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The LA PAZ (BOLIVIA) GORGE

By Herbert E. Gregory

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

ART. XVI.—*The La Paz (Bolivia) Gorge;* by HERBERT E. GREGORY.*

FROM the shores of Lago Pequeno, the nearly enclosed southeastern portion of Lake Titicaca, the surface of the interior plateau of Bolivia (the *altiplano* or *altiplanicie* of the Spanish Americans) ascends toward the Cordillera Real. From Guaqui to Viacha, forty-two miles, the rise is 120 feet and the railroad, after following the irregular course of the Rio Tiahuanaco and

FIG. 1.

FIG. 1. View from Alto looking eastward toward the Cordillera Real. The position of the gorge, on the floor of which the city of La Paz rests, is indicated by the arrow.

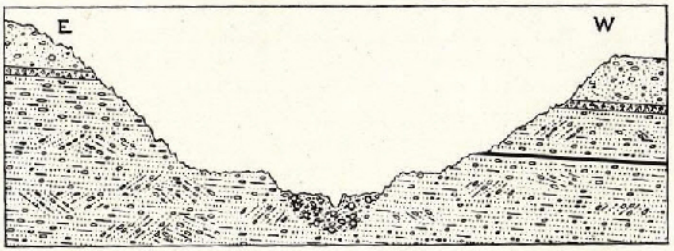
passing a group of low, mature hills, crosses the shallow valleys of the Rio Colorado and the Rio Viacha. From Viacha to Alto, the terminus of the steam railroad, the floor of the *altiplano* is remarkably flat, and slopes westward at the rate of forty feet per mile.† The drainage of this portion of the plateau is sluggish and frequently interrupted by shallow

* Geologist of the Peruvian Expedition of 1912.

† Distances and elevations are as shown on the Mapa General of the Ferro Carril del Sur del Peru, a blue print of which was kindly furnished by T. A. Corey, Chief Engineer.

depressions. No hills rise above the gravel-strewn floor which appears to extend as an unbroken surface to the foot of majestic Illampu. At Alto a surprise awaits the traveler, for here, without preliminary warning in change of slopes or eastward-flowing streams, one finds himself on the brink of a canyon cut entirely in alluvial deposits to a depth of over 1500 feet. At the foot of the canyon wall lies the city of La Paz, whose red tile roofs, cathedral spires and threads of streets, broken by parks and traversed by streams and irrigation ditches compose a unique picture of singular beauty.

FIG. 2.



a, gravel, sand. *b*, tuff. *c*, sands, gravel, clay. *d*, lignite. *e*, sands, gravel, clay.

FIG. 2. Generalized section of La Paz gorge, not drawn to scale.

As shown in the view (fig. 1), looking from Alto station across the La Paz valley, the landscape gives no suggestion of the presence of such a chasm and one is reminded forcibly of the Colorado Plateau of Arizona, where impassable canyons of great depth are revealed only when one is standing on their rim. On descending the canyon walls it is found that the floor is by no means flat, but is cut by streams which flow in gorges one hundred feet and more in depth, between and over which, resting on hills and terraces, the city is built. The larger part of the buildings are distributed along two more or less dissected terraces whose position with respect to the valley walls is shown diagrammatically in fig. 2.

Between San Jorge and Obrajes the La Paz river has sunk its bed into sands and clays whose eroded strata exhibit miniature "bad land" forms. Lying unconformably above these finer deposits at San Jorge and northward through the city are deposits of gravel which stand as nearly vertical walls fifty to one hundred and fifty feet high. The material is excessively coarse and contains bowlders of white granite six inches to six feet in diameter. Above the gravel terraces, forming the knobs and benches and ridges of the western part of the

city as well as the walls of the valley, and extending nearly to the level of the *altiplano*, are beds of gravels and sands and clays eroded into a bewildering maze of forms. Needles in groups or singly, columns unadorned or fluted or capped by tables, rise five to fifteen feet on steep slopes and five to fifty feet on knife-edged, dividing ridges. Innumerable sharply-cut, miniature canyons with sheer walls five to two hundred feet in height together with tunnels and pits in great variety furnish passage for water. Landslides with slopes as great as 50°, frequently accompanied by open cracks, are numerous. Here and there benches and tables composed of cemented gravels and brown concretions project from vertical surfaces or form the capping of columnar masses. The whole deposit is ash-gray in general tone, but is beautifully striated by gray, brown, light pink, bright yellow, purple and white bands from a few inches to one hundred feet in thickness. Vegetation is absent except for patches of wiry grass and tough shrubs which find a foothold on the little flat-topped tables and gentler slopes. The beds in general dip slightly to the south.

