Changes in oxygen 18 as a measure of long-term fluctuations in tropical lake levels and molluscan populations[1]

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Abstract

In Laguna Chichancanab, the largest closed basin in northern Yucatan, large-scale changes in lake levels have been documented by ^{18}O analyses of snail shell carbonates. A continuous 9-m series of lake sediments has been deposited during the last 8,000 years, whereas a discontinuous sedimentary record extends from 9 m to beyond 12 m in depth. At least one marked hiatus occurred in this older record during which time the lake is thought to have been seasonally dry (or very much reduced in size). The fluctuations are verified by other stratigraphic evidence including absolute numbers of shells, loss on ignition, carbon:nitrogen ratios, and major cations (calcium, magnesium, and sodium).

We here consider a new approach to determine lake level stability in tropical, closed lake basins where mean annual temperatures have remained relatively stable in comparison with changes in rates of inflow and evaporation. The general goal is to document long term changes in the lake's water balance and to relate this information to population dynamics of aquatic organisms, particularly benthic molluscs living in the littoral zone. We use "closed lake" to mean a lake which receives inflow from precipitation and its drainage basin but loses water only by evaporation. Many previous studies on lake level stability (*see* Richardson 1969 for a review) have emphasized the need to correlate several independent lines of evidence. This isotopic analysis is another direct approach which can yield unique information unavailable from other types of analyses of closed, tropical lakes.

Naturally occurring isotopes of ^{18}O and ^{14}C can be considered tagged atoms and their movements monitored for the long term study of water balance. These isotopes have been extensively used as tracers in marine hydrologic studies during the last 25 years, but analyses of ^{18}O in lacustrine environments are just beginning. In a closed lake basin at a latitude with relatively equable temperatures and uniform atmospheric circulation, the main variables controlling ^{18}O content will be the relative rates of evaporation and inflow. Vapor from evaporating water contains a proportion of ^{18}O to ^{16}O of about 1:500. Because the abundant ^{16}O is lighter in mass, it evaporates faster than the rarer isotope ^{18}O. As evaporation continues, the remaining water is enriched with ^{18}O. Thus, if the sediment ages can be determined by ^{14}C dating, variations in the $^{18}O : {}^{16}O$ ratio of their carbonates can be used to determine variations with time in evaporation and inflow.

Craig et al. (1963) have documented the relative effects of precipitation and evaporation and the significance of relative humidity, and stressed the importance of molecular exchanges with atmospheric water vapor in determining the ultimate ^{18}O content of water bodies. Measurements of seasonal ^{18}O changes in lake waters (Dinçer 1968; Faure et al. 1970; Gonfiantini et al. 1973; Stuiver 1970) are in agreement with predictions from these experimental studies, and Dinçer (1968) concluded that overall composition is determined by the

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ratio of inflow : evaporation. Using these relationships, Stuiver (1968, 1970) has demonstrated thermal effects in studies of modern and ancient lakes in the temperate zone.

This study, extending this approach to a closed, tropical basin in the Yucatan Peninsula of Mexico, was part of a Ph.D. thesis by A.C. We thank E. S. Deevey and G. E. Hutchinson for their encouragement and support. A.C. received support from the Cave Research Foundation, Explorer's Club of New York, National Defense Education Act, and National Science Foundation. We especially thank A. Barrera, P. E. Cloud, H. Craig, R. Hedlund, H. Konrad, C. J. McCoy, D. C. Rhoades, J. L. Richardson, and B. A. Voorhies.

Study area

The Yucatan Peninsula can be characterized as a flat, low-lying platform (2–3 km thick) of Cenozoic marine limestone projecting northward into the Gulf of Mexico and Caribbean Sea (Robles-Ramos 1958). The south-central portions gradually increase in elevation to a maximum of 300 m in a few areas (the Sierrita de Ticul) with linear topographic features associated with faulting (Murray and Weidie 1967). Laguna Chichancanab is a narrow, sigmoid lake basin oriented along a north-south axis and located 19°50′N, 88°45′W. Chichancanab is a tectono-karstic basin (Hutchinson 1957) presumably having resulted from the same faulting process as the Sierrita de Ticul (Tamayo and West 1964). The base rock is composed of Tertiary limestone and gypsum. Stratigraphic studies on foraminifera (Bonet and Butterlin 1967; Flores-Vargas 1965) demonstrate that the environment of deposition was a marine lagoon in the Eocene.

