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Physical and chemical properties of hypersaline Lago Enriquillo, Dominican Republic

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Introduction

Lago Enriquillo, Dominican Republic, (18°31.7′N, 71°42.91′W) is a hypersaline lake of marine origin. During the middle Holocene, ca. 6000–4800 BP (before present), Lago Enriquillo was an embayment of the Caribbean Sea and supported a fringing coral reef. The embayment was isolated from the Caribbean Sea between 5000 and 2800 BP by tectonic uplift and fluvial damming by the Yaque del Sur River (Taylor et al. 1985, Mann et al. 1984, Bond 1935). Today, Lago Enriquillo is a closed-basin lake, home to a unique flora and fauna, whose sediment may serve as an excellent source of paleoenvironmental information. Here, we present data on modern physico-chemical parameters and microfauna distributions that reflect the system's sensitivity to variations in rainfall, evaporation, and freshwater inputs. These data will aid in interpreting past environmental changes as recorded by faunal and geochemical proxies in sediment cores retrieved from Lago Enriquillo.

Key words: Caribbean, Lago Enriquillo, microbenthos, saline lakes, stable isotopes

Study site

Lago Enriquillo is the largest lake in the Caribbean. Currently its watershed encompasses ~3500 km^2 and lake level is ~46 m below sea level. Its surface area is ~200 km^2, and its estimated mean water depth is 6.10 m (Schubert 2000: Fig. 1). The lake has displayed historic salinities ranging from about 35‰ in 1983 (Margalef 1986) to >100‰. Annual rainfall near Lago Enriquillo ranges from 508 mm on the SE shore to 729 mm on the NW shore (Instituto Nacional de Recursos Hidrólicos, unpubl.). Rainfall maxima occur in May and October. Monthly precipitation in the dry season (December to April) averages <20 mm. Annual rainfall is highly variable, however, and is influenced by tropical depression and hurricane activity in the Caribbean. Mean daily temperatures around the lake vary between 22.3–33.7 °C, and annual evaporation can be as great as 2000 mm (Schubert 2000).

Methods

We collected physical (temperature) and chemical (pH, salinity, ion concentrations, stable oxygen and

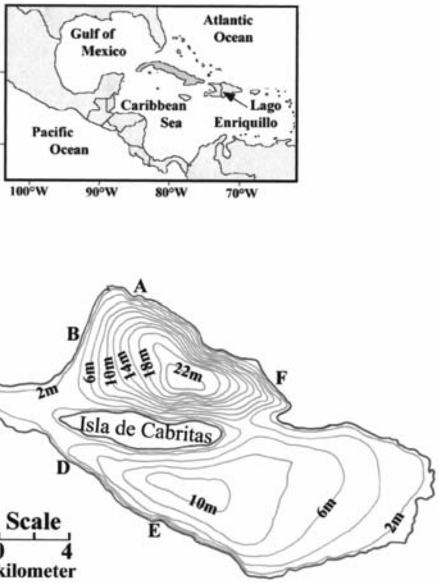

Fig. 1. Map showing the location of Lago Enriquillo on the Caribbean island of Hispaniola. Bathymetric map of Lago Enriquillo showing 2-m depth contours (modified from Araguás-Araguás et al. 1993). Letters along the shoreline indicate the approximate location of springs mentioned in the text: (A) La Azufrada, (B) Borbollones, (C) Boca de Cachon, (D) Caoba, (E) La Zurza, (F) El Guayabal.

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hydrogen isotopes) data as well as surface sediments from Lago Enriquillo (Fig. 1) during three visits in June 2001, November 2002, and March 2003. Water samples for chemical analysis were taken from freshwater springs that discharge into the lake, from the lake surface, and from water-column profiles in the lake's northern and southern basins. Water column temperature and pH were measured with a Horiba U-10 meter. Salinity was measured using a SPER Scientific refractometer. Major cations and anions were measured with a Dionex Model DX 500 ion chromatograph. Chloride concentrations in hypersaline lake waters were determined by titration using 0.1M $AgNO_3$ and K_2CrO_4 indicator solution (Mohr method). Total dissolved inorganic carbon (DIC) was measured with a UIC/Coulometrics Model 5011 Coulometer and 5030 Carbonate Carbon Preparation System.

