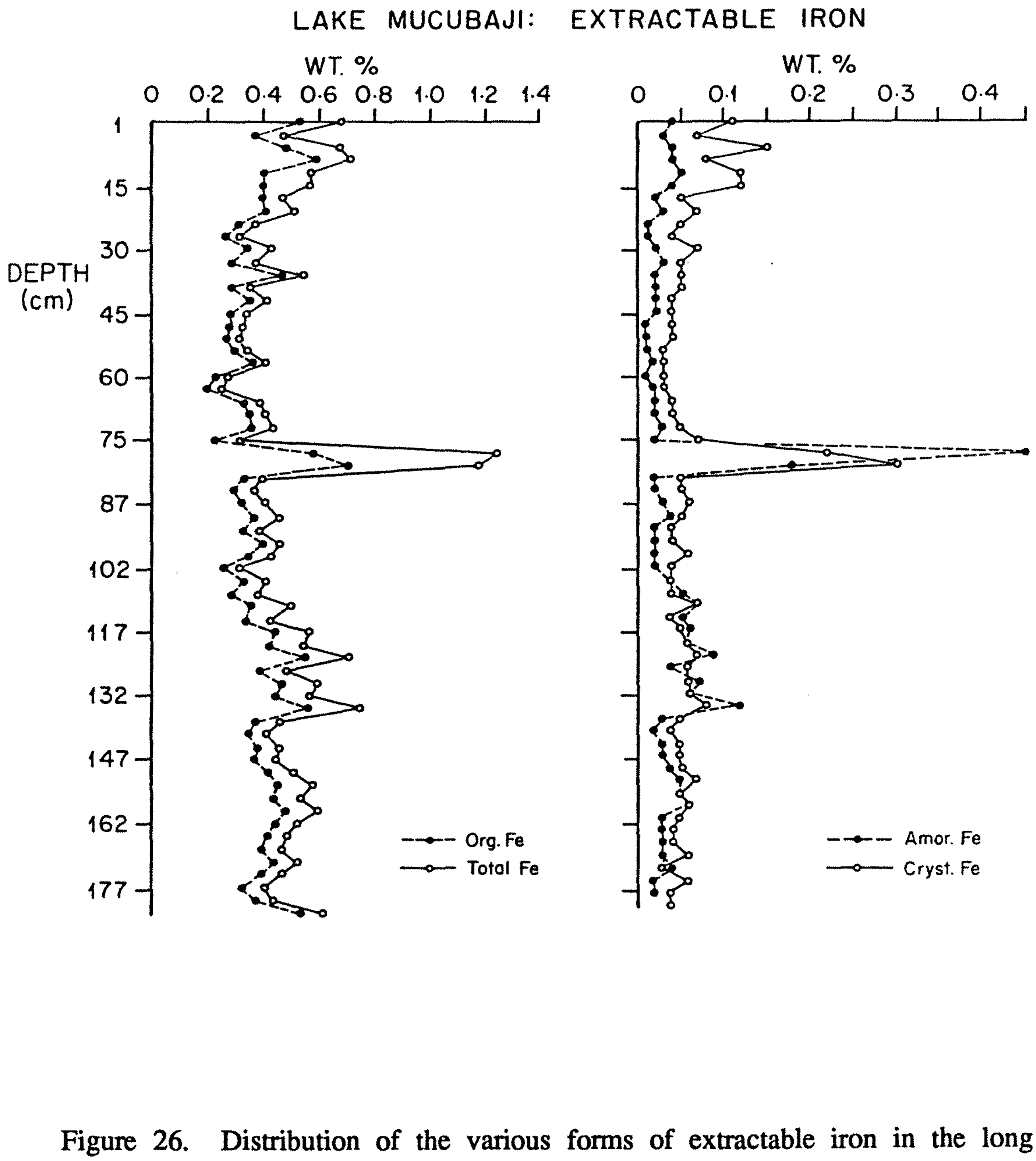

Figure 26. Distribution of the various forms of extractable iron in the long core recovered from Lake Mucabají.

increase in total iron down-core. Furthermore, the contribution of amorphous iron is slightly greater from about 110 cm (ca. 5,800 B.P) to the bottom of the core.

Extractable manganese exhibits patterns very similar to those of iron, although the organic fraction is somewhat different. The total extractable iron/manganese ratio shows some interesting patterns (Fig. 27). The upper 75 cm of the core gives values between 10 and 15, what one would expect in a predominantly detrital sequence. There is a "spike" at about 80 cm depth, no doubt caused by the very high amorphous and crystalline iron present here. At greater depths, the ratio increases gradually, perhaps reflecting an increasing mobilization of Mn up and out of the progressively reducing sediments. However, the magnitude of this manganese loss is small, indicating that much of the original detrital signal is preserved.

Clay Minerals

The Mucabají core contains chlorite, mixed layer illite-chlorite, illite and kaolinite (Fig. 28) with diagnostic (001) reflections at 14, 12, 10, and 7Å, respectively. Some slight variations in the relative clay-mineral abundances occur down core. Of particular interest is the greater amount of chlorite between 75 and 100 cm and an increasing abundance of illite below this depth. In general, the assemblage corresponds to that typical of the modern Tierra Helada lakes. Perhaps the increase in the abundance of chlorite may indicate cooler conditions between 4,600 and 5,500 B.P., but all changes are fairly subtle.

Pollen Data

Analysis of pollen from this core shows only minor vertical variations in pollen assemblage (Fig. 29), indicating that the composition of the vegetation has not changed appreciably during the period of record. Nevertheless, the increase of Compositae and

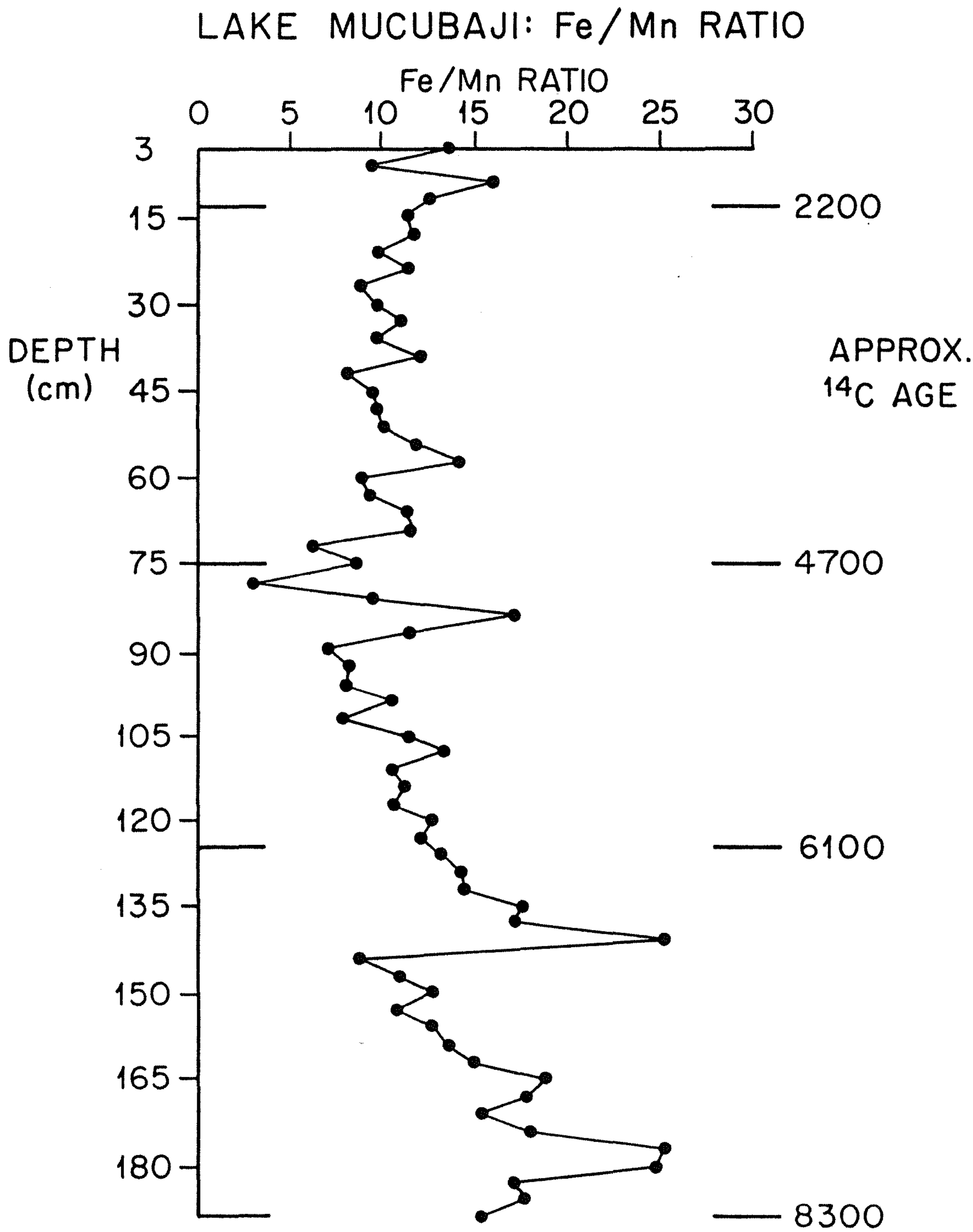

Figure 27. Variations in the ratio of total Fe to total Mn in the long core recovered from Lake Mucabají.

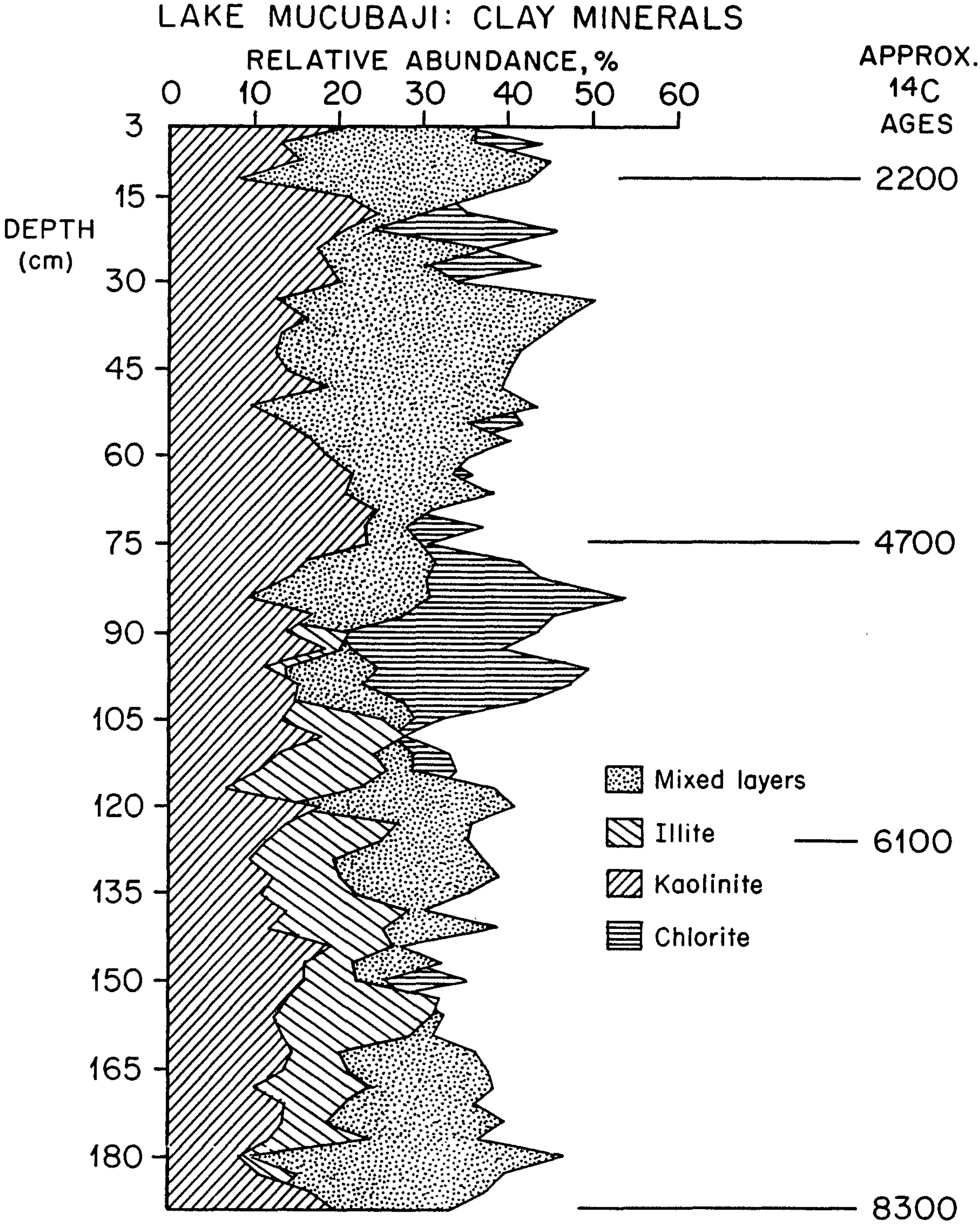

Figure 28. Relative abundance of clay minerals in the long core recovered from Lake Mucabají

the decrease of *Podocarpus* pollen towards modern time, although small, supports the results from other sites (Salgado-Labouriau, 1976; Rull et al., 1987).

Modern deposition in peat bogs of the Mucabají valley show some differences in composition of the pollen assemblages compared with the older lake sediments. This difference is expressed principally by the higher values of Compositae, "aquatic plants" and "other páramo herbs" in the peat bogs compared to the lake sediments. The large amount of Compositae pollen in the recent past probably indicates an increase in abundance of *Espeletia* in the valley. Today, *E. schultzii* is the dominant plant on the moraines.

Pollen transported long distances from the cloud forest (in the Tierra Templada) was relatively more abundant in the past, with a notable maximum between 70 and 90 cm depth (ca. 4700-5100 B.P). This pollen occurs in abundances lower than present levels near the bottom of the core (ca. 8000 to 8300 B.P.).

The total abundance of pollen oscillates between ca. 20,000 and 80,000 grains/cm^3 throughout most of the core. A maximum of ~125,000 grains occurs at depths of 110 to 130 cm (ca. 5400 to 6100 B.P.). This increase is mainly due to Gramineae and Compositae, indicating a denser vegetation in the valley.

Isoetes microspores are very abundant throughout the sediments in concentrations greater than 60,000 grains/cm^3. The quantity of this submerged fern shows that a lake has existed throughout the period of record. Other spores are not as abundant as the pollen, but the páramo pteridophytes (*Lycopodium* and *Jamesonia*) as well as the long-distance spore 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 entire core which also supports the existence of a lake during the entire interval. They are more abundant at depths of 20 to 90 cm (2700 to 5100 B.P). The radiocarbon date of 2200 B.P. at the top of the core, together with the presence of *Isoetes* spores in surface sediments from deeper parts of the

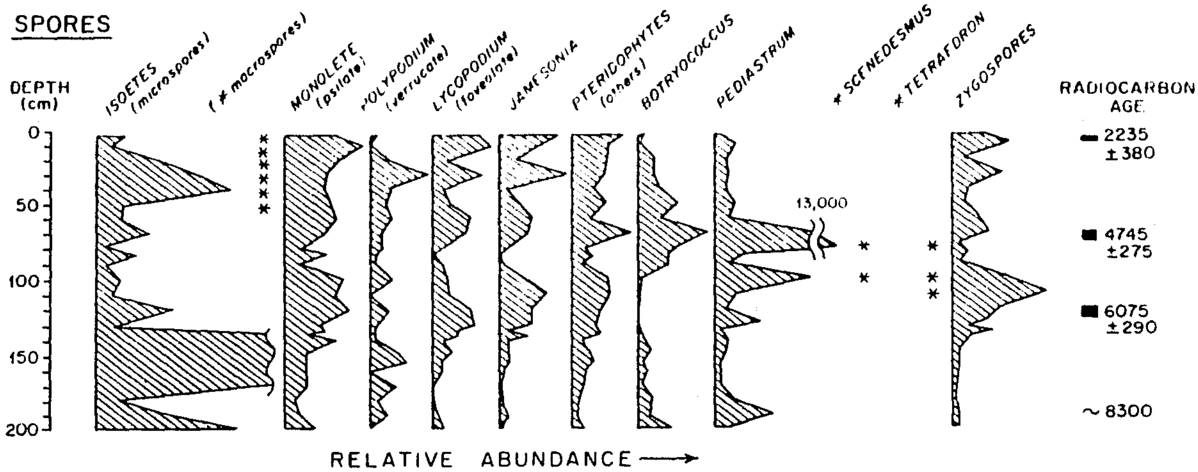

Figure 29a. Variations in the relative abundance of spores in the long core recovered from Lake Mucabají.

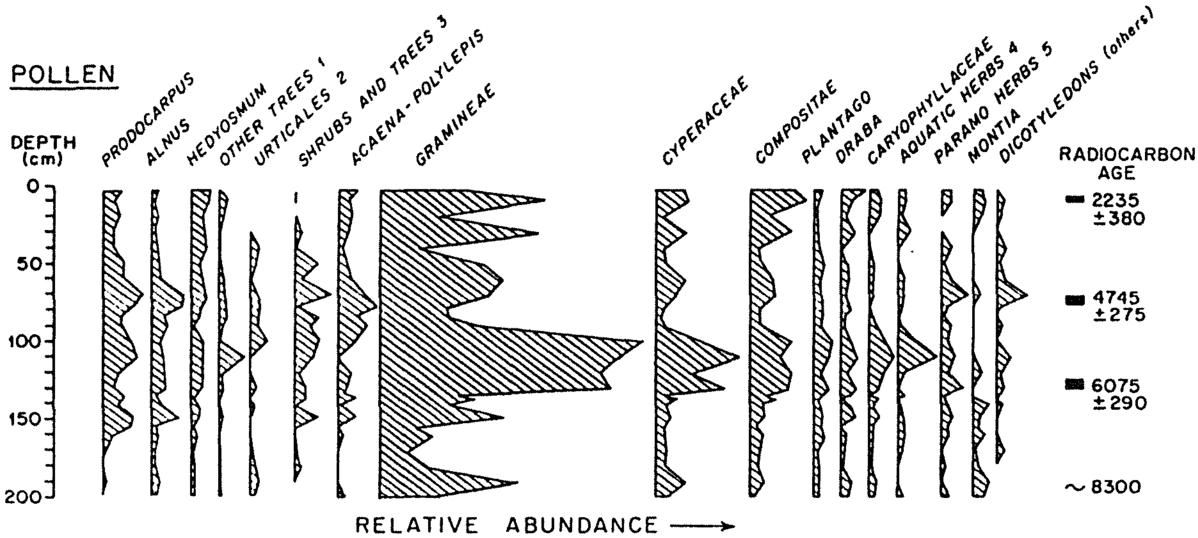

Figure 29b. Variations in the relative abundance of pollen in the long core recovered from Lake Mucabají.

lake, point toward the existence of a shallower lake from ca. 2200 B.P. until modern times.

Paleoclimatic Interpretation

Geomorphological evidence from the Central Venezuelan Andes indicates that during the Merida Glaciation, 18,000-13,000 B.P., this mountain range experienced two glacial stades (Schubert, 1975). During these episodes, the altitudinal climatic belts in the Andes were shifted towards lower elevations. During the earlier stade, moraines formed at 2,600-2,700 m. A later glacial advance reached elevations of 3,000-3,500 m and was most probably associated with the downward shift of periglacial conditions to 2,400 m (Schubert, 1975). The present-day snow line in the Venezuelan Andes is at 4,700 m. Adopting the modern mean annual temperature lapse rate of 0.60^{o}C/100 m (Gonzales Vivas, 1971; Andressen and Ponte, 1973; Bradley et al., 1985) and assuming no change in precipitation, the 1200 to 1500 m descent in snow line during the Merida Glaciation suggests a parallel decrease in mean annual temperature of 7 to 9^{o}C.

Based on this scenario, one might expect a gradual increase in temperature to be the dominant influence on the sediments of Laguna Mucabají. However, the pollen data show that the composition of the vegetation for the past 8,300 years has been very similar to the present. Apparently, the Mucabají valley has been a páramo with the same plants as today, although fewer Espeletias were present in the early Holocene. The same results were found at La Culata (3,600 m), on a nearby ridge (Salgado-Labouriau and Schubert, 1976). However, small oscillations in climate, without significant changes in vegetation characteristics have occurred. The increase of pollen input at depths of 100 to 130 cm in the core (5,400 to 6,100 years B.P) indicates a denser vegetation during this time, perhaps reflecting a more humid climate.

The geochemical and mineralogical data also suggest no major perturbations in climate during the period of record, although there were some mild "events." The chlorite increase (and illite decline) occurs at the level where the cloud forest pollen decreases, reinforcing the interpretation of a slight cooling during this time (4,800 to 5,400 years B.P.). The meaning of the "spike" in extractable iron at 77- 81 cm (~4,900 B.P) is less clear, although it could represent an episode of increased runoff, with correspondingly higher detrital influx of amorphous and crystalline iron oxyhydroxides.