The basin is incompletely mapped but is known to consist of a chain of seven separate bodies of water extending about 20 km. From vegetational zones around these separate impoundments and from data reported here, it is clear that in the past all these bodies of water were confluent; the name Chichancanab is used for the entire basin. The drainage basin area extends over 1,535 km^2 (Secr. Recursos Hidraul. 1971) of tropical forest with scattered, small-scale agricultural clearings. Chichancanab is the largest lake in the state of Yucatan; maximum depth is 12.5 m and most of the water is less than 4 m deep. The water is clear: Secchi disk transparency was 2.5 m in the central portion of the basin during July 1973. Chemical analyses from several subbasins in 1967 showed the following ranges in concentration of principal cations: calcium, 600–700 ppm; magnesium, 360–425 ppm; sodium, 340–400 ppm; potassium, 20–24 ppm; and the principal anion: sulfate, 2,750–2,950 ppm. Earlier chemical analyses by Illescas (1950) gave lower values for magnesium (253 ppm), sodium (105 ppm), and potassium (3 ppm) and higher values for sulfate (2,959 ppm) and calcium (813 ppm) as well as values for chloride (138 ppm) and bicarbonate (71 ppm). Comparisons with even earlier reports are difficult to interpret because of differences in techniques. Conductivity ranges from 3,500 to 4,900 μmhos and pH from 7.0 to 8.1. Surface water temperatures had a diurnal range from 23° to 27°C in January 1969 and from 26° to 30°C in July 1973.

Data on seasonal variations for most limnological parameters are lacking, but inflow from precipitation can be estimated from 40-year records of data on rainfall and evaporation from several stations in the peninsula (Secr. Recursos Hidraul. 1962). The annual rainfall averages 1,000 mm in Merida (150 km NW of the lake) and about 1,300 mm in the Chichancanab basin. As in many areas of Central America, the wettest period is from May through October and the driest from January to March (Garcia 1965). Average monthly temperatures range from 23° to 28°C throughout the year and evaporational losses are considerable. The mean annual evaporation (1950–1954) was 1,521 mm at Santa Rosa (12 km NW of the lake).

Rainfall affects lake levels directly and indirectly. Generally, in the karstic topography of Yucatan, the major inflow is in-direct, i.e. from groundwater seepage (Pinelo-Maldonaldo 1963). Rate of flow has been studied in a few locations by tracing ^{14}C in aquifers (Back and Hanshaw 1970); high permeability and short residence time characterize the interior aquifers. This relatively high flow rate may be significant in determining the rate at which ^{18}O can be concentrated in the lake waters. Sea level appears to control the level to which aquifers can rise (Back and Hanshaw 1970; Lesser-Jones 1965).

Methods

Material for ^{18}O analyses and other tests were extracted from sediment cores obtained with a modified Livingstone piston sampler (Deevey 1965) from the southern portion of the basin about 1 km north of the village of Esmeralda. Water depth at the corning site was 1.5 m. Sites in deeper water (8 and 12 m) could not be sampled below sediment depths of 3 m owing to the hard crystalline nature of the sediments. Cores were taken in 1968 and 1969 and shipped to cold storage (5°–8°C) facilities at Yale University; successively marked sections of about 1-m lengths remained in sealed aluminum sampling tubes until studied in the laboratory. Upon extrusion the samples were cut lengthwise and each half-section was photographed. Core stratigraphy was also recorded with X-ray film (Kodak Industrial Type AA, Estar base) using a dental X-ray source (positioned 25 cm above) for 20-sec exposures at 50 kV. Sedimentary samples from opened cores were submitted to the Yale Radiocarbon Laboratory to determine the ^{14}C ages of four strata. These samples were selected after X-ray films showed variations in stratigraphic features, particularly frequency and thickness of organic laminae and shell abundances. Two dates were obtained on organic carbon in the upper strata. Where organic carbon was very low in the lower strata, two additional dates were obtained on carbonate carbon.