Oxygen isotope ratios ($\delta^{18}O$) of 128 water samples were measured by CO_2 equilibration using a Micromass Multiprep device interfaced to a VG Prism II mass spectrometer. A subset of 32 samples was measured for deuterium (δD) on a ThermoFinnigan MAT253 using an H-Device reduction furnace and a CTC PAL auto-sampler. Data are reported in delta notation (δ) relative to Standard Mean Ocean Water (SMOW).

In addition to collecting limnological data, we took surface sediment samples at the mouths of freshwater springs and from open lake water sites to identify the benthic microfauna of Lago Enriquillo. Surface sediments were processed using standard procedures (MURRAY 1991). Samples were washed through a 63 μm sieve, oven-dried then dry-sieved to separate the sample into >212 μm and >63 μm fractions for identification of microbenthos. Organisms identified included foraminifera, ostracods, and gastropods.

Results and discussion

Temperature and pH

Surface water temperature in the northern basin ranged from 28.6–30.5 °C, with the lowest temperature recorded in March 2003 (Fig. 2a). A temperature difference of < 1 °C between the upper and lower waters was observed. The southern basin was isothermal at the time of sampling in 2002 and 2003, with temperatures

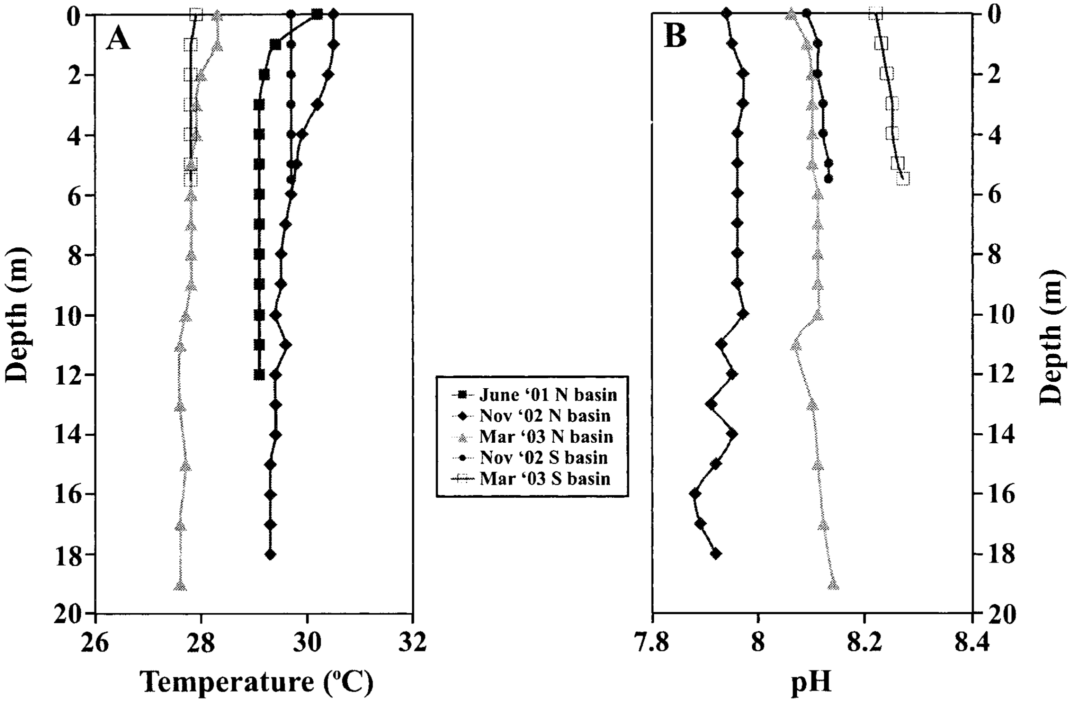

Fig. 2. Water column temperature (A) and pH (B) profiles from the north and south basins of Lago Enriquillo, measured in June 2001, November 2002, and March 2003.

ranging from 27.9 °C (March 2003) to 29.7 °C (November 2002). Among our three sampling dates, November was the time of greatest heat storage in the water column. The pH of Lago Enriquillo waters varied little with time, sampling location, or depth (Fig 2b).

Water column temperature and pH results suggest that each basin of Lago Enriquillo is well mixed. Strong winds and a large fetch, particularly in the southern basin, probably contribute to polymixis. Although the northern basin exhibits subtle thermal stratification, bottom waters are only ~1 °C cooler than surface waters. Seasonal differences between the two basins are comparable.