At present, Lake Mucabají is located in the páramo proper, far from the tree line and the limit between páramo and superpáramo. The results presented here show that this environment has not changed appreciably during the last 8,300 years. It is likely that the relatively stable regime may stem from the high-altitude location of this lake basin; sediments from lakes at lower (warmer) elevations may exhibit more dramatic responses to past climatic changes.

Lake Los Lirios

The total length of Livingstone core raised from Laguna Los Lirios is 5.79 m. The coring device penetrated some 0.5 m below the sediment-water interface before it encountered sufficiently consolidated sediment, so the upper part of the record is not present. Eight sections of the core were ^{14}C dated and the results are summarized in Table 12 and Figure 30. The sedimentation rate calculated from these dates during the last 8,500 years was approximately twice the rates prior to this date. If a constant sedimentation rate is assumed between the ^{14}C date of 16,840 B.P. at 5.61 m and the bottom of the core at 5.79 m, an age of 17,276 B.P. is extrapolated.

Geochemical Data

Most of the geochemical variables demonstrate similar trends down-core. The most conspicuous change in concentration values (wt.%) of the geochemical variables occurs at a depth of 390 cm, which corresponds to a ^{14}C age of ca. 10,200 years B.P. Below this level, concentration values for the different variables are smaller and

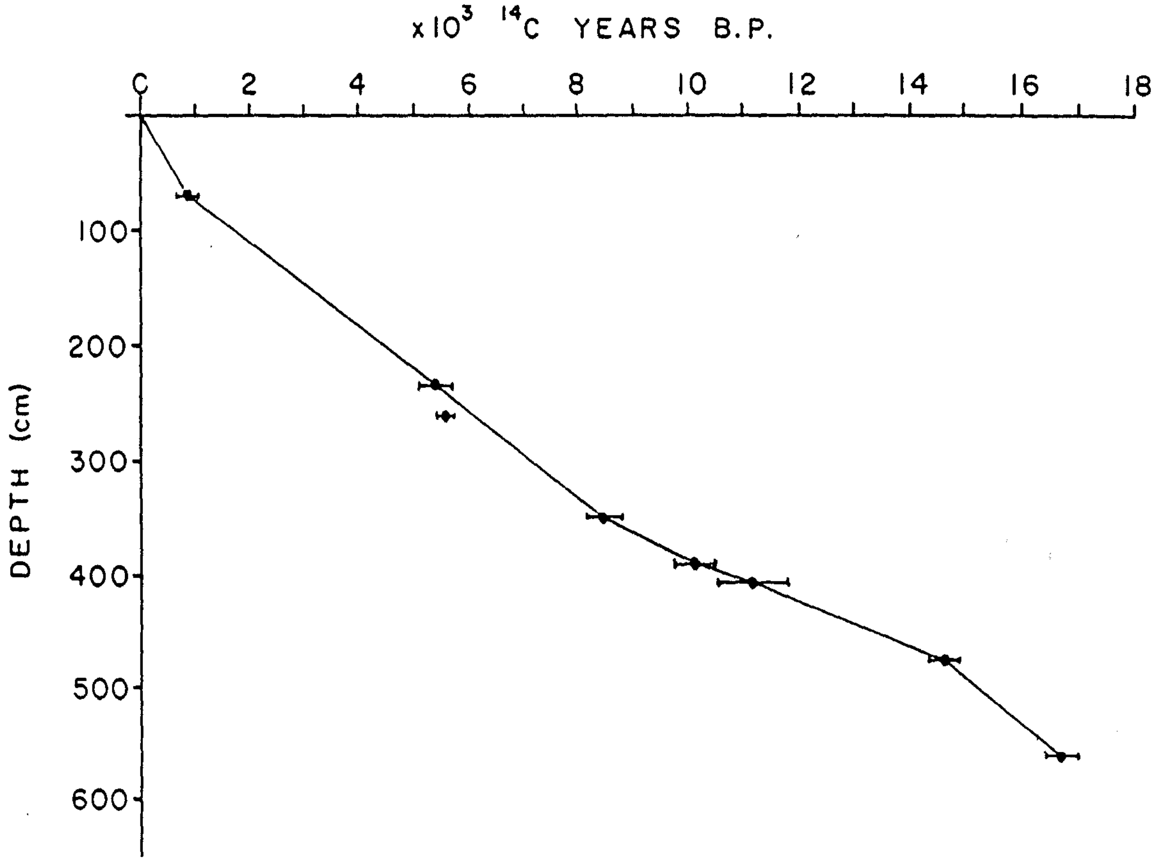

Figure 30. Sedimentation rates determined on the long core collected from Laguna Los Lirios.

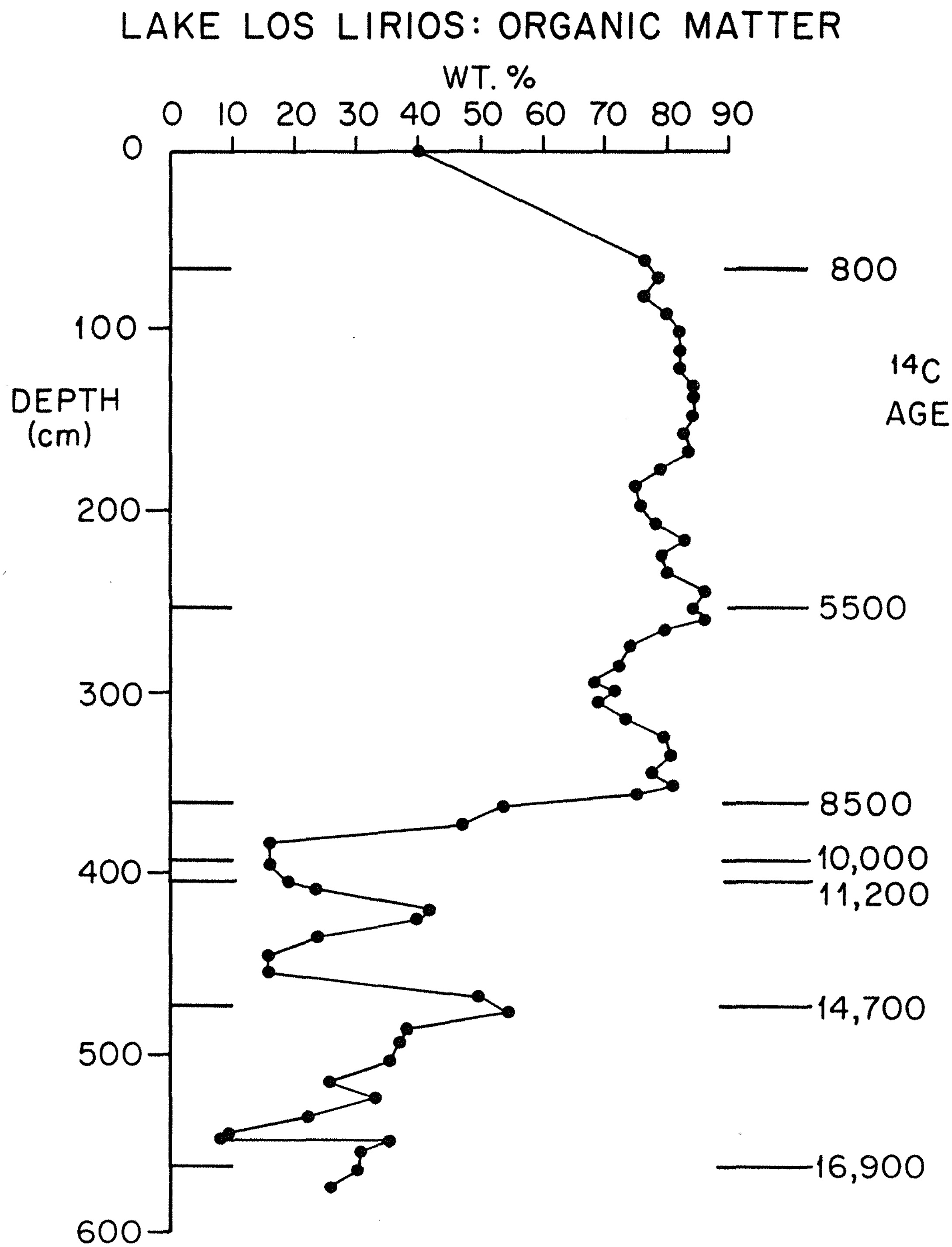

Figure 31. Organic matter in the long core from Laguna Los Lirios.

Table 12. Radiocarbon dates and sedimentation rates for the Laguna Los Lirios sediment-core.

Depth (cm)	^{14}C Years	Lab I.D.	Sed. rate
65	830 +/-180	GX-11613	.78 cm/100 y
236	5,410 +/-270	GX-13328	.37 cm/100 y
260	5,590 +/-170	GX-10364	.41 cm/100 y
359	8,510 +/-310	GX-11614	.40 cm/100 y
389	10,140 +/-330	GX-11615	.18 cm/100 y
405	11,215 +/-635	GX-13329	.15 cm/100 y
473	14,710 +/-230	GX-13330	.19 cm/100 y
561	16,840 +/-310	GX-10326	.41 cm/100 y

fluctuations are minor compared with the upper 400 cm. The only exception is the organic matter content which demonstrates greater variability for the time interval prior to 10,200 B.P. (Fig. 31).

Of the three types of extracted iron (Fig. 32), organic iron is the most prevalent form, accounting for 50 to 80% of the total extractable iron. A close correspondence between the organic Fe and organic matter might be expected in view of the control that the latter assumes in the processes of iron adsorption. However, some fluctuations are not in phase. For example, organic iron shows two maxima at 325 cm (7,500 years B.P.) and 100 cm (2,000 years B.P.) which are not detectable in the abundance of organic matter. At depths greater than 390 cm (10,000 years B.P.), higher abundances of organic matter often correlate with low organic iron. The formation of organo-iron complexes is dependent upon the available amounts of selective organic acids and the pH (e.g. increasing pH enhances iron complexation, Schwertmann et al., 1986). To explain in

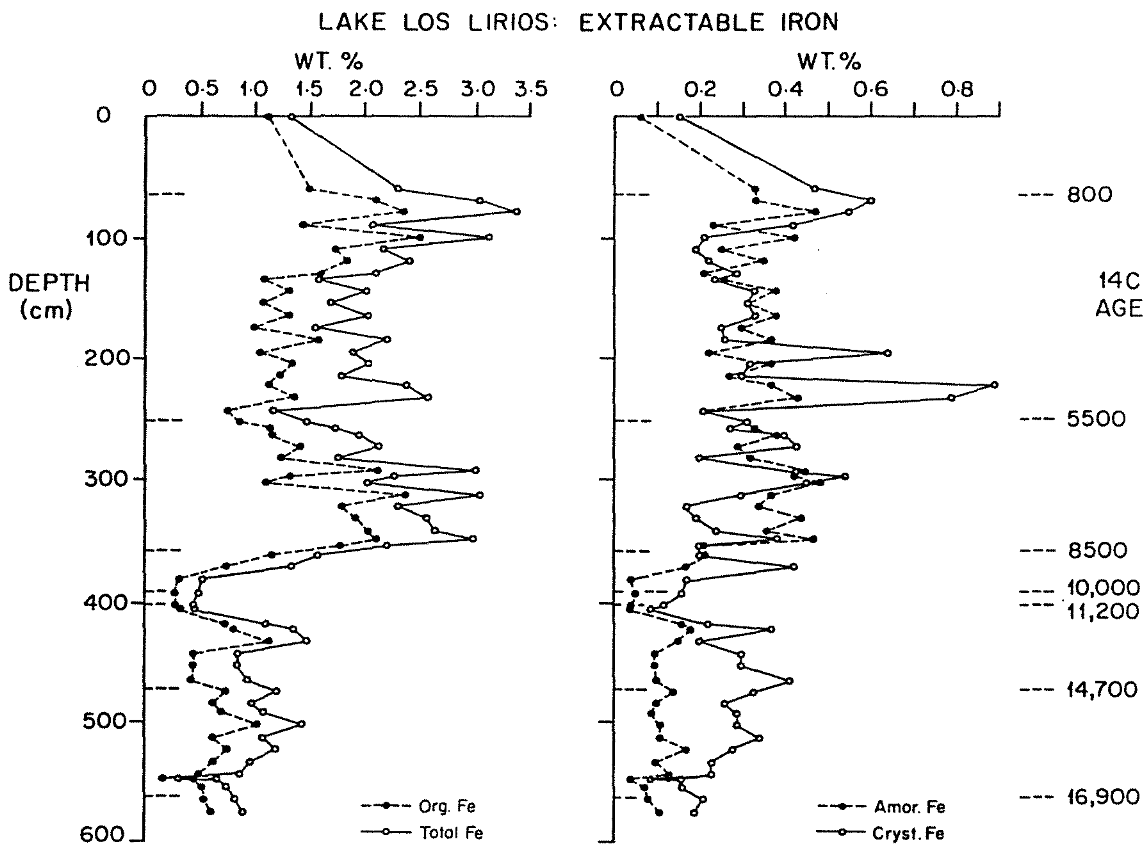

Figure 32. Extractable iron in the long core from Laguna Los Lirios.

more detail the relationships between organic iron and organic matter, an analytical identification of organic components should be pursued in order to establish which types of organic compounds are the most efficient iron adsorbents.

The concentrations of amorphous and crystalline iron are much smaller than organic iron. Amorphous iron is 3 to 4-fold higher in the upper 350 cm of the core compared with the lower part, whereas crystalline iron, with only few exceptions, shows similar concentrations for the entire record.

The Total Fe/Total Mn ratio (TFe/TMn) varies around a mean of 130 (Fig. 33). These very high ratios are typical of the modern Tierra Templada lake sediments. In general, the changes in the ratio correspond to changes in the total extractable Fe (Fig. 32), suggesting a uniformly strong post-depositional remobilization of manganese in these sediments.

Clay Minerals

Samples from the Los Lirios core were also analyzed for their clay mineral content by X-ray diffraction. A significant change is noted at a depth of 363 cm (9,260 B.P.) (Fig. 34). Below this level, the clay mineral assemblage consists principally of chlorite, illite, a mixed layered illite-chlorite and kaolinite, with characteristic (001) reflections at 14, 10, 12 and 7Å, respectively. Chlorite is the most abundant clay mineral, especially in the interval between 420 cm and 495 cm (12,300 to 15,200 B.P.) which is also marked by an abundance of illite and absence of the mixed layer clay. Kaolinite abundance is relatively constant throughout this entire section. From 363 cm to the top of the core, the clay-mineral abundance is masked by a dominance of X-ray amorphous material.

In the modern lake sediments, it was demonstrated that clay mineral assemblages in the Venezuelan lakes change with elevation, a phenomenon principally attributed to the altitudinal change in climate. At high elevations (cold climate), chlorite and illite are principal components of the clay mineral assemblage, whereas as climatic conditions

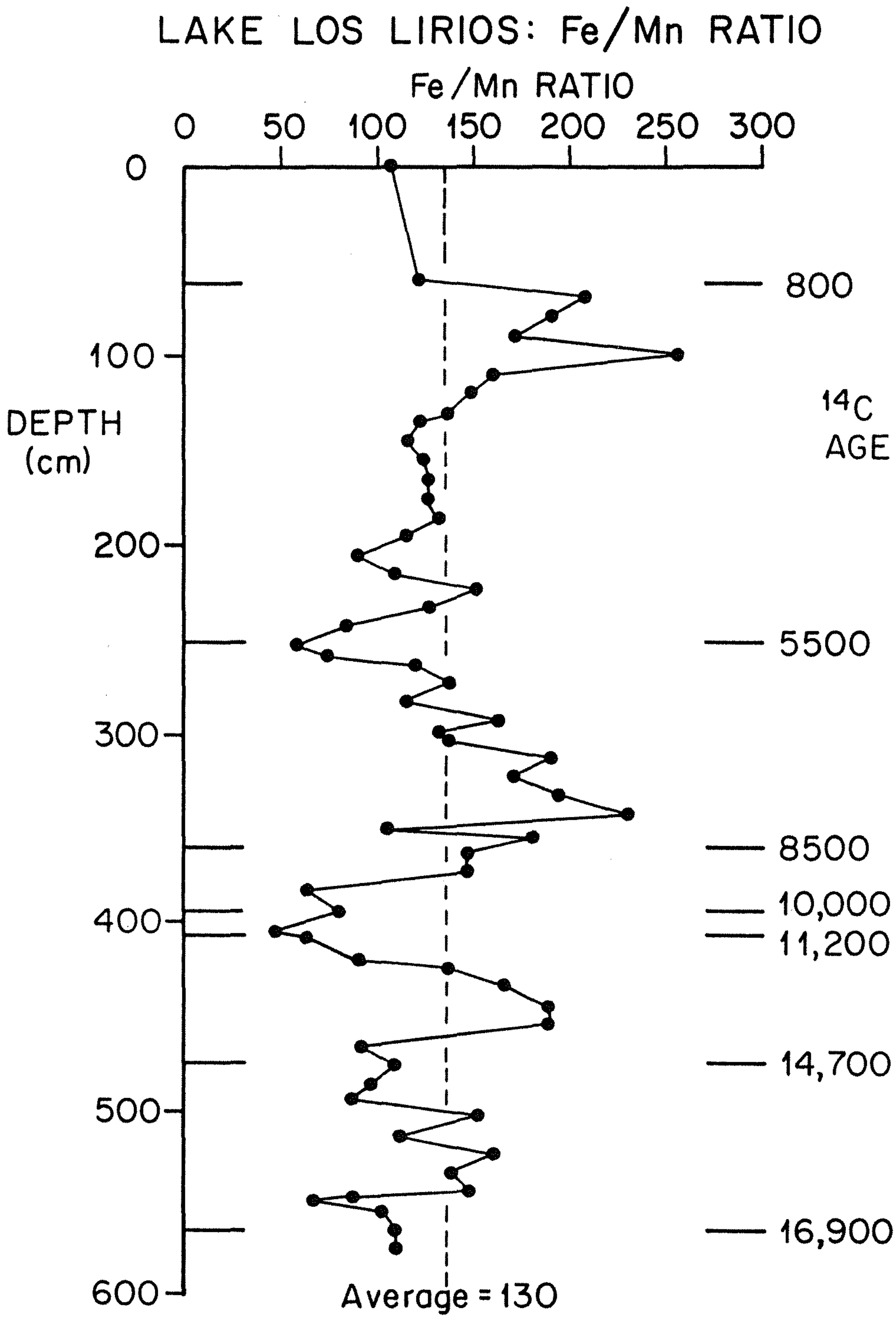

Figure 33. Fe/Mn ratio in the long core from Laguna Los Lirios.

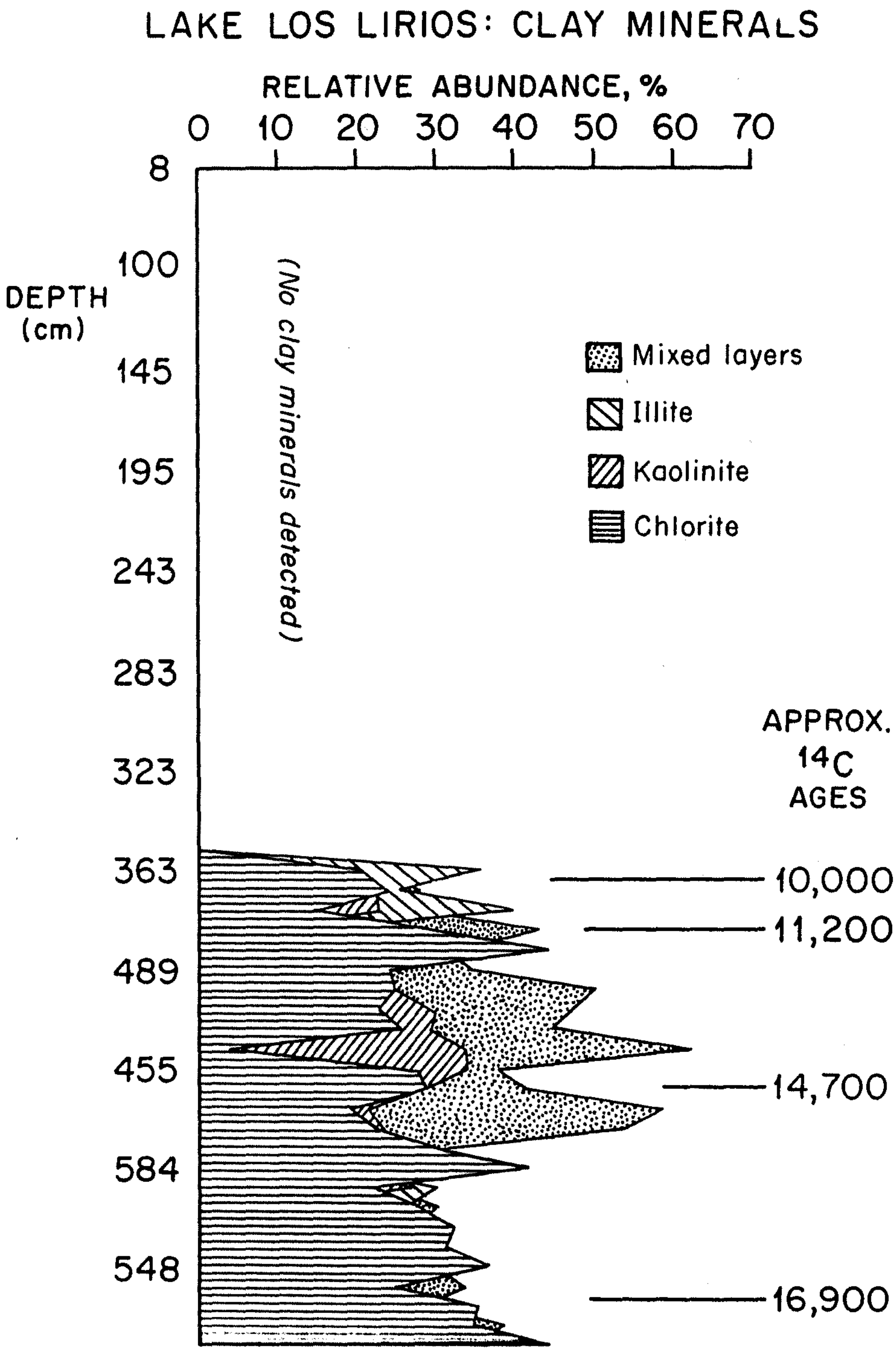

Figure 34. Distribution patterns of the clay mineral assemblage in the long core from Laguna Los Lirios. The apparent disappearance of clay minerals occurred at approximately 9,300 years B.P.

become warmer and wetter at lower altitudes, kaolinite increases at the expense of illite and chlorite.