Samples were taken at 10-cm intervals and consisted of 10 cc of wet sediments. Separate subsamples were taken for analyses of shells (for isotopic studies), loss on ignition (organic matter), major cations (calcium, magnesium, sodium), and carbon : nitrogen ratios (sample sizes of 5 cc of wet sediment). Shell samples were wet sieved and dried at 110°C. Intact shells greater than 1 mm in diameter were sorted, counted, and identified. After preliminary study of other features (*see below*), 21 stratigraphic samples of shells were selected for isotopic analysis after further washing and sorting. Only specimens of the prosobranch gastropod *Pyrgophorus coronatus* (Pfeiffer 1840) *fide* Taylor (1966) were used for isotopic measurements. About 50 mg of these shells were powdered and the organic matrix was then charred under vacuum at 420°C. Carbon dioxide gas from the carbonate was analyzed with a mass spectrometer to determine variations in ^{18}O and ^{13}C relative to standard marine carbonate (PDB-Chicago: Craig 1961). To compare values for ^{18}O from these subfossil shells with the present lake, shell samples from live *P. coronatus* and water samples from several locations in the basin were also analyzed. These samples were collected during July and August 1973.

Loss of weight on ignition was determined by heating samples previously oven-dried at 110°C in a muffle furnace for 2 hr at 550°C: the ash weight was divided by the initial dry weight and expressed as percentage loss (*see* Rybak 1969). An atomic absorption spectrophotometer was used to measure concentration of exchangeable calcium, magnesium, and sodium. Cations were leached from 10 cc of wet sediment for 30 min with 50 ml of 1 N NH_4Cl and the slurry filtered (Whatman No. 1 paper). A mixture of 0.68 atm of air and acetylene was used to atomize and ignite the samples in solution. The instrument consistently measured concentrations as low as 0.2 ppm of sodium and magnesium, but only 1.0 ppm of calcium. Sensitivity to calcium was increased by eliminating interference from sulfates and other ions through additions of small amounts of lanthanum chloride (Slavin 1968; Ward et al. 1969). Carbon, hydrogen,

