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[F O U R T H S E R I E S .]

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ART. I.—*A Geologic Reconnaissance of the Cuzco Valley, Peru*; by HERBERT E. GREGORY.¹ With Plates I and II.

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¹Geologist, Peruvian Expedition of 1912, under the auspices of Yale University and the National Geographic Society.

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INTRODUCTION.

Scope of the paper.—A journey from Mollendo to Lake Titicaca, continued over La Raya Pass and along Urubamba River, is sufficient to indicate the wide range of problems awaiting solution in southern Peru. The Cuzco Valley, in particular, appeals to the imagination of the scientific man. In several respects it is an unworked field. Its unusually rich archeologic material has been inadequately discussed. A study of its present and ancient inhabitants with reference to physical environment has not been undertaken; and its interesting geologic features have received but incidental mention.² The Cuzco Valley is a key area for the interpretation of the history, geography, and geology of the central Andes; it fairly bristles with scientific problems.

It was the writer's good fortune to spend the months of September, October, and November, 1912, in southern Peru. Seven weeks were devoted to geologic field work in the region adjoining Cuzco. The particular object of the expedition was a study of the gravel deposits from which human remains

²The pamphlet prepared by Dueñas (*Aspecto minero del Departamento del Cuzco*, Cuerp. Ing. de Min. del Peru, Bol. 54, Lima, 1907) marks the beginning of modern geologic studies in the Department of Cuzco. The bulletin contains valuable economic and petrographic material.

assigned to the glacial epoch have been reported.³ Time was available, however, for a geologic reconnaissance including certain detailed examinations of the western portion of the Cuzco Valley, and the results of these observations are recorded on the following pages. The geology is very complex, and the time at my disposal was insufficient for the collection of the data necessary for the solution of the many problems which arose. A much larger amount of detailed work is required before the geologic history of this interesting area can be written. The present paper is therefore a contribution to the geology of the Cuzco Valley, not a final report.

Note on the topographic map.—The base map accompanying this report (Plate I) is the first published sheet of a series covering the field of operations of the Peruvian expeditions of 1911, 1912, 1914, and 1915, conducted under the joint auspices of Yale University and the National Geographic Society. An effort has been made to produce maps of a high degree of excellence, and credit is due to the chief topographer, Mr. Albert H. Bumstead and his assistant, Mr. Osgood Hardy, for the success attained in devising field methods for use in this difficult area.

The parallels and meridians of the Cuzco Valley map are based on latitude and longitude established for the Cuzco railroad station in 1914 by Mr. Bumstead, who describes his method as follows:

“Latitude observations were made at 8 located points of a system of triangulation beginning near Cuzco and extending about 60 miles westerly and after reducing each to the Cuzco depot their mean was adopted as the latitude of that point. The instrument used was a small Berger transit reading direct to 30'' and by estimation to 10''. In all 233 observations were made; 177 being meridian altitudes of stars, 32 exmeridian altitudes of stars and 24 exmeridian altitudes of the sun. The probable error in the latitudes of the several stations ranged from 1'' to 9'' with a mean of 4''.”

All the latitude stations were on the highland between the great canyons of the Urubamba and Apurimac rivers which flow approximately parallel from east to west, and about

³Gregory, Herbert E., The gravels at Cuzco, Peru; this Journal, xxxvi, pp. 15-29, 1913. In this paper the topography, structure, history, and age of the enormous gravel fan on the edge of which the city of Cuzco is built are discussed in detail, and they will not be further treated in the present report.

