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Bottom Sediments of Lake Nicaragua and Lake Managua, Western Nicaragua

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FIGS. 1–13, JUNE, 1966

BOTTOM SEDIMENTS OF LAKE NICARAGUA AND LAKE MANAGUA, WESTERN NICARAGUA[1, 2]

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ABSTRACT

Lakes Nicaragua and Managua are large, rather shallow, fresh-water bodies that lie in a late Tertiary and Quaternary graben in western Nicaragua.

The bottom sediments comprise highly organic diatomaceous volcanic silts and clays in which quartz, plagioclase feldspar, dioctahedral montmorillonite and volcanic glass are the principal constituents.

Organic nitrogen content of the lake sediments ranges from 0.3–1.2 percent, about the same range as in eutrophic lakes of higher latitudes. Bitumen content is rather low, much like that of oligotrophic lakes. Hydrocarbon fractions of bitumens are similar in amount to an alkaline lake of western U. S. Non-hydrocarbon bitumens are high in proportion to hydrocarbons. Carbohydrates and amino acids sre similar in amount to those of eutrophic lake sediments. Chlorinoid pigments are similar to but flavinoid pigments are less than the typical pigments in eutrophic lake sediments.

Studies of the pH, Eh, inorganic composition and organic chemical and fossil residues of the lake sediments indicate that they are moderately productive, early eutrophic or mesotrophic lakes. Despite the presence of elasmobranches and of several marine or brackish-water types of invertebrates, no definite evidence of former marine connection has been found in the sediments. It is suggested that the lakes have been fresh-water for all or nearly all of their history and may be a little more highly mineralized now than formerly.

INTRODUCTION

Lake Nicaragua and its smaller neighbor on the north, Lake Managua, are large, relatively shallow fresh-water lakes that occupy part of a structural depression in western Nicaragua (figs. 1, 2). Lake Nicaragua is about 170 km long, 75 km in maximum width and occupies 7,700 km^2 in area. The surface of the lake averages 33 m above sea level, and it attains a maximum known depth of 43 m. Lake Managua covers 1,295 km^2, is about 60 km long and up to 32 km wide. Its maximum depth is at least 28 m near the middle of the lake.

The writer was interested in the bottom sediments of the lakes because they were believed by others to have once been connected to the sea (Hayes, 1899; Hartmann, 1959; Lloyd, 1963) and presumably would record a transition from marine to fresh-water conditions.

Samples of the bottom sediments were collected in March 1961, March 1962 and August 1964. Collections of the Tertiary and Cretaceous rocks around the lake were also made.

A preliminary report has been prepared on the lake sediments (Swain, 1961) and on the Ostracoda and an alga (Swain and Gilby, 1965).

Stratigraphy and Structure of Western Nicaragua

Stratigraphy. The geology of part of western Nicaragua is shown in figure 2. The stratigraphic sequence around the lakes includes the following units (Zoppis, and del Guidice 1958; Wilson and Auer 1942).

The Upper Cretaceous Rivas Formation is exposed in a large anticline along the southwestern part of Lake Nicaragua and consists of about 2700 m of drab, tuffaceous shale, sandstone, arkose and graywacke. In an unpublished report Wilson and Auer (1942) recorded 42 genera of Foraminifera together with Ostracoda, Radiolaria, Echinoidea, fish teeth, Gastropoda and sponge spicules(?) from the Rivas beds.

The Rivas is overlain by the Eocene Brito Formation, also about 2700 m thick, which is exposed west and north of the Rivas anticline. The Brito Formation comprises volcanic breccias, tuffs, shales and limestones containing orbitoid Foraminifera and is brighter in color and more resistant to erosion than the underlying Rivas. The type locality at Brito was, around the turn of the century, the proposed Pacific entrance of the Nicaraguan Canal. Wilson and Auer (1942) recorded 72 genera of Foraminifera and 22 genera of macrofossils, together with unidentified bryozoa, corals, crab claw and sponge spicules from the Brito.

Overlying the Brito Formation is the Oligocene Masachapa Formation which consists of 2400 m or more of bright-colored massive tuffs, breccias and shales. Wilson and Auer (1942) identified 70 genera of Foraminifera, 10 genera of Mollusca as well as echinoids, fish teeth,

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[1] Manuscript received October 1, 1965.

[2] Contribution No. 29 of the Limnological Research Center.

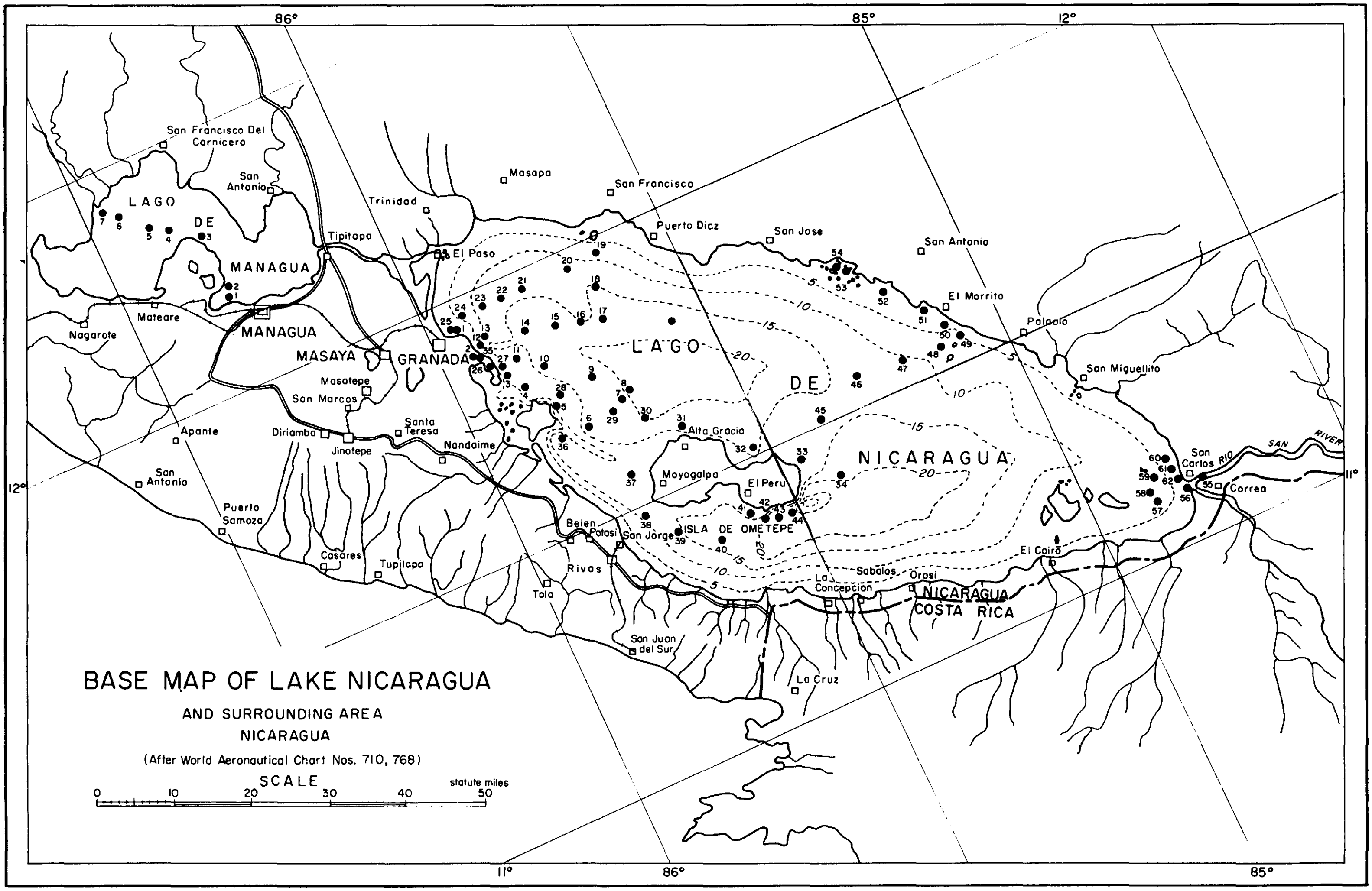

FIG. 1.—Map of Western Nicaragua showing locations of stations sampled in Lake Nicaragua and Lake Managua, and bathymetric map of Lake Nicaragua prepared during the present study.