A striking similarity exists between the clay mineral assemblage present in the Lirios sedimentary record prior to 9,260 B.P. and the modern clay mineral assemblages at higher altitude (Fig. 35). Kaolinite and gibbsite are typical constituents of modern clay assemblages in the modern lake sediments below 2,400 m elevation, but the clay mineral assemblage in the lower part of the Los Lirios core is dominated by chlorite and illite which at the present time are typical of the Tierra Helada. If chlorite is regarded as the prime indicator of cold conditions, the minimum temperature should have occurred between 12,000 and 14,000 years B.P.

Additional support for cooler climatic conditions in the present Tierra Templada climatic zone prior to 9,260 years B.P., is also suggested by the degree of illite crystallinity (Table 13). Illites in the interval from 465 to 545 cm (14,800 to 16,450 B.P), in particular, exhibit crystallinity values typical of those found in the modern Tierra Helada lakes (Table 10).

Paleoclimatic Interpretation

The most prominent change in environmental conditions apparently took place about 10,000 years B.P. as suggested by the increasing concentration of organic iron, organic matter and the loss of clay minerals. This change is also demonstrated by a contemporaneous increase in the relative abundance of amorphous iron. Based upon the patterns seen in the modern Andean lakes, this change suggests a climatic transition from dry and cold to warmer and wetter environmental conditions.

The increase in the abundance of organic matter after 10,000 B.P. could be caused by increased vegetation density and decay or a change in lake productivity, both usually

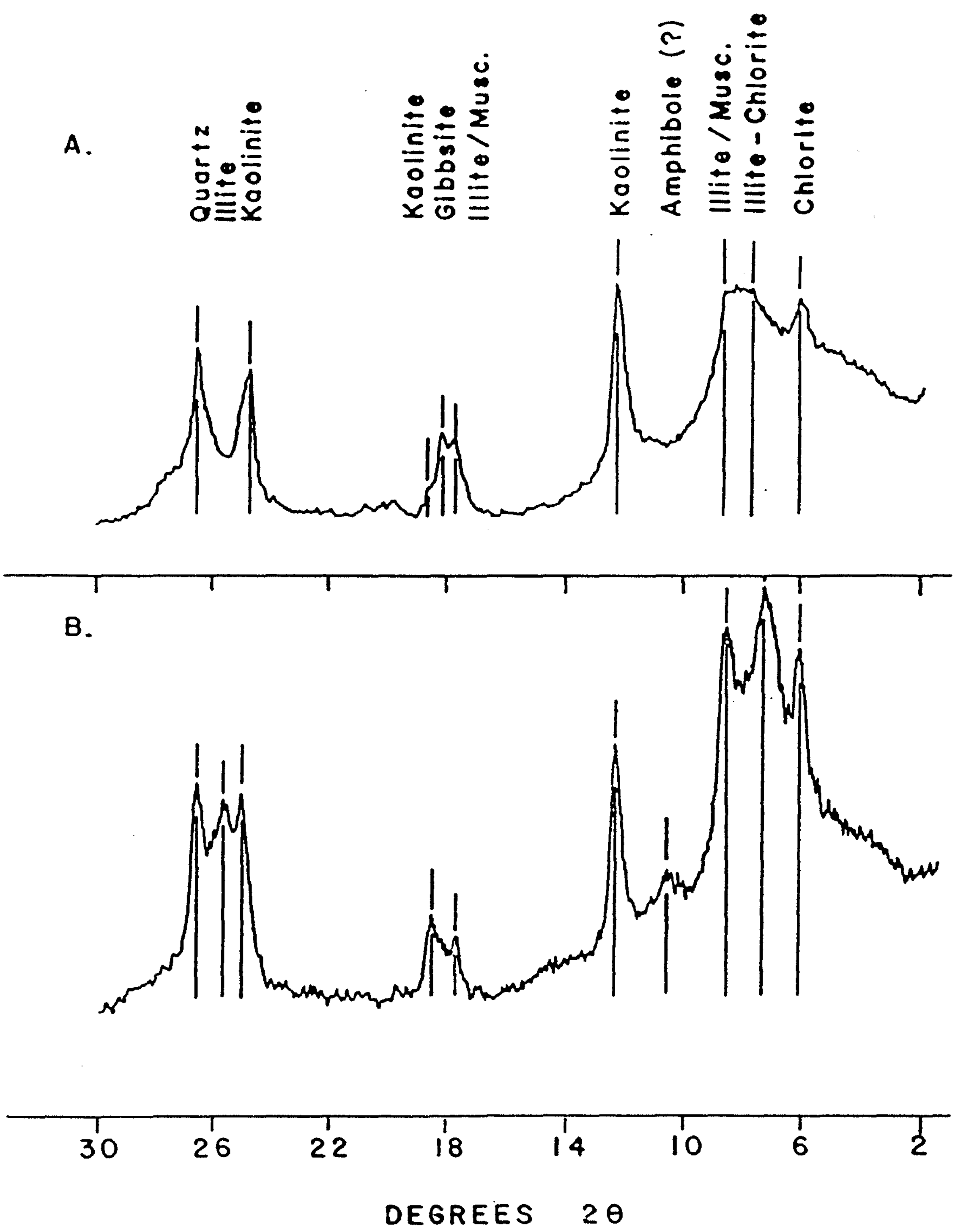

Figure 35. Characteristic X-ray diffraction pattern for the clay fraction in Laguna Los Lirios at 14,400 years B.P. (A) and Laguna Mucabají at 6,000 years B.P. (B).

Table 13. Illite crystallinity (IC) and mean IC values for the 9,300-17,300 years B.P. time interval.

Age (^{14}C Years)	I.C.	Mean I.C.
9,300	0.22	
9,800	0.19	
10,550	0.20	
11,200	0.21	
12,050	0.23	0.21
12,250	0.25	
12,750	0.19	
13,300	0.21	
14,800	0.15	
14,050	0.16	
15,200	0.13	
15,450	0.15	0.15
15,750	0.15	
15,900	0.14	
16,450	0.16	
16,500	0.19	
16,550	0.23	
16,700	0.22	
16,950	0.21	0.21
17,200	0.22	
17,300	0.22	

enhanced under warm and wet climatic conditions. Such a change would also favor the enhanced complexation of iron with organic compounds and the further breakdown of clay minerals, both occurring in the Los Lirios sediments after 10,000 B.P.

We believe that these changes are a direct result of a climatic amelioration corresponding to the end of the Merida glaciation. As the climate warmed, the conditions at the elevation of Lake Los Lirios shifted from a situation similar to that of the modern Tierra Helada to its current state. The suddenness of the change is remarkable, but the climatic change no doubt forced additional restructuring in the hydrological and limnological responses of the basin which could have amplified the climatic signal. Further analysis of the dynamics of change must await completion of the palynological analysis of the Los Lirios core, to see how these in-lake changes correspond to floral migrations.

Comparison between Lakes Mucabají and Los Lirios

The sedimentary records for Lakes Mucabají and Los Lirios overlap for the time interval from ca. 2,000 to 8,000 years B.P. This is the entire length of the Mucabají core, and encompasses the Los Lirios core from a depth of 100 cm to about 330 cm. The differences between the various geochemical variables for the overlapping interval are obvious, yet there are some subtle similarities which are also worth noting. For example, during the period from ca. 5,000 to 8,000 B.P. (223 to 323 cm on the Los Lirios core) the organic matter content shows a general decrease followed by an increase (Fig. 36). Using the guidelines established earlier, this could represent a cooler episode; a conclusion which is not contradicted by the Mucabají pollen data. Similar sympathetic fluctuations can also be observed in the behavior of extractable iron, although a vivid imagination may be required to determine any significant correlation at this juncture! Neveretheless, it appears that the lake sediments could be responding to smaller climatic changes that

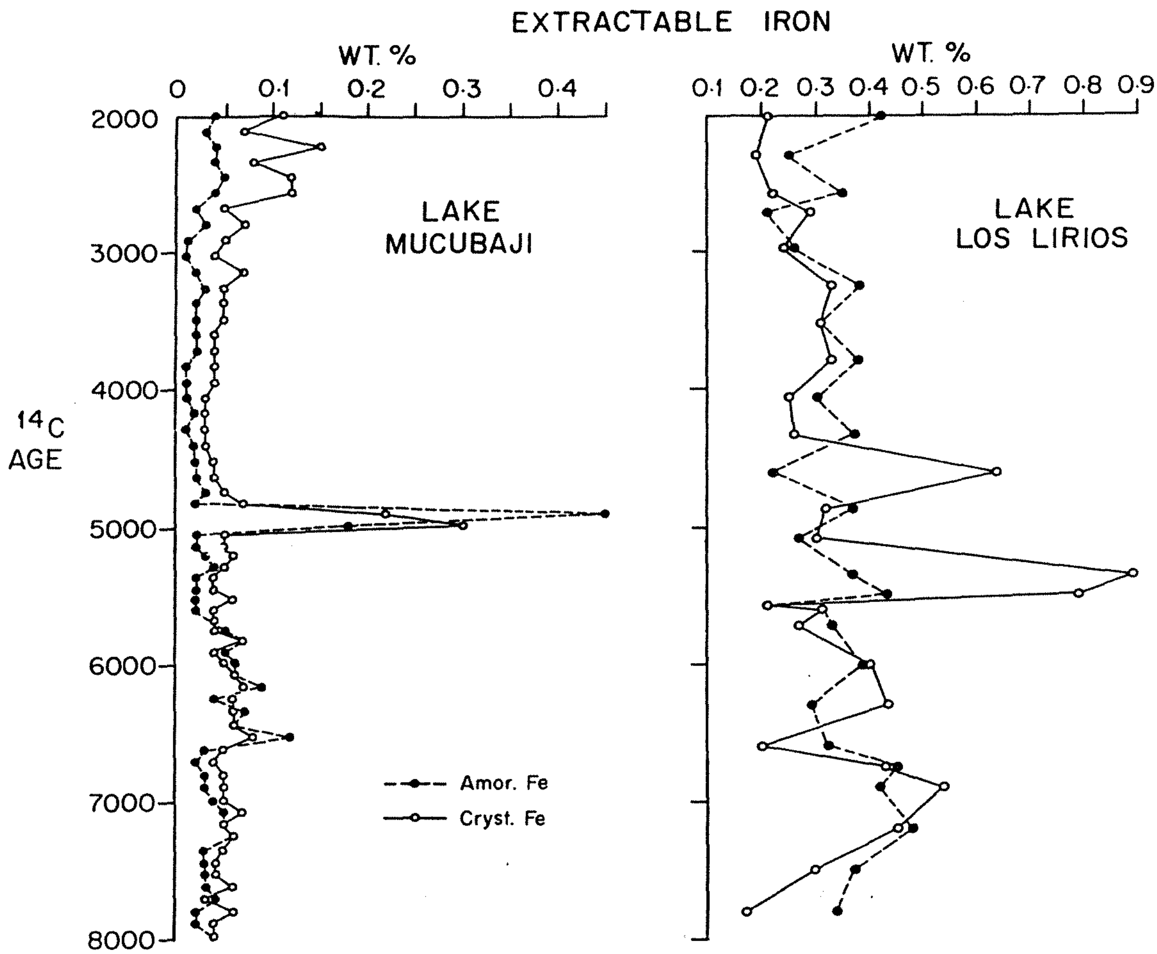

Figure 36. Comparison of contemporaneous changes in Laguna Mucabají and Laguna Los Lirios.

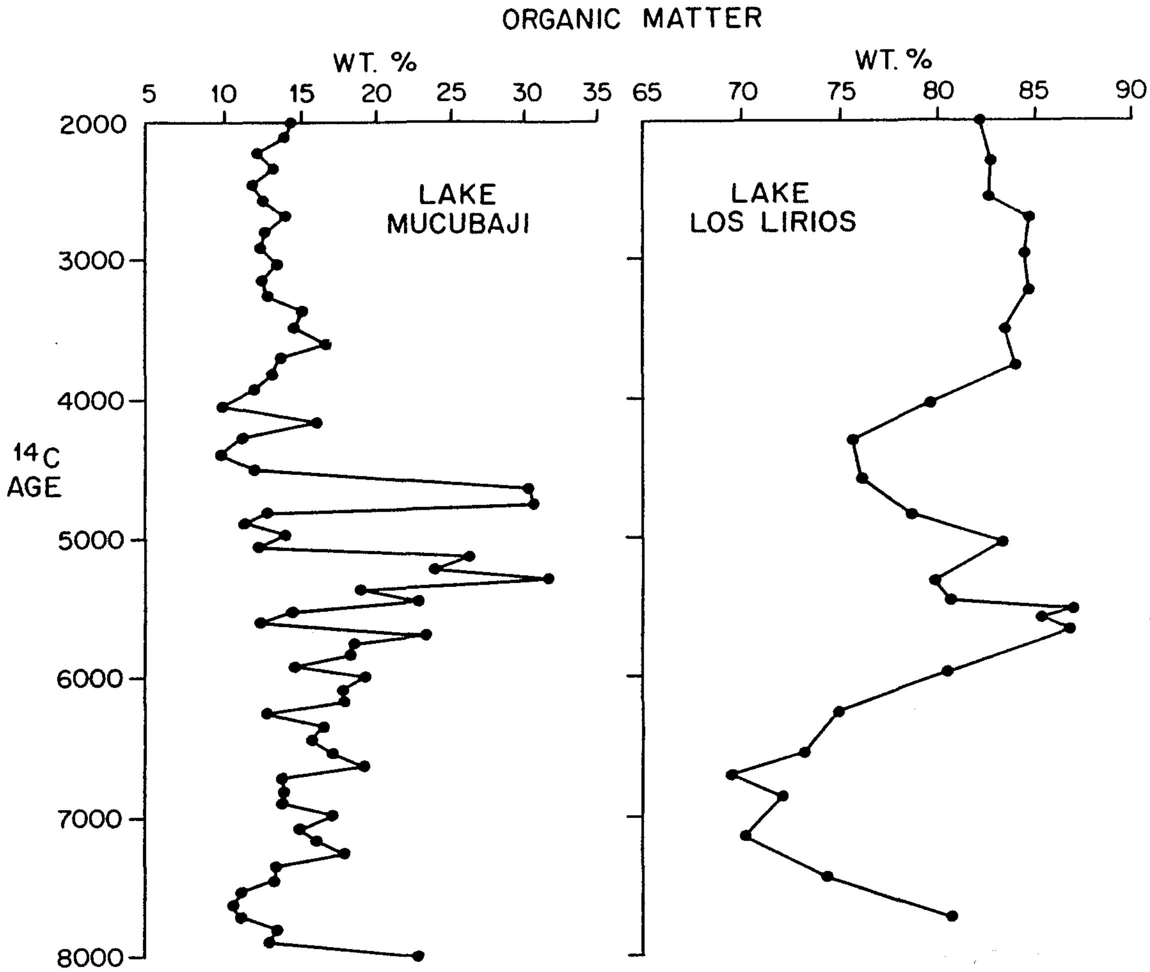

Figure 36 (continued).

affect the whole region, an idea which will require further testing by looking at pollen and perhaps diatom assemblages within the Los Lirios sediment sequences.

Regional Correlations

In order help determine the utility of geochemistry and clay mineralogy in paleoenvironmental interpretations, the resulting climatic reconstruction must be compared against the existing records from other parts of Venezuela and Colombia. The environmental records for the Andes in both countries are almost entirely based on pollen data and show broad similarities (e.g. van der Hammen and Cleef, 1986; Salgado-Labouriau, 1986). The record from Colombia extends further back in time (Hooghiemstra, 1984) and is far more continuous then the data from Venezuela.

Venezuela

The existing paleoenvironmental record for the central Andes of Venezuela dates only as far back as 12,700 B.P. (Giegengack and Grauch, 1976). The available paleoecological data suggest that by 12,650 B.P. glaciers had already retreated from the area of Mucabají (Salgado-Labouriau et al. 1977). According to Salgado-Labouriau (1984), pollen assemblages for the time period 12,650-12,280 B.P. from the Mucabají area, are similar to those found today in the super-páramo zone, a vegetation zone within the upper part of the Tierra Helada climatic belt (Lauer, 1979). This implies climatic conditions which were cooler and drier then those presently prevailing in Mucabají.

By 12,250 B.P., tree pollen assemblages similar to those found at the present time in the páramo zone (close to the limit between Tierra Helada and Tierra Fria climatic belts), were already recorded in the Mucabají area, which suggests increasing temperatures (Salgado-Labouriau et al. 1977). Later, during the time period 11,700-11,000 B.P., pollen analysis indicates that cooler conditions prevailed but humidity remained similar to the previous levels (Salgado-Labouriau and Schubert, 1976). The transition to this cold and humid phase occurred soon after 11,960 B.P. (Salgado-Labouriau, 1984).

The conditions suggested by the geochemical data from Los Lirios indicate that the time period from ~13,000 to ~9,000 B.P. was associated with declining temperatures and decreasing precipitation (Fig. 37). A similar, but more subdued trend, could be postulated for the higher elevations around Laguna Mucabají, since Salgado-Labouriau (1984) notes a warm interval in the period 12,250-11,700 B.P. from the pollen data. High organic content together with a change in crystalline Fe may also reflect this trend (Fig. 37).

At 6,940 B.P. the area of La Culata, northwest of Mucabají, was under environmental conditions similar to these found there today, but at about 6,000 B.P. a significant decrease in pollen rain indicates a change to much cooler conditions (Salgado-Labouriau and Schubert, 1977). The decrease in organic matter coupled with an increase in the relative abundance of crystalline iron in the Los Lirios core also supports a cool phase during this same general time.

