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Short Note

LOW HOLOCENE LEVEL (7700 TO 3650 YEARS AGO) OF LAKE TITICACA (BOLIVIA)

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Abstract

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Preliminary results of sedimentological and paleontological analysis of two cores taken in Lake Titicaca (Bolivia) indicate that between 7700 and 3650 yr B.P. the lake level was up to 50 m lower than at present. Evaporitic deposits occurred at the maximum low lake level.

Introduction

The Bolivian Altiplano is an endorheic basin which extends from 16 to 22°S latitude and from 65 to 69°W longitude, around 4000 m high and covers 200.000 km^2 between the Western and Eastern Cordilleras (which are 6500 m high).

From north to south, three main lacustrine areas occur in the high plateau (Fig.1):

— Lake Titicaca, at 3810 m above sea level, covers 8200 km^2 and is divided in two parts; the northern "main lake" with a mean depth of 135 m and the southern "small lake" with a mean depth of 9 m.

— Lake Poopo at 3686 m above sea level, a very shallow lake (less than 6 m deep).

— Coipasa and Uyuni, a group of dry salt lakes covering 10,000 km^2 at 3653 m high.

During the late Pleistocene, two lacustrine transgressions occurred especially in the south of the Altiplano. Each high water level is marked in the landscape by stromatolites. Between 30,000 and 21,000 years ago, the Minchin phase produced a lake of 63,000 km^2 over Poopo-Coipasa-Uyuni, when at its maximum development, between 12,500 and 11,000 years ago, Lake Tauca covered approximately 43,000 km^2 (Servant and Fontes, 1978). They were reduced to their present size about 10,000 years ago. This gave rise to the evaporitic deposits at Coipasa and Uyuni and has turned the Poopo into a very shallow lake. More recent oscillations of the levels of lakes in the Altiplano have not been studied previously.

A study of the fluctuations of Lake Titicaca during the last 10,000 years was initiated in 1982 when a Züllig corer was used. In 1983, coring was carried out with a Mackereth corer and resulted in 18 cores of 4–6 m. Work is being developed through the GEOCIT program (Géodynamique du Climat Tropical) in collabora-

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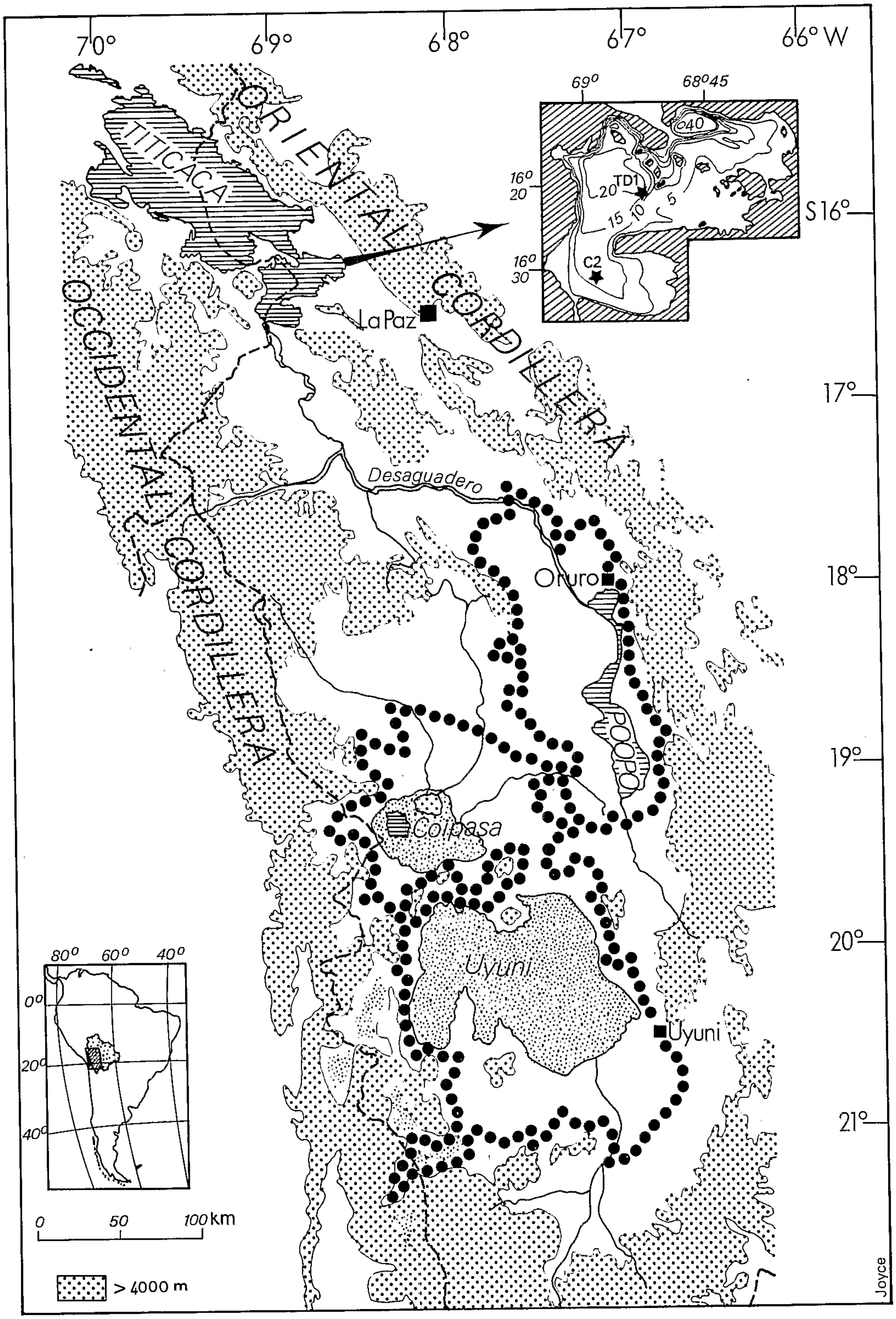