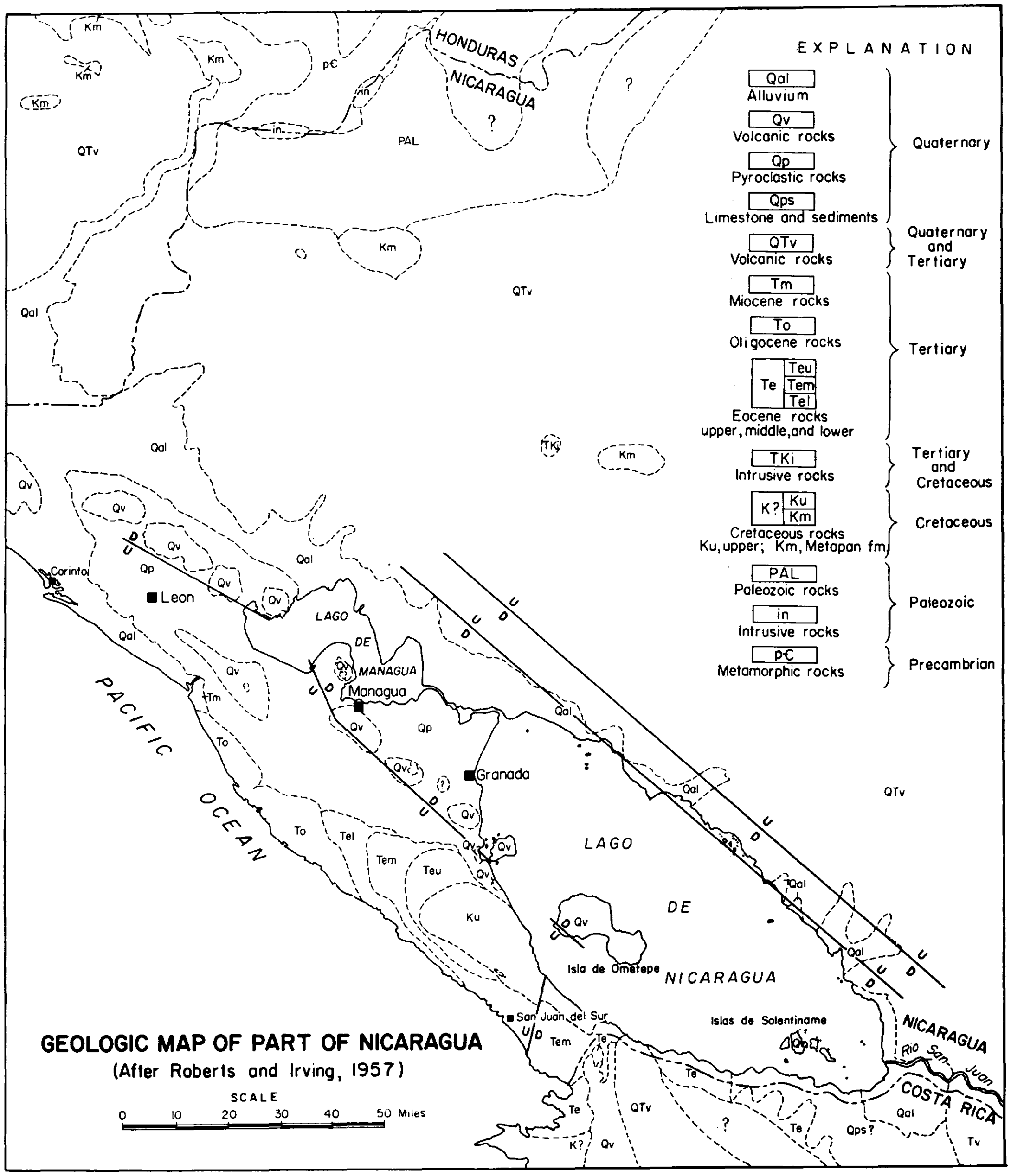

FIG. 2.—Geologic reconnaissance map of Western Nicaragua, after Roberts and Irving (1957).

pteropods?, sponge spicules, wood fragments and ostracodes in the Masachapa.

The El Fraile Formation of Miocene age succeeds the Masachapa Formation. The El Fraile beds are about 2500 m thick and are composed of marine fossiliferous tuffaceous shales, and calcareous sandstones together with the massive, in part acidic, Tamarinda tuff facies with abundant fossil wood. The Tamarinda tuffs occur along the eastern side of Lake Nicaragua as well as north of Managua. Wilson and Auer (1942) recorded 38 genera of Foraminifera and 42 genera of Mollusca, as well as Ostracoda, Radiolaria, fish teeth, whale bone, wood and sponges.

The Pliocene? El Salto Formation overlies the El Fraile and older formations with angular unconformity. The El Salto Formation is 100 m thick, marine, and consists of coquina, marl, fossiliferous shales and conglomerates. Wilson and Auer (1942) identified six genera of Foraminifera and 10 of Mollusca as well as ostracodes in El Salto.

Beginning in the Pleistocene and continuing to the present there formed 650 m or more of mainly extrusive basaltic flows, ash and agglomerate of which the Pleistocene part, at least, is called Las Sierras Volcanic Series. These volcanics occur along the southern, northwestern and northern part of Lake Nicaragua and surround Lake Managua. They form the islands in Lake Nicaragua and occur in some places, not mapped in detail, along the eastern side of Lake Nicaragua.

In addition to beach sands along the Pacific Coast and alluvium of the River valleys and the Nicaraguan depression, the Recent deposits include the sediments of Lakes Nicaragua and Managua and of a few modern marshes and small lakes east of Managua. There are several active volcanoes in or near the lakes; Ometepe in Lake Nicaragua emits dust and ash almost continuously.

In summary the stratigraphic sequence around the lakes includes more than 10,000 m of sedimentary and igneous rocks. Pyroclastic material has supplied a large proportion of the sediment of the lakes by runoff as well as directly from the air.

Structure. The structural history of the Nicaraguan graben is controversial. According to Hayes (1899), the depression now occupied by the lakes formerly connected to the northwest with the Pacific Ocean and was an arm of the sea. In early Quaternary time, between one and two million years ago, the chain of volcanoes, the present Cordillera de los Marabios and the peaks to the southwest as far as Isla de Ometepe, began to form and gradually cut off the Nicaraguan depression from the sea. Interior surface drainage resulted in the formation of present Lakes Nicaragua and Managua.

The level of the lakes rose to a height of 10 to 15 m above their present level and drainage was established eastward to the Caribbean through Rio San Juan and perhaps for a short period through Rio Grande, north of Rio San Juan. The two lakes were once a single larger lake, but additional volcanism, earth movements, deposition by rivers and wave action have modified the slopes of the lake basin and drainage. Rio Tipitapa which connects the two lakes has in historical time carried less and less water, and is now almost an intermittent stream.

Hayes' conclusion that the basin connected to the Pacific was strongly influenced by the opinion of Gill and Bransford (1877) that the sharks of Lake Nicaragua resembled Pacific more than Atlantic species. According to Bigelow and Schroeder (1961), however, the Nicaraguan sharks are *Carcharinus leucas* of the Caribbean. Wilson and Auer (1942) reached a similar, although informal conclusion in an unpublished report.

According to Lloyd (1963) the Nicaragua depression originally opened to the Caribbean rather than to the Pacific. He believes that the area just south of nuclear Central America (that is, northern Nicaragua, Honduras and Guatemala) formed the junction with Costa Rica, Panama and Venezuela in Pliocene time. Prior to the Pliocene he believes the Panamanian extension of northern South America had been offset westwards from the southern extension of North America.

Zoppis and del Guidice (1958), summarizing ideas of geologists of the Servicio Geologico Nacional, state that the Nicaraguan depression is a graben that formed in the late Tertiary and Quaternary. The filling of the lake basins produced by this structural subsidence was accomplished by surface drainage which eventually overflowed eastward through San Juan River. The graben was at no time occupied by the sea. The present writer favors the latter proposal, since no evidence of undoubted marine sediments was found in the present study. According to Zoppis (oral communication) the eastern side of the depression subsided first in the late Pliocene or early Pleistocene, followed in later Pleistocene time, by faulting and volcanism on the western side that are still going on. The greatest depth of Lake Nicaragua, just south of Isla de Ometepe coincides with the strike of the western fault zone.

An estimate has been made of the relative volume of Quaternary volcanic rock bordering the Nicaraguan Depression together with the volume of the present lake basin. For simplification it is assumed that the base of the lake sediments is approximately at sea level.

