II.2. General aspects of present-day sedimentation

LUIS A. RODRIGO and DENIS WIRRMANN

The two principal parameters that control the distribution of the sediments in the lake are on one hand, the relation between allochothonous elements of dertrial origin, and autochothonous elements of bio-geochemical origin, on the other, the nature of bio-chemical sedimentation. Therefore, the different facies of the actual sediments will be defined in function of their carbonate concentration, determined by the Bernard Calcimeter, in organic matter measured by the ashing and insoluble residues left after the acid attack (left in acid solution).

The synthesis is a summary of the results presented by Boulange *et al.* (1981). These authors analyzed some 20 samples taken from the mouths of the main tributaries of the lake, and some from the affluents up river, as well as superficial sediments (top 20 cm) taken by Ekman grab in depths of less than 40 meters and by dredging in deeper water. Samples were taken from a total of 100 stations spread over the Lago Menor and the Lago Mayor.

Riverine inputs

These have been classified by attempting to take into account the homogeneity of the sources of each input (Fig. 1); four types of sand have been distinguished:

- *Sands of volcanic origin*: three types of mineral, occurring in variable proportions, are predominant: monoclinal pyroxene, hypersthene and green and brown hornblendes. The proportion by weight of heavy minerals is always greater than 1% (samples 21, 7 and 5). The light fraction is composed of quartz, labradorite and traces of mica.
- *Sands from Devonian formations* are characterised by a high proportion of tourmaline and weathered zircon associated with metamorphic minerals such as hornblende and andalusite (sample 9). The quartz, which dominates the light fraction, is associated with small quantities of plagioclases, kaolinite and smectites.
- *Sands from Carboniferous formations* have as their main characteristic

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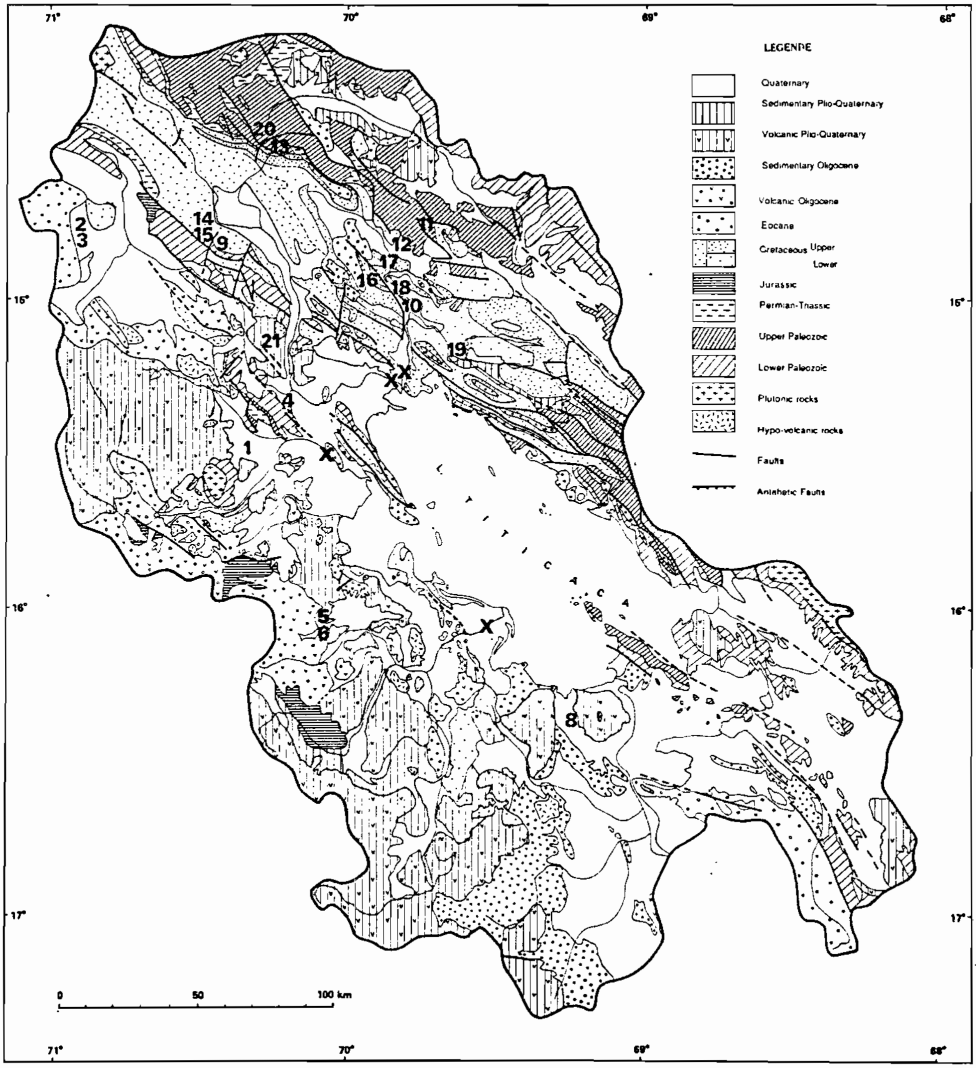

Figure 1. Geology of the catchment of Lake Titicaca and location of the sampling sites in inflow rivers used by Boulangé *et al.* (1981).

the presence of beautiful, clear, unworn andalusites with a salmon pink pleochroism (samples 2, 11 and 13). The light fraction contains quartz associated with traces of micas, plagioclases, kaolinite and smectites.