Fig.1. The Bolivian Altiplano showing Lake Titicaca and the location of the cores. Dots show the extension of Lake Tauca.

tion with the U.M.S.A. (Universidad Mayor de Sán Andrés) of La Paz and the O.R.S.T.O.M. (Office de la Recherche Scientifique et Technique Outre-Mer).

Based on previous results concerning superficial deposits in Lake Titicaca (Boulange et al., 1981) and the cores taken in 1982, three transects, crossing the main parts of the small lake and the bahias of Achacachi and Copacabana in the main lake, were chosen for the Makareth sampling.

Preliminary results

Core C2

This core, 95 cm long, taken at 13,50 m below water in the southern part of the small lake (Fig.1), shows three main lithologic sequences (Fig.2):

— from 95 to 90 cm: a white indurated carbonate unit with a coarse texture, containing calcareous concretions (< 0.5 cm), very few detrital grains and with few gastropods and ostracod shells at the top;

— from 90 to 68 cm: a brown deposit (10 YR 2.5/1) partly indurated very rich in macrophyte remains at the top and containing many shell fragments between 90 and 75 cm; detrital grains (quartz, feldspar) and clays are abundant. Diatoms are well represented in this unit. The contact with the lower adjacent unit is very sharp;

— from 68 to 0 cm: a gelatinous mud (from 5Y[illegible]6/2 to 5Y[illegible]2.5/1) with diffuse banding very rich in gastropods and ostracod shells. Organic laminations are abundant between 25 and 7 cm.

From the base to the top, core C2 shows a transition from carbonate deposits (the lower unit) to an organic-carbonate upper unit with an intermediate organic detrital level (the brown deposits) very rich in diatoms.

According to these sedimentary facies, the paleontological results, based on the diatoms, provide paleobathymetrical and paleohydrological information for these sequences (Fig.2):

— from 95 to 85 cm: the lake was very shallow, less than 2 m, and the water was fresh, less than 1 g/l of dissolved salts.

— from 85 to 55 cm: the level was similar to the preceding stage but the water became more and more saturated. In the interval 75–57 cm, the salt concentration rose to 40 g/l.

Two ^{14}C ages, obtained from analysis of the carbonates of the bulk sediment, are: 5325 ± 395 yr B.P. for the level 80–70 cm and 3650 ± 330 yr B.P. for the level 70–60 cm.

— from 55 to 0 cm: water depth increases progressively to 10-15 meters with a salinity lower than 6 g/l.

Core TD1

A morphologic analysis of the 540 cm marl of core TD1 (Fig.3), taken 19 m below water in the central part of the small lake (Fig.1), shows six main lithologic units:

— from 537.5 to 332.5 cm: a very fine clay sediment with small black dots (color 10YR3,5/1).

— from 332.5 to 181 cm: a plastic clay (color N4).

