



## XXIV.

## HYDROGRAPHIC SKETCH OF LAKE TITICACA.

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FROM the position of Lake Titicaca, its exploration promised to give interesting results in Natural History, judging at least from the materials collected in lakes situated at great heights. It was therefore with considerable disappointment that my companion and myself after a protracted examination of this great sheet of water examined our plunder. We had come prepared with all the necessary apparatus for dredging, for taking observations of temperature and making soundings; and, with the facilities placed at my command by the Peruvian government, we hoped to gather a rich harvest. Mr. Garman spent nearly six weeks in skirting the shores of the lake, stopping at all convenient places for making collections of the Fauna of the lake and of its shores, and for exploring the ancient remains found on the islands in the lake and at several points in the vicinity of the shore line. While Mr. Garman was sailing on the lake in a small iron sloop, the only sailing vessel on the lake, if we except an old flat bottom ferry plying across the Straits of Tiquina, I made two expeditions in the steamers "Yavari" and "Yapura" placed at my disposal by the Peruvian government, landing at all the noted points where interesting Inca ruins existed: the islands in the lower lake, the islands of Coati and of Titicaca, Copacabana, and Tiaguanaco. During these two expeditions, I crossed the lake longitudinally twice, and ran several lines of soundings from shore to shore. The captains of the government steamers, Capt. F. Guerrero especially, taking the greatest interest in my proceedings and assisting me in all possible ways, sparing neither time nor pains to secure proper observations. The first mate of the "Yavari" was fortunately assisted by a number of English sailors, who were devoted in hauling the sounding lines at all times of the day and during all kinds of weather. The sketch map accompanying this notice is compiled from the map of Thompson and of Pentland, with such corrections of the shore line as we could make from per-

sonal examination. The latitude as given by Pentland,  $16^{\circ}$  S. for the northern extremity of the Island of Titicaca, is very nearly correct, Capt. Guerrero and myself having taken several sextant observations off the northwest point of the island, which agreed quite closely with Pentland's positions. The longitude of Puno, however, as given by Pentland,  $70^{\circ}$  W., is probably not quite correct, and too far to the eastward. The distance of Puno from the harbor of Mollendo being only seven minutes in time, as ascertained by telegraph between the two points, of course this is approximate; while taking the longitudes as given on the English admiralty map  $73^{\circ} 39'$  for Mollendo, as given by Fitzroy, and  $70^{\circ}$  for Puno, by Pentland, the difference of longitude is somewhat greater, more than  $3^{\circ}$ .

Mr. Garman and myself took more than sixty-five soundings, from which a number were selected to represent the surface of the bottom. The whole bottom of the lake in its deepest parts, and frequently quite close to the shore, up to the point at which the myriophyllum and the totora grow so plentifully in certain localities, is covered by a thick bed of mud, the finest possible greenish black silt. This bed of mud must have been several feet in thickness, to judge from the ease with which the heavy sounding leads disappeared in it. It contained but few fragments of shells, being almost always made up of pure fine mud. It was only in a small number of localities near the shore, and away from the mouth of any rivers, that occasional patches of sand and of shelly or rocky bottom were found. In the lower lake, however, the bottom was generally sandy, the water having deposited the bulk of the matter held in suspense before reaching the Straits of Tiquina. At the time of our visit to the lake, although during the last part of the rainy season, when all the rivers pouring into the lake were very high and turbid with the mud and materials they brought down from the mountains, yet, a short distance from the shore, the surface water was remarkably pure and clear. According to an analysis made by Professor Raimondi of Lima, there is but a mere trace of saline substances, and not sufficiently large to affect the potability of the water. Having an outlet to Lake Aullagas through the Desaguadero, there is no chance for an accumulation of saline matter, while Lake Aullagas is already, as I am told, somewhat saline, and the sink into which that pours is quite saline. The unpleasant taste of the lake water near the shore is due to the immense amount of decayed vegetable matter abounding in the extensive fields of myriophyllum and of totora, which line the shores for miles, and which extend to a depth of from six to seven fathoms. The totora fields are most extensive in Puno