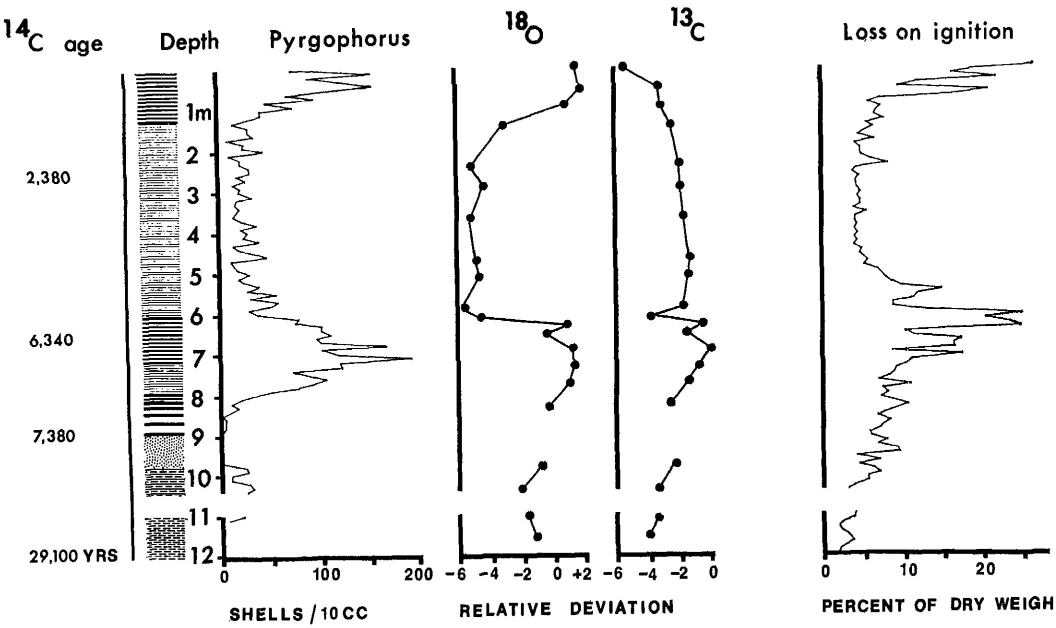

Fig. 1. Stratigraphic distributions of core parameters. Positions of four radiocarbon dates are indicated relative to total core depth below the sediment–water interface (12 m). The frequency and thickness of organic-rich sedimentary laminae are depicted by horizontal lines. Stippled sections denote hard, compacted sediments and dashed horizontal lines denote soft, unconsolidated marl. The number of *Pyrgophorus* snail shells, $^{18}O:^{16}O$, $^{13}C:^{12}C$ ratios, and total carbon (loss on ignition) are graphed relative to total core depth.

and nitrogen were measured with a gas chromatograph coupled with an electrobalance after carbonates were removed with dilute HCl and the organic residues washed in distilled water and dried. Three or four subsamples from each stratigraphic sample were weighed and mixed with a dry catalyst. The mixture was burned in a sealed electrofurnace at 1,200°C and the resulting gas outflows were carried by helium through a prepared column. Quantities of carbon, nitrogen, and hydrogen were plotted relative to original sample weight and converted to percentage values, using calibration constants ($K_C = 0.29$; $K_N = 0.08$; $K_H = 0.14$) determined empirically from a standard sample (2,4-D butyl ester) analyzed by the National Bureau of Standards.

Results

Four radiocarbon dates (Fig. 1) are used to calculate rates of sedimentary deposition throughout the history of the lake. Non-woody organic materials from depths of 3.7 and 6.5 m were dated 2,380 ± 200 years B.P. (Y-2371) and 6,340 ± 160 years B.P. (Y-2471). Carbonate marls from depths of 9 m and from 12 m were dated 7,380 and 29,100 years but must be adjusted to about 7,010 ± 120 years B.P. (Y-2635) and 28,830 ± 500 years B.P. (Y-2620) because of measured ^{14}C deficiency in carbonates from this lake.

Although rates of deposition in the upper 7 m appear to have been relatively uniform, marked oscillations occur (Figs. 1 and 2) in number of *Pyrgophorus* shells, ^{18}O : ^{16}O ratios, loss of weight on ignition, thickness of sedimentary laminae, and exchangeable calcium. Maximal and minimal values for these parameters are incompletely synchronous but their general oscillations are similar. For example, ^{18}O (relative to PDB standard) fluctuates from +1.8 to –5.9 to +1.6‰ and relative deviations are uniformly negative from 1 to 6 m. Concur-