— from 181 to 155 cm: a compact homogeneous fine mud (color 5GY4/1 to N4).

— from 155 to 141.5 cm: a silty-argillaceous sediment (color N5 to N4).

— from 141.5 to 87 cm: a gelatinous mud with diffuse banding, poor in shells, very rich in gyrogonites and macrophytes remains (medium color 5Y5/1).

— from 87 to 0 cm: a gelatinous organic mud with diffuse banding and calcified macrophytes, very rich in gastropods and ostracod shells (medium color 5Y3/1).

These six lithologic units have been regrouped in four major sedimentological sequences, according to the vertical distribution of the physical parameters of the bulk sediment (Fig.4). Further, the observation of the silty fraction (coarser than 63 µm), separated by sieving under distillated water, allows us to precise the lake level for each sequence (Table I and Fig.3):

— sequence IV (537.5–155 cm) corresponds to very fine deposits in which the bulk of the

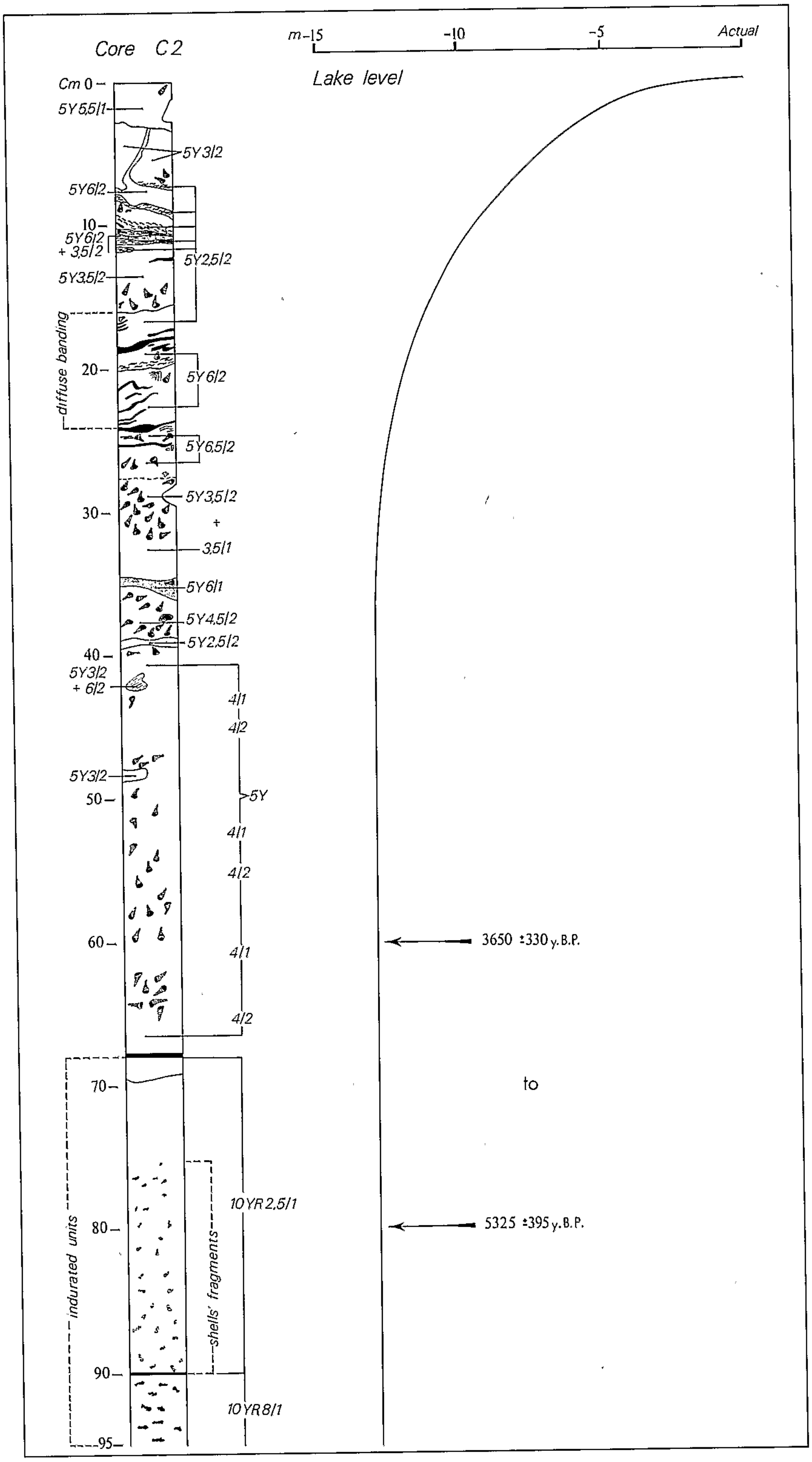

Fig.2. Core C2: Lithologic diagram and lake level fluctuation.