Bay and the southern shores of the lower lake. The *myriophyllum* grows very luxuriantly, and forms an important article of food for the cattle of the lake shore. It is not an uncommon sight to see the cows of Puno wading up to their middle in the water, and diving boldly in search of their food which they cannot find on the shore. This habit has as yet produced no apparent effect on these amphibious cows, although carried on for a good many generations. The fields of *Totora* are also the feeding places of the myriads of aquatic birds which abound along the lake shore, and which are the most characteristic feature of the Fauna of the lake. The fishes and reptiles are not numerous,\* and our collections of the former showed a poverty in species which is most remarkable, and this is also accompanied by a comparative poverty in the number of specimens, except in certain localities. The scarcity of fishes can, however, be readily explained when we examine the physical condition of the water, which is certainly not well adapted to them. In the first place, the whole bottom of the lake, as I have mentioned before, is covered with silt, thus rendering unfit a large part of the area of the lake for the fishes and reptiles, leaving only the shallower bays, a more or less wide belt along the shore according to the nature of the adjoining country, and the lower lake, which appears to be the favorite fishing post of the Indians. This, however, may be due to the greater energy of the Bolivian Indians, who are a finer set of men, more willing to work, and in every way superior to the lazy natives found near Puno and the northern end of the lake. In the second place, the temperature of the water of the lake is so high that none of the fishes which abound in the lakes of our temperate zone are to be found. There are in all only six species of fishes, Cyprinoids and Siluroids, — a remarkably small number for a sheet of water as large as Lake Erie. They were all known before. In the way of reptiles, the most interesting species was a huge frog, which remained often for hours perfectly quiet on the bottom, suspended on fronds of *myriophyllum*, apparently too lazy to come up to the surface to breathe.

The effect of the vertical sun upon the temperature of the water is very marked, extending to its deepest point, and heating the whole body of water to such an extent that the greatest difference we observed was in one case, it is true, as high as  $6\frac{1}{2}$  degrees at a depth of 103 fathoms; but the usual difference between the surface and

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\* See Bull. M. C. L. Vol. III. No. 11.

the bottom, even at the greatest depth (154 fathoms), was not more than from 3 to 4 degrees. The lowest temperature of the bottom was only  $51^{\circ}$ , the general temperature varying from  $54$  to  $55^{\circ}$ ; while the surface temperature ranged from  $53$  to  $59^{\circ}$ , the greater part of the time  $56$  to  $57^{\circ}$  Fahr.

We used the ordinary deep-sea thermometer of Miller Casella, kindly loaned to me by Captain Patterson of the United-States Coast Survey. As is well known, deep-sea observations show that the effect of the sun does not extend in the ocean much beyond 50 fathoms; but, in a closed basin like this, at so great an altitude, the effect of the direct rays of the sun passing through so little atmosphere is very great. It must be remembered, that, even in the winter months of that region (the dry season), the sun never goes farther north than  $52^{\circ}$ , and that only for a short time; and that, in the summer months (the rainy season), it is nearly vertical the greater part of the time. The water, of course, retains its heat readily, and, even in summer, is but little cooler than the surrounding air, which becomes very rapidly chilled by the least cloud interposing between it and the sun. It is a very common thing for the thermometer to rise or fall eight or nine degrees in as many minutes from the effect of the sudden appearance or disappearance of the sun. Ice is said to form only in small quantities along the shores or shallow places: this is easily imagined when we take into account the immense body of water which must be cooled, 120 miles long by 30 wide, and an average depth of about 100 fathoms; the surface of the lake, even in winter, receiving a large amount of heat by absorption, although the air itself is uncomfortably cold. We find here, as is the case in many other sheets of water comparatively isolated, but few species, and these peculiar to the lake. We find at this great elevation a condition of things reminding us of the marine life of arctic regions, — a great abundance of specimens, with a comparatively small number of species; the shoals of *Orestias* and *Siluroids*, which are seen in certain localities, agree with the accounts we have of the swarms of fishes and other animals haunting the arctic realms. Still there are peculiar physical conditions of the bottom of the lake, the immense deposits of mud formed by the settling of the silt brought down annually by the mountain-streams, the great elevation of the lake, the high temperature of the water; all of which causes should tend to specialize to a remarkable degree the genera found to thrive in such a condition of things. We find, however, no such specialization brought about among the fishes: on the contrary, their isolation, even while living under such peculiar physical