- *Sands from Cretaceous formations* are characterised by the abundance of very worn zircons and tourmaline (samples 10 and 19), sometimes associated with titanaugite (sample 14). The light fraction contains quartz and traces of plagioclases and smectites.

In terms of the lake inflow rivers, only the dominant characteristic of the catchment area are recognisable:

- The Río Ramis and its tributaries drain the four formations described above, but the volcanic formations are the one that determine the sand type;
- The Río Huancane has a relatively homogeneous catchment area draining Cretaceous landscapes;
- The Ríos Ilave and Coata transport sands characteristic of volcanic formations with a clay fraction dominated by montmorillonite associated with a little illite;
- The Río Suchez brings to the lake a sandy fraction formed mainly of quartz (due to the presence of aeolian dunes along its banks); the fraction in suspension is dominated by illite associated with a little montmorillonite and traces of kaolinite.

Lacustrine sedimentation

Six sedimentary facies have been defined (Fig. 2) in terms of their concentrations of insoluble residues, carbonates and organic matter.

A) The detrital facies (I)

These are sediments containing more than 70% of clastic components, less than 25% of organic matter and very little carbonate. They are distributed along the lake shores, at the mouths of inflows and in the the deep water zone of Lago Grande, with local differences in granulometry.

On the whole, the most coarse type consists of pebbles of sandstone, quartzite or volcanic rocks coming directly from the Plio-Quaternary formations bordering the lake and deposited on the beaches adjoining these outcrops (Fig. 1). Sandy beaches occur along the west coast of Lago Huiñaimarca and Lago Grande at the mouths of the Río Ilave and Suchez. In the latter, the sandy bottom extends for 5 km, reaching a depth of 50 m. Silty muds form homogeneous compact deposits, coloured brown by the presence of haematite. These occur at the mouths of inflow rivers, and form two large detrital fans in Lago Grande in the bay of the Río Ramis and in Puno Bay (Río Coata). The finest detrital deposits are silty-clay muds forming the superficial sediments in the central depression of Lago Grande.

B) The carbonate detrital facies (II)

These sediments contain less than 25% organic matter and 20 to 70% of carbonates. They are localised in the littoral zone, occurring between the