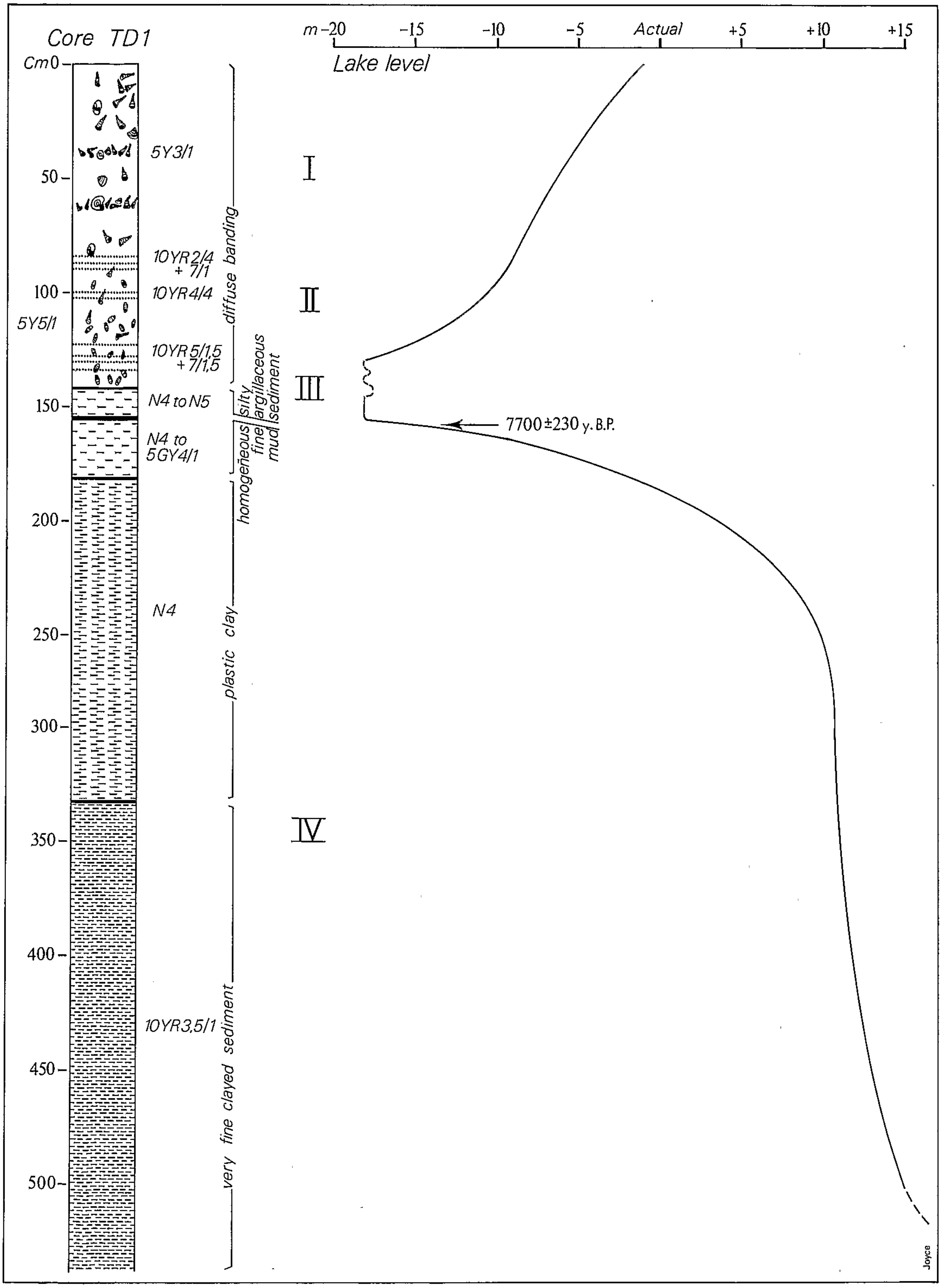

Fig.3. Core TD1: lithologic diagram and lake level fluctuation.