A. Quaternary volcanics	
Area in Nicaragua west of Nicaraguan Depression	11,700.0 km^2
Area in Costa Rica just south of Nicaraguan Depression	3,200.0 km^2
Average elevation above sea level of Quaternary volcanics in western Nicaragua	0.2 km
Average elevation above sea level of Quaternary volcanics in northern Costa Rica	0.5 km
Approximate volume of Quaternary volcanics bordering Nicaraguan Depression	3,940.0 km^3
B. Nicaraguan Depression	
Areas of Lakes Nicaragua and Managua	9,200.0 km^2

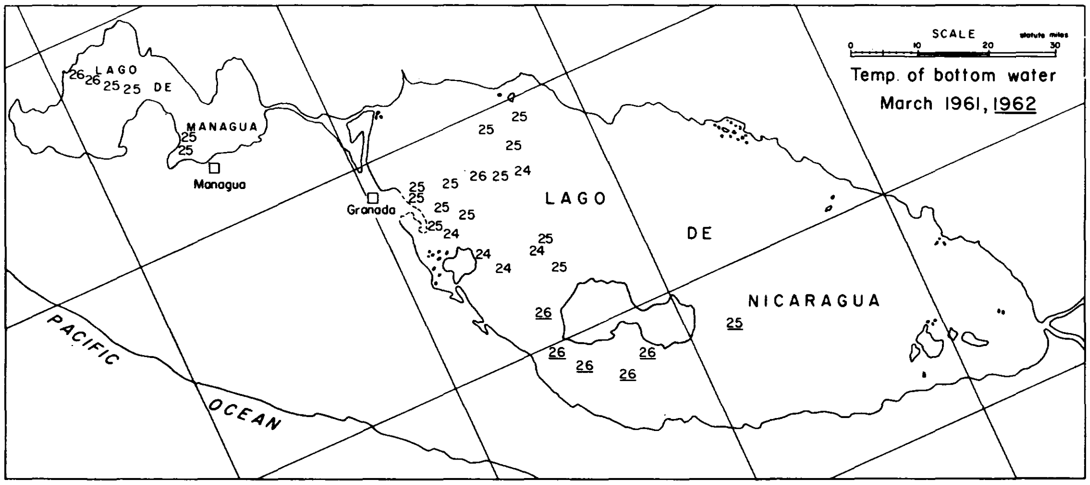

FIG. 3.—Bottom water temperatures of Lake Nicaragua and Managua, March 1961–2.

Average depth of lake basins, including sediments (estimated)	0.1 km
Approximate volume of lake basins	920.0 km^3

The volume of the lake basins seems therefore to be easily accounted for on the basis of subsidence of the Nicaraguan Depression as a result of volcanic extrusion, even though estimates of lake sediment thickness may be in error by a factor of 2 or 3. Furthermore, the depth below sea level to which the Quaternary volcanics extended is unknown. In order to verify the absence of marine sediments, coring should be done through the lake beds near the middle of the lakes.

Some Limnologic Properties of Lakes Nicaragua and Managua

Water Temperature. The locations of the stations sampled are shown in figure 1. The surface and bottom water temperatures in both lakes was relatively uniform; the surface water of Lake Nicaragua ranged from 25° to 28°C. on the dates studied. The surface water of Lake Managua ranged from 24.7° to 26°C. The bottom water ranged from 24° to 26°C. (fig. 3). Neither thermal stratification normeromixis occur in either lake as far as is known. The prevailing easterly winds, strong in the winter months, cause slow westward drift at the surface and corresponding eastward circulation in the deeper waters.

Water composition. The composition of the water of Lake Nicaragua, compared with that in some other lakes, is shown in table 1. The water compares in purity with that of Lake Superior, but sodium chloride and calcium sulfate, rather than calcium bicarbonate, are the main constituents. Lake Managua (table 1) is much higher in dissolved solids (Cole, 1963, p. 402) and is

TABLE 1.—*Analyses of water from Lake Nicaragua, compared with samples from other areas*

Constituent	L. Nicaragua Surface water	L. Nicaragua Bottom water	L. Superior, Minnesota	L. Minnetonka, Minnesota	Pyramid L., Nevada
Analyst	1	1	1	1	2
SO_4ion	22.0	20.0	3.0	3.0	265.0
Total P	00.072	0.344	—	0.022	—
Total Fe	00.04	0.4	0.2	—	0.03
Cl ion	21.0	18.0	nil	6.0	—
NO_2	00.01	0.054	—	0.02	—
Total Kjeld. N	01.32	5.86	0.5	0.68	0.5 (1)
Ca	14.7	13.2	—	—	8.5
Mg	05.4	7.2	—	—	111.0
K	n.d.	4.6	—	—	160.0
Na	n.d.	21.0	—	—	1540.0
Total alkal.	65.0	60.0	48.0	140.0	4700.00

Analysts: (1) Minn. Dept. Conservation, A. Farnham, analyst; and College of Agriculture, Univ. Minnesota, J. Grava, analyst, (2) U. S. Geological Survey reported by Swain and Meader (1958).

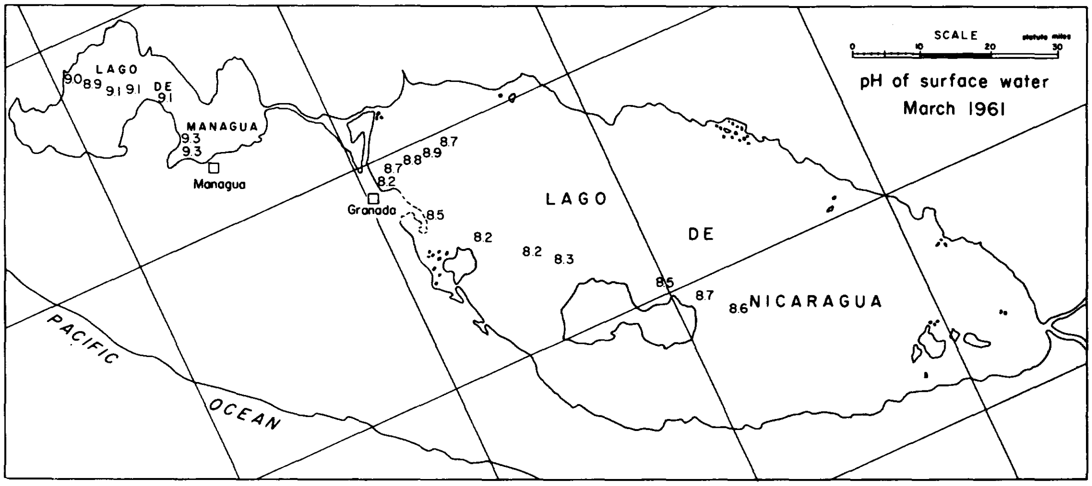

FIG. 4.—pH of surface water of Lake Nicaragua and Managua, March 1961.

much more turbid (Secchi disc transparency 0.5 to 2.0 m) than Lake Nicaragua.

Hydrogen ion concentration. The pH of the surface waters of Lake Nicaragua ranges from 8.2 to 8.9 and that of Lake Managua from 8.9 to 9.3 in the samples studied. The diurnal change in pH is small. Profundal waters of Lake Nicaragua ranged in pH from 7.4 to 7.8 and of Lake Managua from 2.7 to 7.9, owing to dissolved CO_2 and perhaps H_2S (fig. 4). Values obtained near the end of the dry season (March 1961, 1962) did not differ appreciably from those in the rainy season (August, 1964).

Oxidation-reduction potentials. The redox potentials of the surface waters of Lake Nicaragua were nearly all positive, +300 to +400 mv, on the dates measured, which indicates oxidizing conditions. In two localities near Ometepe Island, negative Eh values were found, perhaps as a result of accumulation of H_2S. Whether the volcano or decaying organic matter is responsible for the negative readings is not known.

Oxygen content. Only a few measurements were made of oxygen content of water of southern Lake Nicaragua (table 10). The oxygen content of those samples is in a range representative of many temperate lakes of widely varying limnologic characteristics.

Fauna and Flora. The biota of Lakes Nicaragua and Managua comprise a very rich diatom population, the alga *Elaeophyton*, copepods, cladocerans, worms, abundant teleosts and common elasmobranchs, Ostracoda, Thecamoebae, gastropods, and pelecypods. Only a few elements of the biota have been studied in any detail.

Papers on the fish have been published by Günther (1864a, 1864b, 1866, 1868), by Gill and Bransford (1877), Meek (1907), Bigelow and Schroeder (1961) and Thorson (1962); on the Ostracoda by Hartmann (1959) and Swain and Gilby (1965); on the boghead algae by Swain and Gilby (1965); on the nematodes by Meyl in Hartmann (1959) and on the copepods by Herbst in Hartmann (1959).

