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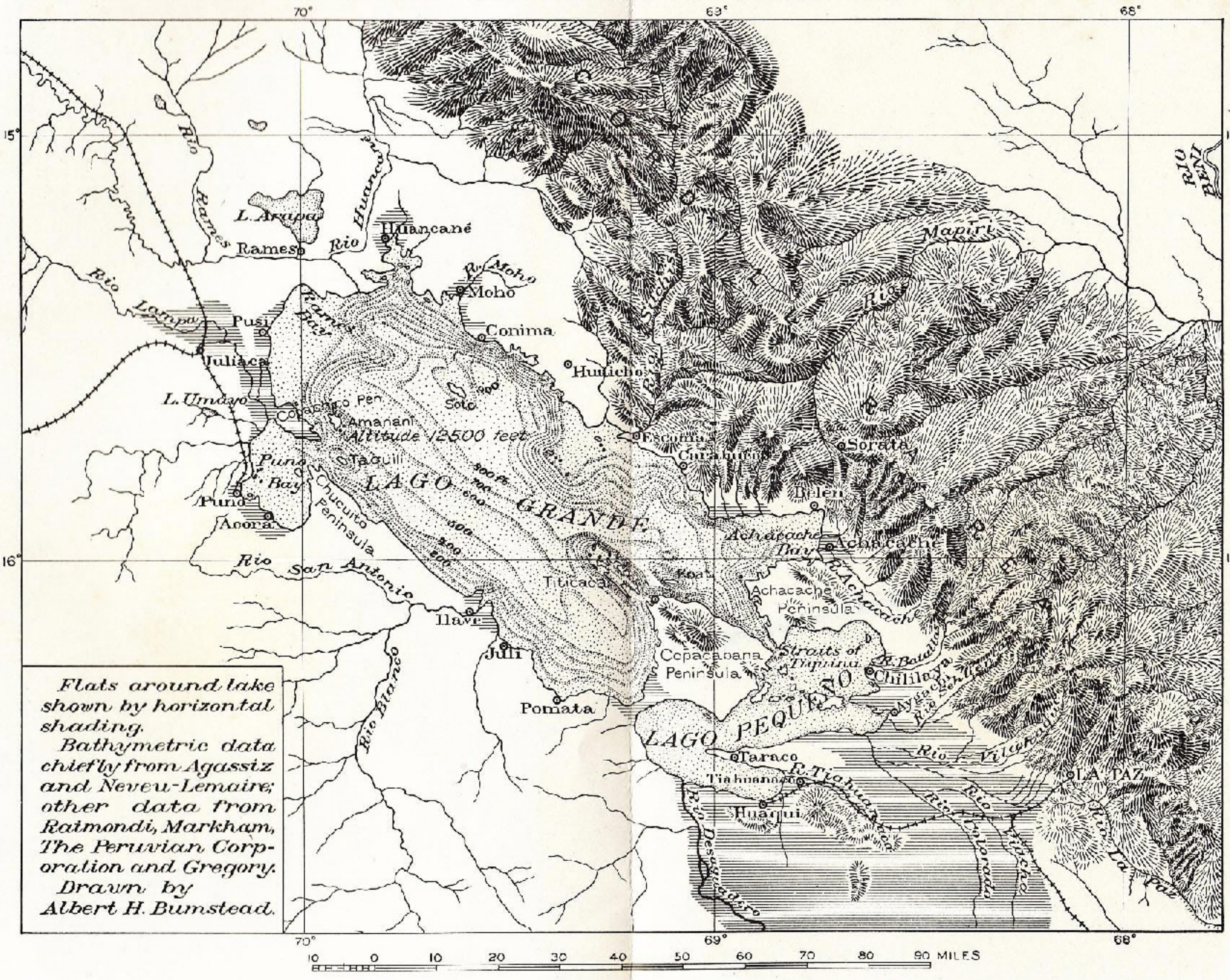
GEOLOGIC SKETCH of TITICACA ISLAND and ADJOINING AREAS.

By Herbert E. Gregory.

Results of the Peruvian Expedition of 1912, under the auspices of Yale University, and the National Geographic Society.

THE PERUVIAN EXPEDITION OF 1912
UNDER THE AUSPICES OF
YALE UNIVERSITY & THE NATIONAL GEOGRAPHIC SOCIETY
HIRAM BINGHAM, DIRECTOR

LAKE TITICACA & VICINITY



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[FOURTH SERIES.]

Art. XXIII.—*Geologic Sketch of Titicaca Island and Adjoining Areas*; by Herbert E. Gregory.* With Plate I.

Introduction.

The great Andean Plateau of southern Peru and northern Bolivia, the "altiplano," has a width in the Titicaca region of approximately 50 miles. Though possessing in itself relief exceeding a thousand feet, its plateau features are well brought out when the lofty ranges of the Cordillera Real and the Maritime Andes, between which it is hung, are taken into view. The bordering range on the northeast maintains a height of over 17,000 feet for a distance of 200 miles and reaches at Sorata (Illampu) a point 21,520 feet (Conway) above sea level. The western border of the plateau is a wide mountainous highland crossed by the railroad at 14,666 feet, and maintaining an average elevation in southern Peru of nearly 14,000 feet. As shown by Bowman, the Maritime Andes is a dissected peneplain and represents a mountain range which may have exceeded in height the present eastern Cordillera.

Occupying an irregular depression in the high plateau, between lat. 15° 20′ S. and 16° 35′ S. lies Lake Titicaca at an elevation of 12,500 feet above sea level. The lake is roughly rectangular in shape, one hundred miles long, and with an extreme breadth of thirty-eight miles.†

Its superficial area, calculated by planimeter from the best available maps, is approximately 4,000 square miles, and the length of the shore line probably exceeds 500 miles.‡ Properly speaking, there are two lakes, connected by the rock-walled straits of Tiquina, five-eighths of a mile wide. The lower

* Geologist, Peruvian Expedition of 1912.

† The figures are from LeMaire. No complete instrumental survey of the lake has yet been undertaken.

‡ The figures given by Paz Soldan (270 miles) and by certain other writers are manifestly too small.

lake (Lago Pequeno) is shallow, with gently sloping bottom flats and large areas of low shore from which rise rock knobs and hogbacks of moderate height. The main lake (Lago Grande) reaches a depth of over nine hundred feet and is bordered by abruptly descending under-water shelves. Twenty-five tributaries, all small and greatly fluctuating in response to seasonal precipitation, supply the lake. Its surplus waters are carried by the Desaguadero into the salt Lake Poopó, thus forming a chain of fresh- and salt-water bodies like the Sea of Galilee–Jordan River–Dead Sea of Palestine and Utah Lake–Jordan River–Great Salt Lake of Utah. Thirty-six islands rise above the surface. The largest of these, Titicaca, has given its name to the lake, and as the Island of the Sun, shares with Koati (the Island of the Moon) and Tiahuanaco, a position as a center for archæological and historical research.

Physiography.

The Lake Floor.—The soundings made by LeMaire* and by Agassiz,† supplemented by scattered data, are sufficient for the construction of a bathymetric map of the basin now occupied by the waters of Titicaca. (See fig. 1, Plate I.)

It will be noted that Lago Pequeno is, properly speaking, not a part of the depression holding the waters of Titicaca. Its floor is remarkably flat, less than one-tenth of its area reaching a depth exceeding 20 feet; and a fall of ten feet in water level would expose about one-fifth of its bed, and effectively impede navigation. Lago Grande is seen to occupy a rectangular basin with abruptly ascending edges on three sides, and with a slope from southwest to northeast. The southeastern extremity partakes of the nature of a canyon,—Tiquina is a sharp-cut valley included between steeply sloping rock walls. The islands of Titicaca (fig. 2), Koati, and Soto are mountains, rising respectively 1,400, 1,500, and 1,300 feet above the basin floor, while the archipelago facing the coast at Escoma includes stacks and pinnacles, erosion remnants, rising above a slightly submerged platform. There are no indications that the tiny islands adjoining Titicaca Island form steps in a submerged causeway uniting Copacabana with the Bolivian mainland at Huaicho, as surmised by Bandelier, and no proof that the straits of Tiquina have been opened by faulting or torrent erosion since the lake attained its present dimensions, as is implied by various writers. How much of the shallowness of the bays of Puno, Rames and Achacache and of Lago Pequeno is due to waste furnished by

* Les Lacs des Hauts Plateaux de L'Amérique du sud, Paris, 1906.

