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Hydrobiologia 143: 191–197, (1986)

Late Quaternary palaeohydrology of Lake Huinaymarca (Bolivia)

Scenarios based on ostracods fauna

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Keywords: Lake Huinaymarca, Lake Titicaca, ostracods, paleohydrology

Abstract

In lake Titicaca, the distribution of the modern ostracod fauna appears to be controlled by a combination of two factors: a) the equilibrium between carbonates and organic matter, b) the ionic composition of the lake water and its tributaries. Therefore, the *Limnocythere-Pampacythere* group generally predominates on an alkaline-carbonate lake floor. In parts of the lake receiving an NaCl input from tributaries, *Cyprideis* and *Cyprinotus* occur. These are generally absent elsewhere. The *Candonopsis* group is found in the deepest part of the lake.

Analysis of ostracod assemblages recovered from a number of cores permitted the reconstruction of the hydrological evolution of lake Huinaymarca for the last 10000 years. This included: low water levels, variations of oxygenation related to the position of the thermocline, and interconnections between different basins of the lake.

Introduction

Lake Titicaca is located on the high plateau of Peru and Bolivia (Altiplano, about 3800 m high) between latitude 15°45′–16°30′ S and longitude 68°30′–70° W. Its surface area is 8000 km^2 (Fig. 1). It is divided into two sub-basins connected by the Tiquina Strait (20 m deep). The northern basin or Great Lake has a mean depth of 135 m while the south-eastern lake or Small Lake or Lake Huinaymarca is 9 m deep. Lake level fluctuations relate to seasonal phenomena (Carmouze *et al.*, 1978, 1981).

Lake Huinaymarca, which is the subject of our study here, is characterized by three interconnected sub-basins (Fig. 1):

a the eastern, which is fairly deep (3–10 m),
b the western, on average quite deep (10–20 m),
c the northern, which forms a 40 m depression (Chua).

The present-day outflow of the lake Huinaymarca is the Rio Desaguadero, which serves as a link with the rest of the Altiplano (Lake Poopo, etc.) area.

Surface sediments are either organic-rich or carbonate-rich, and their distribution is controlled by depth (Boulange *et al.*, 1981). The carbonate sediments occupy the eastern part of the lake (Figs. 1–2). Water masses in the Small Lake are poorly mineralized (2 mg/l) and predominantly carbonate/sodic in nature (Carmouze *et al.*, 1981), except on the coast, near the outlet of the affluents.

Modern day ostracod distribution

The lake comprises a relatively rich benthonic fauna, principally ostracods. Presence or absence of the ostracods appears to be controlled by distribution of the sediments and the depth: the deepest parts of the lake with organic rich sediments are without ostracods; areas situated up to 10 m with carbonate-rich sediments and charophytes well developed are very rich in ostracods. The effects of the ionic composition of the lake water is marked