The fish of Lakes Nicaragua include the following (Meek 1907, Bigelow and Schroeder, 1961); Family Galeidae—*Carcharinus leucas* ("Tigrone"); Family Pristidae—? *Pristus antiquorum* Latham; Family Lepisosteidae—*Lepisosteus tropicus* (Gill); Family Siluridae—*Rhamdia managuensis* Günther ("Bagre, Chuchin"), *R. nicaraguensis* (Günther), *R. barbata* Meek; Family Characinidae—*Astyanax* nasutus Meek, *A. aenus* (Günther), *Brycon dentex* (Günther) ("Sabalo"), *Bramocharax bransford* Gill, *B. elongatus* Meek ("Sabalito"), *Roeboides guatemalensis* Günther; Family Elopidae—*Tarpon atlanticus*? (Cuvier and Valenciennes) ("Sabalo"); Family Dorosomidae—*Dorosma chavesi* Meek ("Sabalo"); Family Poeciliidae—*Paragambusia nicaraguensis* (Günther), *Poecilia sphenops* (Cuvier and Valenciennes) ("Julumina"); Family Atherinidae—*Melaniris guatemalensis* Gill ("Sardinas"); Family Haemulidae—*Pomadasis grandis* Meek ("Roballo"); Family Cichilidae-*Cichlasoma managuense* (Günther) ("Guapote"), *C. lovii* Günther ("Guapote"), *C. granadense* Meek, *C. citrinellum* Günther ("Mojarra contara"), *C. dorsatum* Meek, *C. erythraeum* (Günther), *C. labiatum* (Günther), *C. lobochilus* (Günther), *C. centrarchus* (Gill and Bransford), *C. rostratum* (Gill and Bransford), *C. longimanus* (Günther), *C. nigitum* Meek, *C. nicaraguense* (Günther), *C. balteatum* (Gill and Bransford), *Neetroplus nematopsis* (Günther), *Herotilipia multispinosa* (Günther)

TABLE 2.—*Chemical analysis of composite sample of sediment from Lake Nicaragua*

Constituent	%	Constituent	%
Fe_2O_3	6.25	Na_2O	0.67
FeO	0.63	K_2O	0.60
P_2O_5	0.22	Sulfur	0.60
SiO_2	51.53	Organic C	4.25
MnO	0.15	Co_2	5.66
Al_2O_3	12.52	SO_4	nil
TiO_2	0.26	H_2O	13.41
CaO	2.23	(Ignition loss)	(23.32)
MgO	1.47	Total	100.69

Analysis by University of Minnesota, Mines Experiment Station; V. E. Bye, analyst.

("Picacula"); Family Gobiidae—*Philypmus dormitor* Lacepede ("Guavina").

The *Carcharinus*, *Pristus* and *Tarpon*, primarily marine forms, are not found in Lake Managua; the other species apparently occur in both lakes.

The following nematodes occur in the lake according to Hartmann (1959); *Theristus setosus* (Bütschli) Filipjev, marine to brackish, also in relict-lake Ohrid; *Trilobus longus* (Leidy) Bastion, fresh-water; *Viscosia papillata nicaraguensis* Gerlach, typically a marine species; *Polygastrophora octobulba* Micoletsky, typically a marine species; *Docylaimus prendostagnatis* Micoletsky, ecology poorly known, very euryhaline; *Artinolaimus radiatus* Cobb, widely distributed, fresh-water. Hartmann (1959) placed strong emphasis on the marine-like nematodes in support of his contention that the lakes had once been an arm of the sea.

The copepods of the lake were recorded by Hartmann (1959), as follows: *Mesocyclops longisetus*, *M. meridianus*, *Cyclops* (*Microcyclops*) *dubitabilia*, *C.* (*Metacyclops*) *hartmanni*, *Macrocyclops albidus*, *Diaptomus columbiensis*, *D.*, n. sp., *Paracyclops fimbriatus*, *Eucyclops* cf. *encifer*, *Cletoamptus deitersi*, *Microcyclops* cf. *alius*, *Thermocyclops* sp. All of these are limnetic species.

Hartmann (1959) described the following Ostracoda from Lake Nicaragua: *Physocypria granadae* Hartmann, *Heterocypris nicaraguensis* H., *Potamocypris islagrandensis nicaraguensis* H., *Limnocythere royi* H., *Pericythere marginata* H., Cytheridae sp., *Darwinula stevensoni* (Brady and Robertson). Most of the ostracodes are freshwater types, but the *Pericythere* and the Cytheridae sp. suggest a littoral, mangrove swamp or estuarine environment.

Additional Ostracoda were described from Lakes Nicaragua and Managua by Swain and Gilby (1965); *Darwinula managuensis* Swain and Gilby and *Metacypris ometepensis* S. and G. The latter species represents a genus that typically occurs in estuaries, although a species has been described from bromeliad leaf cups (Tressler, 1956). The occurrence of living *M. ometepensis* in both lakes at offshore stations indicates that its habitat is the lake bottom. The species, however, was not found in the lower part of one-meter sediment cores from Lake Nicaragua which suggests that it only recently migrated into the lakes; perhaps it came up the San Juan River although this has not been verified. No specimens of *Metacypris* were found in Corinto Bay, a lagoon and estuary on the Pacific Coast of Nicaragua.

Cladocerans are very abundant in the lake but have not been studied. Ephippia, tentatively referred to *Moina affinis* (Birge), were obtained from Station 7, Lake Managua.

One of the most widespread and abundant algae in the lakes is *Elaeophyton coorongiania* Thiessen (Swain and Gilby, 1965). This planktonic "Boghead" alga tends to be concentrated in the sediments of the western part of the lake owing to the trade winds. In other parts of the world this, or a similar species, is found in coastal tropical brackish lakes in Australia and Africa (Thiessen, 1925). This and related algae are of waxy consistency, composed of 90 per cent or more oils and other hydrocarbons, and are a major constituent of "boghead" coal.

Only a very cursory examination has been made of the extremely rich diatom population of the lake. The genera of diatoms represented in a single sample from Station 2, Lake Nicaragua were identified by Norman Norton as follows: *Melosira*, *Fragilaria*, *Synedra*, *Navicula*, *Pinnularia*, *Cymbella*, *Epithemia*, *Rhopalodia*, and *Surirella*. According to Norton (oral communication) one of the *Melosira* is close to *M. sulcata* Kützing, commonly an estuarine species.

Small gastropods, pelecypods and bryozoan statoblasts are among the other constituents of the bottom sediments of the lakes, but they have not been studied.

Bottom Sediments of Lake Nicaragua and Managua

General properties. The profundal sediment of both lakes consist of pale gray and grayish brown, waxy-texture, coprogenic, richly diatomaceous clay and silt which in many samples is in the form of fecal pellets or castings (table 2,3). Besides diatoms, Thecamoebae, Oligochetes, cladocerans, gastropods and ostracodes are the most common "fossils" in the lake sediments.

The littoral sediments are principally volcanics and glass shards, while fossil remains in-

TABLE 3.—*X-ray analyses of bottom sediments from Lakes Nicaragua and Managua compared with marine sediments from a bay of the nearby Pacific coast, and two bedrock formations of the area (analyses by Peter Fleischer)*

Locality	Mineral Composition	Description of Sediments
Lake Nicaragua Sta. 4, depth 11 m	Quartz, feldspar (albite); organic complexed dioctahedral montmorillonite; trace kaolinite and chloritoid	Pale grayish-brown, silty, ashy, clayey copropel, fecal pellets, melosiroid and naviculoid diatoms, gastropods (Tyronia?)
Lake Nicaragua Sta. 13, depth 10 m	Feldspar (albite?), quartz, organic complexed dioctahedral montmorillonite, trace kaolinite and chloritoid	Pale grayish-brown ashy, silty, copropelic fine sand and sandy silt, abundant melosiroid, fragilaroid and naviculoid diatoms, cladocerans, few ostracodes
Lake Nicaragua Sta. 15, depth 16 m	Feldspar (albite), quartz, organic complexed dioctahedral montmorillonite, kaolinite and/or chlorite, trace mica	Pale brownish gray waxy, clayey copropel, fecal pellets, melosiroid and naviculoid diatoms.
Lake Managua Sta. 4, depth 26 m	Quartz, feldspar, dioctahedral montomorillonite, organic complexed	Brown copropel
Corinto Bay, Nicaragua Sta. 4	Feldspar (albite), quartz, calcite, small amount of kaolinite, chlorite,? trace mixed-layer clay	Tan argillaceous sand, feldspar and volcanic glass fragments; shell fragments common
Rivas Formation, Upper Cretaceous, Rivas, Nicaragua	Calcite, 7 Å kaolinite and a 9.3 Å group clay mineral	Light greenish-gray finely sandy graywacke shale, planktonic Foraminifera
Brito Formation Eocene, San Juan Del Sur, Nicaragua	Albite, quartz, calcite, pyrite, chlorite and kaolinite	Pale brownish gray, calcareous, sandy siltstone

clude many small gastropods, ostracodes, diatoms and thecamoebans.

Chemical analyses of the bottom sediments (table 2) show that SiO_2, Al_2O_3, Fe_2O_3 and organic matter are the principal constituents. Volcanic glass, quartz, plagiclase feldspar, illite, chloritoid ?, kaolinite ? chlorite and montmorillonite were the mineral substances identified by petrographic and X-ray analyses. (fig. 9; table 3).