conditions, appears to have deprived some of them, at any rate, of any capacity for development in the direction of their congeners. The genus *Orestias* is closely allied to *Fundulus*, one of the most widely distributed of fresh-water genera. The species of the genus *Orestias* resemble in a remarkable degree the young of some species of *Fundulus*, and might be considered, without exaggeration, its embryonic type, at a time when the young *Fundulus* is remarkable for its large head, prominent opercula, its large scales resembling plates along the anterior part of the back and sides. The other genera of fish found in the lakes are eminently fresh-water, having a great geographical distribution. The great number of water-birds recalls to us vividly also the more northern marshy regions, where thousands of ducks and water-hens abound. The mollusca are all species of eminently fresh-water genera, showing nothing very special. The crustacea, on the other hand, belong mainly to the *Orchestiadae*, forms which thus far have not been found in fresh water at all: their nearest allies are nearly all marine (see Bull M. C. L., vol. iii. No. 16).

Although we have from the researches of several geologists, but of Darwin mainly, a pretty good general idea of the immense extent of territory which has been subject to a greater or less elevation along the whole west coast of South America, from the south coast of Ecuador to the eastern coast of Patagonia, this elevation appears to have culminated in Central Peru. Yet there has been nothing shown which would lead us to assume such an immense elevation of the land as 12,000 feet. It is very true that Darwin showed the most positive proof of elevation to a height of about 600 feet; while terraces, shingle-beaches, and other more or less distinct traces of the former level of the sea, he traced to a height of from 1,300–1,500 feet. I have been able to follow up these traces of elevation somewhat higher, having found at Tilibiche, at a height of 2,900 feet above the level of the sea, corals of genera closely allied to those now found living in the West Indies (see Bull M. C. L., vol. iii. No. 13). These corals were attached to rocks, in crevasses formed between them, much as we would find them attached at the present day in the cracks of rocks. This being near the northern extremity of the nitrate-fields of Peru, throws considerable light on the probability of these deposits having been of marine origin. In fact, the geography of the whole of the west coast of the Andes to the north of Chili seems to point to a former condition of things such as we now find on the west coast of Chili. The plains to the southward of Santiago, bounded by the coast range to the westward, and the Andes to the east, gradually pass to

the condition of the coast now prevailing at Concepcion Bay, and south of it, — the coast range forming the archipelago, the Andes forming the coast range, and the plains of the more northern regions becoming changed to bays; the immense basins succeeding each other towards the north which form the so-called Desert of Atacama, the nitrate-beds, the llanos of the coast, the pampas of Peru, through which the rivers flowing to the west have cut deep valleys with more or less marked terraces, showing the different periods of ascent in the elevation of the continent. These plains are everywhere found, either between a coast range and the base of the eastern talus of the Andes, or extending from the summit of the shore terrace, if we may so call it, generally at a height of from 1,200 or 3,000 feet, sloping to the second terrace, with its base at an average height of from 6,000–7,000 feet, and then followed by a second and third more or less indistinct terrace until we reach the main elevated plateau or basin which lies between the eastern and western slope of the Andes. All these basins show more or less distinctly the trace of their former marine origin; so that, if we are to judge from the presence of strictly marine forms, the successive terraces developed on a magnificent scale on the west coast of the Andes, with the interlying basins, we have a fair presumption that the elevation of the Andes to their present height has taken place at a comparatively recent date, and during their upheaval the present nitrate district and saline deposits were left as large lagoons during a considerable period, to judge from the great thickness of the deposits found within their basins, all denoting the presence of a comparatively quiet inland sea.

