II. GEOMORPHOLOGY AND SEDIMENTATION
II.1. Morphology and bathymetry

DENIS WIRRMANN

At an altitude of 3809 metres above sea level, Lake Titicaca, the northern lake basin on the Altiplano (a high endorheic plateau in Peru and Bolivia) is the largest navigable water body in the world lying at over 3000 metres.

Following brief descriptions by Spanish chroniclers, the first scientific observations were undertaken by A. d'Orbigny during his voyage in South America (1826–1833). Until the turn of the century the map considered to be the most reliable was that made by Pentland, following two voyages on the lake (1827–28/1837–38). Further brief or multidisciplinary expeditions then took place, notably those of Agassiz and Garman (1876) and Créqui de Montfort and Sénéchal de la Grange, reported by Neveu-Lemaire in 1906. Each of these attempted to describe the precise geographical setting, with greater or lesser success. Following the last great multidisciplinary expedition, the Percy Sladen Trust Expedition (1936–39), more specialised studies started to be carried out.

Only the most recent data are taken into account in this synthesis chapter. The main reference work is that of Boulangé and Aquize Jaen (1981), the cartographic material used being the 5 maps at 1/100,000 published in 1978 by the Hydrological Services of Peru and Bolivia (Hidronav, 1978) which were drawn from 7000 soundings to the nearest 0.1 m, based on the average measurements over 41 years of observations.

The catchment area

This is shared unequally between the Republics of Peru and Bolivia, with its long axis running NNW-SSE, the coordinates of its extreme points being as follows (Fig. 1):
14°09′06″–17°08′29″ latitude south
68°03′34″–71°01′42″ longitude west

To the north, the catchment area is bounded by the Vilcanota Cordillera culminating at 5480 m, at a point where the eastern and western Cordilleras join and which marks the limit of the Altiplano.