Salinity and major ion concentrations

Lakewater salinity in both basins increased by ~23‰ between June 2001 and March 2003 (Table 1). Salinity in the southern basin was consistently ~2‰ higher than in the northern basin. Changes in salinity were accompanied by proportional shifts in individual ion concentrations. Na^+, K^+, Mg^{++}, and Ca^{++} consistently comprised 80%, 1.5%, 16.5%, and 2% of cation milli-equivalents L^{-1}, respectively. Chloride and sulfate had relative concentrations of 87.5% and 12.25%, respectively. Bicarbonate (HCO_3^-), measured on a subset of water samples, represented only ~0.03% of anion charges.

Spring waters had salinities ≤ 1‰, but displayed differences in relative ion concentrations. Guayabal spring contained the lowest total ionic charge, with Ca^{++} representing 83% of the total cation milliequivalents (Table 1). Boca de Cachon had the highest total ionic charge, dominated by Na^+ and Cl^- ions. Borbollones and Zurza are sulfur springs and emit H_2S.

Stable isotopes

In evaporating water bodies, heavier isotopes of water (H^2HO and $H_2{}^{18}O$) are „enriched“ in lake water because of the preferential evaporation of lighter water molecules (${}^1H_2{}^{16}O$). Enrichment of ${}^{18}O$ and ${}^2H$ (deuterium, or D) provides information on changes in the ratio of precipitation to evaporation in a basin. Therefore, the ratios of ${}^{18}O$ to ${}^{16}O$ ($\delta^{18}O$) and ${}^2H$ to H (δD) in waters provide information about the evaporative history of a water body and can be used to identify different input sources in water balance studies.

In Lago Enriquillo waters, salinity and $\delta^{18}O$ are strongly correlated ($r^2 = 0.95$) (Fig. 3a). Covariance of salinity and $\delta^{18}O$ illustrates the enrichment of ${}^{18}O$ in Enriquillo waters due to evaporation. The relationship between δD and $\delta^{18}O$ in meteoric waters is referred to as the Global Meteoric Water Line (GMWL) and is expressed by the equation $\delta D = 8(\delta^{18}O) + 10$ (Craig 1961: Fig. 3b). Lago Enriquillo waters deviate from the GMWL because of evaporation and specifically, non-equilibrium isotopic fractionation at the air-water boundary between the atmosphere and Lago Enriquillo waters (Gat 1980).

Microbenthos

The foraminfera assemblage of Lago Enriquillo is dominated by milliolid species of the genus *Quinqueloculina*. The rotallid *Ammonia beccarii* is also present. The foraminifera assemblage near freshwater springs contains more taxa, including the rotallid *Criboelphidium poeyanum*, the common saline species *Ammotium salsum*, as well as a less abundant *Rosalina* sp. An unknown species, possibly of the genus *Amphistegina*, was also encountered. Its presence may be attributed to erosion of Holocene coral deposits within Enriquillo's watershed. Ostracods in Lago Enriquillo include *Perissocytheridea rugata*, *P. bicelliforma*, and *Cyprideis* sp. The gastropod *Heleobops clytus* (Thompson & Hershler 1991) was observed adjacent to springs.

Conclusions

Lago Enriquillo exhibits only minor spatial and temporal differences with respect to temperature and pH. Measured chemical differences (i.e. pH, major ions, salinity, stable isotopes) suggest that the two basins are not mixed completely and may have been hydrologically separated at lower lake stage. The range of salinities in Lago Enriquillo enables both halophilic and halophobic taxa to inhabit the system. Freshwater hydrobiid snails (*Heleobops clytus*) occupy spring discharge areas, whereas salt-tolerant foraminifera (e.g. *Quinqueloculina* spp.) are found in the open lake.

Table 1. Salinity, major ion concentrations and stable isotope ratios of Lago Enriquillo waters, spring waters entering the lake, and Caribbean Sea waters.