Lake Titicaca itself must have, within a comparatively very recent geological period, formed quite an inland sea. The terraces of its former shores are everywhere most distinctly to be traced, showing that its water-level must have had an elevation of 300 or 400 feet at least higher than its present level. This alone would send its shores far to the north in the direction of Pucara, forming a narrow arm reaching up to S. Rosa. Lake Arapa is probably only an outlier of the ancient lake, as well as several of the small lakes, now at a considerable distance from the west shore. The immense plain of Cabanillas, extending north beyond Lampa to Juliaca, only 100 or 120 feet above the lake at its highest point, was one sheet of water. The terraces of the former shores are still very distinctly seen. The eastern shores did not probably differ greatly from the present outline, though the peninsula of Achacache was probably an island. The Bay of Puno must have been connected with the plains of Llave,

and those back of Juli; while from the lower lake, back of Aygache, the lake formed huge inlets or deep bays, now represented only by the nearly dry river-beds flowing into the lake at Aygache, Corilla, and Guajui. The sluggish Desaguadero must have been a strait of considerable width, with large islands; and this long lake, connecting Lake Titicaca with Lake Aullagas, must have equalled in extent the upper lake; the upper lake, at that time, extending across the Isthmus of Yungyu, leaving the Peninsula of Copacabana as a large island, connected with the lower lake by a broad pass between the hills to the west of Copacabana, and those to the west of Yungyu. The plains, now laid bare at the northern and western shores of Lake Titicaca, give us an excellent idea the appearance the whole basin of the lake would present if entirely dry. The number of lakes and basins, great and small, which formerly covered the elevated plateau of the Andes, must have been very great; but we now find only here and there a small sheet of water. The former lakes are only represented by the more or less extensive pampas, forming basins at great altitudes, showing plainly that the whole of this district is receiving a much smaller waterfall than in former times, but probably not within historic times, if we take into consideration the position of some of the most ancient ruins of Bolivia (at Tiahuanaco), which are only about 75 feet above the present level of the lake. These ancient basins are thickly covered by huge bunches of rank grass, from which the llamas, alpacas, and vicuñas obtain their only sustenance at the immense heights where they seem best to prosper. It would be an interesting inquiry to ascertain the causes of the difference in the habitat between the other species of camels and the llamas, which do not thrive near the sea-coast.

In the lower lake, which is shallow, the temperature of the surface and that of the bottom varied extremely. From the number of observations taken, I can only state that it is very local, depending upon the prevailing wind and the condition of the sky.

The following soundings, taken from those of the upper lake, show the great uniformity of the temperature of the surface and bottom:—



Depth. Fath.	Surface.	Bottom.	Air.	Time.
5	55° F.	55° F.		7.40 A.M.
8	55	53	56°	10.15 A.M.
28	58	53		12.30 A.M.
18	59	54.5	55	4.30 P.M.
12	55	54.9	42	7.10 A.M.
24	56.5	56	53	9 A.M.
33	54.7	54.5	47	12.20 A.M., cloudy.
30	57.5	56.2	58.5	4 P.M., clear.
43	56.7	55	58	10.20 A.M.
47	55.9	54.9	67	11.05 P.M., sun very bright.
66	56.1	54.3	55	11.10 P.M., sunny.
74	57	54.5	60	2.25 P.M., sunny.
82	55.5	51		8 A.M.
85	56	54	43	6 A.M., rainy.
90	56	54	55	1 P.M.
100	55.3	54.3	44	7.10 A.M., raining hard.
103	56	51.5		6.15 P.M.
111	57.5	54.9	63	12.20 P.M., clear.
106	57	54.5		
112	54.9	54.5	44	7.10 P.M., raining hard.
113	57.5	55	61	10 A.M., clear.
114		55		
116	55	54.6	45	11.14 A.M., raining hard.
124	56.3	56	60	1.09 P.M., sunny.
125	55	54.9	45	8.05 P.M., sunny.
130	56	55		9.10 P.M.
136	57	54	55	10.30 A.M.
132	53	52		
149	55.3	54.5	47	11.40 A.M., cloudy.
150	55	54.5	48	10.25 A.M., cloudy.
151	55.4	55	49	12.25 P.M.
154	54	52		8.45 A.M.