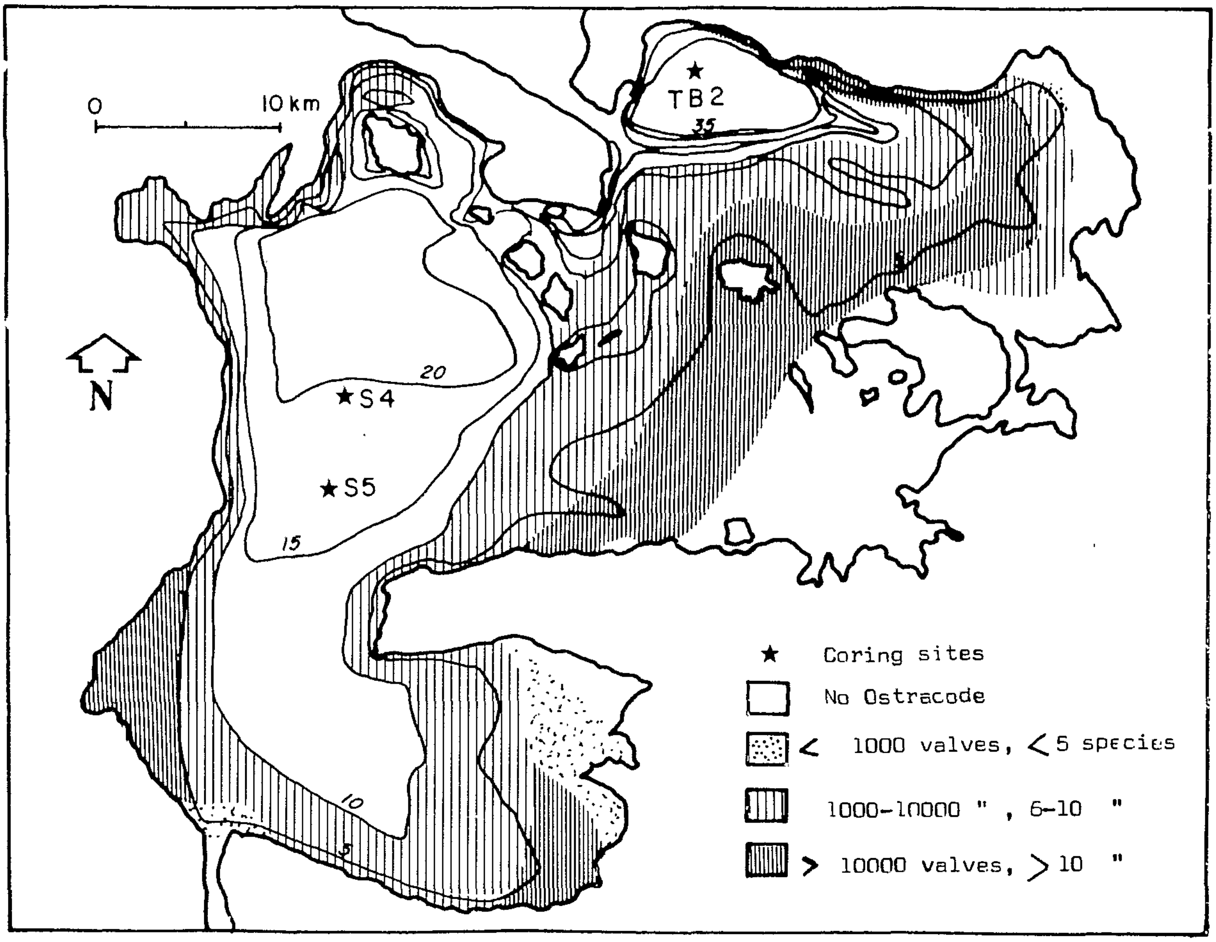


Fig. 1. Distribution of ostracod fauna and location of the cores.

specific composition of the ostracod faunas: the group *Limnocythere-Pampacythere* is generally dominant because the waters are mainly alkaline-carbonate (Carbonel *et al.*, 1983; 1983). In parts of the lake with waters rich in NaCl, *Cyprideis* and *Cyprinotus* generally occur (mouth of Rio Catari-Pallina). In deepest parts the *Candonopsis* group is dominant.

In sum, the ostracod distribution is closely related to development of macrophytes, especially charophytes, to chemical composition of the bottom waters, and to distribution of the sediments, according to the depth (Vargas, 1982, Carbonel *et al.*, 1983). These environments are the result of several processes which varied through time and which are herewith documented from the analysis of a range of cores taken from the lake (Fig. 1).

Analyses of the cores and interpretation of the results

Cores were recovered in the eastern basin (S4 and S5) within a depth range of 15–20 m, and in the Chua depression (TB 2) at the depth of 40 m. Additional sampling in the eastern part of the lake supports the following preliminary observations (A3, A4, B1, B2).

Core S4 (Fig. 3a)