† Hydrographic sketch of Lake Titicaca, Proc. Am. Acad. Arts and Sci., vol. xi, 1875–76.

the tributary streams, and how much to original depression, is impossible to determine, but it is significant that bays of great depths and precipitous shore fronts as Yampupata, Tiquina, Huaicho, Conina, and Huancane do not furnish an outlet for debris-laden streams of large size. Soundings so far available fail to indicate under-water channels or canyons whose orientation may be determined. That the basin, somewhat extended, is a warped, downfaulted area, is suggested by the

FIG. 2.

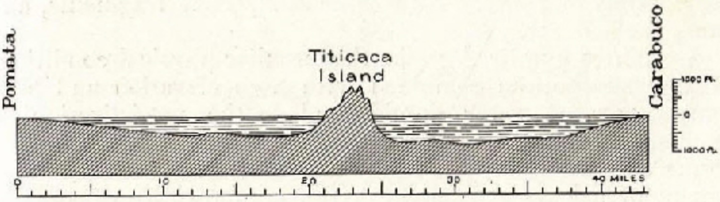

FIG. 2. Section across Lake Titicaca from Carabuca to Pomata showing mountainous character of Titicaca Island.

rectilinear quality of shore and island borders. It would appear also, from the character of the under-water slopes, that the topography had reached a stage of early maturity before the advent of structural movements which prepared the basin for filling by water.

The floor of the lake basin, in its deepest part and frequently near shore, was found by Agassiz* to be covered with "thick mud, the finest possible greenish black silt containing few fragments of shells—the mass being probably several feet thick." In a few localities sandy, shelly, and rocky bottom was found. The bed of Lago Pequeno appears to be covered with sand. Professor Thoulet analyzed three samples obtained by LeMaire, the first from Lago Pequeno near shore at Chillilaya, the second from a depth of 741 feet, the third from near shore at Huaicho on Lago Grande. The gray slime from Chillilaya contained microscopic fragments of siliceous spicules and diatoms, black, ferruginous, combustible specks (coal?), brick-colored particles, minute angular quartzes, black magnetic grains and sparsely distributed obsidian, pumice, hornblende, olivine, pyroxene, and mica. Percentage calculations of these samples gave: sand and plant fragments 13; calcareous slime 3; non-calcareous slime 13; calcareous mud 59; organic residue 12. Both entire and fragmentary shells were recovered. The sample from deep water gave in parts per 100: sand, etc. 3;

* Proc. Am. Acad., vol. xi, p. 284, 1875–76.

slime 78; calcareous mud, a trace; organic residue 18; indeterminable 2. This sample contained the same minerals as were found in Lago Pequeno and differs only in the absence of lime and greater abundance of globular diatoms. From the Huaicho dredging were obtained iron-coated grains of quartz "resembling the sands of Sahara," and a few volcanic fragments. Thoulet's studies show that the deeper parts of Titicaca are mantled with organic materials, chiefly diatoms, mingled with siliceous and calcareous (in Lago Pequeno) grains, minute fragments of minerals either wind-worn or volcanic, rarely meteoric. Near shore sand, plant fragments, and small shells occur.

As pointed out by Agassiz, the peculiar physical conditions of the lake bottom combined with high elevation and high temperature of water should tend to the specialization of genera,—a result which does not occur. The absence of unique forms and the poverty of species are remarkable. The two genera of fish and the mollusks belong to widely distributed fresh-water types. The Crustacea, however, have for their nearest relatives marine forms. An interesting fact pointed out by Orton is that one of the fishes, *Trichomycterus dispar*, occurs also in the Rimac and Guayaquil rivers.

Lake Water.—The temperature of the water, under the influence of the tropical sun and of the rarefied atmosphere, is remarkably uniform at all depths. Of thirty-four measurements made by Agassiz in which the temperature of the water at the bottom was compared with that at the surface and that of the air, the difference between bottom and surface was 3°–4°; the bottom temperature being 54°–55° (one reading 51° at 618 feet), while the surface temperatures were 56°–57°. Only one much larger range, 6·5°, was noted. At the same time (January 1st to March 5th) the temperature of the air ranged from 42°–44° early morning to 55°–63° during the hottest part of the day; extremes of 47° (cloudy) and 67° (very bright) were observed.

The mean of twenty-nine records taken by LeMaire from depths between 11 feet and 925 feet* give a value of 51·51° F., the highest reading being 52·52° F. at 79 feet and 607 feet, and the lowest 48·92° F. at 11 feet, 49·64° F. at 160 feet, and 49·46° F. at 740 feet. A grouping of LeMaire's thermometric observations indicates an increase from surface to 492 feet, reaching a maximum between 500 and 650 feet, followed by a slight decrease to the lowest depths. The temperatures of

* This is the greatest depth obtained by soundings. In Marie R. Wright's elaborate book "Bolivia" (1906) is an illustration of the loose statements frequently found in print: "Its depth varies from 250 feet to 1500 feet, and there are places where it is unfathomable" (p. 243).

the surface waters during July, during the time the above deep water temperatures were recorded, gives a mean of 52·06° F. The mean temperature of the air, including all hours of the day during the same period, was 45·32° F. It thus appears that the temperature of the surface water averages higher than that of the overlying air in summer as well as in winter. These records of water and air, though manifestly inadequate for meteorological discussion, are sufficient to show that freezing temperatures are rare, that ice forms only in narrow bays and then infrequently, and that accordingly the effect of frost in disintegrating rock either in contact with waves or with air is reduced to very low terms. Moreover the diurnal range of temperature is insufficient to aid greatly the disruption of rock masses, conditions which do not hold for the surrounding altiplano.

The water of the lake is fresh and palatable. Raimondi's analysis showed but a trace of saline matter and the analysis of three samples by Malliere gave 1·07 grams per liter of mineral content, of which ·465 of a gram was chloride of sodium. The slightly disagreeable taste of samples taken near shore is due, according to Barranca, to the presence of magnesium and bicarbonate of lime formed by the action of carbonic acid liberated by the decomposition of *Myriophillum* and *totora*, which flourish in the shallower bays. The water is clear, even in the rainy season when mud from streams discolors shore areas, and its transparency is little less than Geneva and Tahoe. The outflow of the lake (the Desaguadero, 45 meters wide, two to seven meters deep) is, according to Reck.* 4·822 cubic meters per minute. Evaporation amounts to five millimeters per day.†

Fluctuation in Level.—The dimensions of the present Titicaca are, as previously stated, one hundred miles by thirty-eight miles, with a superficial area of approximately 4000 square miles. That it formerly had a somewhat greater expanse seems to be sufficiently attested by historical and geological observations. Tovar‡ observes that cultivated fields now occupy small portions of exposed lake bottom at Guarisco, Acora, and Llave, that disputes regarding the ownership of reclaimed land at Capachica and Pusi are listed in local court records, and that in 1877 the waters of the lake reached the suburbs of Puno, now five "cuadras" (city blocks or squares) distant. The ancient ports of Huancavé, Moho, Conima, Ancoraimes, and Achachaci are now two to three kilometers

* Geog. Soc. de Lima, Tomo X.
† Prado, Bol. Soc. Geog. de Lima, Tomo I, 1892.
‡ Bol. Soc. Geog. de Lima, Tomo I, 1892.

inland. Agassiz states* that Lake Arapa and several lakes near the west shore are outliers of an ancient water body, and that the plain north of Lampa "only 100–150 feet above the lake . . . was one sheet of water." "The terraces of the former shores are still very distinctly seen." Tovar also records the tradition that Lake Umayo, now fifteen miles distant and fifty feet more or less above the Titicaca level, was formerly part of Titicaca and that the plains about the northwest end of the lake were formerly less extensive. Viscarra† states that within historical times the peninsula of Copacabana was an island. La Puente,‡ Zundt,§ Posnansky,‖ Markham,¶ and Conway** accept the general view first stated by Orton,†† that the waters of the lake were vastly more extensive and surrounded Tiahuanaco within historical times.‡‡

When the Titicaca coast is examined it appears that the data presented by Tovar have little significance. Most of the places mentioned adjoin very shallow waters which are gradually being reclaimed by stream-borne sediments (fig. 3). This is particularly true of the areas mentioned by Agassiz, in which the Lampa and Rames are aggrading their beds and carrying sediment forward to form deltas. Squier appreciated this fact and remarks that "the region around the mouth of the Rames is a kind of delta, very low and level, interspersed with shallow pools as if but recently half rescued from the lake by deposits from the river." That the lake level has been eight to twelve feet higher than to-day is shown by the whitish band of deposited salts and discolored rock which decorates the bases of rock islands. While in part the evidence of the height reached by breakers, this horizontal band strongly suggests a former level below which the waters have sunk within probably a few decades. The annual fluctuation in lake level is approximately 4 feet, and so shallow is the bottom in places that hogs may feed several hundred feet from shore. In the absence of quantitative measurements and of definite locations of ancient shore lines, the conclusion of Tovar that the lake is "regularly diminishing" in a "surprising manner" is not justified.