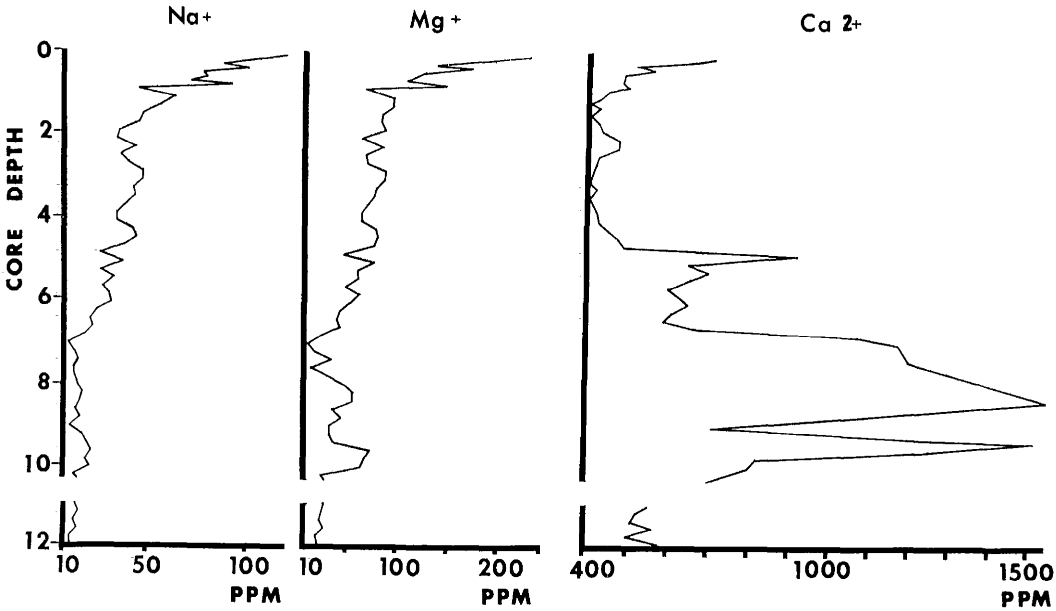

Fig. 2. Stratigraphic distributions of sodium, magnesium, and calcium relative to the same depth profile as in Fig. 1.

rently, laminar couplets (composed of organic and carbonate enriched layers) are distinctly thicker from 0 to 1 m and from 6 to 7 m than in the intermediate sediments.

Ages of the sediments from 7 to 12 m change dramatically as do several stratigraphic features. *Pyrgophorus* shells are completely absent from 8.8 to 9.7 m and terrestrial species of snails were found only in these strata. Also at these depths are the hardest and most consolidated deposits of calcite and gypsum. *Pyrgophorus* shells are also absent from 10.5 to 11 m in these cores because the Livingstone sampler did not retain the soft, unconsolidated oozes present at these depths. The large values for exchangeable calcium from 7 to 12 m occur in large crystalline deposits of calcium sulfate (Fig. 2). Both exchangeable sodium and magnesium (Fig. 2) increase generally as depth decreases: these trends range from 11 to 120 ppm for sodium and from 12 to 234 ppm for magnesium. No distinct oscillations occur in $^{13}C : {}^{12}C$ (Fig. 1) or in C : N (Fig. 3).

Water samples collected from eight sources in July and August 1973 yield ^{18}O values which range from –6.1 to +5.4‰ (relative to Standard Mean Ocean Water or SMOW: Craig 1961). Comparison of the two values for inflowing waters with the six values for lake waters from various subbasins (Table 1) demonstrates that there is appreciable evaporation of the rainfall and spring waters. Since surface water samples from the central basin have the same ^{18}O values as water samples from 10 m, the lake

Table 1. Oxygen 18 content of water samples from Chichancanab basin (14 July–17 August 1973).

	^{18}O ‰
Inflowing Water	
1. Rain	−6.1
2. Subterranean (spring)	−4.7
Lake Water	
1. Northernmost Basin	+3.4
2. Northern Basin	+5.4
3. Central Basin (surface)	+4.0
4. Central Basin (10 m. depth)	+4.0
5. Southernmost Basin	+3.9
6. Lateral Impoundment	+3.5

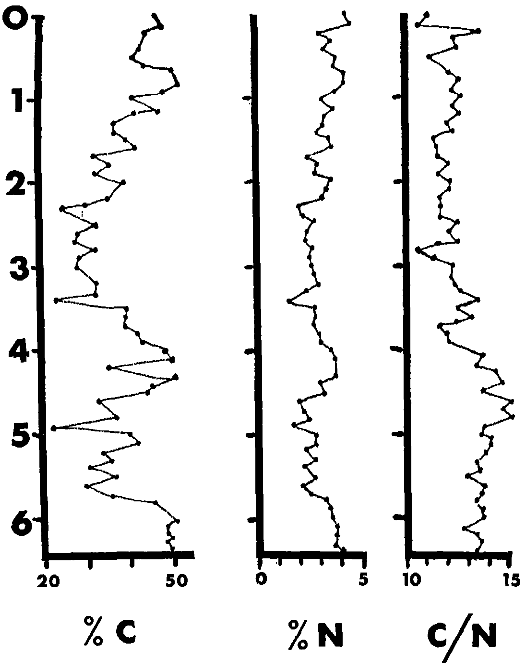

Fig. 3. Carbon and nitrogen distributions in upper 6.5 m of total core profile (core depth vs. percentage composition).