Length: 90 cm and taken at 19 m. Three lithologic units are recognized (Vargas, 1982):

unit 1 (90–32 cm): biogenic-calcareous mud, rich in charophytes,

unit 2 (32–10 cm): organo-calcareous sediments,

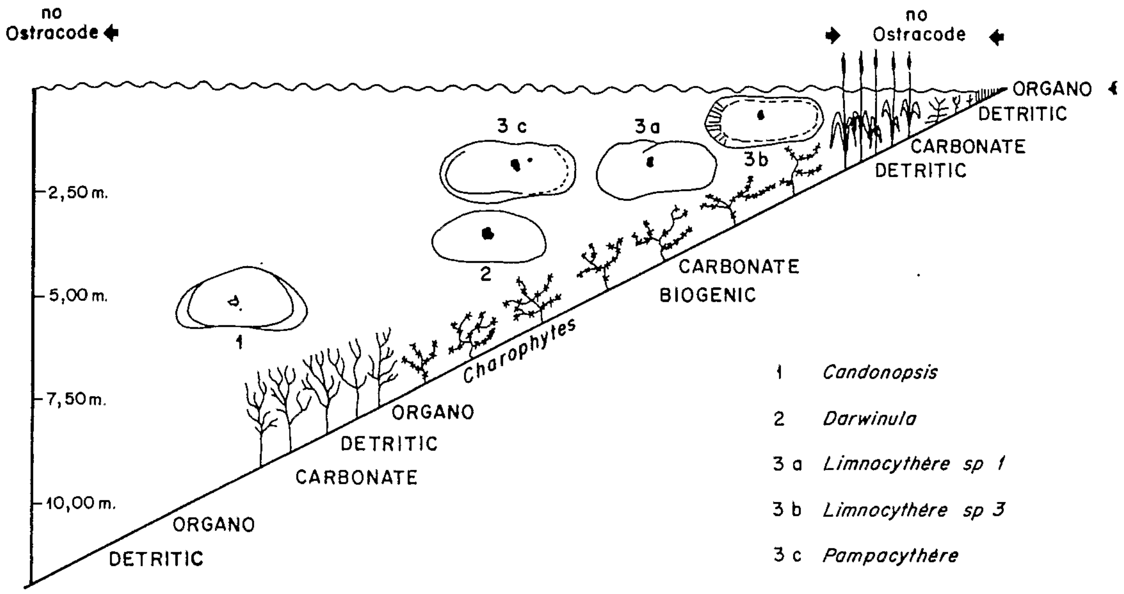


Fig. 2. Distribution of the main groups of ostracods related to water depth and sediment type.

unit 3 (10 cm – top): similar to modern-day muds.

Ostracods occur only in units 1 and 2. In unit 1, the fauna is rich and diversified, dominated by the *Candonopsis* group that characterizes the deepest environments colonized by the ostracods. In unit 2, there is a complete change in faunal structure and composition – density drops and diversity increases. The previously dominant species are replaced by faunas typical of Na, Cl waters: *Cyprideis* and *Cyprinotus*, and phytal forms. The passage from unit 2 to unit 3 occurs without any obvious transition.

Interpretation of the hydrochemical evolution of core S4: in the basal unit (1), there is evidence of an infralittoral calm environment with clear water masses with no obvious change. The overall faunal community points out to carbonate-sodic waters (Carbonel *et al.*, 1983). Unit 2, an important environmental change occurs; it probably relates to a lowering of lake level and waters become NaCl-rich and more saline. In unit 3, the absence of faunas, as well as the presence of organic sediment, imply a sudden deepening of the lake.

To sum up, core S4 testifies to a phase of low lake level, poorly saline waters but with distinct ionic composition, recorded by a change of ostracods assemblage (Carbonel *et al.*, 1983). This phase is followed by a period of lake level some 10 m below the present-day level.

Core TB 2 (Fig. 3b)

Length: 483 cm and taken in the Chua depression at a depth of 39 m. Four lithologic units were recognized:

unit 1 (480 – 360 cm): fine grained clay and azoic mud,

unit 2 (360 – 320 cm): clay vegetable debris and several shelley layers with polygonal agregates,

unit 3 (320 – 260 cm): clay-sand with few molluscs,

unit 4 (260 cm – top): organo-carbonate sediment rich in charophytes and gastropods.

Only unit 4 contains large numbers of ostracods. In this apparently homogeneous sequence, ostracofaunas undergo significant changes.