* Proc. Am. Acad. Arts and Sci., vol. xi, 1875–76.
† Copacabana de los Incas, La Paz, 1901.
‡ Bol. Soc. Geog. de Lima, Tomo I, 1892.
§ Op. cit.
‖ Bol. oficina Nacional de Estadistica de Bolivia, 1911.
¶ Geog. Jour., October, 1910.
** Climbing and Explorations in the Bolivian Andes, 1901.
†† The Andes and the Amazon, 1876.
‡‡ In a paper presented by Professor Bowman before the Association of American Geographers, December, 1912, and later to be published, the rôle played by Lake Titicaca in the history of ancient Tiahuanaco is discussed in detail.

Berglalund reports* that during twenty-three years' residence at Desaguadero the annual fluctuation reached five or six feet and that the level in 1906, following four years of deficient rainfall, was considerably lower than in 1909. Such variations are not uncommon in lakes of the world, even in humid regions

FIG. 3.

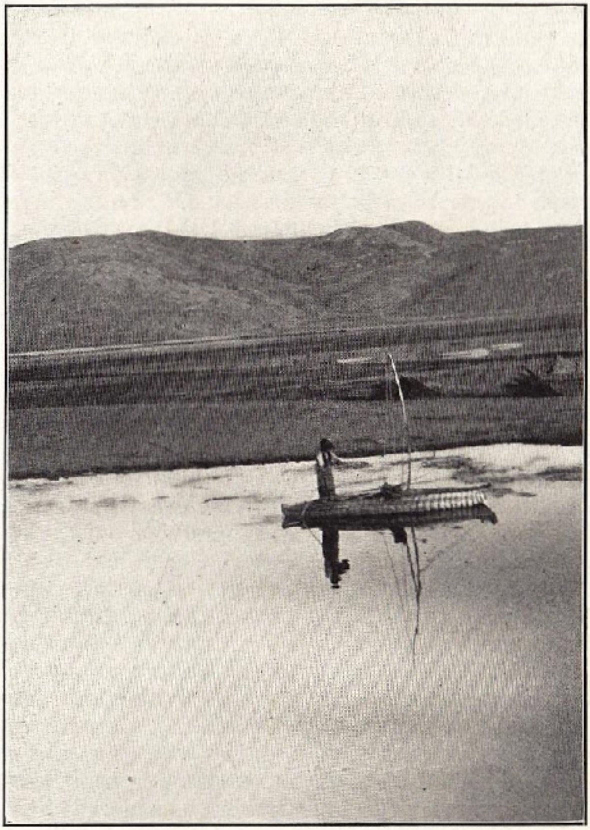

FIG. 3. Bay of Puno, showing a typical portion of the deltas extending into Lake Titicaca from the northwest.

marked by climatic regularity. A seasonal or cyclical change in climate, taken in connection with river-borne sediments, is sufficient to account for all authentic facts so far reported, without involving a hypothesis regarding the geological history

* Geog. Soc. de Lima, Tomo X.

of the lake. Until long-term, continuous records are available, it seems best to assume that Titicaca, in common with other water bodies, rises and falls in response to the increased and decreased precipitation which characterizes climatic cycles, the existence of which has been demonstrated for other parts of the world. The hypothesis of progressive diminution through centuries of time would accordingly be discarded.

Former Extent.—That Titicaca is the diminished representative of a vast interior sea which covered the altiplano in northern Bolivia and southern Peru, is claimed by nearly all students of this region. Thus, Agassiz states,* "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." Le Maire† accepts Agassiz's conclusions, supplemented by the existence of an ancient beach line in the Poopo basin, first observed by Musters,‡ and concludes that Titicaca and Poopo are parts of one interior sea covering the region between 15° and 21° south latitude, including La Paz and Oruro. The outlet was supposed to be through the present La Paz river into the Atlantic. "The largest lake in the world fed the largest river in the world." "Within historical times the Desaguadero has been reduced from a wide strait to its present dimensions." La Puente§ holds the same view but mentions no evidence bearing on this point. Posnansky‖ believes that Titicaca is a remnant of an enormous salt sea separated from the ocean by uplift and drained through the eastern Cordilleras by a passage prepared by a cataclysmic rupture of its barrier. As if this were not sufficient proof of the power of the "titanic forces of nature," Posnansky states that the region was again flooded by waters from Lagunillos freed by the rupture of massive rock walls,—a disaster which destroyed the civilization represented by Tiahuanaco! Zundt's original views¶ were in harmony with those of Posnansky and required the elevation of strata to a height of 13,000 feet without destroying their horizontality. The steep faces of the mesas were considered the work of waves. Zundt's later interpretation** is based on the hypothesis of a late Tertiary river, "Rio Titicaca," which extended from Sicuani, Peru, to Illimani, Bolivia, via La Paz. This

* Proc. Am. Acad. Arts and Sci., vol. xi, 1875–76, p. 288.
† Lagos de Los Altiplanos, pp. 153–154. La Paz, 1909.
‡ Geog. Jour., xlvi, 1871–77. § Op. cit., 1892.
‖ Bol. officina Nacional de Estadistica de Bolivia, 64–66, La Paz, 1911, pp. 689–702.
¶ Appendix, D'Orbigny, 1907.
** Bol. Estadistica, 67–69, 1911, and 70–72, 1912.

ancient channel was blocked by alluvium and glacial debris, thus isolating the present Titicaca. The ancient level of the original lake was not much above the present, and is marked on the rocks at the straits of Tiquina. Dueñas* expresses the view that ancient Titicaca may have extended into the Department of Cuzco. These views are only less extreme than the conclusion of Orton† that the "depression holding Lake Titicaca is apparently a volcanic basin; fragments of lava, porphyry, and jasper are scattered around and towers of igneous rock protrude through the sedimentary strata."

It will be noted that the conclusions of Le Maire, Posnansky, and others rest on the assumption that the hypothetical Titicaca had its outlet through the La Paz canyon, an assumption negatived by the fact that the deposits at La Paz are of later date than the lake basin, and the gorge itself is in large part postglacial and recent. The existence of the hypothetical "Rio Titicaca" of Zundt, flowing in a wide valley or canyon sunk 1000 feet below the altiplano, is supported by no evidence from the lake bed, the altiplano, the valley of La Paz river, or from the upper part of the supposed valley now exposed to view in the region between Huancani and Sicuani. The enormous lake which is supposed to have occupied the basin between the two Andean ranges is believed by Posnansky to have been a detached portion of the sea elevated 12,000 to 13,000 feet without affecting the attitude of the Mesozoic strata. Points urged by Posnansky in favor of the marine origin of the basin are deposits of salt at several localities, deposits of sediments at La Paz and on the altiplano, and the marine affinities of the fauna of the lake. The first two points have little significance, since salt is a constituent of the country rock, and the sediments at La Paz are river deposits, not marine or even wholly lacustrine.‡

The lake fauna exhibits in part a marine facies, but is not necessarily of direct marine origin.§ The fish are fresh-water forms, with marine affinities; the mollusks, copepods, Daphnids, and ostracods are fresh-water forms; the amphipods present a marine aspect, but nothing definite may be said of their origin. The only true marine species mentioned by Posnansky, the *hippocampus*, is not found in the extensive collections of Agassiz and Le Maire. The presence of this species in the lake, a conclusion based on a specimen given to Posnansky by an Indian fisherman, and now in the private museum of the collector, requires further confirmation.