In addition to these high elevation environmental records, recent studies in Lake Valencia (402 m a.s.l.) provide an important source of data for ecological changes in tropical lowlands of Venezuela (Salgado-Labouriau, 1980; Bradbury et al., 1981; Lewis and Weibezahn, 1981; Leyden, 1985). Pollen analysis of sediments from Lake Valencia suggests that at 13,000 B.P., a much drier climate than today prevailed, with the lake being much smaller and possibly desiccated at approximately 13,000 B.P. (Salgado-Labouriau, 1980). A transition to more humid conditions began approximately between 10,340 and 10,200 B.P. and lake expansion began at about 9,840 B.P. According to Leyden (1985), climate in that area was arid between 8,300 and 5,200 B.P., mesic conditions dominated the time interval 5,200 to 2,200 B.P. and the last 2,200 years experienced variable conditions. All these findings for Lake Valencia are also supported by geochemical and limnological data reported by Bradbury et al. (1981), Lewis and

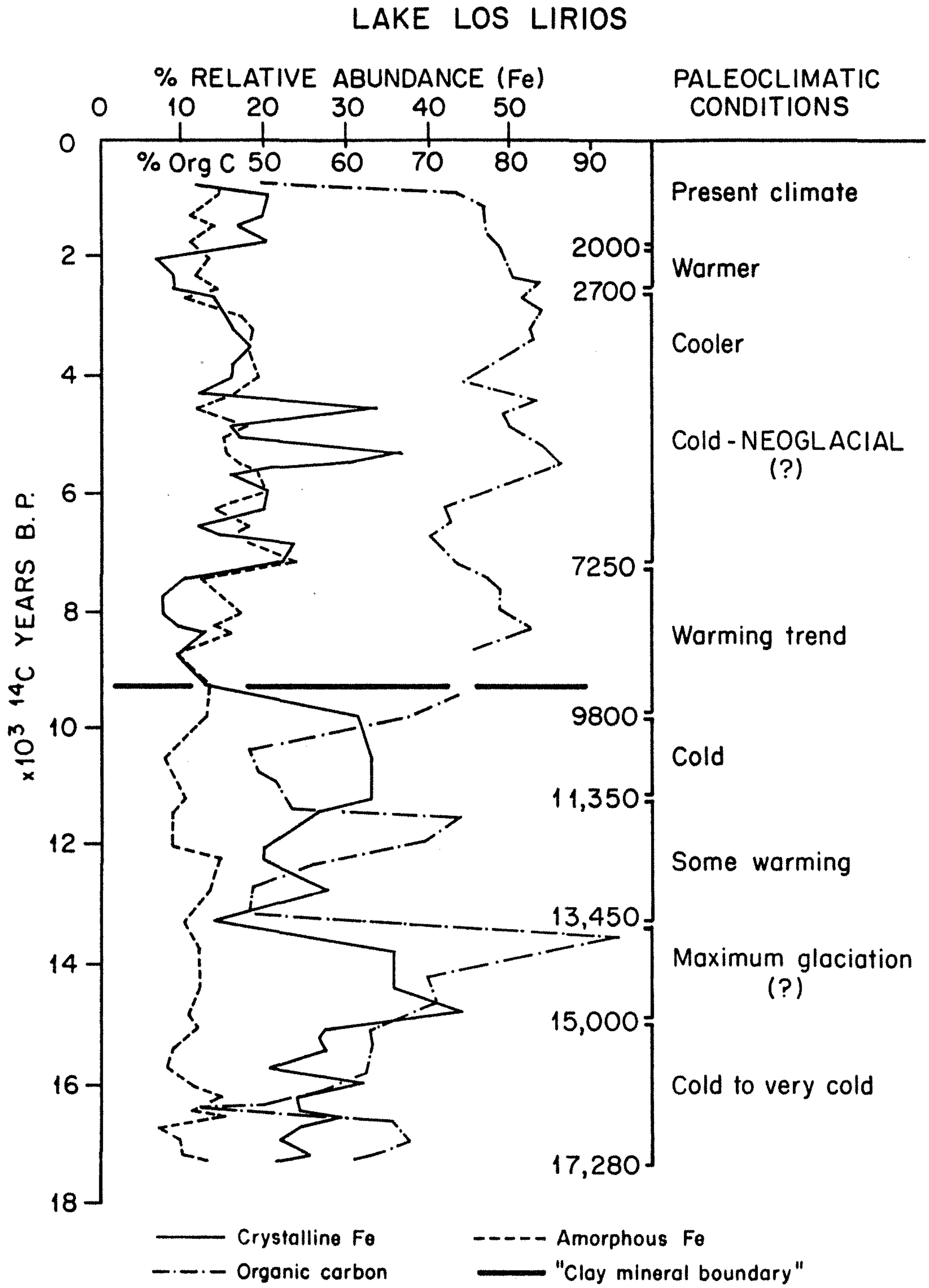

Figure 37. Major paleoclimatic changes in the Venezuelan Andes interpreted from the changes in relative abundances of extractable iron, organic carbon and clay mineral content.

Weibezahn (1981) and Binford (1982).

Good agreement exists between the changing climatic phases in Valencia and the geochemical data from Los Lirios. The marsh conditions in Lake Valencia for most of the time period 13,000 to 9,840 B.P. coincide with the predominantly cold climatic conditions interpreted from the Los Lirios geochemistry. The post-glacial amelioration in Valencia, that began around 9,800 B.P., is similar to that seen in Los Lirios. However, the dry phase in Valencia between 8,300 and 5,200 B.P. disagrees with an increase in moisture and decrease in temperature interpreted from the Los Lirios core (Fig. 37). The mesic conditions in Valencia, for the period 5,200 to 2,200 B.P. may be mirrored in the increasing iron and organic matter in the sediments of Lake Los Lirios up to ~2,000 B.P. Discrepancies between the tropical lowlands and the mountain region can result from differential responses to climatic change at different altitudes.

Colombia

Reconstruction of paleoenvironments in Venezuela and Colombia has produced similar results (Salgado-Labouriau, 1986; van der Hammen and Cleef, 1986). Because the paleoecological record from Colombia is more continuous and far more extensive than that from Venezuela (van Geel and van der Hammen, 1973; Hooghiemstra, 1984), the similarity of these two regions allows a reasonable estimate of the possible environmental changes in Venezuela for the missing portions of the paleoecological record.

Van Geel and van der Hammen (1973) suggest extremely dry and cold climatic conditions for the area of Laguna de Fuquene (approximately 2,600 m a.s.l.) beginning at 20,500 and ending close to 14,000-13,000 B.P. Subsequently, during the Guantiva interstadial (~13,000-10,800 B.P.), the climate became much warmer and wetter but conditions reversed again during the El Abra stadial (10,800-9,500 B.P.). Generally, a good agreement exists between the first 3,000-4,000 years (18,000-14,000 B.P.) of the Lirios record and the coeval time interval of the Fuquene pollen record.

For the Holocene, only the time interval 9,500-7,500 B.P. shows similar climatic conditions in the Colombian and Los Lirios records, indicating an overall increase in temperature and humidity. The subsequent phase in Colombia was increasingly cool and dry. By contrast, the Los Lirios and Mucabají records (7,500-3,000 B.P. in the Los Lirios core) demonstrate significant fluctuations, not suggested by the pollen record from Laguna de Fuquene. Only in the middle of subzone Z-II (van der Hammen and Cleef, 1986) ca. 5,000 B.P., are warmer and wetter conditions interpreted from the pollen data.

Pollen analysis indicates that the last 3,000 years of the Holocene epoch in the Fuquene area, were relatively cooler than the preceding time interval. A contemporaneous increase in the water level of nearby Laguna de Palacio (~2,600 m a.s.l.) also suggests that the climate became wetter, but only for a short period of time before a gradual increase in dryness took over. For the same time interval, the relatively great abundance of organic iron in the Andean lakes argue for relatively high moisture levels which do not show extreme fluctuations except for the period 2,000-1,800 B.P.

Extent of Regional Application

Figure 38 compares the palynologically reconstructed climatic changes for the late Pleistocene and Holocene in northern South American Andes (principally Colombia and the available data for Venezuela) with the Lake Valencia diatom-based reconstruction and the paleoclimatic reconstruction from this study. Although restrictions may apply to the lower, and perhaps the upper, limits of the altitudinal extent of such regional interpretation, it seems that the interpreted climatic changes from the Lirios record are compatible with what Markgraf and Bradbury (1982) refer to as the northern Andes between latitudes 10^{o}N and 35^{o}S.

However, regardless of the extent of its regional application, the paleoclimatic

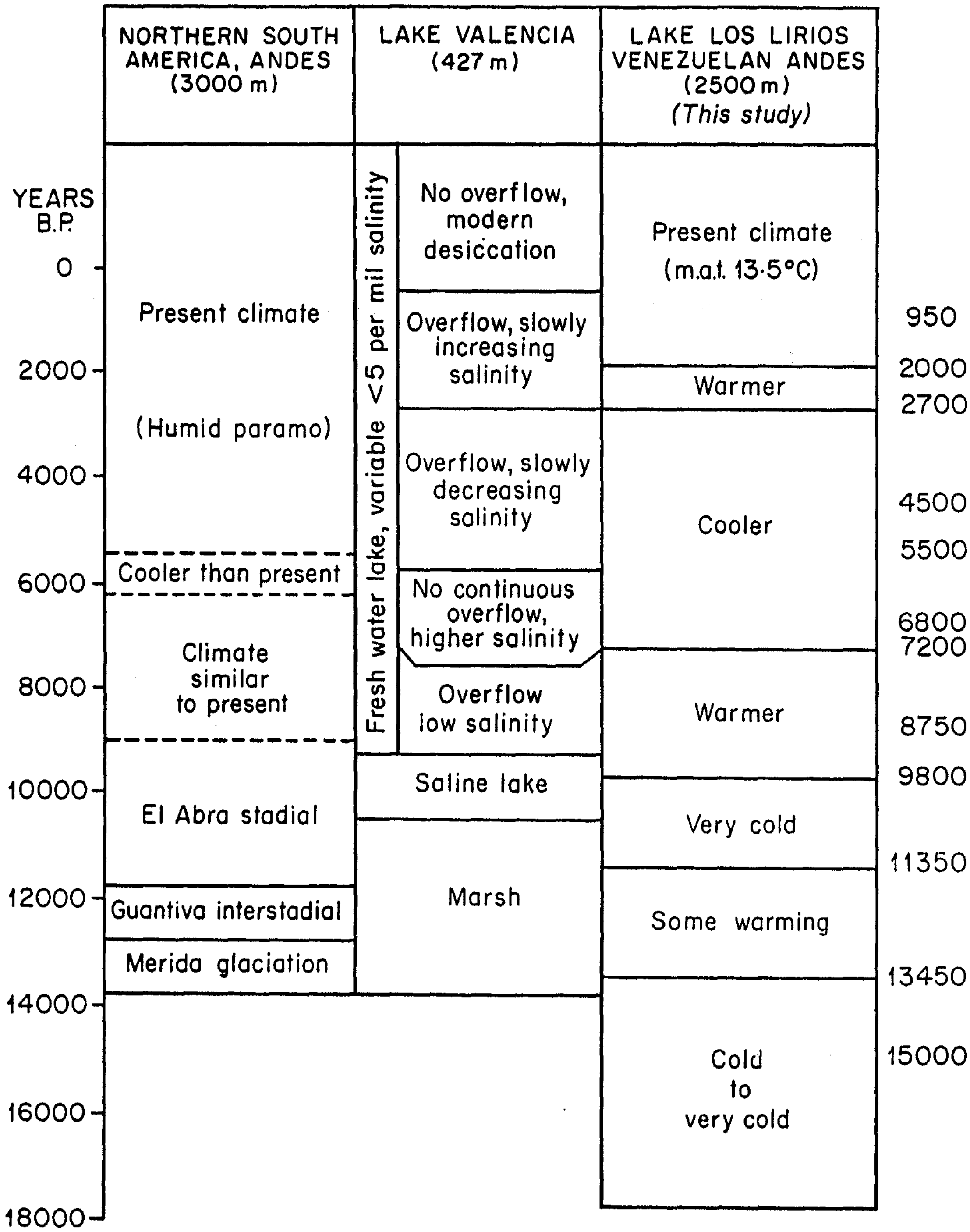

Figure 38. The paleoclimatic changes documented from the present study are similar to the pollen record for northern South America (*from Salgado-Labouriau et al, 1977*). The diatom record for Lake Valencia also shows similar trends (*from Bradbury et al, 1981*).

events in the Los Lirios area (Páramo de Mariño) are representative of past climatic conditions in the Andes of Venezuela above the Tierra Caliente-Tierra Templada altitudinal boundary. The Lake Lirios basin (2,300 m a.s.l.) was not occupied by glaciers during the time span, yet the general agreement between the geochemistry and the pollen in the other areas indicates that the geochemical changes in the lake sediments reflect overall climatic changes associated with glaciations and de-glaciations.

SUMMARY AND SUGGESTIONS FOR FUTURE RESEARCH

Richard Yuretich, Raymond Bradley, Baruch Weingarten
and Maria-Lea Salgado Labouriau

The lakes of the Venezuelan Andes possess characteristics in the geochemistry of both water and sediments, as well as in the clay mineralogy of the sediments, which are representative of the prevailing climate in their surrounding drainage basins. These attributes enable the modern lakes to be classified into groups associated with the Tierra Helada, Tierra Templada and Tierra Caliente altitudinal-climatic belts.

Bedrock and soil are the sources of iron, manganese and clay minerals in lake sediments. Undoubtedly, most of the lake sediment characteristics are acquired during the process of soil formation in which weathering plays a primary role. Consequently, the link between geochemical and clay mineral characteristics of lake sediments and climate arises from the relationship with the intensity of weathering processes. The possible effect that variations in bedrock composition may have on the apparent climatic signal stored in these lakes was not assessed quantitatively. It seems clear that differences between the Sierra Nevada and Mucuchachí Formations contribute to compositional divergences in the Tierra Templada lakes, particularly in the clay-mineral assemblages. However, under colder climatic conditions, such controls may be of lesser importance: witness the strong similarities between the clays in the modern Tierra Helada lakes (Sierra Nevada source) and those in paleo-Los Lirios (Mucuchachí source).

The relationship between climate and clay minerals is well established (Singer, 1980; 1984). In the present study, this relationship can be interpreted from the grouping of clay mineral assemblages in specific altitudinal-climatic zones. The lower relative abundance of chlorite and illite (in comparison to kaolinite and gibbsite at lower elevations) accords with the warmer climates at these altitudes. Support for these relationships also comes from illite crystallinity which suggests that lower values are characteristic of warmer climatic settings because of the enhanced weathering.

Clay mineral data could become an important tool for paleoenvironmental reconstruction especially when the modern weathering and sedimentary processes are well constrained. It can also serve as a useful cross-check on paleoenvironental reconstructions based upon pollen or other traditional proxy climate data.

Using sedimentary geochemistry for paleonvironmental reconstructions is not as easily accomplished. Geochemical data in this study suggest that variations in extractable iron, organic matter and clay minerals are climate-dependent and can be related to climatic fluctuations interpreted from palynological data.

Suggestions for Further Research

This study represents a first step towards using geochemical evidence from lacustrine sediments to reconstruct paleoclimatic conditions in a tropical mountain region. Although several climate-dependent relationships were found, the geochemical data collected in this study require greater constraints before they can be used as an effective paleoclimatic indicator. In particular, a more detailed study of the lake basins already investigated could be helpful. Priorities in this regard fall into several categories. First, soil samples and the sediment input to each lake basin should be carefully analyzed. This will enable a more effective determination of the relationship between source material (bedrock and soil) and sediments in lake. Secondly, sediments from several sites within each lake should be analyzed, in order to place some realistic constraints on the internal compositional variability of the modern surface sediments. Thirdly, a more effective documentation of the basic limnology and hydrology of the lakes is needed. The similarities and differences preserved in the sediments are, in part, a function of currents, turnover, oxygen saturation and the like. Complete documentation of these characteristics will require repeated measurements at each site at different times of the year, coupled with a more precise measurement of lake area, volume and catchment characteristics. Then we could truly evaluate the importance of intrabasinal processes on lake sedimentation. Future studies should also include qualitative analysis of organic matter in sediment and soil samples, as well as studies of lake productivity. Such analyses will provide a significant insight into the balance between terrestrial and aquatic organic matter accumulating on the lake floor, and the variations which occur within and across climatic zones.

Two of the original goals of the project, which remain as yet uncompleted, will also help in establishing the validity of the geochemical climatic signature. The palynogical analysis of the Mucubaji core provided important information for interpreting some of the geochemical fluctuations in the record from that lake. A similar analysis of the Los Lirios core is still in progress (under the supervision of Dr. M.L. Salgado-Labouriau of the Universidade de Brasília); these results will greatly assist in the interpretation of the geochemical data and will provide an independent record to compare with our conclusions.

At the time we started our field program, we also established five automatic meteorological stations at various elevations in the Andes. These used Campbell CR-21 microloggers to record air temperature, ground temperature, relative humidity, precipitation and wind speed at sites proximal to our primary lakes. Unfortunately, our reliance on high technology was not rewarded in these remote locations. Malfunctions and bad luck have left us with a fragmented record of climatic data in these areas, and the editing required to process the information is considerable. Once these data are completely processed, they should provide a better understanding of the site-to-site variability in the climate, which, in turn, may be reflected in differential fluctuations in the sedimentary geochemical measures.

The results from the Lake Los Lirios core demonstrate that the Tierra Templada lakes contain the greatest potential for reconstructing environmental change in the

Venezuelan Andes during the Late Quaternary. The retrieval of long sediment cores from the other three lakes in the Tierra Templada: Brava, Negra (M) and Blanca, should be a high priority for future projects. This will enable further documentation of the record from Lake Los Lirios. The resemblance between the modern sediments in Lake Brava and Lake Los Lirios is confirmed by the organic content, iron distribution and general lack of clay minerals in the two lakes. If the sedimentary records present in the two lower Tierra Templada lakes, Negra (M) and Blanca, extend for the entire Holocene, they may provide a clay mineral record which is missing from Los Lirios. Additionally, since these two lakes are developed on the Sierra Nevada Formation, the importance of bedrock geology can be evaluated further. These core collections should be done in conjunction with a complete hydrographic and limnological analysis of these basins.

Lastly, one lake has become an orphan. Lago de Urao, because of its vastly different geological and hydrogeochemical setting, was only peripherally included in the present study. The long core collected was dated to 6,000 B.P. and it contains a sedimentary record punctuated by evaporite minerals (Appendix D). This record requires further stratigraphic analysis from various perspectives to see what degree of correlation can be obtained with the Tierra Templada fluctuations. A longer core would be useful in this regard, but the effort which produced the present core was ended when we poked through a gas pocket which threatened to (permanently) terminate the entire research project! A complete hydrological and geochemical study of this basin is certainly warranted.

At this stage of this project only qualitative paleoenvironmental interpretations may be made from the geochemical and clay mineral data. However, the climatic signal, evidently stored in some geochemical variables, promises that additional studies of this type can produce sufficient data to statistically quantify the relationship between these geochemical and climatic parameters.

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APPENDIX A

LIMNOLOGICAL FIELD MEASUREMENTS

Table A.1. *Lake Monton.*
Elevation: 3,700 m.
Survey Date: October 13, 1983

Water depth (m)	*T°C*	*D.O.* (ppm)	*E.C.* (umhos)
1.00	10.0	4.4	2.0
3.00	9.2	---	2.0
5.00	9.0	4.6	---
6.00	8.8	---	1.8
9.00	8.8	---	1.2
10.00	8.8	4.4	---
12.00	8.0	---	1.2
15.00	7.8	4.2	---
20.00	7.8	4.3	---
25.00	7.5	4.3	---
30.00	7.5	4.3	---
35.00	7.5	4.3	---

Table A.2. *Lake Saisay.*
Elevation: 3,700 m.
Survey Date: November 11, 1983

Water depth (m)	*T°C*	*D.O.* (ppm)	*E.C.* (umhos)
1.00	11.0	7.1	5.0
2.00	10.8	7.0	5.0
3.00	10.5	7.0	6.0
4.00	10.3	7.2	8.0
5.00	10.3	7.2	8.0
6.00	10.3	7.2	9.0
7.00	10.2	7.1	9.0
8.00	10.0	7.0	9.0
9.00	10.0	7.0	9.0
10.00	10.0	7.0	9.0
11.00	9.8	7.4	8.0
12.00	9.4	7.4	9.0
13.00	9.1	7.5	9.0
14.00	9.0	7.4	10.0
15.00	8.9	7.3	---
16.00	8.9	7.4	---
17.00	8.7	7.2	---
18.00	8.6	7.3	---
19.00	8.6	7.6	---
20.00	8.6	7.6	---
21.00	8.5	7.4	---
22.00	8.2	7.5	---
23.00	8.2	7.4	---

24.00	8.2	7.4	---
25.00	8.2	7.4	---
26.00	8.2	7.4	---
27.00	8.2	7.4	---
28.00	8.2	7.5	---
29.00	8.2	7.4	---
30.00	8.2	7.6	---
31.00	8.1	7.6	---
32.00	8.1	7.6	---
33.00	8.1	7.6	---
34.00	8.0	7.5	---
35.00	8.0	7.4	---
36.00	8.0	7.5	---
37.00	8.0	7.8	---
38.00	8.0	7.8	---
39.00	8.0	7.7	---
40.00	8.0	7.7	---
41.00	8.0	7.7	---
42.00	8.0	7.7	---
43.00	8.0	7.7	---

Table A.3. *Laguna Negra (Apartaderos).*
Elevation: 3,460 m
Survey Date: October 8, 1983

Water depth (m)	T^oC	*D.O.* (ppm)	*E.C.* (umhos)
0.50	8.0	---	10.0
0.75	8.0	4.7	----
1.75	8.0	5.3	----
2.25	8.0	---	10.0
2.75	8.0	5.2	----
3.25	8.0	---	10.0
3.75	8.0	5.2	----
4.25	7.6	---	10.0
4.75	7.5	5.2	----
5.25	7.5	---	10.0
5.75	7.5	4.9	----
6.25	7.4	---	10.0
6.75	7.4	4.6	----
7.25	7.3	---	10.0
7.75	7.3	4.8	----
8.25	7.3	---	11.0
8.75	7.3	5.0	----
9.25	7.2	---	11.0
9.75	7.2	4.8	----
10.25	7.2	---	11.0
10.75	7.2	5.2	----
11.25	7.1	---	12.0
11.75	7.1	5.2	----

12.25	7.1	---	12.0
12.75	7.1	5.3	----
13.25	7.1	---	13.0
13.75	7.0	5.2	----
14.25	7.0	---	13.0
14.75	7.0	5.2	----
15.25	7.0	---	13.0
15.75	7.0	5.2	----
16.75	7.0	5.2	----
17.75	7.0	5.2	----
18.75	6.9	5.0	----
19.75	6.9	4.9	----
20.75	6.9	5.0	----
21.75	6.9	5.3	----
22.75	6.9	5.1	----
23.75	6.9	5.1	----

Table A.4. *Lake Brava.*
Elevation: 2,380 m
Survey Date: October 18, 1983

Water depth (m)	*T°C*	*D.O.* (ppm)	*E.C.* (umhos)
1.00	16.5	6.2	40.00
2.00	16.0	5.9	38.00
3.00	16.0	5.9	38.00
4.00	16.0	6.4	38.00
5.00	15.5	4.2	38.00
6.00	15.5	0.8	40.00
7.00	16.0	0.6	40.00
8.00	15.8	0.4	40.00
9.00	15.8	0.4	42.00
10.00	15.3	0.4	49.00
11.00	15.2	0.4	50.00
12.00	15.1	0.4	53.00
13.00	15.0	0.4	60.00
14.00	15.0	0.4	62.00