Interpretation of hydrochemical changes in summital unit of core TB 2: between 260 and 210 cm, the fauna is poor and poorly diversified. This low density and low diversity suggests the existence of an environment of less than 3 m deep with alkaline-carbonate waters. Between 210 and 160 cm, the microfauna diversifies and is more

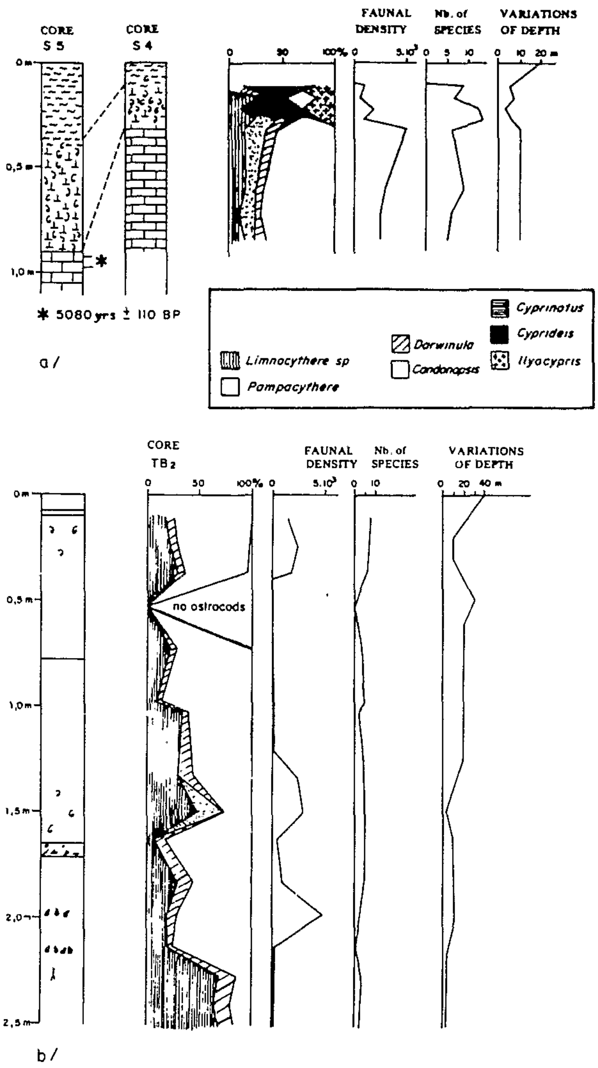


Fig. 3. Lithology and faunal distribution in two cores: a) core S 4 (western basin); b) core TB 2 (Chua depression).

abundant (*Candonopsis* dominance). It implies a significant deepening of the lake without any noticeable change in the water chemistry. Between 160 and 140 cm, the *Pampacythere-Limnocythere* group prevails over *Candonopsis* (< 30%). Furthermore, the biogenous fraction is made up of numerous molluscs, vegetable debris, diatoms and fishes, suggesting a shallow and probably well oxygenated environment, rich in nutrients. Between 140 and 60 cm, the ostracofauna is poor. The faunal assemblage is largely dominated by *Candonopsis.* The low number of individuals suggests a succession of phases with dominant stratification and phases with water mixing and circulation favouring colonization by benthic species. Between 60 and 40 cm, the disappearance of a microfauna reflects an increase in water depth, and consequently the development of a more marked thermocline. Between 40 and 20 cm, the ostracods are abundant and well diversified. It is similar to that at depth 210–160 cm, suggesting therefore a rapid lowering of the lake level. The top of the core is azoic and it corresponds to the thermal stratification conditions that prevail at the present day (Lazzaro, 1981).

Discussion

Evolutionary trends for the two cored sites vary in the following way: changes in water chemistry in the western basin at the water/sediment interface. In the Chua depression, the water chemistry remains the same; however, several hydrological variations were observed, suggesting the existence of a more or less ephemeral thermocline. These variations, in fact, result from lake level fluctuations.