Hydrogen-ion concentration in sediments. The pH of the upper few centimeters of Lake Nicaragua sediment ranges from 4.8 to 7.3 (fig. 5) and averages 6.97. Deeper in the sediments the pH ranges from 6.0 to 7.2 and averages 6.88 (fig. 6). The pH of the bottom sediments is believed to be consistently lower than that of the overlying water because of oxygen depletion and CO_2 and H_2S increases related to accumulation of matter

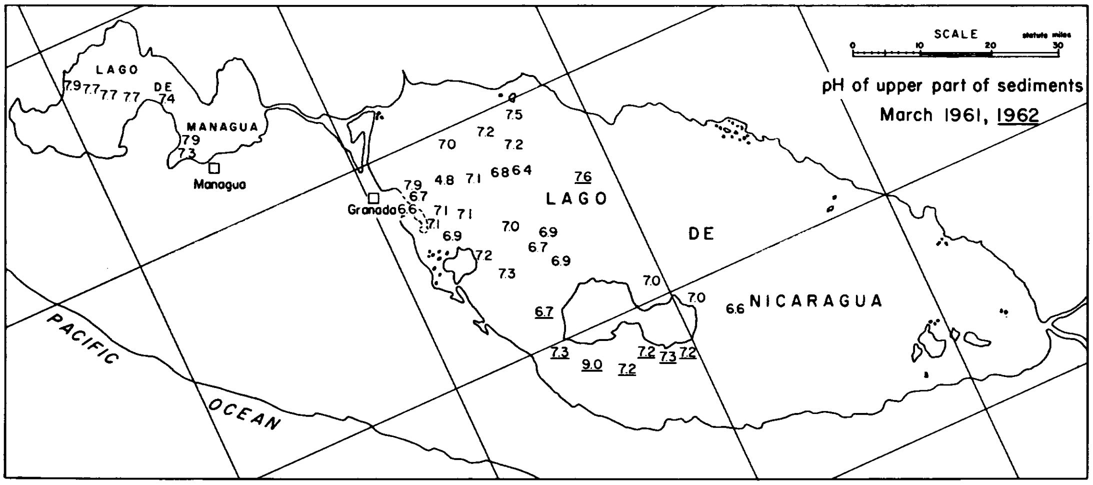

FIG. 5.—pH of upper centimeter of sediment of Lake Nicaragua, March 1961.

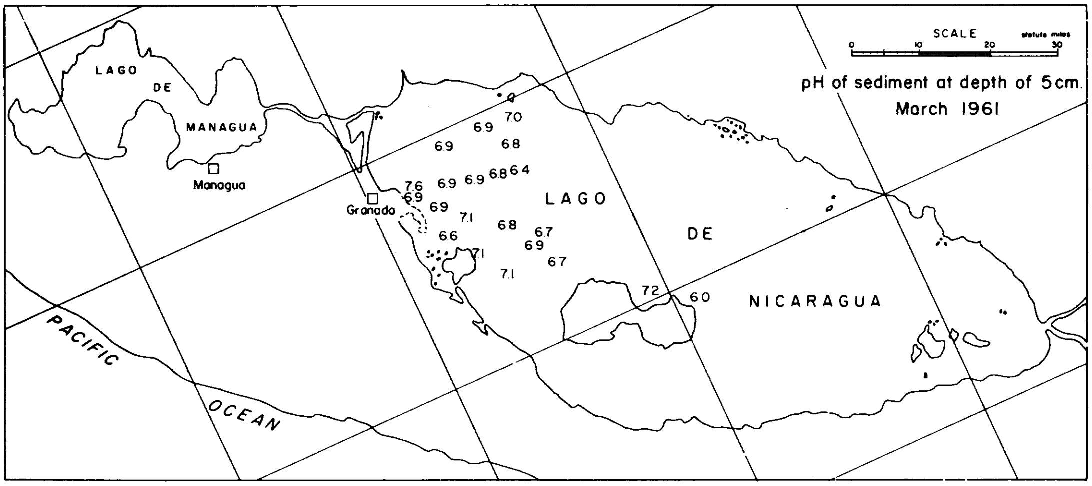

FIG. 6.—pH of sediment at depth of 5 cm in Lake Nicaragua, March 1961.

under partly anaerobic conditions in the sediment. Similar decreases in pH with depth in the sediment was found in Lake Managua, but the pH values there are generally higher than in Lake Nicaragua.

Oxidation-reduction potentials in sediments. The Eh values in the surface sediments are nearly all negative (fig. 7); that is they are below the Eh of the calomel electrode (+245 mv) used in measuring the potentials. The average Eh of the uppermost sediments in Lake Nicaragua measured in March 1961 was +191 mv; in March 1962 the average Eh in the central part of the lake and around Isla de Ometepe was +95 mv. The average for both seasons in Lake Nicaragua was +166 mv. The Eh values of surface sediments in Lake Managua for 1961 averaged +120 mv, and the average for both lakes was +158 mv.

The Eh values of Lake Nicaragua sediments at a depth of about 5 cm (fig. 8) averaged +176 mv in the 1961 samples.

Reducing conditions of low to moderate intensity are indicated by these Eh values.

Organic Geochemistry of Lake Sediments

Total organic matter. The Kjeldahl nitrogen content of several samples of Lake Nicaragua sediment is given in table 4. The average is about 0.63 percent which is equivalent to about 10 percent organic matter (16×percent N). Measurement of organic carbon (tables 3,4) in samples from Lake Nicaragua give higher values (~15 percent) for total organic matter(1.8×per-

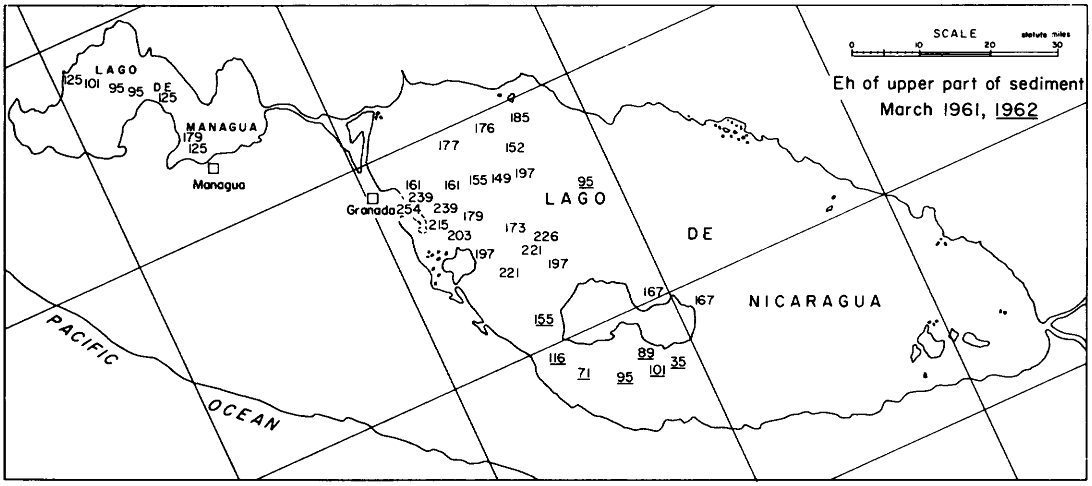

FIG. 7.—Eh of upper 5 cm of sediment of Lake Nicaragua, March 1961.

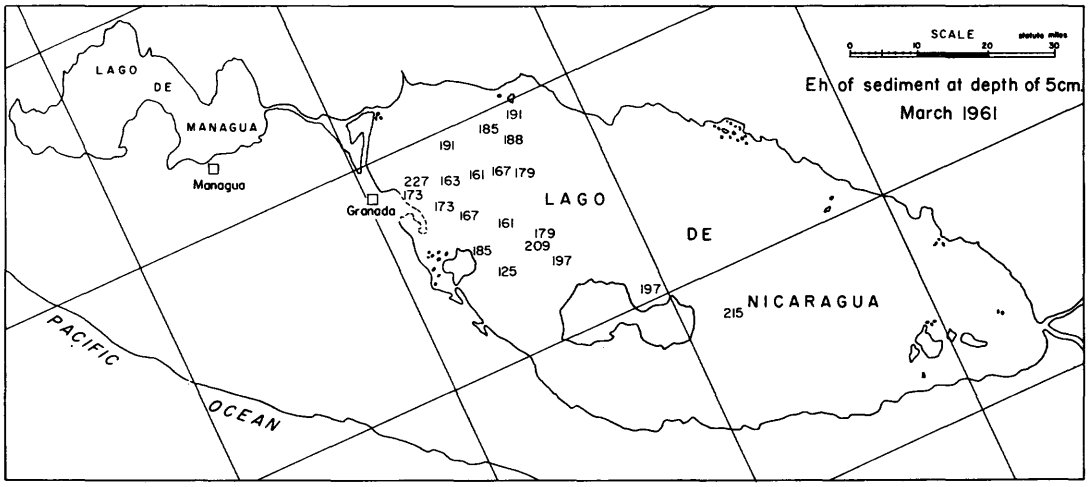

FIG. 8.—Eh of sediments of Lake Nicaragua at depth of 5 cm. March 1961

cent C). Presence of sulfur may account for part of this discrepancy.