C. Dejoux and A. Iltis (eds.), Lake Titicaca, 16–22.

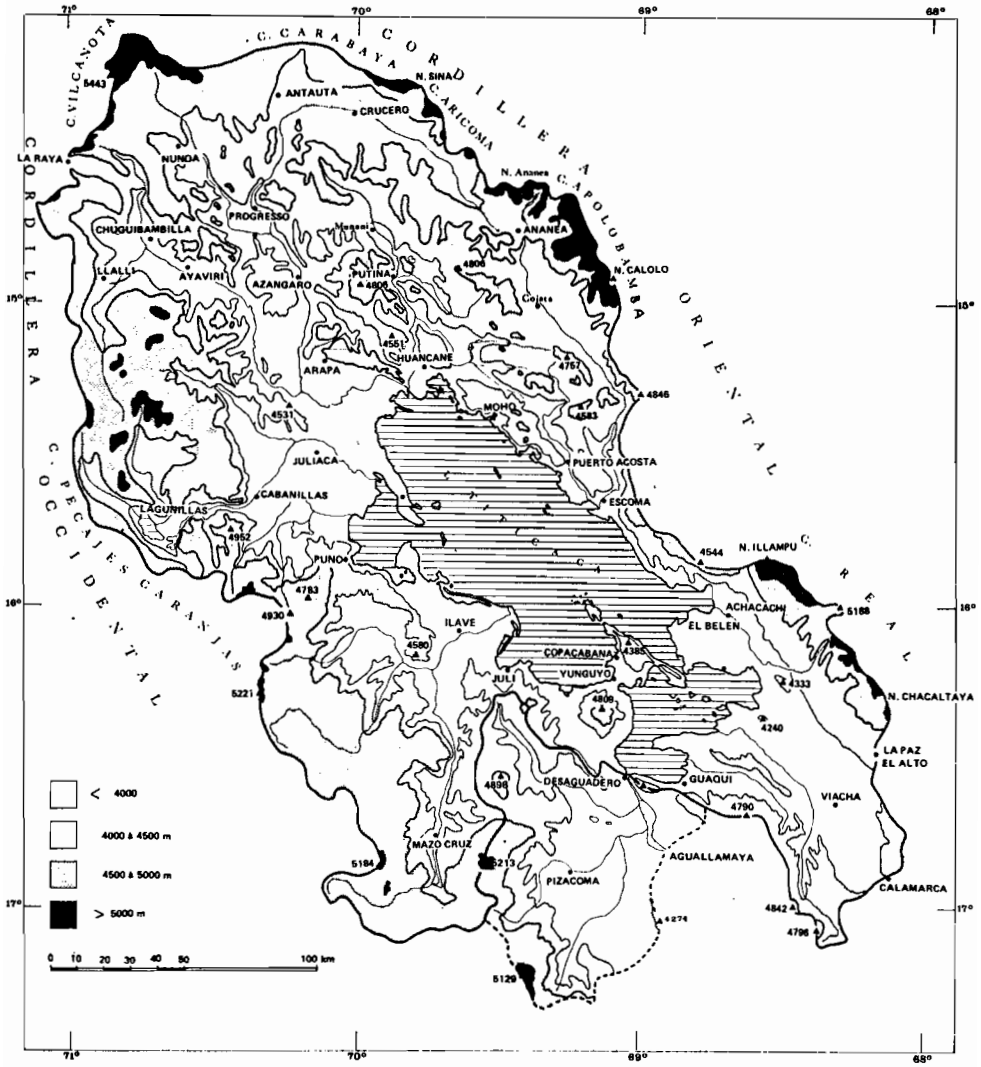


Figure 1. The Lake Titicaca catchment area (adapted from Boulangé and Aquize Jaen, 1981).

The eastern boundary follows the line of the summits of the Carabaya and Aricoma Cordilleras (altitudes over 4800 m) then curves in towards the south to follow the Cordillera Apolobamba whose general level slopes down to 4800 m.

Further south, the limits of the catchment approach within 10 km of the lake and the altitude is of the order 4500 m. This narrowing of the catchment area is related to the heavy erosion on the Amazonian flanks by the Rio Beni, which penetrates the Cordillera up to the foot of the Illampu peak (highest point of the catchment at 6322 m), between the Apolobamba and

Real Cordilleras. The eastern boundary continues along the Cordillera Real and then follows the edge of the Altiplano in the La Paz region (4000 m altitude).

The southern flank of the catchment area runs along summits ranging in height between 4500 and 4800 m and is open to the south by the sole outflow from the lake, the river Desaguadero, which then flows south to drain into Lake Poopo.

The western boundary runs north-west – south-east along the western Cordillera, whose summits do not exceed 5000 m altitude.

The lake basin

The Lake Titicaca basin, having the same orientation as that of the catchment area, is divided into two sub-basins (Fig.2):
–in the north the Lago Grande or Great Lake,
–in the south, the Lago Menor or Lago Huiñaimarca, joined by the Tiquina strait which is about 850 metres wide with a maximum depth of 21 metres.

The geographical limits of the lake are as follows:
15°13′19″–16°35′37″ latitude south and 68°33′36″–70°02′13″ longitude west.

The 915 km long shoreline is poorly defined to the north and west where it merges with the flood plains of the main inflow rivers. The eastern shoreline, in contrast, is better defined since it follows a fault line.

The greatest length over water measured between the furthest points on the shore along NNW-SSE line passing through the Tiquina strait is 178 km, and the greatest width at right angles to this axis is 69 km in Lago Grande and 41 km in Lago Huiñaimarca.

Measurements of the area and volume of Lake Titicaca vary slightly depending on the methods of calculation used -planimetry (Tables 1 and 2) or direct calculation from the Hidronav data (Table 3). These differences lead to estimates which are not incompatible with one another, since a drop in water level of 1 m from the current level (3809 m above sea level) would lead to a decrease in water area of 1000 km^2 and a decrease in volume of about 8 km^3.

From direct calculations from cartographic data, the total area of the lake is 8562 km^2 and the volume of water 903 km^3, the area of the islands being negligible (1.3 % of the total area).