water was apparently completely mixed. Water in the largest, central portion of the basin has an ^{18}O value of 4.0‰. Carbonate precipitated in equilibrium from this water at 25°C would have an ^{18}O value of 2.2‰; if precipitated at 30°C the value would be 1.1‰ (Mook 1968). This range is characteristic of the values obtained from *Pyrgophorus* shell carbonate in the uppermost meter of the sediments.

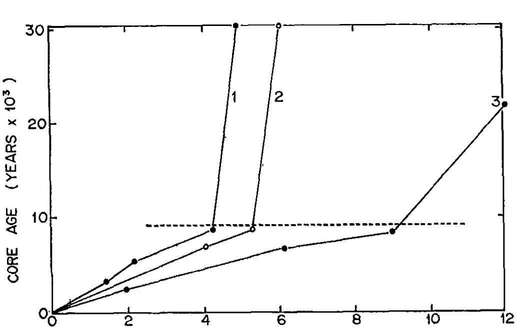

Fig. 4. Sedimentation rates (age vs. core depth) of three lakes: 1—Mud Lake, Florida; 2—Lake Louise, Georgia; 3—Laguna Chichancanab, Yucatan.

Discussion

Our results suggest two periods of major lake level fluctuations. The first was longer (extending from about 22,000 to 8,000 years B.P.) than the second and was terminated by a phase of reduced lake volume (perhaps complete desiccation of the basin). The boundary (or sedimentary hiatus) between the earlier and later periods is characterized by complete absence of aquatic molluscs, the unique occurrence of terrestrial gastropods at this level (9 m below the present mud–water interface), increased sedimentary compaction, and by a layer of crystalline gypsum. The later period occurred during the last 8,000 years and a series of three distinct phases (shallow-deep-shallow) has been inferred from several parameters that can be traced from the continuous sequence of sedimentary deposits in the upper 8 m of core. The lines of evidence used to establish these changes in lake level are the marked oscillations in molluscan abundances, ^{18}O : ^{16}O ratios, percentage loss of weight on ignition, thickness and types of sedimentary laminae, and exchangeable calcium concentrations.

We are uncertain about the relative depths and volumetric stability during the very early period of the lake's development. For example, the low values for organic carbon could have resulted from low productivity, as most workers assume, but also from high turnover of production or from oxidation of organic materials after sedimentation in shallow water. The gypsum deposits could indicate an environment of shallow, rapidly evaporating lake water if the crystals were formed at the time of deposition, but less information can be obtained if this crystallization resulted from localized postdepositional processes. Furthermore, because this study extends over a longer time than previous investigations in Yucatan, no comparative data are available from other nearby lakes for this very early period of the lake's water balance.

The last 8,000 years can be discussed with more certainty because of the sedimentary continuity and the marked, synchronous oscillations of several parameters. The existence of the modern lake and the similarity of present-day molluscan distributions and sedimentary structures also allows for greater confidence in interpreting the results for this period. The most interesting time in the lake's later history is during the first phase of relatively shallow water when the lake apparently began to refill after a long period of reduced volume or complete dryness. The sediments are complexly laminated in a fashion suggesting that seasonal algal mats may have formed in shallow waters (as they do at present). These laminated strata are relatively rich in preserved organic matter, with a relatively low C : N ratio (12 : 1) typical for organic matter autochthonously produced and decomposed (Hutchinson 1957). Apparently throughout the deposition of the upper 6.5 m of sediments there has been little addition of allochthonous organic matter. Despite this uniformity there have been changes in the positions of localized organic production (as indicated by percentage loss of weight on ignition). In this early period, when the lake began to refill, the shallow littoral zone of high productivity was near the fixed sampling point of the core and sediments deposited during this period were high in organic material.