Bitumens. Offshore samples of Lake Nicaragua sediment from Stations 18 and 20 were extracted with benzene and methanol (80:20 mixture). As shown in table 5, the total extract, free of sulfur, is relatively small and compares more closely with an oligotrophic lake (Swain, 1956) than with other types studied.

The extracts were separated on columns of activated alumina by successive elution with n-heptane, benzene and pyridine+methanol. The heptane eluates, taken to represent saturated hydrocarbons, are small in amount and are of the same order of magnitude as the benzene eluates which are taken to represent the aromatic hydrocarbon fraction (fig. 10). These values are much lower in proportion to total bitumens than the oligotrophic lake and are more like values of an alkaline lake (Pyramid Lake, Nevada; Swain and Meader, 1958). The asphaltic fraction, eluted with pyridine and methanol, and the polar components left on the alumina (probably mainly chlorinoid and carotinoid pigments, figs. 10,11) also are relatively higher than in oligrotrophic lakes and are comparable to the alkaline lake.

The data reflect the high content of non-hydrocarbon pigmenting material, perhaps mostly from diatoms, in Lake Nicaragua sediments, compared to hydrocarbons.

Carbohydrates. Several samples of Lake Nicaragua sediment were analyzed (table 6) for total carbohydrates by a phenol-sulfuric technique (Dubois, Gilles, Hamilton, Rebers, and Smith, 1956; Rogers, 1964). The values were found to be similar to eutrophic lakes of Minnesota. The carbohydrates probably are derived from a variety of substances including diatoms, other algae and bacteria, cladocerans, and fragments of terrestrial plants. Individual carbohydrates in the sediments have not yet been studied.

Amino acids. The protein amino acid content of samples of Lake Nicaragua sediments was obtained by hydrochloric acid hydrolysis and paper chromatography (fig. 12) (Swain, Blumentals and Millers, 1959; Swain, 1961; Swain, Venteris and Ting, 1964). The results of the analysis (table 7) are compared with those of several other lakes and are seen to correspond best to the eutrophic lake (Green Lake, Chisago County, Minnesota).

In comparison with the other lakes listed, the basic amino acids lysine, histidine and arginine

TABLE 4.—*Carbon, hydrogen and nitrogen content of Lake Nicaragua sediments*

Station	% C[1]	% H[1]	% N[2]	% Organic Matter[3]
2	n.d.	n.d.	0.32	5.12
5	n.d.	n.d.	0.42	6.72
6	10.13	2.25	1.28	18.23
8	n.d.	n.d.	0.73	11.68
11	6.92	1.91	0.61	12.45
14	n.d.	n.d.	0.62	9.92
16	8.13	2.24	0.77	14.63
17	n.d.	n.d.	0.55	8.80
19	n.d.	n.d.	0.38	6.08
30	n.d.	n.d.	0.91	14.56
32	n.d.	n.d.	0.42	6.72
33	n.d.	n.d.	0.80	12.80
34	n.d.	n.d.	0.41	6.56

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[1] Microanalytical laboratory, School of Chemistry, University of Minnesota, O. Hamerston and J. Johnson, analysts.

[2] F. T. Ting analyst.

[3] Based on 1.8×% C and 16×% N.

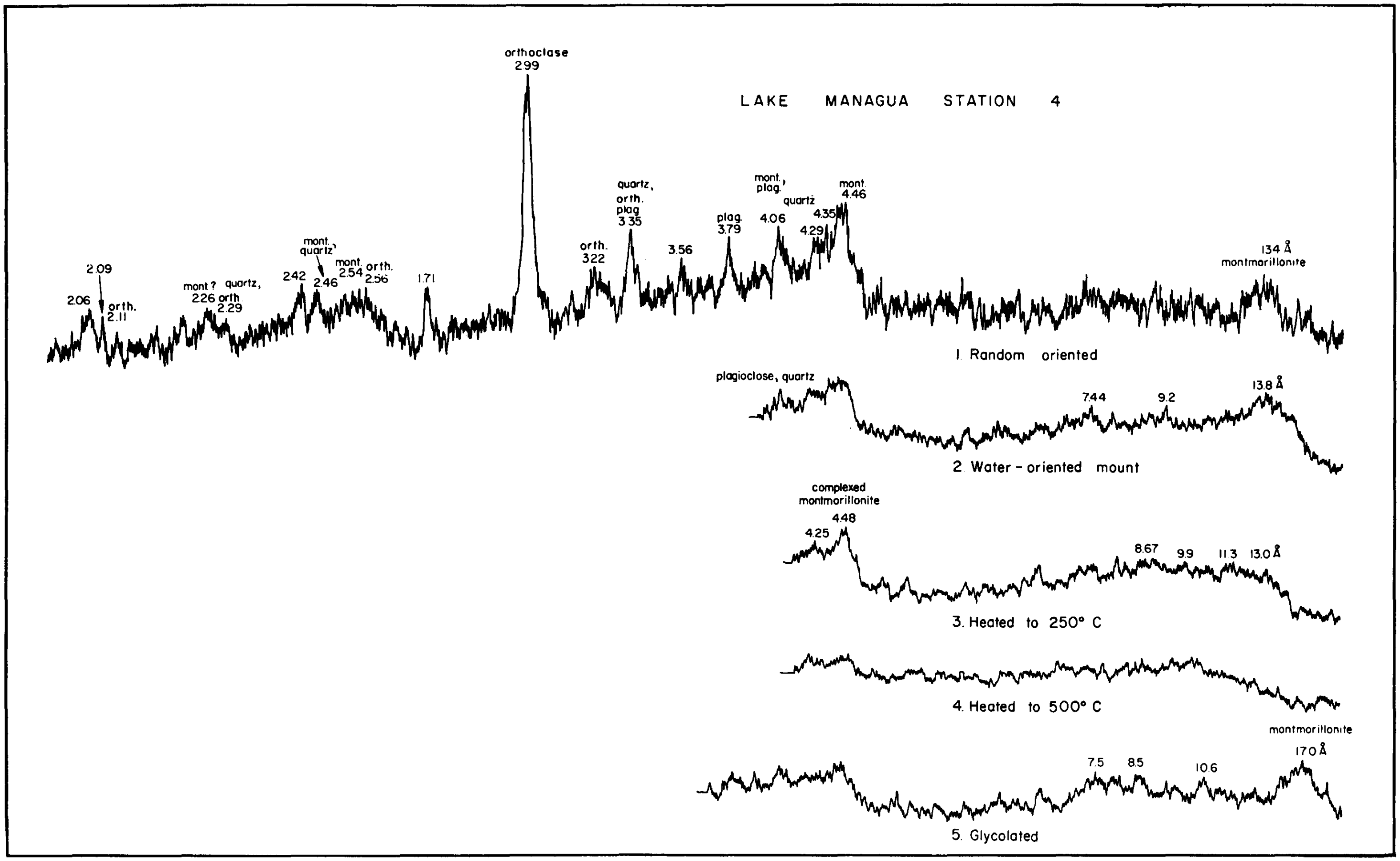

Fig. 9.—X-ray diffraction patterns of clay minerals of Lake Managua sediments.

TABLE 5.—*Chromatographic analyses of lipoid extracts of Lake Nicaragua and other lake deposits in Minnesota and Nevada*

	L. Nica. Sta. 20[1]	L. Nica. Sta. 18[2]	Eutrophic Lake, Minn.[2]	Oligotr. Lake, Minn.[2]	Peat bog, Minn.[2]	Pyramid Lake, Nev.[2]	Lake Superior Minn.[2]
Total extract % of sample	0.090	0.243	0.835	0.380	6.52	.612	0.029
Saturated hydrocarbons % of sample	0.008	0.006	0.038	0.058	0.47	0.021	0.005
Aromatic hydrocarbons % of sample	0.011	0.007	0.051	0.042	0.50	0.011	0.007
Asphaltenes % of sample	0.024	0.023	0.025	0.16	1.60	0.047	0.004
Polar compounds % of sample	0.053	0.208	0.536	0.13	4.29	0.593	0.12
Saturated hydrocarbons % of extract	8.8	2.5	4.8	15.2	6.5	3.4	17.2
Aromatic hydrocarbons % of extract	11.4	2.8	5.1	12.5	4.8	1.8	24.1
Asphaltenes % of extract	25.0	8.9	25.5	42.5	25.5	7.7	15.5
Polar compds. % of extract	54.6	85.6	64.6	27.8	63.2	87.1	53.1

Analyses by D. A. Peterson and F. M. Swain.