Lago Grande

Block diagrams made from sounding points enable 4 bathymetric zones in Lago Grande to be differentiated (Figs 2 and 3): (Figure 3 can be found as a separate figure at the end of the book)
– a deep water zone over 200 metres deep in the central part of the lake;

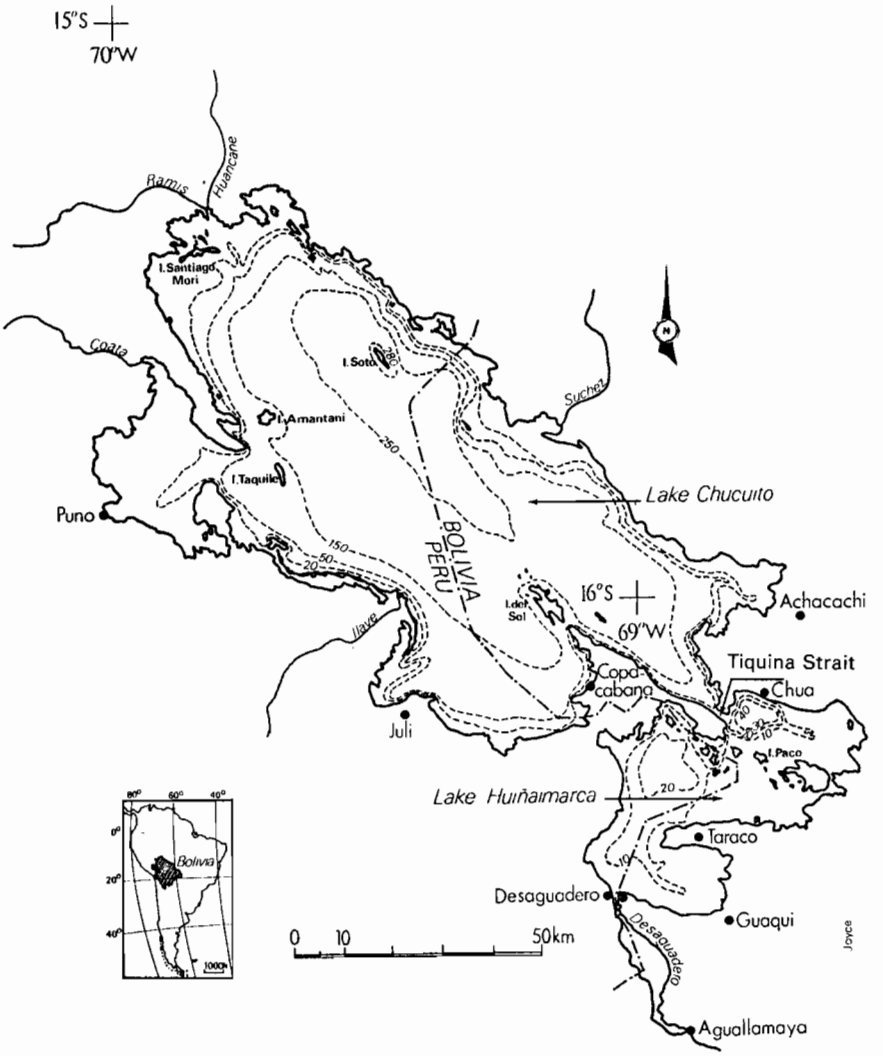


Figure 2. Bathymetry of Lake Titicaca (adapted from Boulangé and Aquize Jaen, 1981).

the deepest point measured by Boulangé and Aquize Jaen (1981), situated near Soto island, was 284 m deep;

- a zone of moderate depths of between 100 and 200 metres depth, best developed along the western margins of Lago Grande;
- a zone of intermediate depths of between 100 and 20 metres, occupying parts of Puno and Achacachi Bays;
- and finally the littoral margins, with less than 20 metres water depth, very narrow along the eastern shore but well developed in the Puno, Rio Ramis and Achacachi Bays.