Table A.5. *Lake Los Lirios.*
Elevation: 2,300 m
Survey Date: October 10, 1983

Water depth (m)	*T°C*	*D.O.* (ppm)	*E.C.* (umhos)
1.00	15.0	7.0	49.00
2.00	15.0	7.2	49.00
3.00	15.0	6.4	49.00
4.00	15.0	5.8	49.00
5.00	14.5	1.1	52.00
6.00	14.2	0.5	141.00
7.00	13.9	0.4	171.00

Table A.6. *Lake Negra (Mariño).*
Elevation: 1,700 m.
Survey Date: October 20, 1983

Water depth (m)	*T°C*	*D.O.* (ppm)	*E.C.* (umhos)
1.00	15.7	1.2	20.00
2.00	15.7	0.7	20.00
3.00	15.5	0.4	20.00
3.50	15.5	0.4	20.00

Table A.7. *Lake Blanca.*
Elevation: 1,620 m.
Survey Date: October 21, 1983

Water depth (m)	*T°C*	*D.O.* (ppm)	*E.C.* (umhos)
1.00	20.0	6.6	10.00
2.00	19.5	6.2	10.00
3.00	19.3	6.5	72.00
4.00	19.1	7.2	72.00
4.50	----	---	80.00

Table A.8. *Lake Urao.*
Elevation: 1,100 m.
Survey Date: September 2, 1983

Water depth (m)	*T°C*	*D.O.* (ppm)	*E.C.* (umhos)
0.50	25.0	---	1740
1.00	25.5	---	1740
1.50	25.0	---	1700
2.00	25.0	---	1680

Table A.9. *Lake Verde 1.*
Elevation: 4,300 m
Survey Date: February 24, 1985

Water depth (m)	*T°C*	*D.O.* (ppm)	*E.C.* (umhos)
0	11	8.1	----
1	8.2	8.4	----
2	8.2	8.5	----
3	8.1	8.6	----
4	9.2	7.2	----

Table A.10. *Lake Verde 2.*
Elevation: 4,300 m
Survey Date: February 34, 1985

Water depth (m)	*T°C*	*D.O.* (ppm)	*E.C.* (umhos)
0	9.8	8.75	----
1	7.8	8.75	----
2	7.9	8.80	----
3	7.2	8.78	----
4	7.2	9.0	----
5	7.1	8.78	----
6	7.2	8.65	----
7	7.2	8.65	----
8	7.0	----	----
9	7.0	----	----
10	7.0	----	----

Table A.11. *Lake Misteque*
Elevation: 3,750 m
Survey Date: February 28, 1985

Water depth (m)	*T°C*	*D.O.* (ppm)	*E.C.* (umhos)
0	9.0	8.8	----
2	9.0	8.8	----
4	9.0	8.6	----
6	9.0	9.0	----
8	9.0	8.9	----
10	8.8	8.9	----
12	8.3	8.9	----
14	8.1	8.7	----
16	8.1	8.8	----
18	8.0	8.8	----
20	---	---	----

Table A.12. *Lake La Canoa.*
Elevation: 3,500 m
Survey Date: March 3, 1985

Water depth (m)	*T°C*	*D.O.* (ppm)	*E.C.* (umhos)
0	9.5	8.9	----
2	9.5	8.8	----
4	9.3	8.8	----
6	9.0	8.7	----
8	8.8	8.3	----
10	8.8	8.3	----
12	8.8	8.8	----

APPENDIX B

ANALYTICAL PROCEDURES

ANALYSIS OF SEDIMENTS

Table B.1. *Extraction Iron and Manganese from Sediments*

B.1.1. *Pyrophosphate Extraction*

1. weigh accurately 0.5 to 1 g of air dried sediment.
2. add 100 ml. of 0.1M $Na_4P_2O_7$ to 1g of (50 ml. to .5 g)
3. shake overnight in a polyethylene bottle @ room temp.
4. centrifuge for 10 min. at 2,000 r.p.m.
5. separate solution from sediment.
6. retain solution for atomic absorption analysis and the sediment for oxalate extraction.

B.1.2. *Oxalate Extraction*

1. rinse with distilled water the sediment sample left from pyrophosphate extraction.
2. add 10 ml. of 0.2M acidified ammonium oxalate.
3. shake in darkness for 4 hours.
4. centrifuge for 10 min. at 2,000 r.p.m.
5. separate solution from sediment.
6. retain solution for atomic absorption analysis and the sediment for dithionite extraction.

B.1.3. *Citrate-Bicarbonate-Dithionite (C.B.D.) Extraction*

1. rinse with distilled water the sediment sample left from oxalate extraction.
2. add 40 ml. of 0.3M Na-citrate and 5 ml. 1M $NaHCO_3$.
3. bring the temp. in a water bath to 75^oC (not more), place the bottle in the water bath.
4. add 1g of $Na_2S_2O_4$, stir for 1 min. and than occasionally for 5 min.
5. repeat step 4 two more times.
6. separate solution from sediment and retain for atomic absorption analysis.

B.1.4. *Atomic Absorption Analysis*

1. prepare 1.0, 2.0, 3.0, 4.0 and 5.0 ppm Fe standards, 0.5, 1.0, 2.0 and 3.0 Mn standards and a blank in 100 ml. volumetric flasks.
2. calibrate the atomic absorption (AA) unit.
3. measure concentrations of Fe and Mn in each of the extracted solution samples; if higher than 5 ppm dilute as necessary.
4. repeat measurements; if results differ by more than 3% measure again; record mean of two closest values.
5. measure the concentrations of Fe and Mn in each of the solutions used in the three extractions.
6. to calculate the final concentrations of Fe and Mn in each sample; multiply by dilution factor, subtract the concentration values of Fe and Mn in the extraction solutions (background) from the Fe and Mn the concentration values in the samples, divide by the weight of the dry sediment sample used for analysis and multiply by 100%

Table B.2. *Carbonate Analysis*

B.2.1. *Combustion Method*

1. weigh accurately a clean crucible.
2. place about 1 g of sediment sample in the crucible and weigh accurately.
3. place the crucible with sample in a pre-heated furnace at 550°C for 1 hour.
4. take crucible with sample out, cool to room temperature and weigh immediately.
5. place same crucible with sample in a pre-heated furnace at 1000°C for 1 hour.
6. take out crucible with sample, cool to room temperature and weigh immediately.
7. to calculate carbonate content (as $CaCO_3$) use the following equations:
   sample wt. @ 550°C - sample wt. @ 1000°C = wt. CO_2
   wt.% $CaCO_3$ = wt. CO_2 x 100/44

Table B.3. *Determination of Organic Matter Content*

B.3.1. *Loss on Ignition (L.O.I.)*

1. weigh accurately a clean crucible.
2. place about 1 g of air dried sediment sample and weigh accurately.
3. place crucible with sample in a pre-heated furnace @ 450°C for 1 hour.
4. take crucible with sample out, cool to room temperature and weigh immediately.
5. to calculate wt.% of organic matter content in sample subtract weight of sample after combustion at 450°C from weight of dry sample and multiply by 100%.

Table B.4. *Clay Mineral Analysis*

1. Air dry about 2 gr of homogenized sediment sample.
2. Once dry, grind it, place in 250 ml plastic bottle and add 100 ml of distilled water.
3. Place bottle(s) in a centrifuge and spin for the time required to achieve a separation of grains at 2 um.
4. Decant the water (now containing material > 2 um in suspension) into a 200 ml beaker and place in an oven at 60^oC.
5. Dry until most of the water evaporates and the sediment in suspension becomes a fairly thick paste.
6. Smear a third of the material onto a glass slide and air dry; save the remaining material, don't dry it.
7. Run the sample on X-ray diffractometer; subsequently place the sample in a glycol chamber for overnight and submit it to X-ray diffraction for a second time.
8. Air dry the sample again; pre-heat a furnace to 550^oC and place the sample for one hour; cool to room temperature and analyze by XRD for the third time;
9. The three runs are the "untreated", "glycolated" and "heated @ 550^oC".
10. Divide the unused material into two portions; saturate one portion with KCl and heat for one hour in a pre-heated furnace; analyze on XRD for vermiculite.
11. Treat the second portion with 1N HCl for two hours; air dry and analyze on XRD for kaolinite.

WATER ANALYSIS

Table B.5. *Sodium and Potassium*

B.5.1. *Atomic Emission*

1. prepare 1, 2 and 3 ppm sodium standards; 0.1, 0.5 and 1.0 potassium standards by properly diluting the Na^+ and K^+ bulk solutions, and a blank (distilled water).
2. analyze samples and calibrate occasionally the atomic absorption unit; dilute samples when necessary.

B.5.2. *Atomic Absorption*

1. prepare a 5% $LaCl_3.7H_2O$ solution (133.69 g/l)
2. prepare 1, 3 and 5 ppm calcium and magnesium standards by properly diluting the respective bulk solutions with 20%, by volume, of the lanthanum chloride solution and 80% distilled water.
3. prepare a blank consisting of 20%, by volume, of lanthanum chloride solution and 80% distilled water.
4. dilute all samples with 20%, by volume, of lanthanum chloride solution.
5. analyze samples and re-calibrate occasionally.
6. divide results by a factor of 0.8 to compensate for the 20% dilution with lanthanum chloride.

Table B.6. *Determination of Chloride*

B.6.1. *Specific-Ion (Chloride) Electrode Method*

1. prepare 0.01M, 0.001M and 0.0001M Cl standards from a 0.1M Cl stock solution using a pipette.
2. analyze standards using the chloride ion electrode with double junction reference in order of increasing concentration.
3. analyze blank (distilled water) and samples.
4. rerun standards; if mV values changed significantly reanalyze samples and standards again.
5. plot mV values versus Cl^- concentrations values of standards on a semi-logarithmic paper.
6. determine Cl^- concentrations of samples using the standard curve.

Table B.7. *Determination of Silica*

B.7.1. *Heteropoly Blue Method*

1. prepare 1, 3 and 5 ppm Si standards.
2. pipette 25 ml of each standard, each water sample and a blank (distilled water) into 50 ml beakers.
3. in a rapid succession add to each beaker: 0.5 ml (10 drops) of 1:1 HCl and 1 ml (20 drops) of ammonium molybdate reagent.
4. mix until yellow color forms.
5. wait 10 minutes and add 1 ml (20 drops) of oxalic acid solution.
6. wait additional 5 minutes and add 2 ml of aminonaphthosulfonic acid; a blue color will form.
7. set the UV spectrophotometer to a wavelength of 815 nm
8. read the transmittance and absorbance of standards, samples and blank.
9. prepare an absorbance calibration curve based on the standards and the blank and determine the concentration of the samples by comparing with the curve.
10. multiply values by a factorial of 2.14 to convert values from Si to silica concentration.

Table B.8. *Alkalinity*

B.8.1. *Titration Method*

1. prepare a standard 0.001N HCl solution.
2. calibrate the pH meter to pH 7 and pH 4.
3. add a drop of red-green indicator to 25 ml of sample and titrate with the HCl solution to pH 4.5; record the volume of acid used.
4. continue to titrate to pH 4.2 and record the final volume of HCl used.
5. calculate total alkalinity using the equation:

   Total alk. = (2A - B) x N HCl x 1000 meq/ml of sample
   N = normality of HCl
   A = ml of HCl used to reach pH 4.5
   B = total ml of HCl used at pH 4.2

APPENDIX C

ANALYTICAL DATA

The following tables contain data of geochemical and clay mineral analyses performed on short sediment-cores. Geochemical data includes concentrations of extracted iron and manganese, carbonate and organic matter. Total iron (TFe) and manganese (TMn) content are sums of three extractions; oFe, aFe, cFe and oMn, aMn, cMn, respectively. Iron and manganese concentration data are given in percent of dry weight (wt.%). Organic matter and calcium carbonate values are given in % weight loss on ignition (% L.O.I.).

Sedimentary data consist of clay mineral analyses of the clay fraction. Values for each of the short-sediment cores represent a continuous sequence of analyzed segments of the sediment-cores and refer to a depth below the water-sediment interface. The depth is given in cm. Ages are interpolated from a ^{14}C date at the bottom of each sediment-core, and an assumed zero age at the top of each core.

Table C.1. *Iron concentration (wt.%) in Lake Monton sediments.*

Age	*Depth*	*oFe*	*aFe*	*cFe*	*TFe*
125	0- 7	1.289	.550	.167	2.006
251	7-14	.585	.454	.296	1.335
376	14-21	.485	.246	.236	.967
502	21-28	.545	.242	.182	.969
627	28-35	.482	.226	.334	1.042
753	35-42	.559	.264	.343	1.166
878	42-49	.615	.279	.247	1.141
1004	49-56	.617	.242	.296	1.155
1129	56-63	.532	.164	.435	1.131
1254	63-70	.561	.336	.276	1.173
1362	70-76	.639	.319	.252	1.210
1470	76-82	.483	.249	.226	.958
1577	82-88	.523	.312	.330	1.165
1667	88-93	.598	.308	.265	1.171

Table C.2. *Iron concentration (wt.%)Lake Saisay sediments.*

Age	*Depth*	*oFe*	*aFe*	*cFe*	*TFe*
178	0- 10	.497	.275	.206	.978
356	10- 20	.531	.106	.133	.770
534	20- 30	.585	.170	.197	.952
712	30- 40	.497	.090	.129	.716
837	40- 47	.548	.114	.273	.935
962	47- 54	.648	.129	.315	1.092
1086	54- 61	.631	.161	.304	1.096
1211	61- 68	.532	.086	.237	.855
1335	68- 75	.605	.132	.159	.896
1460	75- 82	.526	.120	.260	.906
1531	82- 86	.508	.100	.603	1.211
1656	86- 93	.501	.076	.184	.761
1745	93- 98	.566	.109	.219	.894
1816	98-102	.537	.123	.146	.806

Table C.3. *Iron concentration (wt.%) in Lake Mucubají sediments.*

Age	*Depth*	*oFe*	*aFe*	*cFe*	*TFe*
132	0- 7	1.413	.332	.447	2.192
265	7-14	2.067	.400	.336	2.803
397	14-21	2.034	.401	.248	2.683
529	21-28	1.907	.401	.397	2.705
662	28-35	1.905	.451	.322	2.678
794	35-42	1.718	.372	.186	2.276
926	42-49	1.595	.326	.199	2.120
1059	49-56	1.621	.368	.473	2.462
1172	56-62	1.728	.404	.412	2.544
1285	62-68	1.714	.426	.481	2.621
1399	68-74	1.833	.420	.380	2.633
1512	74-80	1.894	.406	.379	2.679
1626	80-86	2.080	.524	.434	3.038

Table C.4. *Iron concentration (wt.%) in Lake Negra (Apartaderos) sediments.*

Age	*Depth*	*oFe*	*aFe*	*cFe*	*TFe*
63	0- 2	.372	.154	.727	1.253
157	2- 5	.056	.018	.087	.161
345	5- 11	.226	.093	.324	.643
564	11- 18	.283	.100	.286	.669
783	18- 25	.255	.104	.129	.488
1003	25- 32	.261	.082	.210	.553
1222	32- 39	.266	.078	.150	.494
1441	39- 46	.275	.074	.222	.571
1661	46- 53	.282	.070	.164	.516
1880	53- 60	.274	.097	.269	.640
2100	60- 67	.250	.075	.178	.503
2319	67- 74	.275	.079	.186	.540
2538	74- 81	.254	.080	.197	.531
2726	81- 87	.308	.092	.207	.607
2914	87- 93	.282	.097	.162	.541
3102	93- 99	.294	.091	.152	.537
3290	99-105	.285	.087	.253	.625

Table C.5. *Iron concentration (wt.%) in Lake Brava sediments.*

Age	*Depth*	*oFe*	*aFe*	*cFe*	*TFe*
186	0- 10	.284	.315	.097	.696
372	10- 20	.338	.582	.135	1.055
558	20- 30	.140	.366	.074	.580
744	30- 40	.107	.310	.054	.471
931	40- 50	.237	.687	.071	.995
1117	50- 60	.433	.835	.077	1.345
1303	60- 70	.285	.522	.042	.849
1489	70- 80	.210	.443	.056	.709
1675	89- 90	.154	.624	.094	.872
1805	90- 97	.231	.704	.099	1.034
1936	97-104	.260	.544	.062	.866
2084	104-112	.338	.597	.046	.981

Table C.6. *Iron concentration (wt.%) in Lake Lirios sediments.*

Age	*Depth*	*oFe*	*aFe*	*cFe*	*TFe*
298	0- 5	1.154	.961	.303	2.418
596	5-10	1.469	1.520	.314	3.303
893	10-15	1.690	1.762	.227	3.679
1191	15-20	1.797	1.671	.245	3.713
1489	20-25	1.962	.910	.101	2.973
1787	25-30	1.973	.493	.034	2.500
2085	30-35	1.293	.870	.085	2.248
2382	35-40	.904	.950	.066	1.920
2680	40-45	.944	1.005	.330	2.279
2978	45-50	1.037	1.057	.142	2.236
3276	50-55	.902	.942	.055	1.899
3514	55-59	.890	1.089	.374	2.353
3812	59-64	1.273	1.349	.061	2.683

Table C.7. *Iron concentration (wt.%) in Lake Negra (Mariño) sediments.*

Age	*Depth*	*oFe*	*aFe*	*cFe*	*TFe*
56	0- 5	.199	.109	.079	.387
113	5- 10	.240	.119	.146	.505
169	10- 15	.163	.093	.188	.444
215	15- 19	.504	.111	.257	.872
260	19- 23	.138	.104	.152	.394
294	23- 26	.196	.094	.156	.446
339	26- 30	.096	.077	.122	.295
395	30- 35	.113	.064	.091	.268
452	35- 40	.106	.058	.076	.240
508	40- 45	.140	.078	.102	.320
565	45- 50	.164	.080	.113	.357
644	50- 57	.182	.057	.096	.335
700	57- 62	.196	.053	.079	.328
757	62- 67	.201	.046	.090	.337
813	67- 72	.196	.058	.078	.332
881	72- 78	.168	.078	.079	.325
949	78- 84	.183	.076	.070	.329
972	84- 86	.170	.111	.193	.474
1006	86- 89	.421	.200	.178	.799
1051	89- 93	.693	.254	.060	.887
1107	93- 98	.285	.163	.078	.526
1164	98-103	.398	.203	.092	.693
1220	103-108	.321	.134	.077	.532

Table C.8. *Iron concentration (wt.%) in Lake Blanca sediments.*

Age	*Depth*	*oFe*	*aFe*	*cFe*	*TFe*
139	0- 7	.123	.074	.069	.266
179	7- 9	.139	.088	.062	.289
279	9-14	.149	.081	.065	.295
398	14-20	.356	.169	.065	.590
498	20-25	.368	.157	.048	.573
597	25-30	.316	.140	.054	.510
736	30-37	.240	.196	.054	.480
876	37-44	.241	.140	.032	.413
995	44-50	.212	.125	.058	.395
1115	50-56	.139	.128	.047	.314

Table C.9. *Iron concentration (wt.%) in Lake Urao sediments.*

Age	*Depth*	*oFe*	*aFe*	*cFe*	*TFe*
113	0- 5	.170	.421	.364	.955
225	5-10	.131	.332	.414	.877
338	10-15	.152	.293	.409	.854
450	15-20	.127	.337	.427	.891
518	20-23	.166	.377	.260	.803
675	23-30	.073	.323	.143	.539
765	30-34	.118	.296	.176	.590
900	34-40	.222	.281	.269	.772
1013	40-45	.173	.278	.519	.970
1125	45-50	.046	.619	.416	1.081
1260	50-56	.058	.678	.488	1.224

Table C.10. *Manganese concentration (wt.%) in Lake Monton sediments.*

Age	*Depth*	*oMn*	*aMn*	*cMn*	*TMn*
125	0- 7	.118	.016	.006	.140
251	7-14	.105	.014	.013	.132
376	14-21	.089	.011	.011	.111
502	21-28	.083	.009	.006	.098
627	28-35	.081	.007	.010	.098
753	35-42	.078	.009	.008	.095
878	42-49	.073	.007	.009	.089
1004	49-56	.070	.008	.008	.086
1129	56-63	.062	.006	.007	.075
1254	63-70	.064	.008	.007	.079
1362	70-76	.070	.007	.007	.084
1470	76-82	.066	.006	.007	.079
1577	82-88	.058	.007	.008	.073
1667	88-93	.052	.007	.007	.066

Table C.11. *Manganese concentration (wt.%) in Lake Saisay sediments.*

Age	*Depth*	*oMn*	*aMn*	*cMn*	*TMn*
178	0- 10	.039	.009	.007	.055
356	10- 20	.041	.005	.006	.052
534	20- 30	.044	.007	.009	.060
712	30- 40	.048	.004	.004	.056
837	40- 47	.050	.005	.008	.063
962	47- 54	.060	.005	.010	.075
1086	54- 61	.060	.007	.009	.076
1211	61- 68	.056	.004	.008	.068
1335	68- 75	.062	.006	.007	.075
1460	75- 82	.066	.005	.007	.078
1531	82- 86	.056	.005	.006	.067
1656	86- 93	.057	.004	.008	.069
1745	93- 98	.058	.005	.006	.069
1816	98-102	.062	.006	.007	.075