A closer examination of the strata exposed reveals the presence of the following materials: (1) Sand, mostly fine, some coarse, composed chiefly of quartz grains, and arranged in beds several hundred feet in extent, or in short lenses. All the strata are more or less cross-bedded, with laminae dipping 0°—25°. (2) Gravel, composed of rounded pebbles from the size of a small pea to three inches in diameter, arranged as lenses which exhibit marked and sudden variation in position and size both horizontally and vertically. The gravels are everywhere cross-bedded and frequently inclose lenses of sand. The component materials in the upper part of the section were found to consist approximately of sedimentary fragments 75 per cent, igneous 15 per cent, metamorphic 10 per cent. The following types of rock were recognized: gray sandstone, brown sandstone, white granite, granite-gneiss, diorite-gneiss, garnetiferous granite-gneiss, black slate, mica or chlorite slate, gray quartzite, brown quartzite. Quartz pebbles are rare and no limestone or volcanic material was observed. All the pebbles are worn, about half of them well-rounded, and a few are faulted and veined. The gravel increases in amount and becomes coarser toward the top, and along the electric railway from La Paz to Alto contains angular, sub-angular and rounded bowlders four inches to one and one-half feet in diameter. At this locality the gravel forms beds of considerable thickness or occurs as lenses embedded in finer gravels, sands and clays, and resembles morainal deposits except for the irregular stratification. (3) Clays, rarely pure, usually highly arenaceous, generally distributed as lenses within the finer sands. In the

localities studied by the writer, clay is relatively small in amount, the larger beds being 100 to 200 feet in length and of inconsiderable thickness. (4) Carbonaceous shale and two

FIG. 3.

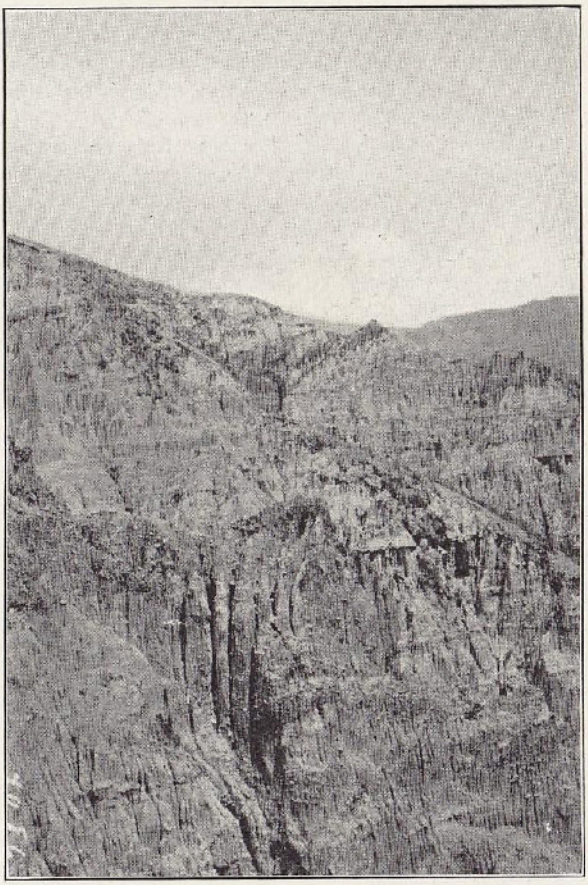


FIG. 3. View of deposits in La Paz gorge, about one mile west of the American Institute.

layers or lenses of impure lignite three to six inches thick, composed of comminuted plant remains too fragmentary for determination. (5) Volcanic ash, eight to fifteen (at one point twenty or more) feet thick, extending as a continuous white

band for over two miles on the west side of the valley and reappearing on the east side at an elevation of about 12,600 feet. Microscopic examination shows the ash to be dacitic.

FIG. 4.