As a general rule, Lago Grande is characterised by a steeply shelving

Table 1. Morphological parameters of the lake (from Boulangé and Aquize Jaen, 1981)

	Lago Mayor	Puno Bay	Total	Lago Menor	Lake Titicaca
A km²	6542	589	7131	1428	8559
A_I km²	49	1	50	61	111
A_I / A %	0.7	0.1	0.7	4.2	1.3
A_E km²	6493	588	7081	1367	8448
L km	151	41		62	178
I_M	69	30		41	69
I_m	43	14	47	23	48
Z_M	284	51		42	284
Z_m	135	8	125	9	105
Z_m / Z_M	0.47	0.16	0.44	0.21	0.37
C km	455	155	610	305	915
DC = C / $\sqrt{\pi . A}$	1.59	1.80	2.04	2.28	2.79
V x 10^9 m³	878.7	4.8	883.5	12.36	895.86

Table 2. Relation between surface area/depth and volume/depth (from Boulangé and Aquize Jaen, 1981)

Depth in m	Water surface area km²	%	Volume m³ x 10^9	%
Lago Mayor and Puno Bay				
0	6493	100	124.5	14.1
20	5407	76.3	153.3	17.4
50	4816	68	217.2	24.6
100	3886	54.8	180.3	20.4
150	3332	47	130.5	14.8
200	1948	27.5	66.6	7.5
250	800	11.3	11.1	1.2
284				
			883.5	100
Puno Bay				
0	588	100	1.95	40.3
5	221	37.6	0.91	18.8
10	146	24.8	1.09	22.5
20	75	12.8	0.89	18.4
50	2	0.3	0.002	0
52				
			4.84	100
Lago Menor				
0	1367	100	5.27	42.7
5	768	56.2	2.97	24.0
10	434	31.7	2.90	23.5
20	167	12.2	0.98	7.9
30	44	3.2	0.20	1.6
40	4	0.3	0.04	0.3
42				
			12.36	100

Table 3. Relation between surface area/depth and volume/depth (from Boulangé and Aquize Jaen, 1981)

Lake Titicaca				
Depth in m	AREAS km²	%	Volume $m^3 \times 10^9$	%
0	8562.7	100	903.7	100
1	7541.5	88	896.2	99
2	7304.7	85	888.9	98
3	7052.7	82	881.8	97.5
4	6889.5	80	875	97
5	6754	79	868.2	96
10	6269.5	73	836	92.5
15	5963	70	805.5	89
20	5714	67	776.5	86
25	5606.5	65	748.2	83
30	5500.7	64	720.5	80
35	5411.2	63	693.3	77
40	5320.7	62	666.5	74
45	5249.2	61	640.1	71
50	5167.2	60	614.1	68

bottom from straight off the shore and its mean depth is 135 metres. The islands represent less than 1 % of the total area of 7132 km^2, which itself represents 84% of the total area of lake Titicaca. The volume of Lago Grande is 889 km^3, or 98.5% of the total water volume.

Lago Huiñaimarca

From the figures given above it can be seen that Lago Huiñaimarca only makes up a very small proportion of the total water volume, although its area of about 1470 km^2 represents 16 % of the area of Lake Titicaca. This reflects its shallow mean depth (9 m) and the large area (of the order of 56%) less than 5 m in depth.

Three bathymetrical zones are differentiated (Figs 2 and 3):