		Isotopes		**Cations**					**Anions**			
sample ID	salinity ppt	$\delta^{18}O$ (‰ vs.	δD SMOW)	Na (meq/L)	K (meq/L)	Mg (meq/L)	Ca (meq/L)	total	Cl (meq/L)	SO4 (meq/L)	HCO3 (meq/L)	total
Enriquillo Lake waters												
June, 2001												
North basin	80.00	4.36	20.87	1077.73	19.31	220.78	26.51	1344.33	1237.20	175.81	n/d	1413.01
South basin	82.00	4.45	n/d	1086.82	19.71	222.54	26.73	1355.80	1220.25	166.70	n/d	1386.95
November, 2002												
North basin	102.00	4.47	22.68	1379.89	26.52	283.01	34.55	1723.97	1515.38	211.63	5.01	1732.02
South basin	104.20	4.66	22.64	1306.17	25.10	277.22	35.52	1644.01	1584.30	221.98	4.39	1810.67
March, 2003												
North basin	103.95	4.81	22.90	1482.57	27.29	302.36	35.44	1847.66	1632.21	215.97	4.90	1853.08
South basin	105.93	4.71	23.31	1433.60	26.15	291.39	34.24	1785.38	1588.70	220.60	4.33	1813.63
Enriquillo spring waters												
Borbollones	<1.00	-4.11	n/d	1.00	0.09	1.33	3.39	5.81	0.99	0.14	4.73	5.86
La Zurza – sulphur	~1.00	-5.66	n/d	3.52	0.11	2.37	2.59	8.59	5.70	0.32	4.36	10.38
Guayabal	<1.00	-4.07	17.14	-0.18	0.02	0.52	3.55	4.27	1.82	0.15	n/d	1.97
Caoba	<1.00	-5.54	-30.49	2.36	0.08	2.09	2.65	7.18	3.41	0.20	4.16	7.77
Boca de Cachon	~1.00	-3.61	-14.65	5.62	0.22	2.45	2.60	10.89	9.12	0.32	n/d	9.44
Caribbean Sea												
Bahia de Neiba	37.50	1.22	6.93	479.01	9.88	112.27	20.45	621.61	550.14	58.90	n/d	609.04
Concentration Factor*	2.13			2.25	1.95	1.97	1.30		2.25	2.98		

* The concentration factor compares the ionic concentrations of Lago Enriquillo waters to local Caribbean Sea waters (Bahia de Neiba). Because of Enriquillo's marine origin, this comparison reveals information about the ionic development of the lakewaters since its isolation from the sea.

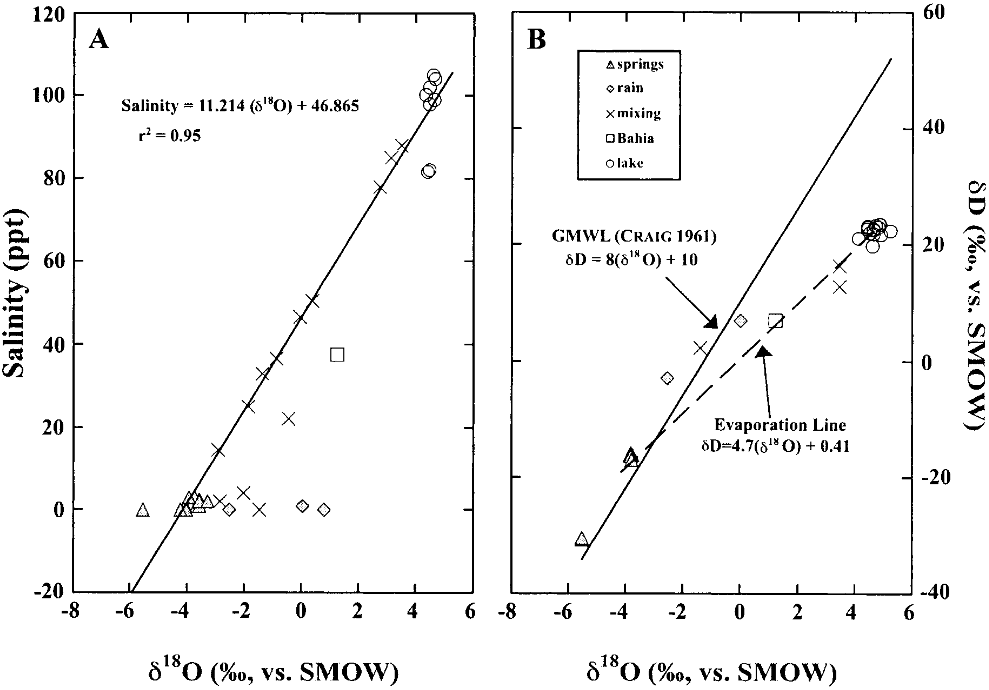

Fig. 3. (A) Oxygen isotopes ($\delta^{18}O$) versus salinity for Lago Enriquillo input waters (rainfall and springs), lakewater, and Caribbean seawater. The regression between salinity and $\delta^{18}O$ is highly significant ($r^2 = 0.95$). Enrichment of ^{18}O and salinity in lakewater reflects intense evaporation from the basin. (B) Solid line is the Global Meteoric Water Line (GMWL), which defines the relation between $\delta^{18}O$ and δD in rainfall worldwide ($\delta D = 8(\delta^{18}O) + 10$ [Craig 1961]). Lago Enriquillo waters (dashed line) deviate from the GMWL because intense evaporation causes non-equilibrium isotopic fractionation.