* Bol. Cuerpo de Ing. de Min., No. 53, Lima, 1907, p. 25.
† The Andes and the Amazon, 1876.
‡ See Gregory: The La Paz Gorge, this Journal, vol. xxxvi, pp. 141–150.
§ For data concerning the habitat of the Titicaca fauna, I am indebted to my colleague, Professor Petrunkevitch.

In this connection Agassiz's statement, quoted above, that "the terraces of its [Titicaca] former shore line are everywhere most distinctly to be traced," at "an elevation of 300 or 400 feet at least higher than its present level," deserves attention. Such high level terraces were not observed by the writer at Puno, Guaqui, Tiquina, Yampupata, or on Titicaca Island,—a fact which surprised me not a little, since I had assumed that such evidences of higher level were to be found on all sides. The shale, sandstone, and limestone, tilted at various angles and of different degrees of firmness, fretted by waves of considerable power, especially during the southern winter, would be expected to produce unmistakable rock benches, and the low-lying borders of parts of the lake offer favorable opportunities for beach-making. Moreover, the conditions for preserval of the shore forms in a semi-arid climate and where freezing is unusual are favorable. This does not prove, of course, that no such evidences of high-water level exist, for no detailed survey has as yet been made; but raised terraces are not "distinctly to be traced." In fact, no rock shelf or raised beach has been mapped or described, and there is no direct evidence of former high levels except for the relatively slight fluctuations discussed above. It is significant that La Puente, who stoutly affirms the former existence of a vast interior sea, made a traverse of the lake borders and visited many islands without recording the presence of ancient shore forms, and that Bowman in 1908 saw no signs of raised terraces.*

It will be noted that the argument against the presence of an ancient interior sea of vast dimensions rests chiefly on evidence of a negative value, and in the absence of topographic maps and of detailed physiographic studies must remain so. The problem involves the unraveling of the geologic history of the entire plateau region. From the data at hand it appears that the great interior depression, itself a plateau, owes its existence to faulting as implied by Bowman,† and that the downfaulted area was given its relative position after uplift and peneplanation of both the eastern and the Maritime Cordilleras in early Tertiary time. It is also probable that the floor of the sunken area was further modified by warping and selective faulting which produced a number of secondary depressions at considerable depths below the general floor. It is reasonable to suppose that such a downfaulted, warped surface would be occupied by a number of lakes, whose extent and permanency and degree of salinity would bear direct relations to the original topography, abundance of waste and climatic fluctuations.

* Private communication.
† This Journal, vol. xxviii, 1909.

Titicaca Island.—Titicaca Island is a representative of a large class of elevations including hogbacks, eroded folds, mesas, igneous masses, and probably fault blocks, which project above the general floor of the great interior basin or plateau. In common with its companions it has reached a mature stage of development and is, in brief, a residual prominence now partly submerged in the waters of a lake.

In outline Titicaca Island is very irregular (fig. 8). Five large bays set deeply into the land, in addition to ten or twelve other bays of one-fourth mile or less in width which scallop the island's border. Although the island has an area of 102 square miles, with an extreme length of only seven miles, and width nowhere exceeding three miles, the length of the coast line is 33 miles. Only at the southwest, where the sandstone ridge of Kakáyo-Kéna forms an unbroken wall for nearly five miles, does the coast assume a rectilinear quality.

The dominating feature of the island's surface is a backbone or central ridge, extending from Bilcokyma to Sicuyo, a distance of about seven miles, and following the direction of strike of the sedimentaries which compose it. On the northeast the Kea Kollu dome, extending far into the lake, assumes a commanding position, and on the southwest the long, straight ridge of Kakáyo-Kéna, culminating at Chullun-Kayani with an elevation of 800 feet, constitutes a conspicuous feature of the landscape. At the north the peninsula of Marcuni, tied to the land by the low isthmus of Challa, is a prominent feature when viewed from the lake. Approximately two-thirds of the island maintains a height of 400–500 feet, a few small areas are over 700 feet, and at Palla-Kasa a barometer reading of 13,330 feet, 830 feet above lake level, was obtained. This is probably the culminating point on the island, and Squier's figure, 2,000 feet, for the hills back of Challa is clearly an error. Back from the shore the surface has little sharp relief; cliffs and precipices and deeply cut chasms, except those formed by differential erosion of strata, are absent. Rounded ridges, flattened domes, flat saddles, and graded slopes form the surface, but not to the exclusion of minor steep rock slopes developed on the edges of tilted strata. In fact dip slopes and cuesta fronts in many places determine the topography and point to structural control of subordinate features. The valleys separating the rounded heights are broad V-shaped, frequently nearly flat, and the divides are everywhere inconspicuous. Only in their lower courses do the stream channels become steep-walled ditches and then only where wave-worn headlands have destroyed previously established grades. In short, the topography is mature or post-mature and youthful features are exceptional. (See figs. 4, 5 and 6.)

The coast shows everywhere signs of vigorous erosion; headlands of bare rock, rising 100–300 feet above water, are numer-

Fig. 4.

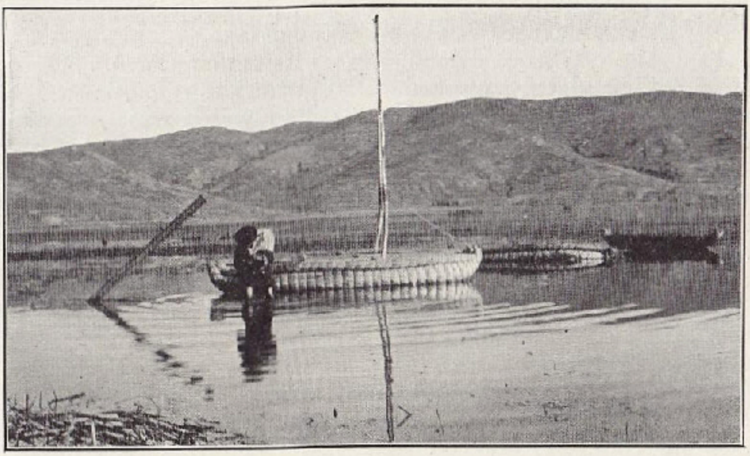

Fig. 4. General view of the Peruvian shore of Lake Titicaca.

Fig. 5.

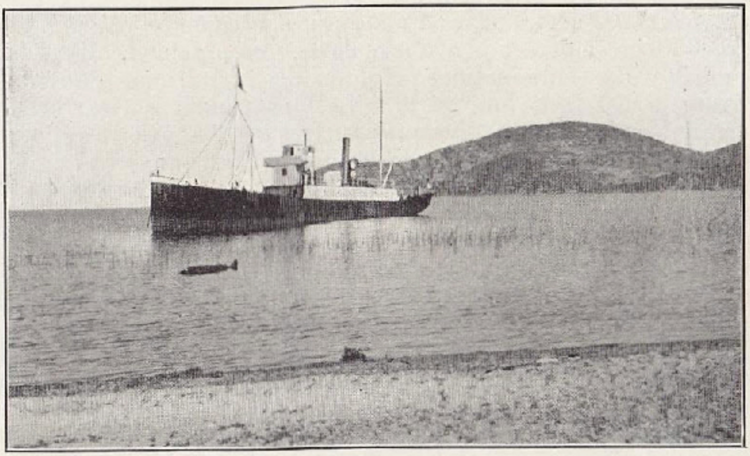

Fig. 5. Bay of Challa, Titicaca Island, showing beach and quality of hill slopes.

ous, and the short stretches of crescent beach are piled high with gravel. (Figs. 6 and 7.) The longer beaches, as at South Yumani and Challa, are built of fine materials with flat gradients and in more sheltered places luxuriant fields of reeds

FIG. 6.