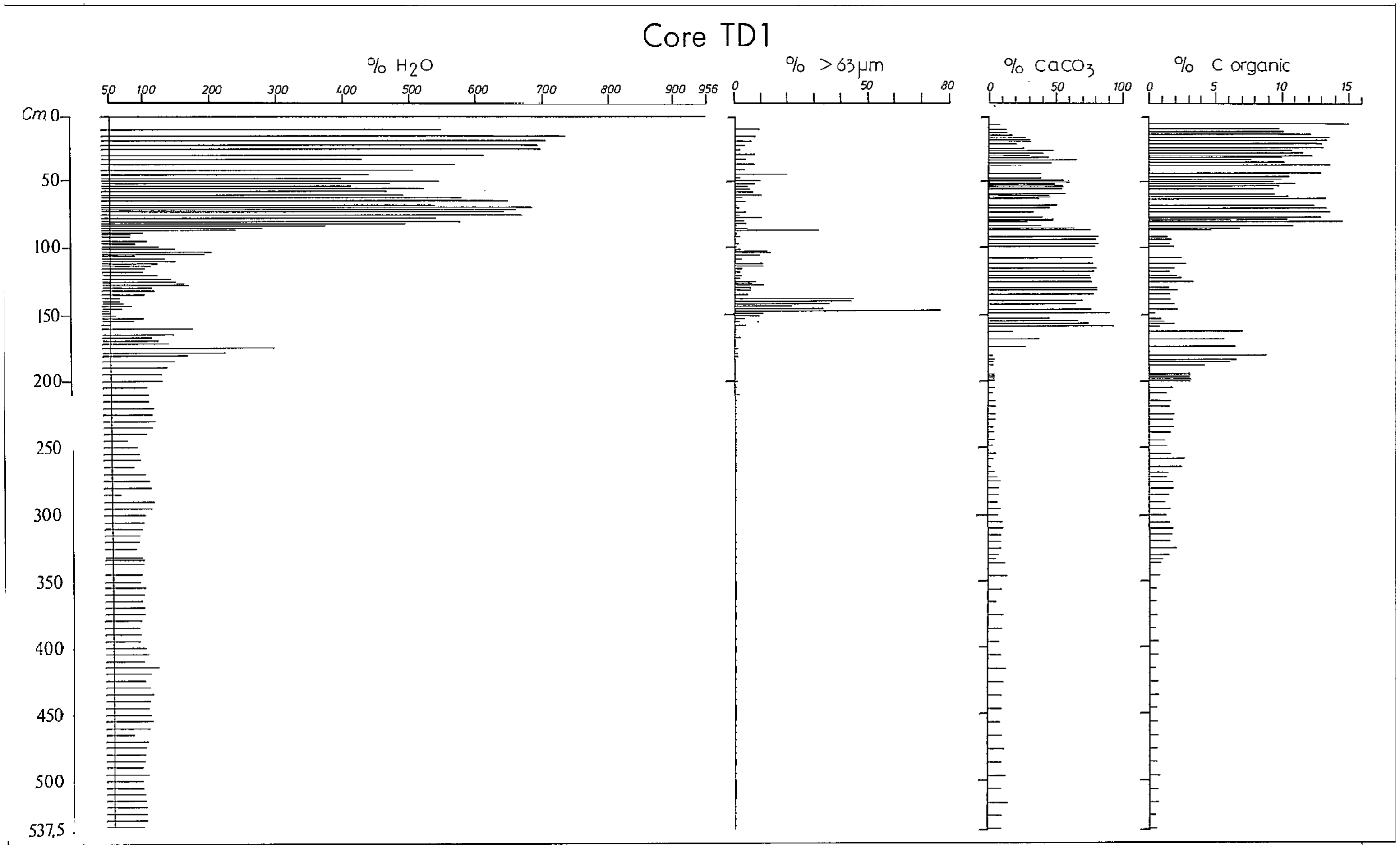

Fig.4. Vertical distribution of the physical properties of core TD 1.