Table C.12. *Manganese concentration (wt.%) in Lake Mucubají sediments.*

Age	*Depth*	*oMn*	*aMn*	*cMn*	*TMn*
132	0- 7	.041	.013	.012	.066
265	7-14	.066	.015	.014	.095
397	14-21	.061	.014	.007	.082
529	21-28	.070	.013	.012	.095
662	28-35	.063	.015	.007	.085
794	35-42	.062	.014	.007	.083
926	42-49	.071	.012	.009	.092
1059	49-56	.070	.013	.013	.096
1172	56-62	.069	.014	.014	.097
1285	62-68	.069	.014	.010	.093
1399	68-74	.066	.014	.012	.091
1512	74-80	.069	.014	.010	.093
1626	80-86	.063	.016	.012	.091

Table C.13. *Manganese concentration (wt.%)in Lake Negra(Apartaderos) sediments.*

Age	*Depth*	*oMn*	*aMn*	*cMn*	*TMn*
63	0- 2	.010	.008	.016	.034
157	2- 5	.005	.001	.003	.009
345	5- 11	.022	.004	.006	.032
564	11- 18	.023	.004	.005	.032
783	18- 25	.021	.004	.005	.030
1003	25- 32	.021	.004	.005	.030
1222	32- 39	.022	.003	.005	.030
1441	39- 46	.023	.003	.004	.030
1661	46- 53	.022	.003	.004	.029
1880	53- 60	.022	.004	.005	.031
2100	60- 67	.024	.004	.004	.032
2319	67- 74	.025	.004	.004	.033
2538	74- 81	.023	.003	.004	.030
2726	81- 87	.023	.003	.004	.030
2914	87- 93	.023	.003	.004	.030
3102	93- 99	.023	.003	.004	.030
3290	99-105	.023	.003	.003	.029

Table C.14. *Manganese concentration (wt.%)in Lake Brava sediments.*

Age	*Depth*	*oMn*	*aMn*	*cMn*	*TMn*
186	0- 10	.006	.002	.003	.011
372	10- 20	.005	.002	.004	.011
558	20- 30	.003	.001	.003	.007
744	30- 40	.002	.001	.001	.004
931	40- 50	.003	.002	.003	.008
1117	50- 60	.003	.001	.003	.007
1303	60- 70	.002	.001	.002	.005
1489	70- 80	.002	.001	.001	.004
1675	80- 90	.003	.001	.002	.006
1805	90- 97	.003	.002	.004	.009
1936	97-104	.003	.001	.003	.007
2084	104-112	.002	.001	.003	.006

Table C.15. *Manganese concentration (wt.%)in Lake Lirios sediments.*

Age	*Depth*	*oMn*	*aMn*	*cMn*	*TMn*
298	0- 5	.000	.002	.005	.007
596	5-10	.000	.002	.002	.004
893	10-15	.000	.002	.002	.004
1191	15-20	.000	.002	.002	.004
1489	20-25	.000	.002	.003	.005
1787	25-30	.000	.002	.004	.006
2085	30-35	.000	.003	.003	.006
2382	35-40	.000	.003	.003	.006
2680	40-45	.000	.002	.004	.006
2978	45-50	.000	.003	.005	.008
3276	50-55	.000	.002	.004	.006
3514	55-59	.000	.003	.005	.008
3812	59-64	.000	.003	.006	.009

Table C.16. *Manganese concentration (wt.%) in Lake Negra(Mariño) sediment.*

Age	*Depth*	*oMn*	*aMn*	*cMn*	*TMn*
56	0- 5	.028	.004	.005	.037
113	5- 10	.020	.005	.009	.034
169	10- 15	.018	.005	.011	.034
215	15- 19	.007	.005	.006	.018
260	19- 23	.007	.004	.009	.022
294	23- 26	.006	.003	.007	.016
339	26- 30	.009	.003	.008	.020
395	30- 35	.008	.003	.005	.016
452	35- 40	.008	.002	.005	.015
508	40- 45	.012	.003	.005	.020
565	45- 50	.010	.003	.005	.018
644	50- 57	.009	.003	.003	.015
700	57- 62	.009	.004	.003	.016
757	62- 67	.007	.004	.002	.013
813	67- 72	.006	.004	.002	.012
881	72- 78	.019	.004	.004	.027
949	78- 84	.021	.004	.003	.028
972	84- 86	.015	.005	.009	.029
1006	86- 89	.039	.007	.007	.053
1051	89- 93	.043	.006	.002	.051
1107	93- 98	.032	.005	.004	.041
1164	98-103	.029	.005	.004	.038
1220	103-108	.023	.004	.002	.029

Table C.17. *Manganese concentration (wt.%) in Lake Blanca sediments.*

Age	*Depth*	*oMn*	*aMn*	*cMn*	*TMn*
139	0- 7	.009	.003	.003	.015
179	7- 9	.013	.002	.003	.018
279	9-14	.034	.003	.003	.040
398	14-20	.041	.003	.003	.047
498	20-25	.037	.003	.002	.042
597	25-30	.035	.003	.002	.040
736	30-37	.036	.004	.003	.043
876	37-44	.031	.003	.002	.036
995	44-50	.030	.003	.003	.036
1115	50-56	.020	.002	.002	.024

Table C.18. *Manganese concentration (wt.%) in Lake Urao sediments.*

Age	*Depth*	*oMn*	*aMn*	*cMn*	*TMn*
113	0- 5	.017	.046	.046	.109
225	5-10	.013	.039	.028	.080
338	10-15	.015	.045	.025	.085
450	15-20	.008	.038	.031	.077
518	20-23	.015	.042	.045	.102
675	23-30	.007	.002	.056	.065
765	30-34	.014	.052	.043	.109
900	34-40	.022	.088	.032	.142
1013	40-45	.032	.060	.039	.131
1125	45-50	.022	.080	.018	.100
1260	50-56	.026	.041	.017	.084

Table C.19. *Loss-on-ignition (wt.%) in Lake Monton sediments.*

Age	*Depth*	*250°C*	*450°C*	*550°C*	*$CaCO_3$*
125	0- 7	16.86	41.89	39.34	03.05
251	7-14	17.11	36.79	35.40	02.70
376	14-21	19.96	37.41	37.24	02.54
502	21-28	20.61	38.54	51.01	02.17
627	28-35	25.44	41.78	45.31	03.26
753	35-42	24.13	39.58	35.73	02.47
878	42-49	21.85	37.57	35.07	02.14
1004	49-56	26.26	37.55	35.15	02.83
1129	56-63	22.56	39.91	37.58	02.91
1254	63-70	22.96	39.29	36.26	03.44
1362	70-76	20.44	38.76	35.51	03.47
1470	76-82	25.68	42.33	39.16	02.99
1577	82-88	24.96	34.82	31.92	03.23
1667	88-93	20.09	33.37	30.35	04.40

Table C.20. *Loss-on-ignition (wt.%) of Lake Saisay sediments.*

Age	*Depth*	*250°C*	*450°C*	*550°C*	*$CaCO_3$*
178	0- 10	20.39	46.19	44.10	03.43
356	10- 20	22.64	47.09	42.73	03.61
534	20- 30	23.65	47.33	43.17	03.86
712	30- 40	20.38	43.35	40.92	02.64
837	40- 47	19.14	43.05	39.55	02.74
962	47- 54	20.01	44.40	41.04	02.35
1086	54- 61	20.14	45.70	41.17	03.02
1211	61- 68	22.78	45.80	41.77	03.16
1335	68- 75	25.89	47.40	42.72	03.21
1460	75- 82	23.38	51.29	45.89	02.73
1531	82- 86	23.45	41.28	36.79	03.93
1656	86- 93	22.41	41.28	36.71	03.55
1745	93- 98	22.16	41.18	35.96	04.50
1816	98-102	22.10	41.60	35.78	03.89

Table C.21. *Loss-on-ignition (wt.%) of Lake Mucubají sediments.*

Age	*Depth*	*250°C*	*450°C*	*550°C*	*$CaCO_3$*
132	0- 7	24.70	33.01	29.00	03.15
265	7-14	27.01	38.20	34.16	03.42
397	14-21	26.85	36.58	33.90	03.79
529	21-28	27.60	36.47	34.60	03.85
662	28-35	28.41	36.92	33.60	04.00
794	35-42	26.38	37.96	33.71	04.48
926	42-49	23.14	37.16	32.67	03.81
1059	49-56	20.82	36.31	30.81	03.99
1172	56-62	21.19	35.38	33.49	01.67
1285	62-68	25.40	36.91	32.12	02.32
1399	68-74	21.24	35.80	32.49	02.31
1512	74-80	24.55	35.72	31.06	02.73
1626	80-86	24.78	35.01	30.44	03.09

Table C.22. *Loss-on-ignition (wt.%) from Lake Negra (Apartaderos) sediments.*

Age	*Depth*	*250°C*	*450°C*	*550°C*	*$CaCO_3$*
63	0- 2	11.65	30.41	31.65	06.34
157	2- 5	0.96	12.06	09.20	04.85
345	5- 11	15.63	40.26	35.23	04.16
564	11- 18	17.52	39.70	35.31	04.42
783	18- 25	18.46	39.99	37.80	03.94
1003	25- 32	17.07	39.57	38.18	02.06
1222	32- 39	14.79	39.41	38.22	02.32
1441	39- 46	8.07	40.69	37.37	02.45
1661	46- 53	21.85	40.92	37.80	03.28
1880	53- 60	19.17	40.97	37.46	04.12
2100	60- 67	18.90	40.01	46.19	02.27
2319	67- 74	19.08	41.91	38.35	02.92
2538	74- 81	19.41	41.60	38.09	03.63
2726	81- 87	16.97	41.68	37.39	03.67
2914	87- 93	15.47	41.30	37.20	05.15
3102	93- 99	15.72	39.80	37.67	04.04
3290	99-105	20.27	39.95	37.66	05.79

Table C.23. *Loss-on-ignition (wt.%) of Lake Brava sediments.*

Age	*Depth*	*250°C*	*450°C*	*550°C*	*$CaCO_3$*
186	0- 10	26.97	73.08	72.73	00.18
372	10- 20	28.70	74.46	72.94	01.05
558	20- 30	32.47	72.35	71.42	01.81
744	30- 40	32.02	72.53	72.88	01.36
931	40- 50	25.11	73.21	73.10	01.57
1117	50- 60	27.65	75.00	72.79	02.43
1303	60- 70	37.38	73.40	71.56	02.08
1489	70- 80	28.05	77.70	78.05	01.77
1675	80- 90	24.73	77.09	77.50	02.23
1805	80- 97	17.16	77.94	77.18	03.42
1936	97-104	19.77	77.65	77.10	00.76
2084	104-112	27.52	80.78	79.90	00.82

Table C.24. *Loss-on-ignition (wt.%) of Lake Los Lirios sediments.*

Age	*Depth*	*250°C*	*450°C*	*550°C*	*$CaCO_3$*
298	0- 5	14.57	52.75	49.42	00.00
596	5-10	15.05	80.66	77.91	00.00
893	10-15	22.83	80.17	79.08	00.70
1191	15-20	22.55	80.15	78.34	00.87
1489	20-25	22.58	83.94	82.31	00.91
1787	25-30	17.15	84.58	85.24	00.74
2085	30-35	20.60	84.79	84.89	00.87
2382	35-40	20.77	84.96	85.20	00.00
2680	40-45	22.14	84.91	85.19	00.27
2978	45-50	22.76	84.43	84.67	01.06
3276	50-55	18.12	84.11	84.44	02.95
3514	55-59	16.42	83.44	84.53	02.80
3812	59-64	21.05	82.64	80.74	02.61

Table C.25. *Loss-on-ignition (wt.%) of Lake Negra (Mariño) sediments.*

Age	*Depth*	*250°C*	*450°C*	*550°C*	*$CaCO_3$*
56	0- 5	26.27	54.15	55.09	02.87
113	5- 10	20.00	50.61	53.49	02.85
169	10- 15	9.03	43.52	48.25	03.22
215	15- 19	8.12	20.41	26.23	03.17
260	19- 23	20.00	42.53	45.82	03.10
294	23- 26	17.60	37.39	46.11	03.35
339	26- 30	12.89	52.35	47.15	02.59
395	30- 35	14.53	49.60	52.92	02.36
452	35- 40	20.41	47.42	47.07	02.96
508	40- 45	11.49	50.17	45.26	02.71
565	45- 50	16.77	39.37	33.46	02.50
644	50- 57	12.92	33.83	34.51	02.14
700	57- 62	7.77	26.18	28.21	02.13
757	62- 67	6.14	21.73	27.10	02.25
813	67- 72	9.62	20.91	25.66	01.90
881	72- 78	24.69	49.47	57.13	02.17
949	78- 84	22.12	48.56	46.84	01.51
972	84- 86	16.54	43.75	41.21	01.88
1006	86- 89	27.20	57.98	50.32	02.49
1051	89- 93	65.75	74.70	66.24	01.64
1107	93- 98	37.29	69.69	58.31	01.22
1164	98-103	27.51	53.29	52.84	01.57
1220	103-108	13.23	49.26	45.04	01.81

Table C.26. *Loss-on-ignition (wt.%) in Lake Blanca sediments.*

Age	*Depth*	*250°C*	*450°C*	*550°C*	*$CaCO_3$*
139	0- 7	8.46	44.79	24.99	02.15
179	7- 9	11.16	33.08	35.84	01.86
279	9-14	20.27	51.00	56.26	01.86
398	14-20	38.11	57.62	57.51	02.21
498	20-25	21.37	55.96	50.06	01.76
597	25-30	28.60	48.81	45.24	01.93
736	30-37	23.88	58.99	46.45	02.00
876	37-44	25.26	54.56	47.40	02.85
995	44-50	26.27	50.48	49.48	02.67
1115	50-56	23.47	46.28	47.54	03.72

Table C.27. *Loss-on-ignition (wt.%) of Lake Urao sediments.*

Age	*Depth*	*250°C*	*450°C*	*550°C*	*CaCO3*
113	0- 5	3.82	17.62	21.14	25.16
225	5-10	5.76	17.21	18.62	23.14
338	10-15	5.21	17.62	16.46	29.35
450	15-20	7.01	15.99	13.70	34.58
518	20-23	4.89	14.00	15.12	48.00
675	23-30	7.45	15.19	15.81	49.91
765	30-34	1.70	7.94	12.43	34.92
900	34-40	1.76	7.15	06.60	27.45
1013	40-45	1.51	6.97	06.56	26.43
1125	45-50	0.53	4.55	03.96	07.59
1260	50-56	0.69	4.93	04.78	10.22

The following tables contain clay mineral data interpreted from the resulting X-ray diffraction analyses of the short sediment-cores. The numbers are percents (%) of relative abundance of the clay minerals present. No clay minerals were found in the surface sediments of Lake Los Lirios.

Table C.28. *Relative abundance of clay minerals in Lake Monton.*

Age	*Depth*	*Chlor.*	*Mixed*	*Illite*	*Kaol.*	*Gibbs.*
125	0- 7	20.39	0.00	41.75	37.86	0.00
251	7-14	13.27	6.19	11.50	69.04	0.00
376	14-21	15.60	10.18	31.36	42.86	0.00
502	21-28	24.24	9.09	43.43	23.24	0.00
627	28-35	22.04	12.37	19.89	45.70	0.00
753	35-42	14.64	11.30	25.94	48.12	0.00
878	42-49	21.55	13.80	29.97	34.68	0.00
1004	49-56	19.23	0.00	17.97	62.80	0.00
1129	56-63	22.05	6.65	33.53	37.77	0.00
1254	63-70	0.00	0.00	0.00	0.00	0.00
1362	70-76	17.48	13.29	32.87	36.36	0.00
1470	76-82	28.69	15.57	0.00	55.74	0.00
1577	82-88	8.79	0.00	15.38	75.83	0.00
1667	88-93	15.91	8.18	36.82	39.09	0.00

Table C.29. *Relative abundance of clay minerals in Lake Saisay.*

Age	*Depth*	*Chlor.*	*Mixed*	*Illite*	*Kaol.*	*Gibbs.*
178	0- 10	25.49	10.21	33.67	30.63	0.00
356	10- 20	38.24	0.00	35.29	26.47	0.00
534	20- 30	11.91	12.14	40.00	35.95	0.00
712	30- 40	4.97	3.87	65.93	25.23	0.00
837	40- 47	0.00	0.00	0.00	0.00	0.00
962	47- 54	0.00	0.00	0.00	0.00	0.00
1086	54- 61	7.18	14.36	42.56	35.90	0.00
1211	61- 68	17.05	0.00	37.21	45.74	0.00
1335	68- 75	0.00	0.00	0.00	0.00	0.00
1460	75- 82	0.00	0.00	47.37	52.63	0.00
1531	82- 86	4.88	7.04	66.40	21.68	0.00
1656	86- 93	0.00	0.00	0.00	0.00	0.00
1745	93- 98	14.15	17.17	34.34	34.34	0.00
1816	98-102	0.00	0.00	53.93	46.07	0.00

Table C.30. *Relative abundance of clay minerals in Lake Mucubaji.*

Age	*Depth*	*Chlor.*	*Mixed*	*Illite*	*Kaol.*	*Gibbs.*
132	0- 7	11.81	14.26	54.30	19.63	0.00
265	7-14	14.27	17.66	50.81	17.26	0.00
397	14-21	18.80	0.00	58.19	23.01	0.00
529	21-28	05.19	5.71	60.26	28.84	0.00
662	28-35	14.36	5.02	61.46	19.16	0.00
794	35-42	16.07	0.00	50.00	33.93	0.00
926	42-49	12.42	0.00	48.56	39.02	0.00
1059	49-56	14.94	13.97	52.35	18.74	0.00
1172	56-62	16.69	8.35	54.56	20.40	0.00
1285	62-68	26.48	13.96	36.77	22.79	0.00
1399	68-74	12.06	11.36	45.80	30.78	0.00
1512	74-80	19.12	8.36	47.13	25.39	0.00
1626	80-86	18.07	10.33	44.61	26.99	0.00

Table C.31. *Relative abundance of clay minerals in Lake Negra (Apartaderos).*

Age	*Depth*	*Chlor.*	*Mixed*	*Illite*	*Kaol.*	*Gibbs.*
63	0- 2	6.25	0.00	62.68	31.07	0.00
157	2- 5	0.00	0.00	0.00	0.00	0.00
345	5- 11	6.78	0.00	71.30	21.92	0.00
564	11- 18	4.91	0.00	77.46	17.63	0.00
783	18- 25	4.86	0.00	75.60	19.54	0.00
1003	25- 32	5.01	0.00	74.43	20.56	0.00
1222	32- 39	5.03	0.00	69.27	25.70	0.00
1441	39- 46	3.66	0.00	69.11	27.23	0.00
1661	46- 53	4.62	0.00	73.37	22.01	0.00
1880	53- 60	3.29	0.00	74.54	22.17	0.00
2100	60- 67	4.49	0.00	78.24	17.27	0.00
2319	67- 74	8.16	0.00	62.76	29.08	0.00
2538	74- 81	0.00	0.00	70.41	29.59	0.00
2726	81- 87	0.00	0.00	66.67	33.33	0.00
2914	87- 93	3.43	0.00	80.32	16.25	0.00
3102	93- 99	5.16	0.00	77.81	17.03	0.00
3290	99-105	3.58	0.00	63.03	33.39	0.00

Table C.32. *Relative abundance of clay minerals in Lake Brava.*

Age	*Depth*	*Chlor.*	*Mixed*	*Illite*	*Kaol.*	*Gibbs.*
186	0- 10	00.00	00.00	00.00	00.00	00.00
372	10- 20	00.00	00.00	00.00	00.00	00.00
558	20- 30	00.00	00.00	00.00	00.00	00.00
744	30- 40	00.00	00.00	00.00	00.00	00.00
931	40- 50	00.00	00.00	00.00	00.00	00.00
1117	50- 60	00.00	00.00	00.00	00.00	00.00
1303	60- 70	00.00	00.00	00.00	00.00	00.00
1489	70- 80	00.00	00.00	00.00	00.00	00.00
1675	80- 90	00.00	00.00	00.00	00.00	00.00
1805	90- 97	00.00	00.00	00.00	00.00	00.00
1936	97-104	00.00	00.00	00.00	00.00	00.00
2084	104-112	00.00	00.00	00.00	00.00	00.00

Table C.33. *Relative abundance of clay minerals in Lake Los Lirios.*

Age	*Depth*	*Chlor.*	*Mixed*	*Illite*	*Kaol.*	*Gibbs.*
298	0- 5	00.00	00.00	00.00	00.00	00.00
596	5-10	00.00	00.00	00.00	00.00	00.00
893	10-15	00.00	00.00	00.00	00.00	00.00
1191	15-20	00.00	00.00	00.00	00.00	00.00
1489	20-25	00.00	00.00	00.00	00.00	00.00
1787	25-30	00.00	00.00	00.00	00.00	00.00
2085	30-35	00.00	00.00	00.00	00.00	00.00
2382	35-40	00.00	00.00	00.00	00.00	00.00
2680	40-45	00.00	00.00	00.00	00.00	00.00
2978	45-50	00.00	00.00	00.00	00.00	00.00
3276	50-55	00.00	00.00	00.00	00.00	00.00
3514	55-59	00.00	00.00	00.00	00.00	00.00
3812	59-64	00.00	00.00	00.00	00.00	00.00