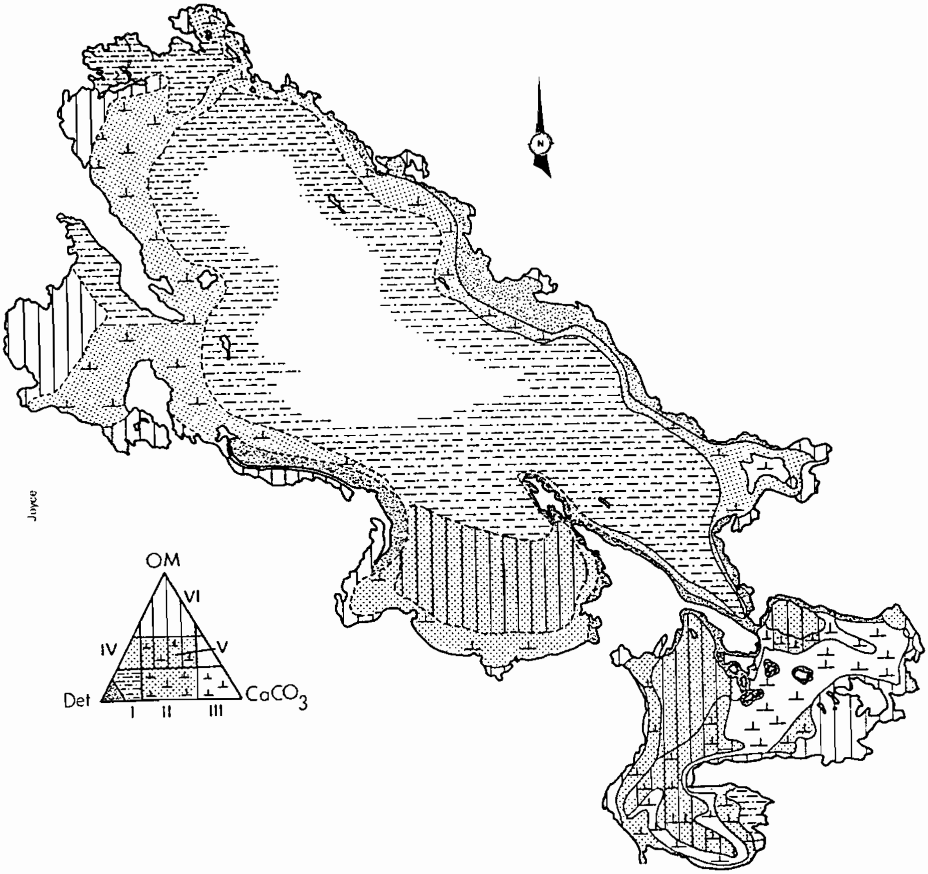

Figure 2. Distribution map of the surface sediment facies, adapted from Boulangé *et al.* (1981).

detrital (I) and organic (VI) facies. Despite similarities in facies between Lago Grande and Lago Huiñaimarca, the following differences should be noted:

- because of the abundant aquatic vegetation related to the shallowness of the water column, the organic content is higher in Lago Huiñaimarca (mean 17% compared to 12%) as is the $CaCO_3$ content (mean 44% compared to 34%).
- The residual, more sandy fraction, is greater in Lago Grande.

C) *The carbonate facies* (*III*)

These are sediments containing more than 60% of carbonates (calcite and aragonite) and less than 25% organic matter derived from plankton decomposition. These fluids, homogeneous sediments contain remains of macrophytes, mollusc shells and crustacean carapaces. The silty-clay fraction, making up 80% of the total sediment, is formed mostly of grains of calcium carbonate, associated with a small proportion of illite and montmorillonite. This facies occurs particularly in the zone occupied by Characeae, that is to say in depths of 4 to 10 metres and is better represented in Lago Huiñaimarca.

D) The organo-detrital facies (IV)

This facies, characterised by an organic matter content of between 25 and 50% and by less than 15% of carbonates, occurs in the deeper water areas of Lago Huiñaimarca (between 20 and 40 m) and between 80 and 100 m in Lago Grande. These are dark, gelatinous muds with a strong odour of hydrogen sulphide and contain very few shells.

E) The carbonate organo-detrital facies (V)

These are also gelatinous muds made of 95% silt and clay, containing some shells and plant remains and in which the organic matter and carbonate contents vary between 25–50% and 15–50%, respectively. It is intermediate between the carbonate (III) and organo-detrital (IV) facies and has only been recorded in Lago Huiñaimarca on flat bottoms between 10 and 20 m depth.

F) The organic facies (VI)

This is the sediment occurring in bays in shallow water areas (<2 m) where totora is abundant. The organic matter content exceeds 50% and there is very little carbonate. The detrital fraction (25 to 45%) is made up of medium and fine sands, silt and a high proportion of clay.

The spatial distribution of the various facies is related to water depth, as this controls the distribution of the aquatic vegetation, which plays an important role as filter for the allochthonous input. For example, in going from the shore to the centre of the basin in Lago Huiñaimarca, the following succession is recorded: in the shallow water areas (<2 m) either a detrital facies (I) in areas close to inflow rivers, or an organic facies (VI); then between 2 and 4 metres, the sediments are of the carbonate detrital facies (II), grading into the carbonate facies (III) in the zone of maximum development of Characeae. Between depths of 10 and 20 metres, the superficial sediments are of the carbonate organo-detrital type (V). Beyond the zone colonised by aquatic vegetation the sediments are organo-detrital (IV), the detrital phase having a finer grain size than at the lake margins.

The same sequence is found in the main bays of Lago Grande, but in the central basin itself the most common sequence is as follows:

- a zone of sediments of detrital origin, which can extend down to 50 m depth depending on the slope, with the grain size classification being of finer sands at the margins and of medium sands at between 20 and 50 metres depth.
- carbonate detrital sediments (or organo-detrital) between 50 and 100 metres depth and beyond this depth, fine detrital deposits.

The sedimentation dynamics are still poorly known, but the sedimentation rates vary according to the facies and between Lago Grande and Lago Huiñaimarca. For example in the case of carbonate deposits (III), Boulangé *et al.* (1981) give a velocity of sedimentation rate of 0.5 mm y^{-1} for Lago Grande, whereas in Lago Huiñaimarca this rate was 10 times higher (Wirrmann *et al.*, 1988). According to the latter, the sedimentation rate for the organo-detrital facies in Lago Huiñaimarca was of the order of 0.2 mm y^{-1}.

Plate 2. Above: very accidented reliefs resulting from the Andes formation occur at the altitude of the Lake Titicaca. They form high islands or steep margins as in many places along the Lago Grande shoreline. Center: view from the Tiquina Strait towards the Lake Huiñaimarca and the Taquiri and Paco Islands; Down: the lake region receives in sommer heavy rainfalls. Rain and hail are frequent but, despite the altitude, snowfalls are very occasional. (Photos Claude Dejoux.)

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