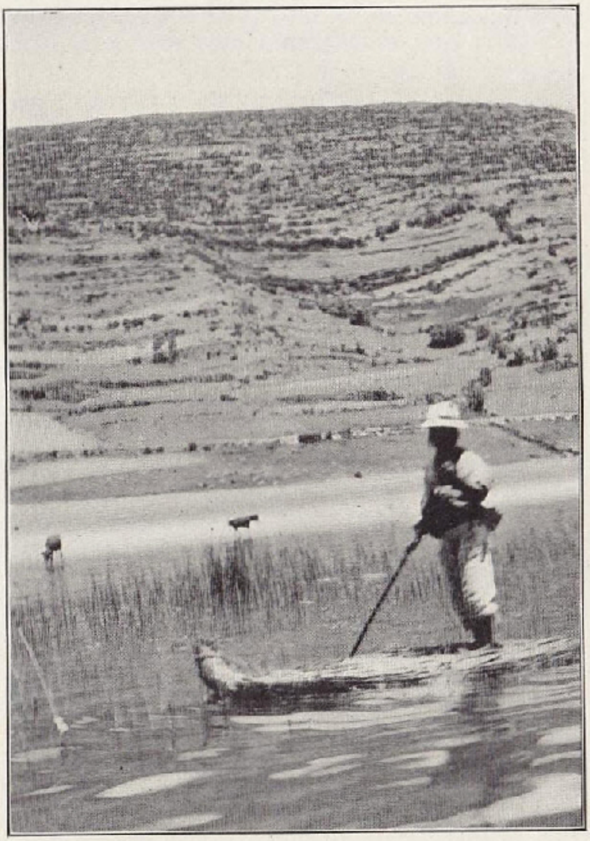

FIG. 6. Kona Bay at South Yumani, showing beach, hill slope, and quality of the short drainage channels.

(*totora*) are found. The Marcuni peninsula is tied to the land by a double-faced, wave-made beach. A traverse of the strand involves clambering over jutting rocks, climbing precipitous headlands, and walking on beaches of yielding sand. Most of the headlands plunge into deep water and the low sand beaches which occupy sheltered coves slope gently lakeward for a few feet only to drop abruptly into the depths. The one hundred-foot bathymetric contour lies very close in-shore, except to the northwest, where the under-water platform forms a foundation for six islands, the largest only a little over a square mile in area, and all within two miles of Titicaca itself.

The agencies concerned in molding Titicaca are none of them vigorous except the waves, which are very efficient tools,

FIG. 7.

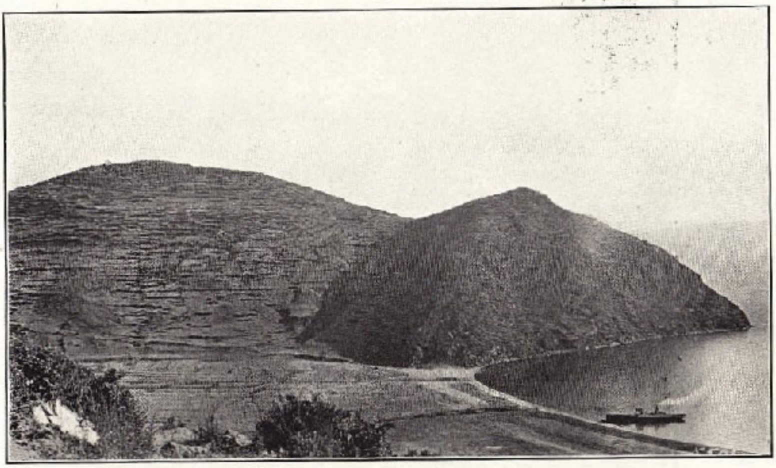

FIG. 7. Ahyjadero Bay, Titicaca Island, showing beach, lake cliff, and terraced fields (*andenes*). The strata exposed are limestones of Pennsylvanian age and mark the northwest side of the Ahyjadero fault. K. C. Heald, photo.

particularly during the southern summer. Chemical decomposition is favored by continuously moist atmosphere; stream erosion is checked by infrequency of rain and by flat gradients, which is offset only in part by the severity of sudden showers. The peeling of rocks occasioned by diurnal changes of temperature is little in evidence, owing to a nearly constant temperature which, influenced by the lake, maintains a mean of about 55° and very rarely drops below freezing. The waves, however, are vigorously attacking the shores and by selective erosion have developed dikes of sandstone by removing the less resistant shales, and here and there have surrounded masses which stand as stacks and skerries.

Structure.

The meager and disconnected geological mapping resulting from studies of Titicaca is an insufficient basis for the discussion of structural detail, and has allowed the perpetuation of such notions as that the basin is igneous in origin and that "smoldering fires still keep the waters warm;" that the Straits of Tiquina resulted from a volcanic eruption; that the coal is Tertiary; that the succession of strata and the age of the rocks are identical with those represented in the Alps, etc. The investigations of Forbes and D'Orbigny are, however, sufficient to indicate that the strata, Devonian and Carboniferous in age, have been thrown into folds, the truncated edges of whose limbs are responsible for the innumerable rounded hogbacks which form such conspicuous features of the landscape.

The basin of Lago Grande has the appearance of a "graben"—one or more down-sunken fault blocks bordered in places by escarpments, elsewhere by areas of steep faulting.

Faults are present in large numbers, but their length and amount of displacement and structural control are as yet unknown. In a section extending from Achacachi to La Guardia, entirely across the lake basin, Forbes encountered volcanics and highly contorted Devonian (D'Orbigny) strata, presumably cut off from overlying strata by a fault, the Carboniferous dipping westward until the Straits of Tiquina are reached, then dipping eastward across Copacabana. The straits are described as the locus of a fault, a "broken arch." Agassiz believed the Carboniferous to consist of a series of rather limited elongated basins with axes (determined by Forbes) running northwest-southeast. "By a series of such faults [as at Tiquina], more or less prominent, the successive basins of Carboniferous . . . . have been separated."*

Structurally, Titicaca Island is a continuation of Copacabana peninsula. The strata are alike in composition, exhibit the same folds and nearly identical strikes and dips. This connection is well shown by a narrow sandstone hogback which projects as a cape from Copacabana and terminates in a line of islands, progressively decreasing in size. On Titicaca Island, the same bed apparently is included in the strata carried northwest along the line of strike. With the exception of the rounded knobs and eastward-facing cliffs carved by waves from the limestone, the whole surface of the island is formed of more or less modified hogbacks facing southwest and exhibiting the influence of structure. From a structural standpoint the island may be considered as a group of eroded, folded strata, drowned by the waters of the lake. The northwest-

* Agassiz, p. 283.

southeast trend of the ridges is characteristic. At Challa the strike is N. 60°; at Ahyjadero (Pucára) the strike is N. 55°–60° W.; and measures between N. 40° W. and N. 60° W. were taken at several localities. For Yampupata the figures are the same. Near South Yumani where the strata are faulted, N. 25° W. and N. 20° W. were measured, and at a few places, as on the ridge of Kuru-pata where a strike of N. 20° W. becomes in half a mile N. 40° E., the presence of minor horizontal and vertical folding is demonstrated. In addition to the faults traced by K. C. Heald and the writer and indicated on the map (fig. 8), there are many minor dislocations which are of economic importance, but only one so far observed has interrupted the stratigraphic succession to any considerable degree. The Ahyjadero-Kona fault has offset the strata for nearly one-half mile.

Economic.

The presence of coal at Yampupata and on Titicaca Island is mentioned by Forbes (1861) but was doubtless recognized at a much earlier date, since the absence of fuel other than llama dung for domestic purposes, as well as for smelting and for making steam, encouraged a search for mineral fuels. Agassiz (1875) found the mine at Yampupata producing "30 tons of coal per day," "of fair quality." More recent studies of these deposits were made by engineers in the employ of the Peruvian corporation and by Dereims, who reported a narrow band of coal running the length of the island.