TABLE I

Distribution of the main components of the coarse fraction in Core TD-1

Sequences	Level (cm)	Ostracods	Gastropods	Calcified macrophyte remains	Gyrogonites	Diatoms	Sponge spicules	Others
I	0–84.5	+ +	+ + +	+	–	t	–	–
II	84.5–132	+	+	+ +	+ + +	t	t	–
III	132–155	–	–	–	–	+	+	gypsum + + +
IV	155 537.5	–	–	–	–	+ + from 250 cm	+ + + from 170 cm	+ + + pyrite greigite vivianite detrital grains

t = trace; + = present; + + = abundant; + + + = very abundant.

coarse fraction is composed of syngenetic concretions, more abundant at the top of the sequence-associated with detrital grains (quartz, feldspar, etc). From the base to the top of this segment, the concretions are: vivianite, greigite and pyrite. From 250 cm, diatoms and sponge spicules are very abundant and the spicules compose 99% of the coarse fraction between 170–160 cm;

— sequence III (155–132 cm) is characterized by evaporitic grains in the shape of lenticular gypsum (some of the basal ones are corroded) and of small "roses des sables" more abundant between 155 and 148 cm;

— the silty fractions of sequences II and I consist of a majority of biocarbonated remains (shells and macrophytes).

One ^{14}C dating has been obtained from analysis of carbonates of the bulk sediment for level 158–157 cm and this yielded an age of 7700 ± 230 yr B.P.

The nature and texture of the basal samples are representative of a high water level sedimentary epoch, which gave rise to a strong biogenic production along the edges of the lake (possible formation of vivianite).

After this episode, a regression perhaps with minor oscillations, occurred, marked by gypsum precipitation, while the lower gypsum crystals were partly dissolved. A transgression followed and the sedimentation became more and more biogenic; firstly macrophytes, and then, shells. The depth corresponding to sequence II never exceeded 10 m, because none of the aquatic plants grew deeper than 10 m (Collot, 1980).

Discussion

Comparison between the two cores allows us to give a first interpretation of the lake level fluctuation during the Holocene for Lake Titicaca.

Prior to 7700 years ago, the lake basin was deeper than now and the deposits are characterized by fine clays. Sequence IV of Core TD1 is representative of such deposits which might partly correspond to the Tauca episode.

After 7700 years ago, a gradual decrease of the water occurred, until the establishment of evaporitic conditions in the central north hollow of the small lake. During this episode, seen in sequence III of Core TD1, the southern part of the basin was dry; the sharp contact between the basal unit and the intermediate brown deposits of core C2 must be attributed to the lack of sedimentation.

The following transgression is seen in core TD1 (sequence II) as well as in core C2. For this period, the calcareous deposits (including euhaline diatoms) indicate that the inflow of salt water came from the central main part of the lake and was going to the outlet of the Desaguadero river (Fig.1).

After 3650 years ago, the level of the lake has been rising progressively, to the present one; this is seen in sequence I of Core TD 1 and in the uppermost deposits of Core C2.

Conclusion

These preliminary observations demonstrate that during 4000 years the level of Lake Titicaca was much lower in comparison with the present one. According to sedimentological studies in progress, the lowering of the lake surface was at least 50 m.

The global nature of these changes in Lake Titicaca presents a good correlation with the glacial evolution in Bolivia. After the high lacustrine level stages Minchin and Tauca (the latter one took place after the glacial maximum of the last glaciation in the tropical Andes: Servant and Fontes, 1978) attributed respectively to increases of 75 and 50% of the rainfall on the Altiplano (Hastenrath and Kutzbach, 1985). The glacial evolution during the Holocene between 10,000 and 500 yr B.P. is marked by a general retreat of ice in the Bolivian Oriental Cordillera (Gouze et al., 1986), despite a temperature fall of 4–5°C during this epoch at high altitudes (Servant-Vildary, 1982). However, this evolution seems more related to a notable decrease of precipitation, which induced a global change of water flowing (Servant and Fontes, 1984). Parallel with the time intervals 7000–5000 and 3900–1400 yr B.P., the dense amazone forest, in the southeast of Bolivia decayed and disappeared (Servant et al., 1981).

Although it is still speculative to present a general interpretation for the climatic changes in the intertropical belt of South America, one can ascertain that the dryness between 7700 and 3650 yr B.P. was drastic and remarkably consistent. It is seen in the Brasilian Amazone forest between 4–6°S latitude and 56–54°W longitude (Soubies, 1979–1980), in Colombia (Van der Hammen, 1974) and on the Galapagos Islands (Colinvaux, 1972). The occurrence of a similar tendency recognized in North America (i.e. Pyramid Lake, Nevada: Benson, 1981; Lake Mendota, northern Midwestern U.S.A.: Winkler et al., 1986), suggests that these Holocene climatic variations imply a global meteorological change.

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