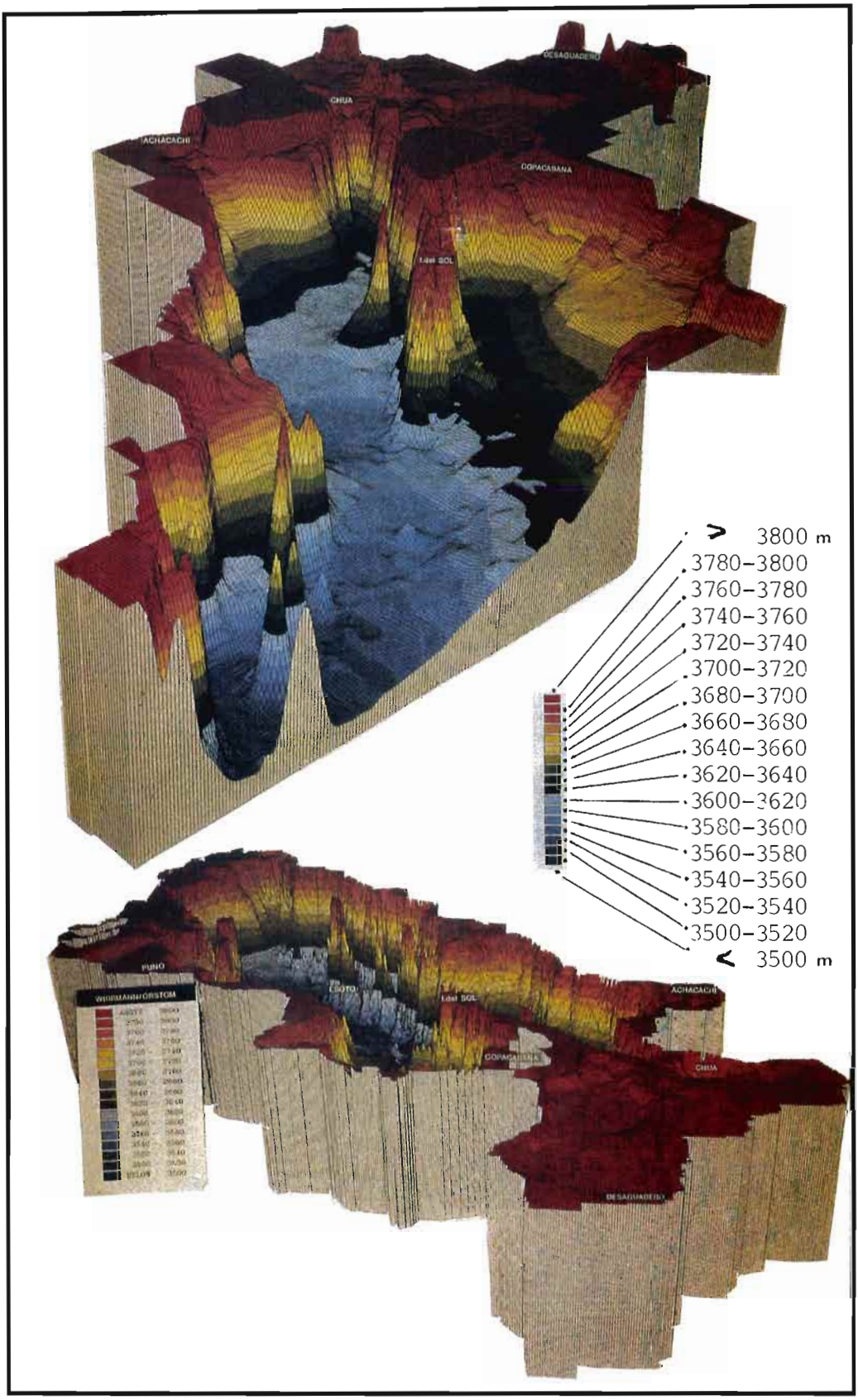
- the deepest zone down to 41 m in the north, known as the Chua trough,
- a central basin in the centre-west beyond the line of islands with a maximum depth of 20 metres,
- a shallow area extending between and around these two zones, with a sill about 7 metres deep between the Chua trough and the central depression.

As a general rule, the slopes are very gentle, with the exception of the eastern margin of the Chua trough. The outflow of the Rio Desaguadero is not deeply cut, but forms a sill (5 metres deep) so it is only when the lake level is at 3804 m or higher that the lake and the upper reaches of the Desaguadero are in communication. The current at the outflow from Lake Huiñaimarca is slight, and sometimes even reversed (Carmouze and Aquize Jaen, 1981), the true outlet being situated further south at Aguallamaya (Fig. 2).

At the point where the Tiquina Strait enters Lago Huiñaimarca there is

a sill 21 m deep. Lago Huiñaimarca would thus appear to be a basin that could have functioned as an entity independent of the Lago Grande in the past and in which two separate basins could have existed (see Chapter III).

Plate 1. Computed depth diagrammes of the Lake Titicaca.


DESAGUADERO
CHUA
ACHACACHI
COPACABANA
Isla SOL
> 3800 m
3780–3800
3760–3780
3740–3760
3720–3740
3700–3720
3680–3700
3660–3680
3640–3660
3620–3640
3600–3620
3580–3600
3560–3580
3540–3560
3520–3540
3500–3520
< 3500 m
PUNO
WORMANN/ÖRSTOM
ACHACACHI
COPACABANA
CHUA
DESAGUADERO

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