30 miles apart. As would naturally be expected, there was a decided disagreement between the latitudes as observed and the latitudes as computed by triangulation, starting from any given place, due to local deflections of the plumb line. The effect was to shorten the radii of curvatures of the meridians crossing this upland and to make all latitudes observed near its southern margin come out too far south and all near the northern margin too far north. Owing to the extremely irregular character of the surface these plumb line deflections can be only roughly estimated, so that it is to be expected that when the Cuzco Valley map is connected to a more extended system of triangulation, an error possibly as great as 4 or 5 seconds may be found in the latitude. Mr. Bumstead reports:

“The greatest differences between plumb line deflections were found between two stations north and south of the great peak of Salcantay which rises more than 15,000 feet above the canyons on either side. There the difference of latitude by triangulation is $15' 37''.1$ and by observations $16' 13''.5$, a difference of $36''.4$, only a small part of which can possibly be accounted for by uncertainties in the observations.”

The astronomical latitude of the Cuzco depot as found from meridian altitudes of 66 stars is— $13^{\circ} 31' 29'' 1''.4$, and the geodetic latitude adopted as described by Mr. Bumstead is— $13^{\circ} 31' 33''.5$.

In 1914 the Peruvian Government and the Harvard Observatory coöperated with the field party in a series of wireless time signals. At about 7 o'clock each night 30 signals were sent out from the powerful station at San Cristobal at intervals of about ten seconds. These were received in the field and at the Observatory at Arequipa, where the exact times at which the signals were sent were noted by the Observatory clock, corrected by frequent observations of stars. Thus by a subsequent comparison of notes the error of the field chronometer was deduced. The success of this method of comparison is shown by an average error probably of only ± 0.03 .

Immediately after comparing the chronometer, local time was observed by altitudes of east and west stars taken with the transit previously described.

The following table from Mr. Bumstead's report shows the four values from which the longitude of the Cuzco depot was derived:

Longitude Station Number.	Probable error of comparison of field chronometer. Seconds.	Probable error in local time. Seconds.	Longitude reduced by triangulation to Cuzco depot.	Weight (inversely proportional to probable error in local time).
57	± 0.02	± 0.11	71° 58' 38" .9	1.
46	± 0.04	± 0.16	42 .8	0.7
363	± 0.02	± 0.11	41 .6	1.
636	± 0.03	± 0.19	54 .7	0.6
Weighted mean			71° 58' 43" .4	

It is probable that these results are affected by local deviations of the plumb line, but not so much as the latitude, for the trend of the mountain ranges is east and west.

Azimuths determined by solar compass in 1912 were checked by more precise methods in 1914.

The altitudes of the topographic map are based on the height of the rails at Cuzco station, as determined by Mr. T. A. Corry. As a basis for plane-table triangulation a base line 2 miles in length was measured along the railroad, and angles from its ends were measured to points on the rim of the valley. Two of these points, 6.4 miles apart, were used as bases for the whole map.

Owing to conditions incident to exploration, the quality of the map is not uniform. The area marked C on the accompanying sketch (fig. 1) was surveyed by Mr. Robert Stephenson. This portion of the Cuzco Valley is intricately dissected, and the time at the disposal of the topographer was brief. The features are therefore somewhat generalized. The area marked A is covered by a plane-table survey made by Mr. Bumstead, who describes his method as follows:

"I went over the ground very thoroughly, making many stations by the three point method and locating almost all the features by intersection. The fact that the ground is entirely unobscured by trees made this the ideal method, and levels were always obtainable by vertical angles to some point or points whose elevation had been previously determined.

In a country of so great differences of elevation, the use of steep vertical angles for topography is unavoidable, and unless distances are known more accurately than they can be scaled on a map of so small a scale, resulting determinations of eleva-

tions are subject to considerable error. To reduce this error as much as possible, and to prevent the accumulation of errors of elevation, I ran a line of levels down the railroad from Cuzco to the ends of the base line and then with vertical angles and the computed distances of the transit triangulation found the elevations of Corao and Pícol, on the north side of the valley, and Huanacapia, on the south side. Then, in making plane-table stations I was able to get a fairly flat vertical angle to

FIG. 1.