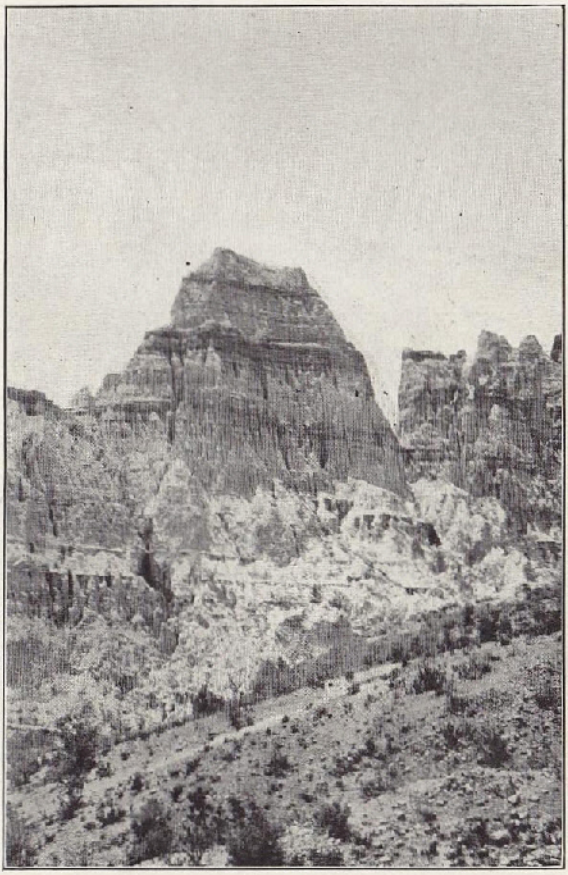


FIG. 4. View of deposits in La Paz gorge, about one and one-half miles west of the American Institute.

The general appearance of the deposits and the arrangement and alternation of strata are shown in figs. 3 and 4, with which, for purposes of comparison, is inserted a typical view of the Dakota bad lands (fig. 5).

The texture and structure of a portion of the beds taken about midway between the top and bottom are shown in fig. 6. Figs. 7 and 8 exhibit details and are fairly representative of a large number of occurrences.

The profound gorge of La Paz with its great accumula-

Fig. 5.

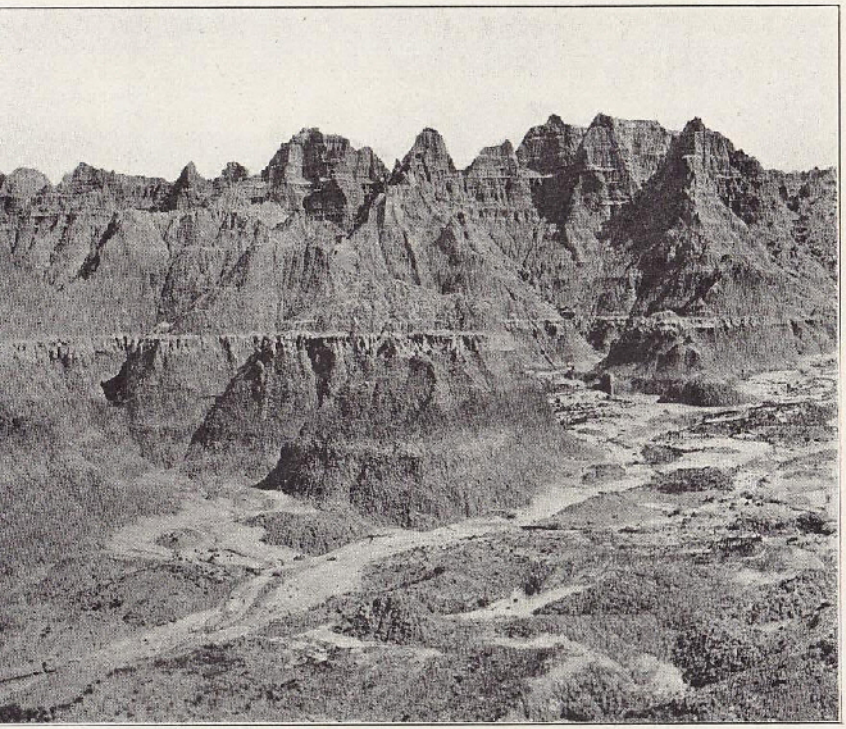


Fig. 5. View of Bad Lands, South Dakota. Photo by Darton, U. S. Geological Survey.