Table C.34. *Relative abundance of clay-minerals in Lake Negra(Mariño).*

Age	*Depth*	*Chlor.*	*Mixed*	*Illite*	*Kaol.*	*Gibbs.*
56	0- 5	2.66	0.00	2.18	81.74	13.42
113	5- 10	4.08	0.00	3.42	84.52	7.98
169	10- 15	5.83	0.00	3.19	81.66	9.32
215	15- 19	5.48	0.00	3.90	76.69	13.93
260	19- 23	4.60	0.00	4.35	81.89	9.16
294	23- 26	2.32	0.00	3.06	85.12	9.50
339	26- 30	2.53	0.00	2.64	83.78	11.05
395	30- 35	2.35	0.00	2.22	85.16	10.27
452	35- 40	2.80	0.00	3.20	83.89	10.11
508	40- 45	3.31	0.00	3.11	86.36	7.22
565	45- 50	0.61	0.00	0.00	72.56	26.83
644	57- 57	1.85	0.00	0.96	76.11	21.08
700	57- 62	1.99	0.00	1.18	78.27	18.56
757	62- 67	1.16	0.00	2.66	74.78	21.40
813	67- 72	1.64	0.00	0.00	68.64	29.72
881	72- 78	2.44	0.00	3.58	80.58	13.40
949	78- 84	3.27	0.00	2.46	82.77	11.50
972	84- 86	1.48	0.00	1.71	57.79	39.02
1006	86- 89	3.01	0.00	1.43	57.40	38.16
1051	89- 93	0.00	0.00	2.92	46.82	50.26
1107	93- 98	1.21	0.00	1.78	72.25	24.76
1164	98-103	2.88	0.00	2.81	79.05	15.26
1220	103-108	3.65	0.00	1.93	76.14	18.28

Table C.35. *Relative abundance of clay-minerals in Lake Blanca.*

Age	*Depth*	*Chlor.*	*Mixed*	*Illite*	*Kaol.*	*Gibbs.*
139	0- 7	1.65	0.00	3.11	89.31	5.93
179	7- 9	1.13	0.00	4.15	88.75	5.97
279	9-14	1.33	0.95	2.77	87.92	7.03
398	14-20	0.99	0.00	2.18	88.56	8.27
498	20-25	1.29	0.94	3.53	90.19	4.05
597	25-30	1.04	0.87	2.26	88.50	7.33
736	35-37	0.77	0.00	1.32	83.74	14.17
876	37-44	1.56	0.00	1.90	88.79	7.75
995	44-50	1.64	0.00	2.79	90.16	5.41
1115	50-56	0.47	0.58	2.00	90.11	6.84

Table C.36. *Relative abundance of clay-minerals in Lake Urao.*

Age	Depth	Chlor.	Mixed	Illite	Kaol.	Gibbs.
113	0- 5	1.17	0.00	82.89	15.94	0.00
225	5-10	1.51	0.00	81.03	17.46	0.00
338	10-15	2.28	0.00	81.09	16.43	0.00
450	15-20	1.99	0.00	84.66	13.15	0.00
518	20-23	2.23	0.00	81.92	15.85	0.00
675	23-30	1.33	0.00	85.42	13.25	0.00
765	30-34	2.66	0.00	86.09	11.25	0.00
900	34-40	4.21	0.00	84.86	10.93	0.00
1013	40-45	4.86	0.00	79.64	15.50	0.00
1125	45-50	4.56	0.00	83.93	11.51	0.00
1260	50-56	4.67	0.00	83.33	12.00	0.00

The following tables contain geochemical and clay mineral analytical data from the long core from Lake Los Lirios..

Table C.37. *Iron concentrations (wt.%) in Los Lirios sediments.*

Age	*Depth*	*oFe*	*aFe*	*cFe*	*TFe*
766	0- 60	1.11	0.060	0.150	1.32
964	60- 70	1.49	0.330	0.470	2.29
1232	70- 80	2.10	0.330	0.600	3.03
1500	80- 90	2.35	0.470	0.550	3.37
1767	90-100	1.43	0.230	0.420	2.08
2035	100-110	2.50	0.420	0.210	3.13
2303	110-120	1.73	0.250	0.190	2.17
2571	120-130	1.84	0.350	0.220	2.41
2705	130-135	1.60	0.210	0.290	2.10
2973	135-145	1.08	0.260	0.240	1.58
3241	145-155	1.31	0.380	0.330	2.02
3508	155-165	1.07	0.310	0.310	1.69
3776	165-175	1.31	0.380	0.330	2.02
4044	175-185	1.00	0.300	0.250	1.55
4312	185-195	1.58	0.370	0.260	2.21
4580	195-205	1.05	0.220	0.640	1.91
4848	205-215	1.34	0.370	0.320	2.03
5062	215-223	1.23	0.270	0.300	1.80
5330	223-233	1.13	0.370	0.890	2.39
5463	233-243	1.36	0.430	0.790	2.58
5538	243-253	0.75	0.210	0.210	1.17
5575	253-258	0.86	0.310	0.310	1.48
5678	258-263	1.14	0.330	0.270	1.74
5973	253-273	1.16	0.390	0.400	1.95
6268	273-283	1.42	0.290	0.430	2.14
6563	283-293	1.25	0.320	0.200	1.77
6711	293-298	2.13	0.450	0.430	3.01
6858	298-303	1.32	0.420	0.540	2.28
7153	303-313	1.10	0.480	0.450	2.03
7448	313-323	2.38	0.370	0.300	3.05
7743	323-333	1.81	0.340	0.170	2.32
8038	333-343	1.93	0.440	0.190	2.56
8245	343-350	2.03	0.360	0.240	2.63
8392	350-355	2.13	0.470	0.380	2.98
8727	355-363	1.80	0.210	0.200	2.21
9271	363-373	1.17	0.210	0.200	1.58
9814	373-383	0.75	0.170	0.420	1.34
10543	383-395	0.31	0.040	0.170	0.52
11215	395-405	0.28	0.050	0.160	0.49
11421	405-409	0.29	0.040	0.120	0.45
12037	409-421	0.33	0.040	0.090	0.46
12243	421-425	0.74	0.160	0.220	1.12
12757	425-435	0.81	0.180	0.370	1.36
13271	435-445	1.14	0.150	0.200	1.49
13785	445-455	0.45	0.100	0.300	0.85
14402	455-467	0.45	0.100	0.300	0.85

Age	Depth	oFe	aFe	cFe	TFe
14807	467-477	0.43	0.100	0.410	0.94
15049	477-487	0.74	0.140	0.330	1.21
15218	487-494	0.63	0.100	0.260	0.99
15460	494-504	0.70	0.090	0.290	1.08
15727	504-515	1.04	0.110	0.290	1.44
15969	515-525	0.63	0.110	0.340	1.08
16211	525-535	0.75	0.170	0.280	1.20
16453	535-545	0.64	0.100	0.230	0.97
16525	545-548	0.51	0.130	0.230	0.87
16550	548-549	0.18	0.040	0.090	0.31
16695	549-555	0.47	0.040	0.160	0.67
16937	555-565	0.52	0.070	0.160	0.75
17179	565-575	0.54	0.080	0.210	0.83
17276	575-579	0.61	0.110	0.190	0.91

Table C.38. *Manganese concentrations (wt. %) in Lake Los Lirios sediments.*

Age	Depth	oMn	aMn	cMn	TMn
766	0- 60	0.0098	0.0004	0.0022	0.0124
964	60- 70	0.0133	0.0020	0.0036	0.0189
1232	70- 80	0.0114	0.0005	0.0027	0.0146
1500	80- 90	0.0127	0.0015	0.0035	0.0177
1767	90-100	0.0091	0.0004	0.0026	0.0121
2035	100-110	0.0094	0.0009	0.0019	0.0122
2303	110-120	0.0104	0.0000	0.0031	0.0135
2571	120-130	0.0124	0.0012	0.0025	0.0161
2705	130-135	0.0128	0.0000	0.0026	0.0154
2973	135-145	0.0109	0.0000	0.0020	0.0129
3241	145-155	0.0124	0.0018	0.0032	0.0174
3508	155-165	0.0108	0.0004	0.0025	0.0137
3776	165-175	0.0123	0.0017	0.0021	0.0161
4044	175-185	0.0100	0.0005	0.0018	0.0123
4312	185-195	0.0129	0.0016	0.0024	0.0169
4580	195-205	0.0138	0.0005	0.0024	0.0167
4848	205-215	0.0171	0.0017	0.0039	0.0227
5062	215-223	0.0143	0.0005	0.0018	0.0166
5330	223-233	0.0115	0.0014	0.0029	0.0158
5463	233-243	0.0146	0.0019	0.0038	0.0203
5538	243-253	0.0111	0.0011	0.0018	0.0140
5575	253-258	0.0179	0.0009	0.0066	0.0254
5678	258-263	0.0193	0.0009	0.0035	0.0237
5973	263-273	0.0130	0.0012	0.0020	0.0162
6268	273-283	0.0126	0.0009	0.0021	0.0156
6563	283-293	0.0127	0.0009	0.0018	0.0154
6711	293-298	0.0135	0.0013	0.0037	0.0185
6858	298-303	0.0140	0.0014	0.0019	0.0173
7153	303-313	0.0112	0.0017	0.0020	0.0149
7448	313-323	0.0125	0.0012	0.0024	0.0161
7743	323-333	0.0113	0.0008	0.0015	0.0136

Age	*Depth*	*oMn*	*aMn*	*cMn*	*TMn*
8038	333-343	0.0092	0.0012	0.0028	0.0132
8245	343-350	0.0090	0.0009	0.0015	0.0114
8392	350-355	0.0205	0.0011	0.0068	0.0284
8727	355-363	0.0103	0.0006	0.0013	0.0122
9271	363-373	0.0080	0.0008	0.0020	0.0108
9814	373-383	0.0066	0.0010	0.0015	0.0091
10543	383-395	0.0070	0.0000	0.0011	0.0081
11215	395-405	0.0050	0.0001	0.0010	0.0061
11421	405-409	0.0082	0.0000	0.0014	0.0096
12037	409-421	0.0064	0.0001	0.0009	0.0074
12243	421-425	0.0100	0.0000	0.0024	0.0124
12757	425-435	0.0084	0.0002	0.0014	0.0100
13271	435-445	0.0066	0.0001	0.0023	0.0090
13785	445-455	0.0034	0.0002	0.0009	0.0045
14402	455-467	0.0035	0.0009	0.0001	0.0045
14807	467-477	0.0078	0.0010	0.0014	0.0102
15049	477-487	0.0095	0.0002	0.0015	0.0112
15218	487-494	0.0088	0.0003	0.0012	0.0103
15460	494-504	0.0113	0.0002	0.0011	0.0126
15727	504-515	0.0080	0.0003	0.0012	0.0095
15969	515-525	0.0085	0.0001	0.0010	0.0096
16211	525-535	0.0060	0.0004	0.0011	0.0075
16453	535-545	0.0056	0.0000	0.0014	0.0070
16525	545-548	0.0047	0.0000	0.0012	0.0059
16550	548-549	0.0024	0.0000	0.0012	0.0036
16695	549-555	0.0083	0.0000	0.0017	0.0100
16937	555-565	0.0057	0.0000	0.0016	0.0073
17179	565-575	0.0053	0.0000	0.0024	0.0077
17276	575-579	0.0063	0.0000	0.0021	0.0084

Table C.39. Loss-on-ignition (wt. %) for Lake Los Lirios sediments.

Age	*Depth*	*250°C*	*450°C*	*550°C*	*$CaCO_3$*
766	0- 60	16.02	39.77	49.13	02.82
964	60- 70	17.50	76.69	73.35	02.59
1232	70- 80	22.92	78.67	77.43	02.64
1500	80- 90	20.71	76.52	77.25	02.57
1767	90-100	21.04	80.32	77.87	01.78
2035	100-110	25.16	82.20	79.55	02.15
2303	110-120	22.74	82.68	80.30	01.63
2571	120-130	20.93	82.62	81.07	02.13
2705	130-135	15.22	84.64	84.26	02.06
2973	135-145	16.81	84.43	82.08	02.12
3241	145-155	14.24	84.61	84.78	02.18
3508	155-165	13.84	83.47	83.02	01.62
3776	165-175	16.27	83.95	83.53	01.76

Age	*Depth*	*250°C*	*450°C*	*550°C*	*$CaCO_3$*
4044	175-185	18.35	79.63	79.65	02.25
4312	185-195	20.52	75.65	76.55	02.23
4580	195-205	21.70	76.15	76.46	02.26
4848	205-215	15.28	78.70	83.98	01.73
5062	215-223	14.19	83.25	79.54	02.05
5330	223-233	08.50	79.83	80.46	01.98
5463	233-243	09.88	80.69	83.87	01.63
5538	243-253	22.83	86.89	85.85	01.55
5575	253-258	22.26	85.28	85.13	00.67
5678	258-263	23.93	86.73	85.13	00.67
5973	263-273	32.27	80.52	78.41	01.85
6268	273-283	32.25	74.84	72.00	02.23
6563	283-293	52.66	73.11	72.92	01.79
6711	293-298	30.19	69.51	71.04	01.85
6858	298-303	28.68	72.19	71.04	01.85
7153	303-313	22.38	70.19	72.93	01.87
7448	313-323	12.08	74.35	77.03	01.75
7743	323-333	20.49	80.66	79.45	01.83
8038	333-343	25.43	81.66	78.95	02.06
8245	343-350	21.16	78.84	81.33	02.33
8392	350-355	19.32	81.98	83.17	02.37
8727	355-363	21.36	76.53	75.03	01.72
9271	363-373	33.47	54.70	47.45	02.71
9814	373-383	33.46	48.17	37.83	02.90
10543	383-395	10.18	17.17	17.69	02.84
11215	395-405	11.42	17.32	18.97	03.19
11421	405-409	12.24	20.15	21.20	03.34
12037	409-421	18.09	24.71	23.42	02.55
12243	421-425	32.56	42.92	44.55	02.35
12757	425-435	29.53	40.94	39.60	02.70
13271	435-445	13.72	24.84	25.50	02.42
13785	445-455	08.95	17.11	18.28	02.56
14402	455-467	08.26	16.96	17.54	02.37
14807	467-477	23.42	51.04	65.15	02.09
15049	477-487	24.89	55.99	49.74	02.84
15218	487-494	16.20	39.21	39.95	03.79
15460	494-504	14.98	38.60	41.24	04.16
15727	504-515	23.53	36.77	33.09	03.10
15969	515-525	15.42	27.26	33.15	02.23
16211	525-535	23.38	34.64	32.52	02.94
16453	535-545	12.95	23.90	23.33	03.44
16525	545-548	05.92	10.87	19.67	04.19
16550	548-549	05.24	9.71	11.52	02.79
16695	549-555	20.65	36.98	35.20	03.09
16937	555-565	17.91	32.22	38.10	04.06
17179	565-575	18.48	31.76	30.91	03.31
17276	575-579	13.54	27.37	31.22	04.50

Table C.40. *Relative abundance of clay minerals in Lake Los Lirios.*

Age	*Depth*	*Gibbs*	*Chlor*	*Mixed*	*Illite*	*Kaol.*
766	0- 60	00.00	00.00	00.00	00.00	00.00
964	60- 70	00.00	00.00	00.00	00.00	00.00
1232	70- 80	00.00	00.00	00.00	00.00	00.00
1500	80- 90	00.00	00.00	00.00	00.00	00.00
1767	90-100	00.00	00.00	00.00	00.00	00.00
2035	100-110	00.00	00.00	00.00	00.00	00.00
2303	110-120	00.00	00.00	00.00	00.00	00.00
2571	120-130	00.00	00.00	00.00	00.00	00.00
2705	130-135	00.00	00.00	00.00	00.00	00.00
2973	135-145	00.00	00.00	00.00	00.00	00.00
3241	145-155	00.00	00.00	00.00	00.00	00.00
3508	155-165	00.00	00.00	00.00	00.00	00.00
3776	165-175	00.00	00.00	00.00	00.00	00.00
4044	175-185	00.00	00.00	00.00	00.00	00.00
4312	185-195	00.00	00.00	00.00	00.00	00.00
4580	195-205	00.00	00.00	00.00	00.00	00.00
4848	205-215	00.00	00.00	00.00	00.00	00.00
5062	215-223	00.00	00.00	00.00	00.00	00.00
5330	223-233	00.00	00.00	00.00	00.00	00.00
5463	233-243	00.00	00.00	00.00	00.00	00.00
5538	243-253	00.00	00.00	00.00	00.00	00.00
5575	253-258	00.00	00.00	00.00	00.00	00.00
5678	258-263	00.00	00.00	00.00	00.00	00.00
5973	263-273	00.00	00.00	00.00	00.00	00.00
6268	273-283	00.00	00.00	00.00	00.00	00.00
6563	283-293	00.00	00.00	00.00	00.00	00.00
6711	293-298	00.00	00.00	00.00	00.00	00.00
6858	298-303	00.00	00.00	00.00	00.00	00.00
7153	303-313	00.00	00.00	00.00	00.00	00.00
7448	313-323	00.00	00.00	00.00	00.00	00.00
7743	323-333	00.00	00.00	00.00	00.00	00.00
8038	333-343	00.00	00.00	00.00	00.00	00.00
8245	343-350	00.00	00.00	00.00	00.00	00.00
8392	350-355	00.00	00.00	00.00	00.00	00.00
8727	355-363	00.00	00.00	00.00	00.00	00.00
9271	363-373	0.00	22.64	36.03	20.49	20.84
9814	373-383	0.00	27.76	25.32	22.78	24.14
10543	383-395	0.00	22.86	39.91	22.95	14.28
11215	395-405	0.00	43.21	15.49	10.71	30.59
11421	405-409	0.00	31.21	0.00	24.45	44.34
12037	409-421	0.00	34.83	19.35	21.73	24.09
12243	421-425	0.00	50.00	0.00	25.00	25.00
12757	425-435	0.00	47.12	0.00	30.07	22.81
13271	435-445	0.00	44.90	0.00	29.34	25.76
13785	445-455	0.00	62.12	0.00	34.08	3.80
14402	455-467	0.00	37.62	0.00	34.29	28.09
14807	467-477	0.00	41.39	0.00	29.46	29.15
15049	477-487	0.00	58.96	0.00	21.64	19.40
15218	487-494	0.00	53.87	0.00	23.59	22.54

Age	*Depth*	*Gibbs*	*Chlor*	*Mixed*	*Illite*	*Kaol.*
15460	494-504	0.00	32.15	21.88	16.16	29.81
15727	504-515	0.00	31.09	12.36	14.88	41.67
15969	515-525	0.00	21.52	30.19	26.51	21.78
16211	525-535	0.00	30.43	26.21	15.14	28.22
16453	535-545	0.00	27.98	18.54	21.11	32.37
16525	545-548	0.00	22.18	24.25	22.23	31.34
16550	548-549	0.00	29.42	18.58	15.08	36.92
16695	549-555	0.00	33.66	23.04	18.62	24.68
16937	555-565	0.00	29.27	18.72	16.77	35.24
17179	565-575	0.00	38.48	14.12	12.69	34.71
17276	575-579	0.00	34.56	0.00	21.22	44.22

The following tables contain geochemical and clay mineral data from the long core from Lake Mucubaji. Top 79 cm of the core are disturbed, therefore no extrapolated ages are available for this section.