[1] Extracted cold in ultrasonic tank, with benzene 80%, methanol 20%.

[2] Extracted with Sohxlet apparatus with benzene 80%, methanol 20%, at boiling temperature of solvent.

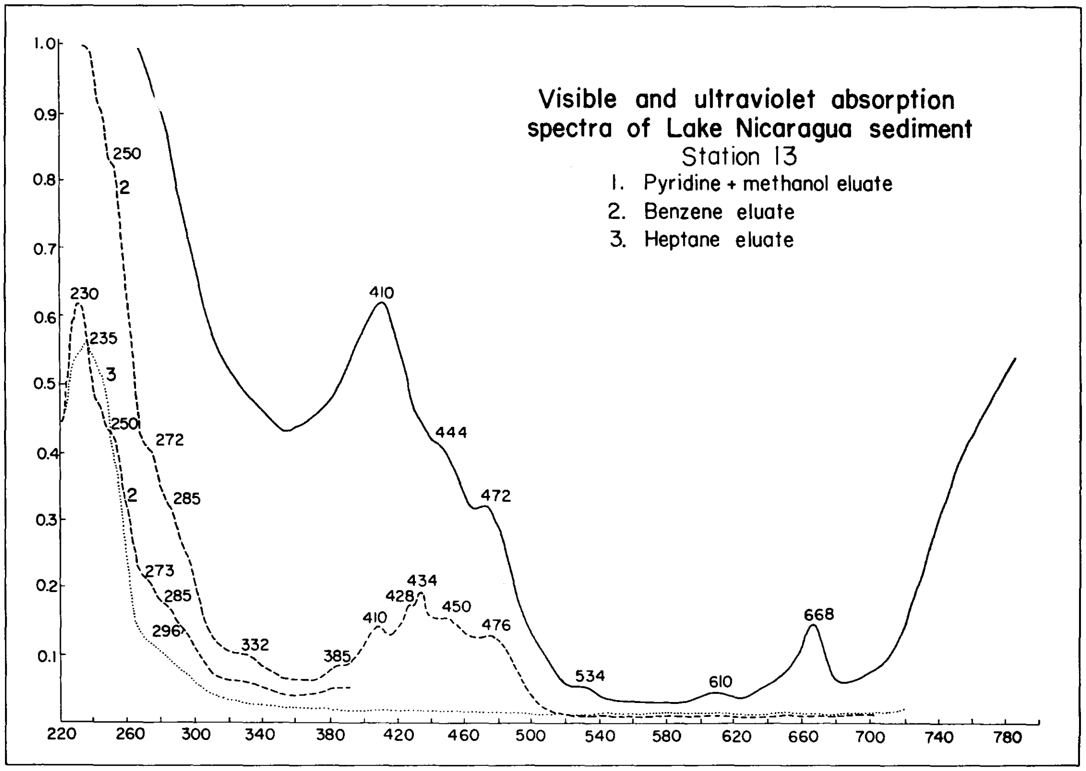

FIG. 10.—Ultraviolet and visible absorption spectra of chromatographic fractions of benzene+methanol extracts of Lake Nicaragua sediments.

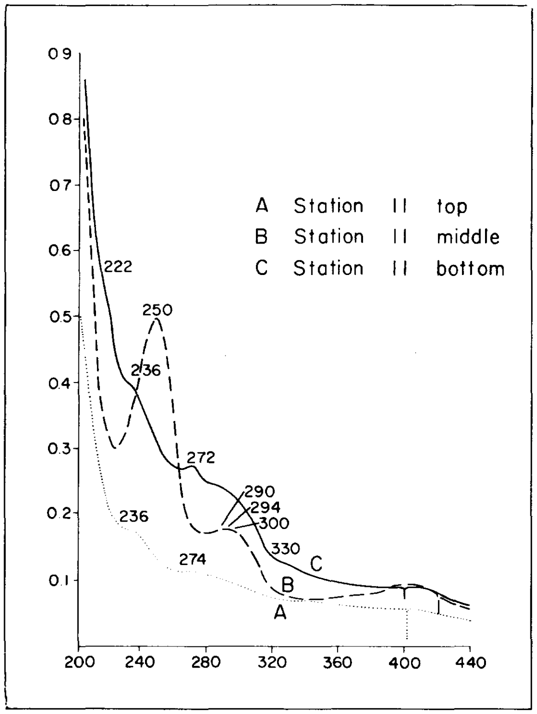

FIG. 11.—Ultraviolet and visible absorption spectra of acetone extracts of Lake Nicaragua sediment, dried and taken up in hexane.

are higher than seems to be typical of lake sediment low in carbonate content (Swain, 1961).

Chlorinoid pigments. Short-core samples of Lake Nicaragua sediments were extracted with 90 percent acetone, and the absorption of the extract at 665–670 mμ was measured (fig. 13). Comparison was made with known quantities of pheophytin and quantities estimated (tables 8, 9). The upper parts of the cores typically are higher in pheophytin than lower in the core, but there are several exceptions that are not noticeably caused by variations in total organic content. In some instances low pheophytin content throughout the core is indicative of low total organic, as well as pigment, content (cores No. 1, 17, Davis and 18, Davis). In other cores (13, 17), degradations of chlorinoid pigments seems to have occurred markedly in the deeper part of the sediment. The striking increase in pheophytin in similar sediments a few cm below the surface in cores 7 and 14 is unexplained but was noticed previously in Minnesota lake sediments (Swain, Paulsen and Ting, 1964); the latter was atypical in that most Minnesota lake sediments decreased rapidly in pheophytin with depth.. Total pheophytin content of Lake Nicaragua sediments is of the same order of magnitude as that of Minnesota eutrophic lake sediments, assuming 8–10 percent organic matter in the Nicaragua sediments.

Flavinoid pigments. Small traces of yellow-fluorescing substances were separated from acid extracts of Lake Nicaragua sediments by paper chromatography. The fluorescing spots, which had Rf values of 0.25 in butanol:acetic acid:water (4:1:5), showed absorption maxima of 268–270 mμ. The quantities of such material in Lake Nicaragua sediments are evidently much less than in eutrophic and dystrophic lake sediments

TABLE 6.—*Total carbohydrate content of Lake Nicaragua sediments compared to Minnesota lake sediments; analyses by M. A. Rogers*

Station	Description of Sediment	Glucose equivalent, mg per g of dry sediment
2	Pale grayish brown, pelletal diatomaceous copropel	10
3	Pale tan cladoceran, diatomaceous copropel	10
4	Pale medium gray pelletal diatomaceous copropel	10
7	Pale brownish gray pelletal copropel with gastropods and ostracodes	18
9	Pale brownish gray pelletal diatomaceous copropel	12
10	Pale medium gray diatomaceous copropel	14
11	Pale brownish gray pelletal diatomaceous copropel	17
15	Pale brownish gray, pelletal waxy diatomaceous copropel	18
30	Pale grayish brown pelletal diatomaceous copropel	28
Average		15
Blue Lake, Minn. surface sediment	Marly sapropel	30–35
Clear Lake, Minn.	Copropel and marl	18–34
Hall Lake, Minn. surface sediment	Silty copropelic marl	11

TABLE 8.—*Pheophytin a content of Lake Nicaragua sediment samples. Analyses by I. Porietis and F. M. Swain. The values for pheophytin a are on a dry weight, but not ash free basis*

Station No.	Position in core	Description of Sediment	Pheophytin *a*, ppm
35	top	Light brown ash and peat, pumice fragments	5.9
35	middle	Same as above	5.2
35	bottom	Pale gray, reddish and greenish silty, peaty sand and gravel	3.7
36	top 6 cm	Pale gray to tan very diatomaceous copropelic silt	21.3
36	middle 13 cm	Same as above, less diatomaceous	24.4
36	bottom	Pale tannish gray, diatomaceous ashy silt and silty clay.	13.6
41	top 6 cm	Pale gray to tan shy silty, slightly diatomaceous copropel	17.1
41	middle 14 cm	Same as above, more diatomaceous, cladocerans	35.4
41	bottom 8 cm	Same as above, less silty, more diatomaceous and copropelic	41.1
45	top 8 cm	Medium grayish brown copropelic silt, common *Elaeophyton*	72.6
45	middle 11 cm	Pale gray silty diatomaceous copropel	45.7
45	bottom 4 cm	Pale gray waxy, silty, copropelic, very diatomaceous clay	38.2
47	top 10 cm	Pale gray, very diatomaceous copropelic clay with *Elaeophyton*	69.5
47	middle 13 cm	Same as above, *Elaeophyton* uncommon	2.8
47	bottom 14 cm	Pale gray silty and finely sandy copropelic clay	6.3
48	top 4 cm	Pale gray very diatomaceous copropelic clay	7.7
48	middle 11 cm	Pale gray very diatomaceous copropelic clay or diatomite	70.4
48	bottom 8 cm	Pale gray waxy, silty copropelic diatomaceous clay	50.6
51	top 9 cm	Fine-grained tan carbonaceous diatomaceous, silty angular sand	31.9
51	middle	Pale grayish brown finely sandy silt and silty sand, diatomaceous	13.6
51	bottom	Pale gray reddish and greenish silty peaty sand and gravel; igneous rock fragments predominantly	12.5
51	Davis core 7 cm	Fine- to coarse-grained argillaceous and silty peaty sand	9.0
52	Davis core 11 cm	Light grayish green sandy clay and fine- to medium-grained angular to rounded sand; many rock grains	8.9
53	top 5 cm	Pale gray very diatomaceous clayey silt	24.8
53	middle 14 cm	Pale gray ashy very diatomaceous, copropelic silt	22.6
53	bottom	Pale gray very diatomaceous silt	25.1

defines the western sides of the two large lakes, and the earthquake epicenters seem to have much the same concentrations. A graben origin for the Nicaraguan depression and a prevailingly fresh-water history of the lakes is more nearly consistent with available information than is an origin as a marine embayment.