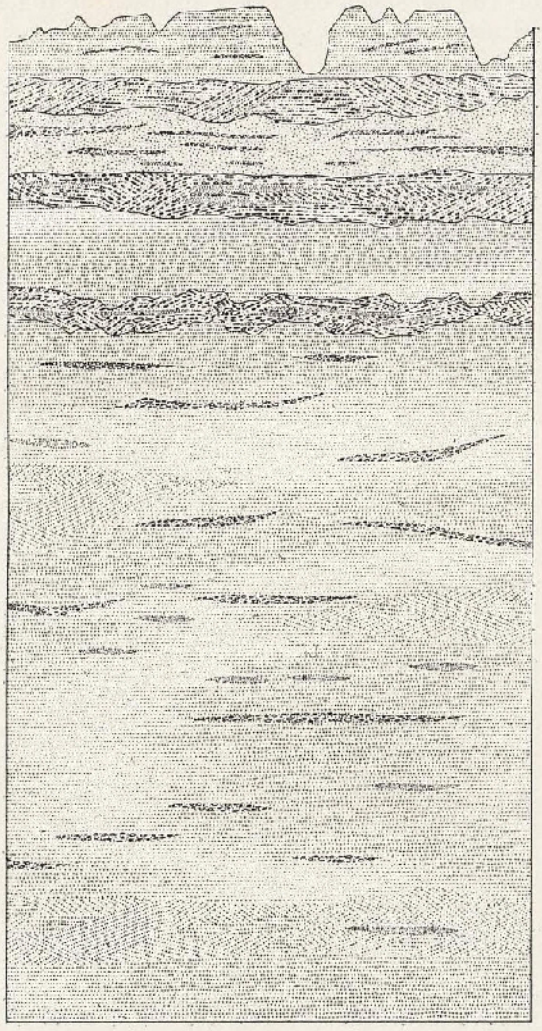
tion of unconsolidated sediments and striking erosion features has naturally attracted the attention of scientists and travelers alike. D'Orbigny* speaks of the La Paz deposits as "alluvial," and notes that sandstone pebbles were more abundant in the upper beds. He also recognized kaolin deposits at Miraflores,—a suburb not visited by the writer. Forbes† assigns

* Voyage dans Amérique Méridionale, Tomo III, 1842, partie 3, p. 120.

† Report on the Geology of South America, Quar. Jour. Geol. Soc., vol. xvii, 1860.

to these beds a thickness exceeding 2000 feet. The band of "trachytic tuff" "300 feet below the surface of the plain,"

FIG. 6.



a, 15 ft., fine sand with thin lenses of gravel. *b*, 4 ft., cross bedded gravel. *c*, 24 ft., fine sand, consolidated in places and lenses of gravel. *d*, 14 ft., cross-bedded gravel, with lenses of fine sand. *e*, 20 ft., fine sand. *f*, 8 ft., cross-bedded gravel with lenses of fine sand. *g*, 200 ft., thin-bedded sands with gravel lenses; portions of sand firmly cemented.

FIG. 6. Section of a portion of the west wall of the La Paz gorge. Drawn to scale.

"20 to 30 feet in thickness," Forbes considered as part of a wide-spread "diluvial formation," occupying a basin between the Silurian rocks of the high Andes and the low Devonian hills to the west, and believed the impure lignite to be an extension of the carbonaceous strata exposed at the foot of Illimani and also near Poto-poto. The material composing

FIG. 7.

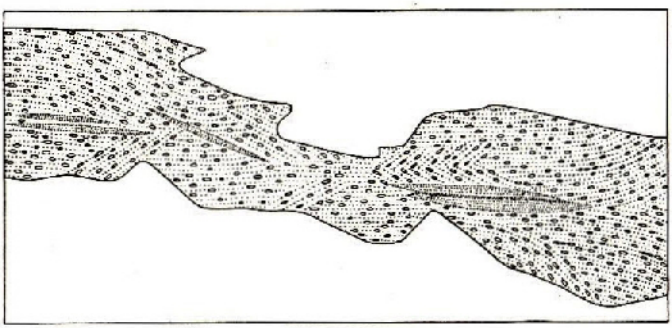
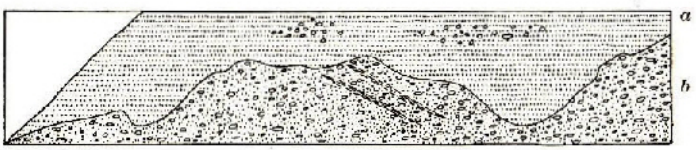


FIG. 7. Portion of gravel lens; extent and thickness of gravel and sand and orientation of cross-bedding laminæ drawn to scale.