The principal coal-bearing shales and sandstones traverse the island from South Yumani to Taana Bay as a belt ten to fifty feet in width, a limited proportion of which is of commercial value. The coal occurs in lenses and overlapping layers interleaved with argillaceous and sandy shales. Bands of true coal from a few inches to more than two feet in thickness were observed at South Yumani and northwest of Challa. The conditions of original deposition as well as field observation indicate that the maximum thickness of a given stratum of true coal will probably not exceed three feet and that such beds will vary greatly in linear extent. It is improbable that workable beds over three feet in thickness, continuous for more than 300 or 400 feet, will be found on the island. In several places examined, the coal lenses have much smaller dimensions.

Three exposures bordering South Yumani Bay show respectively: (1) 14 feet of carbonaceous shale with abundant thin streaks of impure coal of no value. (2) At a prospect hole, 10 feet more or less of carbonaceous shale contains beds of coal three inches to three feet thick, exceedingly variable in thickness, extent and quality. One two-foot coal bed is fully half shale. The coal-bearing beds are overlaid by 6 feet of cross-bedded sandstone and underlaid by 30 feet of shale with lenses of sandstone. (3) Between South Yumani and Bilcokyma the section from bottom upwards is:

1. Shale with ½″ to 1′ lenses of coal	15 feet
2. Sandstone	4 "
3. Shale	2 "
4. Sandstone	3 "
5. Carbonaceous shale with ¼″–2″ beds of coal	5 "
6. Sandstone containing scattering fragments of coal	30 "

At Challa (Kcasa claim) the group of coal beds about 12 feet in thickness are approximately one-third "bone" and the thickest band of workable coal is probably less than two feet.

The section examined on the Taana claim shows at bottom thin-bedded sandstones and shales followed upward by

1. Carbonaceous shale, about half of which is coal in wavy, impure lenses	4–6 feet
2. Shales and sandstone	20 "
3. White sandstone	60 "
4. Shales and sandstone with ½″–1″ layers of coal	20 "
5. White sandstone	10 "

In quality the coal is not very satisfactory, pyrite is abundant, and "high ash" is reported by the engineers of the Titicaca steamers, but the tests made by the Bolivian Rubber Company appear to have been fairly satisfactory. Mining on the island will necessarily be expensive owing to high dip of strata, irregular distribution of coal, the presence of water, and the distant source of supplies.

Stratigraphy.

Our knowledge of the stratigraphy of the Titicaca region is based primarily on the work of D'Orbigny,* Forbes,† and

* Voyage dans L'Amerique Meridionale, tomo iii, pt. 3, Paris, 1842. This volume, based on field studies during the years 1826–33, includes nine large hand-colored maps and sections and twenty-two lithographic plates of fossils. The government of Bolivia has made an important part of this rare work accessible by the publication of a Spanish edition (Estudios sobre la Geologica de Bolivia, translated and annotated by Victor E. Marchant La Paz, 1907).

† Report on the Geology of South America by David Forbes, with notes on fossils by Huxley, J. W. Salter, and T. Rupert Jones. Part 1, Bolivia and southern Peru. Quar. Jour. Geol. Soc., vol. xviii, 1861. A Spanish translation by Edmundo Sologuren was issued by the Sociedad Geographica de La Paz, 1901. The Carboniferous as delineated by Forbes manifestly occupies too small an area.

Agassiz.* Steinmann,† and especially Dereims,‡ have by their recent studies extended and somewhat modified the conclusions reached by earlier explorers. The publication by the Bolivian Ministerio de Justicia y Industria, La Paz, 1912, of a Mapa Geologico de Bolivia by Leonardo Olmos, serves as a basis for further field studies.§

This map so far as the Titicaca region is concerned is essentially a reproduction of D'Orbigny's Plate VIII, which exhibits Paleozoic formations as bands with prevailing northwest-southeast extensions. The periods represented west of the Cordillera Real are in succession: Silurian, forming the base of the range; Devonian, in a broad belt forming the eastern shore of Lago Pequeno, as well as the peninsula of Taraco; Carboniferous, forming the west shore and part of the south shore of Lago Pequeno, the peninsulas of Achacachi and Copacabana, and all the islands. No Cambrian has been reported from southern Peru or northern Bolivia. The presence of Silurian rests on ten species collected by D'Orbigny, none of which are accepted by Salter as properly determined; five Lower (?) Silurian and fourteen Upper Silurian species, mostly from the Cordillera Real, collected by Forbes and described by Salter; Ordovician graptolites described by Steinmann (1904); Steinmann's collection from southern Bolivia described by Ulrich,‖ and on a collection of graptolites from Santa Domingo presented to the writer by Mr. Collins, manager of the Inca Mining Co. Dereims also reports Silurian at several localities south of Lake Titicaca. The presence of Devonian in the Titicaca region was first demonstrated by the discovery of seven species by D'Orbigny, four of which are accepted by Salter as characteristic of that era. These species, including three additional ones collected by Forbes, are unlike forms found elsewhere. Dereims found Devonian fossils in brown sandstone and shales near Lake Titicaca, a collection which as yet has not been reported upon.

Carboniferous strata were encountered by D'Orbigny on the shores and islands of Lago Pequeno, where brown sandstone is underlain by compact bluish gray "mountain limestone." The fossils collected from Amasa and Quebaya islands and from Yarbichambi comprise twenty-five species, all specifically unlike European forms, but resembling, according

* Agassiz and Garman, Exploration of Lake Titicaca, Bull. Mus. Comp. Zool., Harv. Coll., vol. iii, 1871–76, fossils described by Derby.

† A Sketch of the Geology of South America, Am. Naturalist, 1891, pp. 855–860.

‡ Excursiones Cientificas 1901–04. Anexo de la Memoria de Gobierno y Fomento. La Paz, 1906.

§ One of the cross sections accompanying this map is confusing, in that the relations between Devonian and Carboniferous in the Copacabana area are not in harmony with the surface geology.

‖ Paleozoische Versteinerungen aus Bolivia, Neues Jahrbuch, 1892.

to D'Orbigny, the fauna of Boulonais de Vise (Belgium). Salter lists thirteen species from the Carboniferous of Copacabana, many of which are identical with known European forms. The Carboniferous fossils from Yampupata collected by Agassiz and described by Derby include nine species; viz.: *Spirifera camerata*, *Athyris subtilita*, *Chonetes glabra*, *Productus costatus (?)*, *Productus chandlessii*, *Productus cora*,

FIG. 8.

GEOLOGICAL MAP OF TITICACA ISLAND

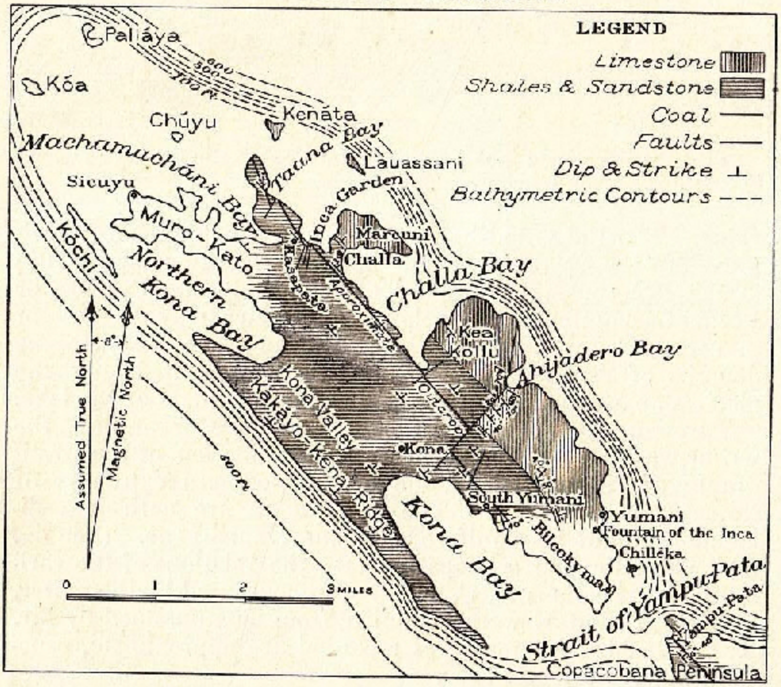

FIG. 8. Geologic sketch map of Titicaca Island based on observations by K. C. Heald and the writer. The base map is essentially that of Bandelier. The magnetic declination is assumed to be 8°.