Modern Lago Enriquillo is a dynamic system that is susceptible to short-term hydrologic variations. Both basins are prone to pronounced shifts in salinity, chemical composition, and isotopic concentration on short time scales (i.e. seasonal/annual). Furthermore, long-term changes in Lago Enriquillo's salinity appear to be related to climate-driven shifts in freshwater input expressed in lake level changes. During the past 55 years, lake stage has been positively correlated with the passage of hurricanes and tropical storms in the area (Fig. 4).

Future research will focus on reconstructing decade to century-scale variability in lake hydrology during the Holocene through analysis of sedimentary archives retrieved from Lago Enriqullo. Changes in abundance of the gastropod *H. clytus* will serve as a valuable proxy for changes in freshwater input into the system. Past variations in foraminferal assemblages will aid in interpreting past changes in lake water salinity. In addition, oxygen isotope analysis of the carbonate shells of aquatic invertebrates (e.g. foraminifera, ostracoda, gastropoda) collected from sediment cores will aid in the reconstruction of past moisture conditions (Covich & Stuiver 1974). Understanding the ecology and distribution of microfauna and the modern physico-chemical properties in Lago Enriquillo will aid in interpreting past changes in the hydrologic budget as observed in sediment cores.

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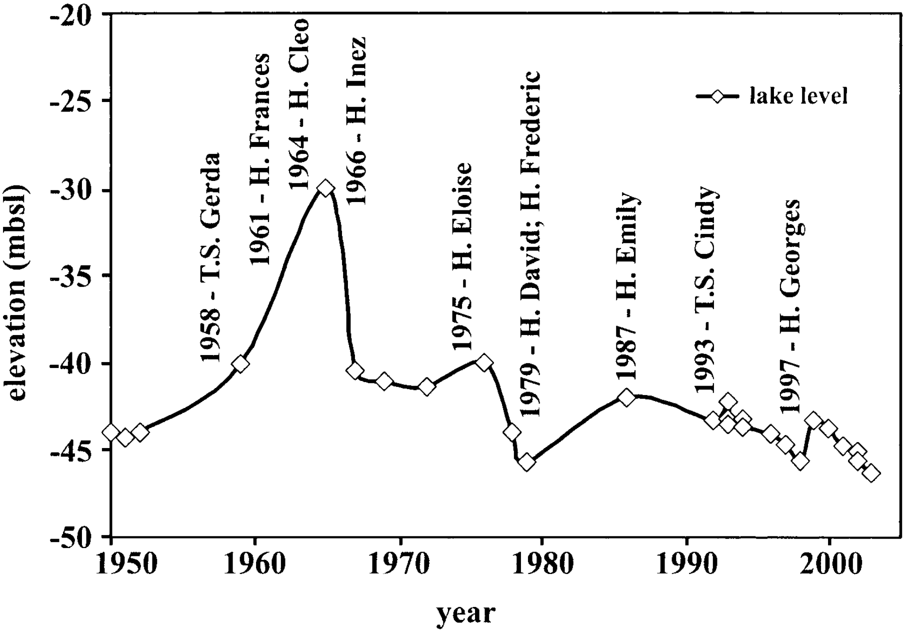

Fig. 4. Elevation of Lago Enriquillo in meters below sea level (mbsl) from 1950 to 1963, and the timing of hurricanes (H.) and tropical storms (T.S.) passing near the Enriquillo basin. Lake level data were provided by Roberto Cruz, Tesis Duquela-Gonzalez, and Juan Saldaña of Indrhi (pers. comm..). Hurricane and tropical storm data are from the National Oceanic and Atmospheric Administration (NOAA) National Hurricane Center (http://www.nhc.noaa.gov/). Irrigation canals constructed around Lago Enriquillo in the 1960s may account for the muted response of lake level to storm activity since the 1970s.

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