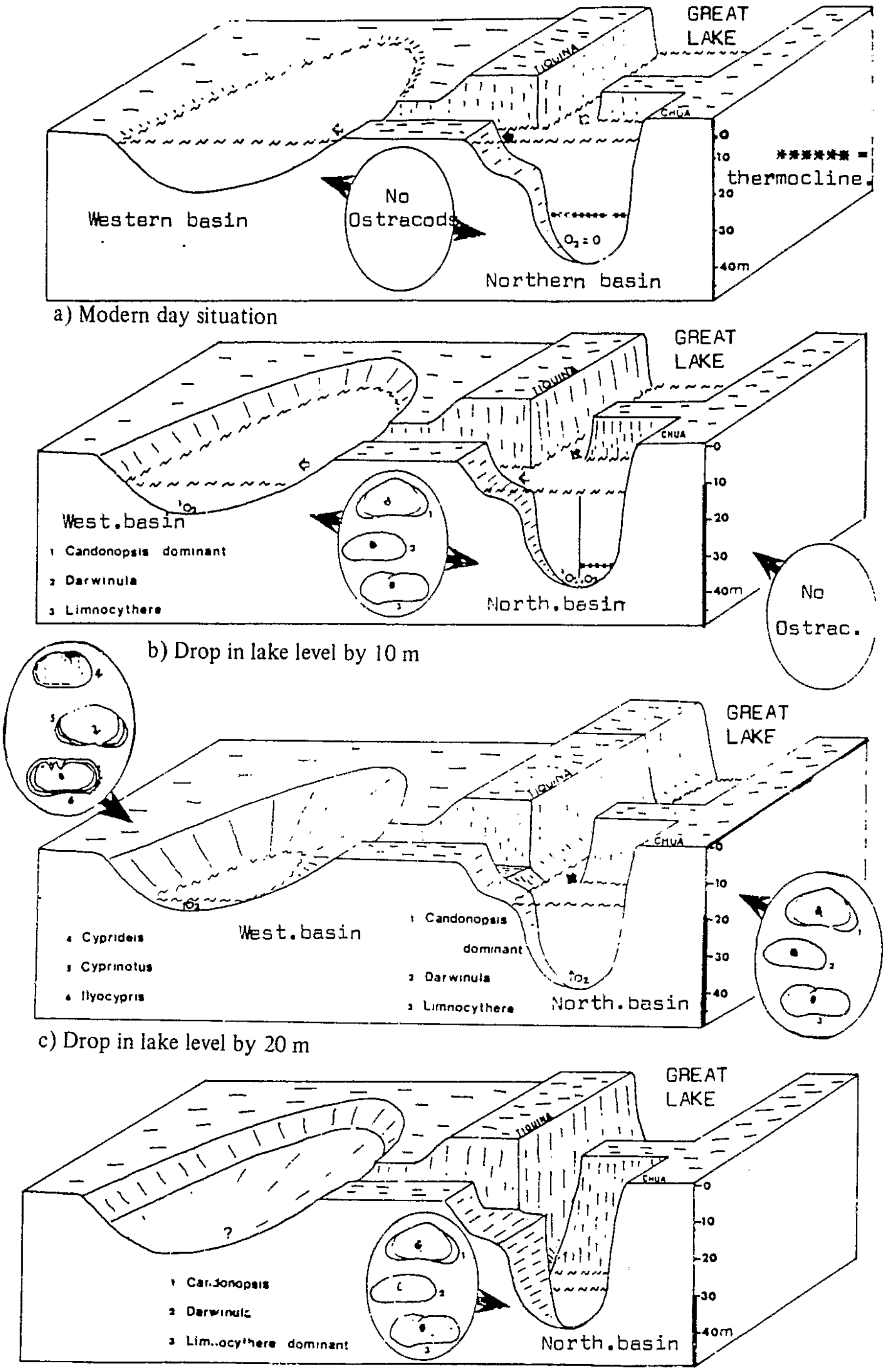
In the western basin, the change in water chemistry at the water-sediment interface is probably caused by a disconnection of the Great Lake. This qualitative change cannot however, be accounted for only by the lowering of the water level. It is likely that the presence of NaCl-rich waters resulted from an inversion of the circulation in the southern part of the lake. This would have provoked the arrival of waters draining evaporitic sediments deposited previously (Wirrmann, in prep.).

In the Chua depression, the seasonal thermocline, observable today, became increasingly ephemeral with the lowering of the water level and it finally disappeared. This is well reflected in the quantitative and qualitative structure of the ostracod fauna (core TB 2).