Euomphalus antiguus, *Tropidoleptus carinatus* and *Vitulina pustulosa*; all but one of which "are represented in the coal measures of North America and Brazil by identical or closely related species."* Dereims describes Carboniferous strata from the Titicaca region including Copacabana. The fossils

* Bull. Mus. Comp. Zool., vol. iii, p. 282, 1871–76.

from Titicaca Island collected by K. C. Heald and the writer in 1912 are, according to Schuchert,* of characteristic Pennsylvanian aspect.

The Permian, Triassic, Jurassic, Cretaceous, and Tertiary from the Titicaca area have as yet not been satisfactorily differentiated. Forbes assigned certain strata to the Permian on the ground of lithologic resemblance to the Russian Permian. D'Orbigny mapped Triassic which Dereims considers Permo-Carboniferous. The fossil *Chemnitzia potosensis*, relied upon by both these writers, seems not to be of sufficiently diagnostic

Fig. 9.

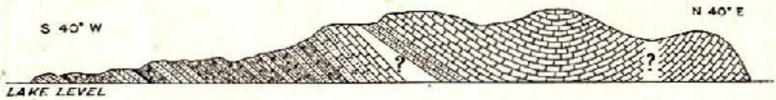

Fig. 9. Approximate geologic section from Kea-Kollu to South Yumani to illustrate section A, below.

value. The Puca sandstone at Cora-cora which extends northward into Peru,† and which is believed by Steinmann (1906) to be Cretaceous, is assigned by Dereims to the Permian or Permo-Carboniferous. Fresh-water Tertiary may be present in certain lake deposits of the Andean basin. Pleistocene deposits of considerable thickness are represented, but the glaciers appear not to have extended to the borders of the lake.

Through the courtesy of the Peruvian Corporation, the writer was enabled to make a brief examination of the stratigraphy of Titicaca Island, and of the northern extremity of Copacabana peninsula. The strata here are entirely sedimentary and of Carboniferous (Pennsylvanian) age. (See fig. 8.) The following sections indicate the relations of the various beds. Sections A, C, and D were measured by the writer. Sections B and E were compiled from data obtained by Mr. K. C. Heald. All measures recorded are approximate, especially for the thickest beds.

Section A.

Ahyjadero Bay (Pucara) to South Yumani. (Fig. 9.)

Distances determined by pacing, elevations estimated or measured by hand level.

* This collection, now in the Yale University Museum, will be discussed by Professor Schuchert at a later date.

† Adams, G. I., Ann. Report of the Smithsonian Institution for 1908, p. 404.

		Feet
1.	Limestone; dense, blue-gray, fossiliferous, in beds 2′–6′ thick; numerous fractures with slight displacement. Strike N. 60° W., dip S.W.	340
2.	Covered; probable locus of north-south fault zone	
3.	Limestone; massive, blue-gray; in beds 2′–6′ thick; separated by ½″–3″ beds of calcareous sandstone; weathers like ornamental moulding; abundantly fossiliferous. Strike N. 60° W., dip S.W. ∠ 20°	250
4.	Like Number 3. Dip S.E. ∠ 10°–20°	200
5.	Sandstone; brown with yellow and green tones; calcareous; in beds 6″–3′	100
6.	Limestone; blue and purple; with flat pancakes and cylindrical concretions of arenaceous material; dip E. ∠ 20°	50
7.	Limestone and shaly sandstone, interbedded; fossiliferous. Dip E. ∠ 40°	150
8.	Limestone; gray; calcareous sandstone; yellow-gray, calcareous shales; in beds 3″–1′ thick; forms wide bench. Dip E. ∠ 50°	200
9.	Sandstone, in beds 4′–10′; medium- to fine-grained, loosely cemented, quartz grains, some black grains, gray with greenish and yellowish tones; slightly cross-bedded; one layer of dark red shale included	70
10.	Shale; dark red; argillaceous and arenaceous; includes 10″ band of gray sandstone; rare fossils	25
11.	Sandstone; coarse, cross-bedded; brown, gray, green; with lenses of shale	4
12.	Shale; red, drab, green; lenses and thin bands of fine sandstone and 2′ bed of coarse, cross-bedded sandstone	30
13.	Sandstone; gray; coarse, cross-bedded; made up of overlapping sandstone lenses (1″–3″) with plant fragments	6
14.	Shale; argillaceous, arenaceous and carbonaceous; and yellow sandstone in thin beds including ½″–2″ beds and lenses of coal	14
15.	Shale; argillaceous; dark red and drab; with lenses of red-brown sandstone	30
16.	Sandstone; brown, coarse, with red chert pebbles	5
17.	Partly covered. Shales, shaly sandstone, and sandstone in thin beds, becoming increasingly arenaceous with depth. A few thin calcareous shale beds included. Dip E. ∠ 55°	160
18.	Sandstone; white, coarse, even-grained quartz; cross-bedded; massive and composed of overlapping lenses. At base are two lenses of excessively fine-grained, white, micaceous, paper-thin shales. Dip E. ∠ 50°	200
19.	Sandstone; white quartz, cross-bedded	10
20.	Shale; arenaceous, paper-thin, white; with plant impressions, and 3″–4″ lenses of concretionary sandstone; with limonite	6

		Feet
21.	Shale; arenaceous, argillaceous, and carbonaceous; with abundant plant impressions and lenses of impure coal	15
22.	Sandstone; white and arenaceous; drab shale in beds 2″–1′	40
23.	Sandstone; white, cross-bedded, as No. 18	40
24.	Sandstone; brown; in beds 2′–4′, with thin brown and drab shale partings	30
25.	Sandstone; brown and gray; in beds 3′–15′, with argillaceous, arenaceous, and carbonaceous shales, exhibiting ripple marks, sun-cracks, and worm prints	200
26.	Sandstone; in three beds (30′, 10′, 10′) with white and gray shale partings	50
27.	Sandstone; gray and yellow; in thin beds with black and drab shales, constituting about ¼ of the material	75

Section B.

Southeast end of Titicaca Island from summit of ridge to Kona Bay.

Measured by K. C. Heald. General strike N. 25° W.

		Feet
1.	Thin layer of ash (?).	
2.	Limestone; blue-gray; fossiliferous; massive. Dip, N. 20° E.	515
3.	Talus-covered, but mostly thin-bedded limestone; fossiliferous; two bands of shale	200
4.	Limestone; thin-bedded; hard	75
5.	Sandstone; medium-grained; pebbles, red and white; matrix, and general color, green; soft, thin-bedded, cross-bedded in places; three bands of dove-colored limestone	35
6.	Limestone; hard, blue-gray and soft yellow; top bed dove-colored; beds 6″–1′; fossiliferous	65
7.	Sandstone; coarse, clear and white, well-rounded grains	40
8.	Sandstone; medium-grained; gray to green; rounded, clear, green and red grains; massive; hard to medium. Dip N.E. ∠ 48°	40
9.	Sandstone; soft; medium to coarse; purplish to gray, top greenish; quartz grains, clear, red, green, and black, besides specks of lime. Bed of lime (4′) in middle. Sparingly fossiliferous. At top sandstone is harder and includes zone of brecciation	150
10.	Sandstone; massive; medium-grained quartz, clear, green, red and black; also lime specks; all in green cement; soft, but forms cliff face	13
11.	Shale; maroon, in part gray-green; bed of soft sandstone at 50′; some seams of limestone running across strike	100
12.	Shale, gray-green	16