The elevation of the lake above the Pacific has been taken from the surveys of the railroad engineers, obtained while laying the line from Arequipa to Puno. Professor James Orton inclines to the opinion that the whole basin of Lake Titicaca, with the high plateau to the westward, is gradually sinking, because the successive observations made from early times give a gradually diminishing height. Thus far, the few measurements taken can hardly be more than a chance coincidence, when we remember the uncertainty and great divergence attending all measurements of heights taken to within a comparatively very recent period. The experience of the topographers of the late geological surveys in the Rocky Mountains has been very similar; and yet we are hardly prepared for such a sweeping generalization as the sinking of the greater part of the Rocky Mountains from much

more abundant data than those accessible from Lake Titicaca and its vicinity.

Along the eastern coast of Lake Titicaca, the mountains forming its former shores nowhere rise to any considerable height. The greatest elevations are found along the general line forming the western edge of the high plateau, to the south of which the lake is situated, from the Nevados of Tacorara to those east of Moquega, the Pichupichu, Chachani, Coropuno. A lower nearly parallel range extends about half-way between the line of the former and the axis of Lake Titicaca. This range, however, does not rise to more than 16,000 or 17,000 feet, and, sweeping to the northward at a distance of about one hundred miles to the north-east of the lake, forms the water-shed between the rivers leading to the headwaters of the Amazonas and those flowing into Lake Titicaca, the eastern sides of this great basin being formed by the northern extension of the huge range which culminates near the south-eastern shores of Lake Titicaca in the snowy giants of Guaina Potosi, Mamini, and Mampu. The range runs nearly northward from the head of the Bay of Achacache, forming the southern boundary of Carabaya on the north, and uniting with the northern water-shed of the great Titicaca basin. This eastern range of snowy mountains retreats from the shore of the lake about as far as the western intermediate range, and forms at the same time the line between the waters flowing to the Pacific and those belonging to the basin of the lake. The hills of the peninsula of Copacabana do not rise more than 800 to 1,000 feet above the level of the lake; and, to the south of the lake, low ridges form the dividing-lines of the torrents flowing from the heights between La Paz and Corocoro into the lower lake. The view from the crest of one of these ridges immediately to the eastward of Tiahuanaco is truly magnificent; and the panorama of snowy heights rising from 8,000 to 10,000 feet above the level of the lake is one of the most beautiful stretches of mountain-scenery it has been my fortune to see. Rising as these mountains do behind the islands of the lower lake as a foreground, with the low hills beyond Huarina on the opposite shore of the lake at the base of the snow-line coming down to within a couple of thousand feet of the shore, we have within a radius of thirty-five miles no less than six or seven peaks varying from 20,000 to 22,000 feet above the level of the sea. Looking over the peninsula of Copacabana extends the upper lake, with its sacred islands hardly visible on the horizon; while to the westward extend, as far as the eye can reach, the huge flat-topped hills, the dividing-ridges between the torrents flowing into the lake,

which comprise the immense elevated plateau reaching a height of some 16,000 feet above the level of the sea, with an endless number of somewhat higher peaks rising slightly above this general elevation ; while to the westward of Tiahuanaco the sharply-cut outline of the mountain-chain which forms the dividing-boundary between Bolivia and Peru shuts out the view in that direction. But while the outline of many of these chains is most graceful, and the grandeur of the Nevada de Sorata is not to be forgotten, the barrenness and utter desolation of the whole scene deprives it of much of its beauty. There is absolutely nothing green to rest the eye ; the whole country is dry, arid, stony ; here and there a patch of rank grass, upon which the vicuñas manage to eke out their existence ; an occasional shrub, with a stem as large as one's little finger, only left because it has thus far escaped the eye of the Indian gathering the few shrubs remaining as the only firewood, which, with characteristic imprudence, he does not cut down to give it a chance to grow again, but pulls up roots and all, to get as much fuel for the present needs as possible.

The accompanying map illustrates the general hydrography of the basin of Lake Titicaca.