The second phase began about 5,500 years ago and is characterized by relative declines in ratios of ^{18}O, numbers of shells, organic matter and exchangeable calcium, and by an absence of laminae. Such relatively low values remained uniform during this phase for 4,000 years and we think indicate a stable, deep lake. There is no evidence of strong seasonal changes in lake level at the site of deposition sampled by these cores, but short term fluctuations could have occurred in the supralittoral zone. This possibility may not be testable, however, because the lake level apparently began to decline during the next phase, exposing any sedimentary deposits from these marginal zones to erosional processes.

The lake has remained essentially stable at its present-day level during the last 1,500 years with some short term fluctuations inferred from modern vegetational zonations around the lake and some small seasonal changes that have been documented directly. All parameters during this third phase appear similar to those during the first shallow-water phase. There is an abundance of shells and organic laminae and relatively high values for ^{18}O and exchangeable calcium. In addition, the concentrations of sodium and magnesium increase rapidly in the uppermost sediments.

We consider rates of evaporation and inflow to be the main variables affecting $^{18}O : ^{16}O$ ratios in Chichancanab and fractionation by a direct temperature effect only a minor influence. Temperature changes in the basin during the last 8,000 years could be independently determined if changes in distributions of temperature-sensitive plants could be inferred from fossil pollen grains, but unfortunately, pollen grains are not well preserved in these sediments. Palynological studies on cores from Laguna de Petenxil, a small lake in the southern base of the peninsula, show no marked climatic changes (Tsukada 1966). Geochemical data from the Petenxil cores led Cowgill and Hutchinson (1966, p. 126) to conclude that "there has been no significant climatic change over the past four millenia." Although major climatic changes during the last eight millenia are unlikely, minor variations in rainfall patterns, temperature, or evaporative potential during the period from 8,000 to 4,000 B.P. cannot be ruled out, given the limited data now available for Yucatan. Palynological studies of cores from the Gatun basin, Panama Canal Zone, suggest that temperatures were the same 7,300 years ago as they are today in Panama (Bartlett and Barghoorn in press) but may indicate a drier, more seasonal climate during the interval from 7,300 to 4,200 B.P., based on changes in the distribution of *Myrica* and *Ilex* pollen which may indicate shifts in altitudinal zonations resulting from climatic changes.

Bartlett and Barghoorn also have evidence that earlier periods from about 12,000 B.P. had temperatures at least 2.5°C lower than those in present-day Panama. Extrapolation of these results from Panama, and others from the southeastern United States (Watts 1971), to Yucatan appears unwarranted until further studies on pollen distributions have been completed in the peninsula. However, the effects of temperature relative to effects of evaporation and inflow on $^{18}O : ^{16}O$ values need to be evaluated more completely when adequate data are available.

The two main variables of evaporation and inflow are complexly linked to $^{18}O : ^{16}O$ fractionation, but the precise relationships between these two variables and rates of lake level fluctuation are uncertain. Other variables may need to be considered. For example, tectonic movements in the base rock limestone or changes in inflow : outflow ratios could have influenced lake levels. Inflow to the lake can be altered by changes in groundwater seepage, by absolute changes, and by seasonal distributional changes in rainfall. Outflow is affected by seepage into a lower aquifer if the groundwater table is lower than the lake level and by evaporational and transpirational losses to the atmosphere. These effects cannot be completely evaluated with current data. For instance, no data on transpirational losses are available, but some loss is known to occur because the current shoreline is vegetated by mats of sedges and "buttonwood" mangroves (*Conocarpus erecta*).