The two lakes are relatively shallow for their size, unstratified and low to moderate in dissolved solids content. Sodium chloride and calcium sulfate are the principal dissolved salts of the lake water, but their concentration is so low that drainage from the volcanic rocks and/or sea spray may account for their presence rather than relict seawater.

The slightly alkaline lake waters are characterized by pH of 8 to 9 at the surface and 7 to 8 at deeper depths. Positive Eh values indicating moderately oxidizing conditions prevail in the surface waters while somewhat lower values, but still positive, are found in the profundal waters.

The lakes support a rich, undescribed, population of diatoms and cladocerans. Thirty-five species of fish, six of nematodes, 11 of copepods, nine of ostracodes and an alga have been described from the lakes. Most of these are fresh-water types, but the following are suggestive of marine or estuarine origin:

- Fish
  - *Carcharinus leucas*
  - ?*Pristus antiquorum* Latham
  - *Tarpon atlanticus* (Cuvier and Balenciennes)
- Nematodes
  - *Theristus setosus* (Bütschli) Filipjev
  - *Viscosia papillata nicaraguensis* Gerlach
  - *Polygastrophora octubulba* Micoletsky
- Ostracodes
  - *Pericythere marginata* Hartmann
  - *Metacypris ometepensis* Swain and Gilby
  - *Cytheridae* sp.
- Diatoms
  - *Melosira sulcata* Kützing

The bottom sediments of both lakes consist of pulpy-textured, diatomaceous ashy, copropelic gray and tan clay and silt in which fecal pellets are very common. Volcanic glass, quartz, feldspar, and ferromagnesian minerals are the principal minerals. pH values are slightly acid in most of the shallower sediment although slightly alkaline or more strongly acid samples were also obtained. Nearly all Eh values in these sediments were negative owing to their content of organic matter and, judging from the prevalence of hydrogen sulfide, owing also to active bacterial decay of the sediments.

Bituminous extracts of the lake sediments were found to be relatively small and to compare with amounts in sediments of oligotrophic lakes. Chromatographically separated hydrocarbons and asphaltic fractions are comparable to those of an alkaline lake in Western U.S. rather than to oligotrophic lakes. Non-hydrocarbon pigmenting materials from diatoms and other algae are suggested to have produced these observed differences.

Total carbohydrates and total protein amino acids are similar in amounts to those of eutrophic lakes. The basic amino acids lysine, histidine and arginine are higher than those in most of the eutrophic lakes studied by the writer, but they are more like quantities in dystrophic, low-carbonate, subtropical Dismal Swamp, Virginia.

Pheophytin *a* content of the sediments resembles that of eutrophic temperate lakes and typically decreases rapidly below the microzone in the upper few cm of sediments. As in other lakes, a typical increase in pheophytin below the surface and low content throughout the upper meter of sediment occurred at a number of stations. Carotenoid pigments are common in the sediments but have not been studied in detail. Other substances in part of aromatic and heteroaromatic nature are widely distributed in ppm quantities in the lake sediments and should be examined further for their possible value in environmental interpretation.

Classification of Lake Nicaragua and its sediments into a trophic scheme is difficult because of the variations in its characteristic. It is probably early eutrophic or mesotrophic (Patrick, 1954; Hutchinson, Patrick, and Deevey, 1956) judging

TABLE 9.—*Ultraviolet spectral data on organic substances extracted from Lake Nicaragua sediments with:* (a) *benzene+methanol (80:20), followed by separation on activated alumina, data presented on benzene eluates re-dissolved in n-heptane;* (b) *acetone, followed by drying and re-dissolving in n-hexane; prominent absorption maxima in italics. The spectra suggest presence of aromatic hydrocarbons, phenols and pyridine, but further characterization has not been made*

Station and type of sample	Solvent	Absorption 200–300 mμ	Absorption 300–400 mμ
13, dredge	a	230, 252, 272, 285, 296	332, 385
20, dredge	a	231, 252, 275, 286	302, 328, 333
35, top of core	b	234, 256, 288	320, 336, 360
35, middle of core	b	256, *288*	320, 336, 384
35, bottom of core	b	234	
36, top of core	b	236	300, 310
36, middle of core	b	236	310
36, bottom of core	b	236	310
41, top of core	b	236, 272	300
45, top of core	b	236	
45, middle of core	b	*250*, 290, 294	300
45, bottom of core	b	222, 236, 272, 296	300
47, top of core	b	238	300
47, middle of core	b	236, 286	
47, bottom of core	b	236	
48, top of core	b	236, 272	300
48, middle of core	b	236	300
48, bottom of core	b	234, 244	310
51, top of core	b	*229*, *234*, 263, 284	
51, middle of core	b	*229*, *234*, 244, 248, 251, 292	306, 330
51, bottom of core		234, 252	
52, Davis core	b	282	318, 330
53, top of core	b	235	
53, middle of core	b	235	
53, bottom of core		238	300

TABLE 10.—*Properties of lake sediments from the southern part of Lake Nicaragua*

Station	Depth, meters	Description of Sediment	pH of sediment (s) and bottom water (w)	Eh of sediment (s) and bottom water (w) m.v.	O_2 content of surface water mg/l
55	5	Dark greenish-brown fine sand, composed of volcanic ash grains; high organic content	6.8 (s)	+249 (s)	n.d.
56	4	Black to brownish gray, fine, volcanic ash and basaltic sand and copropelic clay; wood fragments, many bryozoan statoblasts, gastropods, pelecypods	6.2 (s)	+279 (s)	n.d.
57	2.7	Gray and tan silty, copropelic, diatomaceous clay; *Melosira* sp., etc., slight H_2S odor	6.9 (s) 7.4 (w)	+129 (s) +219 (w)	5.98
58	3.3	Gray and tan, copropelic, diatomaceous, cladoceran-rich, highly pelletal clay; *Elaeophyton* frequent, living rotifers very abundant, slight H_2S odor	6.9 (s)	+105 (s)	n.d.
59	3	Gray and tan, copropelic, diatomaceous cladoceran-rich, pelletal clay; *Elaeophyton* frequent, large crop of rotifers; H_2S odor	6.9 (s) 7.9 (w)	+129 (s) +183 (w)	13.65
60	1	Gray and tan, diatomaceous, copropelic clay; cladocerans and *Elaeophyton* abundant, *Cocconeis* sp. common, H_2S odor	6.8 (s) 7.4 (w)	+135 (s) +195 (w)	n.d.
61	0.7	Gray and tan silty, diatomaceous, copropelic, cladoceran-rich clay, fecal pellets, strong H_2S odor	6.7 (s)	+135 (s)	14.04
62	0.5	Gray and tan, copropelic, diatomaceous, pelletal, cladoceran-rich clay; many fry of pelecypods; *Surirella* sp. and *Melosira* sp. abundant	6.8 (s)	+123 (s)	n.d.

from the abundance of *Melosira*, general water composition, and organic residues. Lake Managua is even more difficult to classify but appears to be mesotrophic-argillotrophic (Hutchinson, 1937) because of the high content of silt and clay brought in by runoff from cleared and cultivated land around the lake.

The major problem of marine versus nonmarine early history of the lakes has not been satisfactorily solved and requires a program of core-drilling and geophysical exploration that was beyond facilities available for this study.

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Errata

p. 539, 6th line from bottom — colorimetric
p. 540, line 11 — limnology
" line 15 — backbone
" line 20 — Roberts
" line 46 — bromeliads

Reference omitted: "Swain, F. M., 1961, Reporte preliminar de los sedimentos del fondo de los lagos Nicaragua y Managua; Bol. Serv. Geol. Nac. Nicaragua, No. 5, p. 11–32, 7 figs.