Table C.41. *Iron concentrations (wt.%) in Lake Mucubají sediments.*

Age	*Depth*	*oFe*	*aFe*	*cFe*	*TFe*
0000	0- 3	0.530	0.040	0.110	0.680
0000	3- 6	0.370	0.030	0.070	0.470
0000	6- 9	0.480	0.040	0.150	0.670
0000	9- 12	0.590	0.040	0.080	0.710
0000	12- 15	0.400	0.050	0.120	0.570
0000	15- 18	0.400	0.040	0.120	0.560
0000	18- 21	0.400	0.020	0.050	0.470
0000	21- 24	0.410	0.030	0.070	0.510
0000	24- 27	0.310	0.010	0.050	0.370
0000	27- 30	0.270	0.010	0.040	0.320
0000	30- 33	0.340	0.020	0.070	0.430
0000	33- 36	0.290	0.030	0.050	0.370
0000	36- 39	0.470	0.020	0.050	0.540
0000	39- 42	0.290	0.020	0.050	0.360
0000	42- 45	0.350	0.020	0.040	0.410
0000	45- 48	0.280	0.020	0.040	0.340
0000	48- 51	0.280	0.010	0.040	0.330
0000	51- 54	0.270	0.010	0.040	0.320
0000	54- 57	0.300	0.010	0.030	0.340
0000	57- 60	0.360	0.020	0.030	0.410
0000	60- 63	0.230	0.010	0.030	0.270
0000	63- 66	0.200	0.020	0.030	0.250
0000	66- 69	0.330	0.020	0.040	0.390
0000	69- 72	0.350	0.020	0.040	0.410
0000	72- 75	0.360	0.030	0.050	0.440
0000	75- 77	0.230	0.020	0.070	0.320
1914	77- 79	0.580	0.450	0.220	1.250
2086	79- 82	0.700	0.180	0.300	1.180
2200	82- 84	0.330	0.020	0.050	0.400
2372	84- 87	0.300	0.020	0.050	0.370
2544	87- 90	0.320	0.030	0.060	0.410
2716	90- 93	0.370	0.040	0.050	0.460
2888	93- 96	0.330	0.020	0.040	0.390
3059	96- 99	0.400	0.020	0.040	0.460
3231	99-102	0.350	0.020	0.060	0.430
3403	102-105	0.260	0.020	0.040	0.320
3575	105-108	0.330	0.040	0.040	0.410
3747	108-111	0.290	0.050	0.040	0.380
3919	111-114	0.360	0.070	0.070	0.500
4091	114-117	0.340	0.050	0.040	0.430
4262	117-120	0.450	0.060	0.050	0.560
4434	120-123	0.430	0.060	0.060	0.550
4606	123-126	0.550	0.090	0.070	0.710
4778	126-129	0.390	0.040	0.060	0.490
4950	129-132	0.470	0.070	0.060	0.600

Age	Depth	oFe	aFe	cFe	TFe
5122	132-135	0.450	0.060	0.060	0.570
5294	135-138	0.560	0.120	0.080	0.760
5466	138-141	0.380	0.030	0.050	0.460
5637	141-144	0.350	0.020	0.040	0.410
5809	144-147	0.380	0.030	0.050	0.460
5981	147-150	0.370	0.030	0.050	0.450
6153	150-153	0.420	0.040	0.050	0.510
6325	153-156	0.460	0.050	0.070	0.580
6497	156-159	0.440	0.050	0.050	0.540
6669	159-162	0.480	0.060	0.060	0.600
6840	162-165	0.450	0.030	0.050	0.530
7012	165-168	0.420	0.030	0.040	0.490
7184	168-171	0.400	0.030	0.040	0.470
7356	171-174	0.440	0.030	0.060	0.530
7528	174-177	0.400	0.040	0.030	0.470
7700	177-180	0.330	0.020	0.060	0.410
7814	180-182	0.380	0.020	0.040	0.440
7986	182-185	0.540	0.040	0.040	0.620

Table C.42. *Manganese concentrations (wt.%) in Lake Mucubají sediments.*

Age	Depth	oMn	aMn	cMn	TMn
0000	0- 3	0.034	0.005	0.011	0.050
0000	3- 6	0.035	0.005	0.010	0.050
0000	6- 9	0.031	0.003	0.008	0.042
0000	9- 12	0.037	0.008	0.012	0.057
0000	12- 15	0.031	0.006	0.013	0.050
0000	15- 18	0.037	0.002	0.009	0.048
0000	18- 21	0.039	0.002	0.007	0.048
0000	21- 24	0.036	0.003	0.006	0.045
0000	24- 27	0.034	0.003	0.005	0.042
0000	27- 30	0.028	0.001	0.004	0.033
0000	30- 33	0.032	0.002	0.005	0.039
0000	33- 36	0.031	0.002	0.005	0.038
0000	36- 39	0.037	0.002	0.006	0.045
0000	39- 42	0.035	0.003	0.006	0.044
0000	42- 45	0.034	0.004	0.005	0.043
0000	45- 48	0.027	0.003	0.005	0.035
0000	48- 51	0.028	0.001	0.004	0.033
0000	51- 54	0.022	0.001	0.004	0.027
0000	54- 57	0.019	0.001	0.003	0.024
0000	57- 60	0.040	0.003	0.003	0.046
0000	60- 63	0.025	0.001	0.003	0.029
0000	63- 66	0.016	0.002	0.004	0.022
0000	66- 69	0.030	0.001	0.003	0.034
0000	69- 72	0.059	0.002	0.004	0.065
0000	72- 75	0.045	0.002	0.004	0.051

Age	*Depth*	*oMn*	*aMn*	*cMn*	*TMn*
0000	75- 77	0.090	0.003	0.009	0.102
1914	77- 79	0.111	0.012	0.010	0.133
2086	79- 82	0.045	0.012	0.012	0.069
2200	82- 84	0.028	0.002	0.005	0.035
2372	84- 87	0.046	0.002	0.004	0.052
2544	87- 90	0.044	0.002	0.004	0.050
2716	90- 93	0.051	0.002	0.004	0.057
2888	93- 96	0.031	0.002	0.004	0.037
3059	96- 99	0.052	0.002	0.004	0.058
3231	99-102	0.033	0.001	0.004	0.038
3403	102-105	0.020	0.001	0.003	0.024
3575	105-108	0.034	0.002	0.003	0.039
3747	108-111	0.028	0.003	0.003	0.034
3919	111-114	0.040	0.004	0.003	0.047
4091	114-117	0.028	0.003	0.003	0.034
4262	117-120	0.040	0.002	0.004	0.046
4434	120-123	0.036	0.002	0.004	0.042
4606	123-126	0.040	0.005	0.005	0.050
4778	126-129	0.028	0.002	0.004	0.034
4950	129-132	0.029	0.002	0.003	0.034
5122	132-135	0.028	0.002	0.003	0.033
5294	135-138	0.025	0.002	0.003	0.030
5466	138-141	0.045	0.002	0.005	0.052
5637	141-144	0.032	0.001	0.004	0.037
5809	144-147	0.030	0.002	0.004	0.036
5981	147-150	0.036	0.002	0.004	0.042
6153	150-153	0.033	0.002	0.005	0.040
6325	153-156	0.035	0.002	0.006	0.043
6497	156-159	0.031	0.002	0.003	0.036
6669	159-162	0.027	0.002	0.003	0.032
6840	162-165	0.024	0.002	0.004	0.030
7012	165-168	0.027	0.002	0.003	0.032
7184	168-171	0.022	0.001	0.003	0.026
7356	171-174	0.017	0.001	0.003	0.021
7528	174-177	0.015	0.001	0.003	0.019
7700	177-180	0.020	0.002	0.002	0.024
7814	180-182	0.021	0.001	0.003	0.025
7986	182-185	0.035	0.002	0.003	0.040

Table C.43. *Loss-on-ignition (wt.%) of Lake Mucubají sediments.*

Age	*Depth*	*250°C*	*450°C*	*550°C*	*CaCO3.*
0000	1- 3	10.25	14.32	10.46	3.38
0000	3- 6	10.23	13.96	9.44	3.05
0000	6- 9	8.29	12.13	8.78	2.88
0000	9- 12	8.81	13.20	3.49	1.41
0000	12- 15	7.97	11.81	9.52	2.76
0000	15- 18	8.40	12.57	10.37	2.61
0000	18- 21	9.89	13.99	8.50	4.08
0000	21- 24	8.56	12.77	7.79	3.94
0000	24- 27	7.64	12.48	8.13	4.11
0000	27- 30	8.77	13.52	7.92	5.26
0000	30- 33	7.66	12.50	8.58	3.31
0000	33- 36	7.56	12.83	9.62	2.02
0000	36- 39	9.74	15.29	12.34	1.52
0000	39- 42	9.57	14.81	10.98	1.60
0000	42- 45	11.58	16.86	11.66	2.17
0000	45- 48	9.49	13.87	9.45	2.94
0000	48- 51	8.92	13.40	9.62	2.26
0000	51- 54	8.10	12.16	8.38	2.08
0000	54- 57	5.89	9.87	8.18	1.86
0000	57- 60	8.94	16.35	12.93	2.26
0000	60- 63	7.97	11.24	8.06	3.25
0000	63- 66	6.35	9.92	7.38	2.53
0000	66- 69	8.45	12.20	10.36	2.43
0000	69- 72	21.47	30.63	20.90	2.42
0000	72- 75	14.81	30.96	17.04	1.89
0000	75- 77	8.26	13.17	12.06	2.20
1914	77- 79	10.85	11.57	9.30	3.82
2086	79- 82	10.64	14.35	8.11	3.34
2200	82- 84	7.20	12.45	9.87	2.74
2372	84- 87	14.60	26.66	23.58	2.65
2544	87- 90	18.58	24.42	24.02	2.36
2716	90- 93	24.00	31.92	25.08	1.73
2888	93- 96	15.57	19.49	16.22	1.93
3059	96- 99	19.11	23.32	19.18	2.71
3231	99-102	11.51	15.00	12.88	2.12
3403	102-105	9.59	12.65	10.49	1.95
3575	105-108	19.17	23.75	17.03	1.58
3747	108-111	15.22	19.04	15.13	2.42
3919	111-114	15.83	18.97	15.71	2.16
4091	114-117	12.01	15.07	13.31	1.77
4262	117-120	14.09	19.78	17.06	2.33
4434	120-123	12.60	18.49	15.17	2.42
4606	123-126	14.07	18.46	16.57	2.39
4778	126-129	9.51	13.31	10.54	2.63
4950	129-132	12.22	17.08	15.52	2.29
5122	132-135	11.62	16.34	14.06	2.58
5294	135-138	12.45	17.74	13.56	2.66
5466	138-141	13.73	19.65	15.48	3.03
5637	141-144	9.70	14.39	13.07	3.35

Age	Depth	250^oC	450^oC	550^oC	CaCO3.
5809	144-147	9.16	14.49	11.31	2.86
5981	147-150	10.81	14.37	11.34	2.48
6153	150-153	13.09	17.76	15.87	2.52
6325	153-156	11.36	15.60	14.29	2.76
6497	156-159	12.23	16.62	13.08	2.29
6669	159-162	14.25	18.56	14.49	2.22
6840	162-165	10.38	13.95	13.04	3.31
7012	165-168	10.11	13.82	11.73	1.95
7184	168-171	8.24	11.73	9.29	1.78
7356	171-174	8.69	11.21	8.67	2.53
7528	174-177	8.40	11.62	8.05	3.12
7700	177-180	10.55	14.09	9.65	2.54
7814	180-182	10.42	13.76	11.39	2.19
7986	182-185	18.50	23.55	22.27	2.17

Table C.44. *Relative abundance of clay minerals in Lake Mucubají sediments.*

Age	Depth	Chlo.	Mixed	Ill.	Kaol.
0000	0- 3	32.84	36.26	9.50	21.40
0000	3- 6	44.19	36.26	6.20	13.35
0000	6- 9	28.34	45.02	11.11	15.53
0000	9- 12	38.56	42.55	10.14	8.75
0000	12- 15	32.40	36.61	9.95	21.04
0000	15- 18	35.48	29.83	9.83	24.86
0000	18- 21	46.00	23.60	9.60	20.80
0000	21- 24	36.06	37.60	8.59	17.75
0000	24- 27	43.90	30.24	6.83	19.03
0000	27- 30	32.46	34.18	12.94	20.42
0000	30- 33	28.38	50.26	8.44	12.92
0000	33- 36	26.82	46.93	9.94	16.31
0000	36- 39	33.28	44.15	9.43	13.14
0000	39- 42	36.66	41.50	9.22	12.62
0000	42- 45	34.31	40.12	11.60	13.97
0000	45- 48	36.56	39.21	5.29	18.94
0000	48- 51	40.09	43.27	6.91	9.73
0000	51- 54	41.72	35.01	9.43	13.84
0000	54- 57	34.46	40.27	8.26	17.01
0000	57- 60	31.55	35.35	13.90	19.20
0000	60- 63	35.96	33.39	8.81	21.84
0000	63- 66	30.14	38.36	10.38	21.12
0000	66- 69	26.38	31.23	17.36	25.03
0000	69- 72	37.34	28.17	11.09	23.40
0000	72- 75	30.53	29.92	15.93	23.62
0000	75- 77	41.46	31.58	10.65	16.31
1914	77- 79	44.14	30.47	11.33	14.06
2086	79- 82	54.20	30.93	5.28	9.59
2200	82- 84	45.41	28.77	8.49	17.33
2372	84- 87	43.55	20.66	21.57	14.22

Age	*Depth*	*Chlo.*	*Mixed*	*Ill.*	*Kaol.*
2544	87- 90	39.28	21.60	20.26	18.86
2716	90- 93	49.63	24.81	14.14	11.42
2888	93- 96	47.29	23.10	14.08	15.53
3059	96- 99	41.77	27.67	15.55	15.01
3231	99-102	32.05	29.22	25.19	13.54
3403	102-105	27.41	26.21	28.03	18.35
3575	105-108	33.27	29.08	24.43	13.22
3747	108-111	34.13	29.09	26.05	10.73
3919	111-114	31.67	38.60	22.71	7.02
4091	114-117	26.99	40.99	13.65	18.37
4262	117-120	22.21	36.04	27.36	14.39
4434	120-123	27.23	35.58	25.31	11.88
4606	123-126	32.81	37.22	20.04	9.93
4778	126-129	28.03	38.85	20.62	12.45
4950	129-132	31.10	35.25	22.53	11.12
5122	132-135	26.63	30.43	28.82	14.12
5294	135-138	23.18	38.97	25.75	12.10
5466	138-141	26.27	27.19	26.96	19.58
5637	141-144	28.77	32.74	22.21	16.28
5809	144-147	35.77	25.49	22.48	16.26
5981	147-150	23.36	29.93	32.36	14.35
6153	150-153	22.96	32.84	31.53	12.67
6325	153-156	26.02	31.49	28.78	13.71
6497	156-159	27.58	36.79	20.68	14.95
6669	159-162	26.24	38.02	21.82	13.92
6840	162-165	26.86	38.62	24.24	10.28
7012	165-168	28.61	36.25	21.25	13.89
7184	168-171	27.54	39.89	18.89	13.68
7356	171-174	26.92	36.81	24.23	12.04
7528	174-177	34.57	47.10	9.70	8.63
7700	177-180	33.13	40.12	15.79	10.96
7814	180-182	31.89	38.00	13.32	16.79
7986	182-185	24.61	33.60	22.10	19.69

APPENDIX D

DESCRIPTION OF SEDIMENT CORES

Table D.1. *Lake Urao*

Depth (cm)	*Color*	*Description*
0-21	2.5Y-4/2	rich in organic matter; loose; increasing cohesiveness with depth
21-32	5Y-4/3	increasing cohesiveness; sharp decrease in organics; snails
32-56	5Y-4/1	compacted, gray clay

Table D.2. *Lake Blanca*

Depth (cm)	*Color*	*Description*
1- 8	5Y-4/3	nonsticky; very loose
8-14	5Y-3/1	cohesive; abundant fine plant roots.
14-25		pronounced increase in organic matter fragments
25-37	5Y-3/2	slight decrease in organic matter
37-50		decrease in organics and cohesiveness
50-56	2.5Y-3/2	lack of organic fragments

Table D.3. *Lake Negra (M)*

Depth (cm)	*Color*	*Description*
0-10	2.5YR-3/4	very fine and loose material
10-15	2.5YR-4/4	very fine and loose material
15-19	2.5YR-3/4	colored, thinly layered fine material and clay
	2.5YR-6/4	" "
	5Y-4/1	" "
19-23	2.5YR-3/2	" "
23-26	5Y-4/3	" "
26-45	2.5YR-3/2	cohesive with occasional clear streaks of clayey material
45-73		very finely layered, sticky, gray, black and olive green clayey material
73-84	2.5YR-3/2	nonsticky, cohesive, increasing abundance of fine layering with depth
84-85	5Y-3/1	with a 1/2 cm thick black layer
85-89		abundance of rootlets
89-93	2.5YR-2/0	high abundance of leaves and roots
93-108	5Y-2.5/1	very uniform, nonsticky fine material

Table D.4. *Lake Brava*

Depth (cm)	*Color*	*Description*
0-112	5Y-3/2	very fine, high in organics and water content; very uniform texture for the entire length with the exception of stems present at 43 and 59 cm.

Table D.5. *Lake Negra (A)*

Depth (cm)	*Color*	*Description*
0- 2	2.5Y-3/2	very loose, high water content
2- 4		well delimited white layer of highly cohesive, nonsticky fine material with rootlets.
4-105	2.5Y-3/2	very uniform, fine, cohesive, nonsticky material.

Table D.6. *Lake Mucubaji*

Depth (cm)	*Color*	*Description*
0-86	2.5YR-3/2	cohesive, nonsticky, dark, fine material, with scattered rootlets.

Table D.7. *Lake Saisay*

Depth (cm)	*Color*	*Description*
0-12	5Y-3/2	very loose, slightly sticky materialwith organics
12-34	5Y-3/2	increasingly cohesive
34-35	5Y-4/2	slightly brighter
35-47	5Y-3/2	increasing presence of rootlets
47-84	5Y-3/2	no rootlets except for a high abundance at 75 cm
84-86	5Y-4/3	brighter layer
86-102	5Y-3/2	highly cohesive material

Table D.8. *Lake Monton*

Depth (cm)	*Color*	*Description*
0-93	5Y-3/2	nonsticky, fine, black material, with high water content in top 15 cm; thereafter cohesive with a uniform texture.

Table D.9. *Lake Los Lirios (long core)*

Depth (cm)	*Description*
50-135	medium to light olive gray, fairly uniform organic rich mud; suggestion of lamination; scattered rootlets and other plant material
135-223	slightly more cohesive than in the upper section except for high concentration of leaf and plant fragments at 149 and 215 cm
223-258	medium olive gray, organic rich mud; suggestion of laminae; accumulation of organic fragments at 243 cm
258-298	very apparent laminae 2-5 mm thick; laminae intensity increasing with depth; three colors of laminae: black, olive gray and light reddish-brown
298-313	no lamination; material becomes dryer; more cohesive
313-330	medium olive gray material with suggestion of lamination
330-333	layer of organic material followed by a yellow layer approximately 5 mm thick
333-356	olive gray matrix with yellow lenses; no lamination observed;
356-363	bright yellow layer
363-371	concretions, up to 3 cm in diameter
371-373	light yellow laminated interval
373-383	concretions and rock chips
383-395	dark olive gray, fine grained clay with some organic matter
395-410	much dryer material; more cohesive; concretions at top 5 cm
410-425	mottled yellow, gray and black; additional decrease in organic matter
425-445	olive gray with mottles;
445-467	uniform olive gray; mostly fine grained mud
467-487	olive gray fine grained matrix with large (up to 5 cm) schist concretions
487-513	dark olive gray, dry, peaty mud
513-526	light gray clay;
526-549	olive gray; more cohesive; breaks irregularly
549-551	light gray clay layer
551-576	olive gray clay with a prominent light tan layer at 565-566 cm
576-579	very compacted peaty material

Table D.10. *Lake Mucubaji (long core)*

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 grayish; some rootlets
58- 59	a prominent black-brown layer
59- 65	gradual change from olive to gray (63 cm)
65- 76	dark gray 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	gray, 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 color material showing concentric bands organic-rich, within light to dark brown material
148-174	dark-brown with abundant mica flakes
174-177	dark gray
177-179	black
179-192	olive-gray-green, clayey and dryer
192-197	black

Table D. 11. *Lake Urao (long core)*

Depth (cm)	*Description*
0- 23	Very fine-grained, olive-gray clay; scattered plant debris
23- 27	A few shells; increased organic matter?
25- 37	Dark brown, very organic-rich, peaty mud
37- 58	Thicker layers of light gray material alternating with gray/brown lighter layers, clay rich, with black (sulfidic?) splotches throughout the lower
58- 65	Olive-gray clay
65- 75	Dark brown peaty zone
75-102	Very fine-grained mud, mostly olive-gray with black zones; no real laminations visible, but darker shadings more abundant toward bottom
102-118	Color change to red-brown, some black mottling
118-132	Black mottling more abundant
132-141	Very fine grained laminated gray clay
141-157	Laminations become splotchy
157-166	Alternating black and yellow layers
166-170	Uniform black layer
170-211	Mostly uniform, light-gray clay with abundant black mottles; amount of black increases with depth
211-221	Gray clay with black layers
221-231	Yellow clay with black layers
231-280	Alternating gray with black layers
280-303	Mostly black clay with some gray showing
303-320	Mostly light gray mud with black layers
320-330	Small Na_2CO_3 crystals in sediment
330-358	Black mud with several horizons of large crystals
358-369	Red-brown laminated with black
369-377	Several large crystals
377-392	Prominent red/black layering (1-3 cm thick)
392-402	Crystal-rich zone
402-417	Mostly black mud with gray mottles and Na_2CO_3 crystals
417-426	Alternating re/black; crystals present
426-450	Red and yellow interlayered with black, lamination visible in some layers
450-462	Black mud with roots
462-487	Gray clay with some black layering
487-570	Alternating black and dark olive-gray clay, layers ranging 2-5 cm thick; several horizons of small crystals
570-667	Indistinct, but regular layering of black, dark gray and rarely yellow, 1-2 cm thick, with layers of crystals throughout
667-682	Black, very fine-grained mud with large (4-5 cm long) Na_2CO_3 crystals
682-701	Alternating but indistinct layers of black with dark gray mud; scattered small crystals
701-707	White, hard layer of crystal mush
707-742	Black and dark gray, very fine-grained mud
742-750	Yellow-white, hard evaporite crystal mush