Among this array of factors, change in sea level is probably the most significant cause of lake level changes in Yucatan. We believe that changes in groundwater level had pronounced effects on rates of inflow and thus on the lake level of Chichancanab. These changes were caused by a eustatic change in sea level in the Gulf of Mexico and Caribbean Sea. In Yucatan groundwater is bounded at its lowest depths by saline waters which percolate through the deep strata of porous limestone (Back and Hanshaw 1970; Lesser-Jones 1965). As sea level began to rise 11,000 years ago, this body of deep saline water also rose to upper strata of permeable limestone and the fresh groundwater "floated" at a higher level. Some geologists suggest that sea level rose until about 5,000 B.P., with no significant fluctuations since that time; another view is that sea level has continued to rise (*see* Guilcher 1969; Mörner 1973). Establishment of the rate of sea level rise in the neotropics has recently been possible from studies of mangrove swamp deposits in Panama (Bartlett and Barghoorn in press), where a definite shift in rates of rise has occurred during the last 11,000 years. The early phase (8,000 to 11,000 B.P.) is characterized by exponential increases. By 7,300 B.P. the rate of rise had lessened and sea level reached an equilibrium value. In the Florida Everglades there was a rapid rise of about 8.3 cm 100 yr^{-1} about 3,500 B.P., but then the rate slowed to 3.5 cm 100 yr^{-1}; sea level has risen continuously, but at a decreasing rate, during the last 6,500 to 7,000 years (Scholl et al. 1969).

The record before 11,000 B.P. and its implications for interpreting the earliest history of Chichancanab are less clear, but the shifts in rate of sea level rise during the last 8,000 years are well documented and suggest an explanation for lake level changes. Initially, the rapid rate of sea level rise resulted in raising the groundwater level and refilling the desiccated lake. As the lake reached its maximal level, the rate of sea level rise slowed while the evaporation rate remained constant per unit area. Changes in the balance between inflow and evaporation subsequently resulted in the lowering of the lake to its present-day level: this most recent change is not necessarily connected with sea level changes.

The effects of changing sea levels on lakes in Yucatan are further established by comparisons with four other basins. Core studies of these four basins demonstrate a widespread lowering of coastal water tables during the period of greatly reduced volume (or complete dryness) at Chichancanab. Both Mud Lake (Marion Co.) in Florida and Lake Louise (Lowndes Co.) in Georgia have discontinuous sedimentary records (Fig. 4). Watts (1969) noted that a sand layer at 4.9 m in Mud Lake marks a major hiatus between detrital sediments with dates of 8,160 ± 200 B.P. at 4.2 m and greater than 35,000 B.P. at 5.2 m. He suggested that the sand layer represents a period of littoral erosion during a shallow-water phase. At Lake Louise there is a hiatus between dates of 8,510 ± 100 B.P. and greater than 49,000 B.P. (Watts 1971).

Two other discontinuous sedimentary records can be interpreted as results of sea level changes and these may have been influenced directly by the sea level rather than indirectly by effects on water tables. Lake Maracaibo, a large coastal lake in Venezuela, has a direct connection with the Caribbean Sea. The ancient level of Maracaibo rose at a rate of about 0.5 cm yr^{-1} during the period from 9,250 to 7,370 B.P. This rise in lake level was documented by changes in algal assemblages indicating a transition to brackish water conditions as the fresh lake waters mixed with marine saline waters (Sarmiento and Kirby 1962). Before this rise in sea level, a hiatus in deposition is indicated by eroded and oxidized clays. Deep cores from the Gatun basin in Panama also record a rise in sea level and a hiatus in deposition. Radiocarbon dates on these sediments indicate that no sedimentation occurred from 35,500 to 11,300 B.P. Bartlett and Barghoorn (in press) conclude that sea level was relatively high (but perhaps from 36 to 68 m below present sea level) during the period dated 35,500 ± 2,500 B.P.

From results for these four basins and from comparisons with Chichancanab, some time lags evidently occur between the onset of deglaciations in the higher latitudinal regions and the effects of sea level changes on water tables and lake levels in the lower latitudes. The extent to which these time lags vary in different basins is not very large and is consistent with their variations in elevation and distance from direct coastal influences. Fluctuations in lake level of Laguna Chichancanab appear to have been quite distinct, apparently influenced by the lake's central location within the peninsula's flow of groundwater and the basin's morphology.

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