		Feet
13.	Sandstone; massive; medium-grained; quartz, lime and limonite, and a green stone in purple cement; crumbles on weathering; dip 34° in 30′ (probably fault between numbers 13 and 14)	6
14.	Shale; maroon and gray-green; one 2′ pinkish bed; lenses of coal	45
15.	Sandstone; or arenaceous limestone; medium-grained; beds 1′–3′; hard, weathers in checks. Dip N. E. ∠ 45°	13
16.	Coal (bloom); clean; strike N. 25° W.; dip N.E. ∠ 47°	1½
17.	Limestone, gray; thin-bedded; with drab shale	60
18.	Shale; gray-green; talus-covered	6
19.	Limestone; impure; has plant fragments	2
20.	Shale; argillaceous; drab-gray; capped by 2′ of arenaceous shale filled with plant remains	8
21.	Sandstone; fine-grained; rounded quartz pebbles; calcareous; general color gray-white; included beds and cap of gray-green; soft, thin, even beds; one belt of gray shale; very few round, pea-sized limonite concretions. Dip N.E. ∠ 40°	85
22.	Sandstone; white; coarse to medium, with clear, subangular quartz pebbles. Some bands almost a conglomerate. Soft, massive, weathers in rounded knobs. Hard to tell from No. 13 at contact, but No. 13 is finer and has lines of shale	100
23.	Coal. Four feet bone in middle; weathered gray; fair quality. Dip N.E. ∠ 39°	8
24.	Limestone; thin-bedded, grading into sandstone at top; interbedded with shale; much checked or broken; weathers gray or red-brown	30
25.	Sandstone; fine grain; clear quartz, well-rounded and white flakes; more lime near top than bottom. Color white with some buff-yellow bands; massive; many cracks across bedding. Like No. 33 except for absence of specks of carbonaceous matter	70
26.	Sandstone; fine-grained; clear quartz, rounded and white flakes; weathers yellow-brown; fresh buff-gray. Even-bedded 1″–3′. One soft lens of buff-brown; at top is a yellow band of limonite	35
27.	Like No. 29, but limestone grades into a sandstone with fine, rounded quartz grains at top; brownish gray; mica on bedding planes	70
28.	Gray shale; contains lenses of limestone like No. 32 from 3″ to 1′ thick; has two seams of coal, one 1½″ about 11′ from bottom, the other 13″; very clean bloom at top	16
29.	Limestone and shale; limestone like No. 30. Slate greenish gray; very thin-bedded; mica on bedding planes	61
30.	Sandy limestone; buff-gray; weathers mottled gray and red-brown. Thin, regular bedding	30
31.	Shale; gray; with 2′ red-brown limestone 8′ from bottom,	25

	Feet
32. Limestone; begins as limy sandstone and ends as limestone; first beds buff to gray; last beds blue-gray (fresh fractured); beds even; 2″–3′; heaviest beds near bottom; much mica on bedding planes; fracture uneven and often breaks in rounded forms; between beds a parting of gray shale. Top contains limonite concretions like No. 33, and is weathered brown	50
33. Sandstone; fine-grained at top, medium at bottom; quartz grains rounded, not colored; a few tiny muscovite flakes and occasional black specks of carbonaceous matter. Much white lime or decomposed feldspar. Rare pea-sized pebbles of quartz; gray-white on weathered surfaces; soft, weather-rounded; bedding massive; cross-bedding poorly developed; contains seams of limonite-stained rock; one little streak of quartz showing garnet; round limonite concretions, size of pinhead to small pea; at 130′ bed of shale about 32′ thick. Shale is gray-drab to drab; contains carbonaceous matter, clear quartz grains, and occasional flakes of mica. Strike N. 24° W.; dip N.E. ∠ 43°	275

Section C.

Taanu Bay.

Strike N. 45° W; dip N. E. ∠ 50°.

	Feet
1. White, cross-bedded sandstone	10
2. Shale and thin sandstone; a few very thin carbonaceous layers	20
3. Sandstone; white, cross-bedded	60
4. Sandstone and sandy shales; thin-bedded; with plant fragments irregularly distributed	40
5. Shale, carbonaceous; coal in wavy lenses constitutes about ⅓ of the stratum; the remainder consists of lignite intimately mixed with shale and sandstone; coal appears to be of good quality	4
6. Drab shales and sandstone like No. 8	20
7. Carbonaceous bed, one-half shale; abundant pyrite	4
8. Sandstone, gray, thin-bedded, ½″–2″; shales, black and drab; wavy, cross-bedded; concretionary; with ripple-marks arranged in overlapping patches a few inches in diameter; contains muscovite and a few plant impressions	200

The interleaving lense character of the coal is well shown here; 500′ distant, across a little bay, numbers 5 and 8 are scarcely represented and shale occupies nearly the whole section.

Section D.

North end of Copacabana Peninsula, measured along the lake shore. Strike N. 40° W; dip E.∠30°.

		Feet
1.	Shales and thin sandstones with three beds of carbonaceous shale, 3′, 4′, 4′ in thickness. Approximately one-half of each bed consists of coal of commercial value	200
2.	Sandstone; gray-white; cross-bedded	60
3.	Shales, sandy; alternating with very thin (½″–1½″) beds of drab and gray sandstone; rare streaks of carbonaceous material	35
4.	Shales, black; alternating with gray-brown sandstone in lenses, and cross-bedded shale, in part carbonaceous; with some thin (½″±) lenses of true coal. At top is 1′± of impure coal	20
5.	Shale; black, lumpy, in part stained by limonite; breaks in flakes; contains lenses of gray-brown sandstone	20
6.	Sandstone; yellow-gray; in 6″–10″ beds	9
7.	Shale; black to drab; like No. 9	20
8.	Sandstone; yellow-gray	4
9.	Shales; drab; thin-bedded (⅛″) concretionary with wavy surfaces	6
10.	Sandstone; yellow-brown; thin bedded (1″–4″); cross-bedded, micaceous, lumpy, with mud concretions and sun-cracks; surface of sandstone wavy and beautifully ripple-marked. Shales; drab, sandy, lumpy, intricately folded on minute scale	30
11.	Sandstone; yellow; in beds 4″–10″ thick; interbedded with drab, arenaceous shales. Bedding very uneven and surface of each stratum reveals overlapping flakes	15
12.	Shales; brown, yellow and drab; with uneven, flaky surfaces	25
13.	Sandstone; white to gray; cross-bedded; medium-fine grain; in beds 4′–6′	30

Section E.

Coal Mine at Yampupata, Copacabana Peninsula.

Measured by K. C. Heald.

		Feet
1.	Sandstone; medium-grained quartz, red and white; cement green; general color green; soft	10
2.	Sandstone; fine to medium; rounded red and white quartz; cement a maroon color; general color purplish; soft	100
3.	Sandstone; fine-grained; rounded quartz; slightly cross-bedded; beds about 1′ thick	5
4.	Shale; gray	3
5.	Sandstone; medium-grained, brownish white; soft; cross-bedded, massive	6

		Feet
6.	Shale; purplish drab; full of plant fragments; two thin beds of limestone included	20
7.	Shale and thin-bedded limestone; transverse seams stained with limonite	175
8.	Sandstone; medium-grained quartz, clear, subangular to rounded; occasional large grains; some lime; gray-white with limonite stains; cross-bedded; thin to heavy; some rare spots of conglomerate	267
9.	Sandstone; fine-grained, rounded quartz; much stained by limonite; even-bedded; mica on bedding planes	50
10.	Shale; drab with lenses of yellowish limestone	4
11.	Limestone; gray, sandy	$\frac{1}{3}$
12.	Coal, with 2″ band of sandstone. Coal of fair quality and with little "bone"	2
13.	Shale; gray to drab with purple streaks resembling rootlets	8
14.	Sandstone; fine-grained, with clear, rounded, quartz pebbles, white flakes and limonite; even, heavy beds; toward top assumes greenish tone and contains much mica and lime	20
15.	Shale; gray to purple	30
16.	Sandstone; fine, with well-rounded quartz grains, and white specks; some muscovite; thin, even bedding	6
17.	Shale; gray, with thin beds of limestone	40
18.	Sandstone; fine, with clear, well-rounded quartz grains and white specks. Mica on bedding planes; weathers gray-white; some raised veins of harder, dark rock; bedding fairly even; some cross-bedding; some twisted beds; calcareous at top	135
19.	Limestone and shale; the latter predominate; shale is drab; limestone is gray, to a limonite yellow; cross-bedded and twisted; has much mica on bedding planes.	55
20.	Sandstone; fine, with rounded, clear grains of quartz, and numerous blotches of lime or other white material; general weathered color gray-white with spots and bands of yellow; medium hard; even-bedded; massive; occasional small, rounded concretions of limonite. Strike N 46° W; dip N. E. ∠ 40°.	30

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