It is therefore apparent that all the changes mentioned above were triggered by the water level variations. Circulation patterns in both basins can also be inferred from the water depth. Assuming a sequence of water level drops, the following scenario can be envisaged (Fig. 4):

a) Today, the western basin and the Chua depression receive water from the Great Lake. The thermocline in the Chua depression is very high and water depth clearly controls the absence of ostracods (Fig. 4a).

b) A 10 m level drop: circulation and communica-



a) Modern day situation

b) Drop in lake level by 10 m

c) Drop in lake level by 20 m

d) Drop in lake level by 30 m

Fig. 4. Schematic diagram explaining the possible scenarios that would occur when the lowering of the lake is recorded, based on ostracods.

tion patterns are the same as above. As a result of this drop, reoxygenation at the water-sediment interface within the western basin is indicated by the fauna. The scarcity of the microfauna suggests a decrease in the thermocline of the Chua depression (Fig. 4b).

c) A 20 m level drop: circulation conditions within the Chua depression do not alter, but the thermocline disappears. The predominance of *Candonopsis* indicates a water depth of about 15 m. Communication with the western basin is, however interrupted (submerged ridges). Ionic concentration of waters increases, but more importantly, water chemistry changes (seen by the occurrence of *Cyprideis*), because of a probable reversal of the Desaguadero water and the arrival of Cl-rich waters from this particular region (Fig. 4c).

d) A 30 m level drop: communication with the Great Lake is minimal; the Chua waters just reach 10 m (*Limnocythere* predominance). The western basin is probably fully drained (Fig. 4d).

In sum, declining lake level leads to the isolation of basins and subsequently to a completely different chemistry at the water/sediment interface, probably due to a change in water quality. This change is well shown by the faunas (Table 1).

However, a question remains: how can lake level fluctuations be integrated in the evolution pattern since the last glacial maximum? For the time being, it is very difficult to propose a detailed chronology of the lake's fluctuating levels because of lack of dates. Nevertheless, results so far obtained suggest the timing of a low lacustrine level encountered in core S4: less than 5100 years B.P. and more than 3,650 years B.P. (Wirrmann *et al.*, 1983).

Conclusion

Preliminary results based on sedimentological analysis and the distribution of the ostracod fauna from two cores taken in the lake Huinaymarca show that significant water level fluctuations occurred in the lake after the last glacial maximum, i.e. at about 13000 years B.P. (Servant & Fontes, 1978). Environments determined by present-day faunas are also detectable in the past. Some of the faunal assemblages recorded in the sediments differ in structure from those represented at present day. They indicate environmental conditions and ecosystems for which no present day analogues exist, as well as different chemistry at the water-sediment interface and different water depths. These variations may, of course, be attributed to the level fluctuations and consequently to regional climatic variations. Nevertheless, one has to be aware that water chemistry and subsequently the river inputs are also controlled by the basin's tectonism.

Additional data, mainly from the polymorphism of the ornamentation of the shells analyses will provide further informations on the changes of water chemistry (Carbonel *et al.*, 1983), whereas sedimentological and mineralogical data will provide informations on the dynamic evolution of the lake (Servant & Fontes, 1984).

Finally, an accurate chronology of events should enable us to envisage possible 'scenarios', and thus reconstruct with more accuracy the history of the lake at the end of the Pleistocene.

Table 1. Scenarios of water circulation between Great Lake Titicaca and Lake Huinaymarca with lowering of the lake level by faunal recording.

	Faunas		Communications between	
	Western basin	Northern basin	Great lake/W. basin	G. lake/Chua
1 – Present level	No ostracods	No ostracods	+	+
2 – – 10 m	*Candonopsis* Limnocythere	No ostracods or very rare Candonopsis	+	+
3 – – 20 m	Cyprideis Cyprinotus	*Candonopsis* Limnocythere	–	+
4 – – 30 m	No ostracods	*Limnocythere* Candonopsis	–	±

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Acknowledgements

This work was carried out within the 'GEOCIT' research program part in cooperation between O.R.S.T.O.M. and the Department of Geology of the University of La Paz (Bolivia). We wish to thank P. de Deccker (Monash University, Australia) for revision of the text and Pr. Oldfield (University of Liverpool, U.K.) for his suggestions. We thank Mrs. D. Morel (I.G.B.A.) for translating our original text.

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Accepted 13 May 1986.