FIG. 8.



a, sand with irregularly distributed gravel. *b*, gravel with two lenses of clay.

FIG. 8. Section on line of Arica-La Paz railroad, showing contact between gravel and sand. Drawn to scale.

these beds has its source, according to Forbes, in the Silurian strata of the Cordillera Real; with the exception of the volcanic ash, which he assumes had been carried by streams from Achacachi on the shores of Lake Titicaca. Zundt* assigns the

* Appendix to Spanish edition of D'Orbigny, La Paz, 1907.

granite bowlders to the Cordillera Real at the north, the quartz to the same area, and also to the mountains near Viacha and Colquencha to the west, clays to the Ramos formation (Tertiary?) underlying the *altiplano*, and the ash to the Letania mountains.

As to the condition of deposition of these deposits, D'Orbigny and Forbes appear to have held no definite views. Evans* expresses the opinion that "the enormous deposits of alluvium . . . represent not the alluvium of a lake, but the infillings of a longitudinal valley." Zundt† speaks of the ash deposit as carried by wind, dropped into a lake or sea and spread by the waves. Minchin‡ speaks of lake beds, a part of the floor of ancient Titicaca, now covered by glacial gravels. D'Arlach§ speaks of floods induced by earthquakes which cut the La Paz gorge and drained an interior sea. Posnansky‖ apparently considers the base of the La Paz beds as marine-built, the upper portion deposited in an ancient sea detached from the Pacific by uplift. Zundt, whose previous views involved the existence of a salt sea, considers the deposits in the La Paz gorge as lacustrine,—the fillings of a temporary lake formed by blocking an ancient river which drained the interior basin. The upper end of the La Paz gorge is believed by this writer to have been excavated by glaciers. Bowman¶ recognized the fluviatile origin of the La Paz beds, but in speaking of the deposits as "the coarsest alluvium, the sort of material that mountain torrents carry," evidently had in mind the upper beds of the section and the material forming the banks of the present stream, rather than the fine-textured, stratified deposits to the west and south of the city.

From the general and detailed sections described and figured above it appears that the deposits which line the La Paz gorge are in no way typical of lacustrine formations. The absence of continuous beds of thinly laid clays, silts and the finest sands of uniform texture, the presence of cross-bedding and channeling and the rapid alternation of gravels and sands both horizontally and vertically argue against deposition in the quiet waters of a lake. All the phenomena disclosed by the study of the sections may be accounted for on the theory that the region was traversed by low grade, piedmont streams. Such streams with a shifting net-work of distributaries and interlaced channels alternately depositing and cutting in a capricious manner

* Geog. Jour., vol. xxii, pp. 634–35, 1903.
† Loc. cit, 1907.
‡ Geog. Jour. vol. xxxvi, pp. 396–7, 1910.
§ Bol. Oficina National de Estadistica, No. 64–66, p. 756, La Paz, 1911.
‖ Bol. Oficina National de Estadistica, No. 64–66, pp. 689–702, 1911.
¶ This Journal, vol. xxviii, p. 400, 1909.

in response to seasonal rainfall would produce just such sediments as the strata under discussion. Temporary lakes,—annual or lasting for decades,—are normal features of such a piedmont flood plain and are ample to account for the lenses of clay and the thin, short bands of carbonaceous material occurring in the section.

The geologic history of the La Paz gorge can not be written on the basis of the data at hand. The significance of the inner gravel terrace pointing to a second, or perhaps a third, cycle of filling and erosion, the conditions under which the remarkably coarse upper beds were deposited, the character of the floor on which the finer sediments were laid down, the extent of the deposits and the pre-glacial history of the La Paz river itself, are problems which will repay detailed physiographic research.