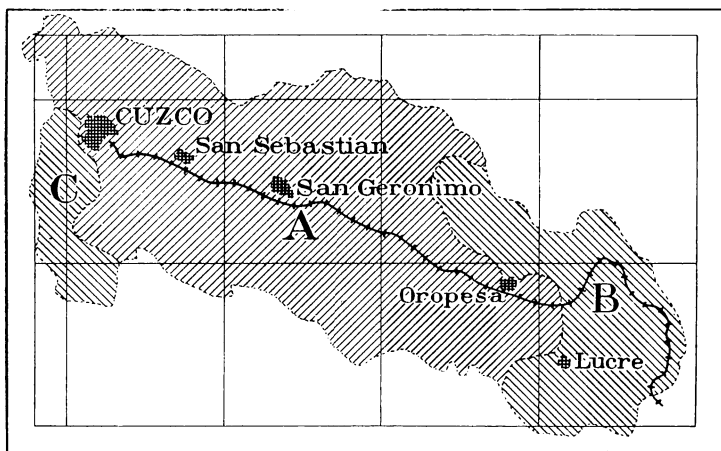


FIG. 1. Areas surveyed by members of the Peruvian Expedition of 1912,—A, A. H. Bumstead; B, A. H. Bumstead and Robert Stephenson; C, Robert Stephenson. Cities mapped by J. P. Little. Osgood Hardy acted as Mr. Bumstead's assistant throughout.

some one of these points, or to points of known elevation along the railroad. I soon had a considerable number of points scattered about the sheet, whose elevations were well determined and checked, and from these I always worked."

The area marked B is mapped from a reconnaissance survey by Mr. Bumstead and Mr. Stephenson, following the methods adopted for area A. The streets of Cuzco, San Sebastian and San Geronimo were surveyed by Mr. J. P. Little, topographic assistant; the plats of Oropesa, Lucre, and other villages are generalized. Time did not permit the tracing of trails, and therefore many important ones are not shown.

For the spelling of geographic names, the expedition is indebted to the Centro Geográfico del Cuzco, and its President, Dr. A. A. Giesecke, Rector of the Cuzco University.

Note on the geologic map.—The geologic map of the Cuzco Valley (Plate II) represents the results of reconnaissance, not detailed work. At the time the geologic work was done only an incomplete print of the central portion of the topographic map was available, and it has not been possible to avoid errors in transferring to the completed map observations obtained by compass traverse. No boundaries of formations have been traced throughout their extent; and the directions of fault traces are only approximately known. The altitude of the strata is indicated by dip and strike symbols; but it has not seemed wise to record my incomplete observations regarding trends of the intricately interlocking synclines and anticlines or to undertake at this time a systematic discussion of local and regional structure.

Though obviously subject to radical revision, the map represents substantially the present state of knowledge regarding the geology of the Cuzco Valley, and I trust it will be found helpful to those who undertake detailed work in the little cultivated but fertile field of Peruvian geology.

I. TOPOGRAPHY.

Topographic setting.—The geographic position of the Cuzco Valley is shown in fig. 2. Though possessing unusual scientific interest, it is relatively a minor topographic feature. Viewed broadly it is one of many small valleys tributary to a group of canyons whose waters supply the Amazon. A surface profile of southern Peru drawn through Cuzco reveals the presence of an extensive area of upland sharply bounded on the southwest by the Peruvian coastal plain and on the northeast by slopes leading to the Amazon (fig. 3). This surface, which may be called the Peruvian Plateau, is part of the Andean Plateau—one of the greatest of the world's highlands. Above this plateau surface, which stands at 13,000 to 15,000 feet above the sea, rise snow-clad peaks—volcanic on the Pacific side and erosion remnants on the Amazon side—and below it are sunk profound canyons. The upward and downward departures from a level at approximately 14,000 feet are about equal in amount and involve areas of about equal extent. On the southern border of Peru the upland surface is broken into a

Western Plateau and an Eastern Plateau by the sunken interior basin holding the waters of Lake Titicaca. In the latitude of Cuzco these relations are not duplicated; the Andean plateau is practically uninterrupted and the terms Eastern Cordillera

FIG. 2.

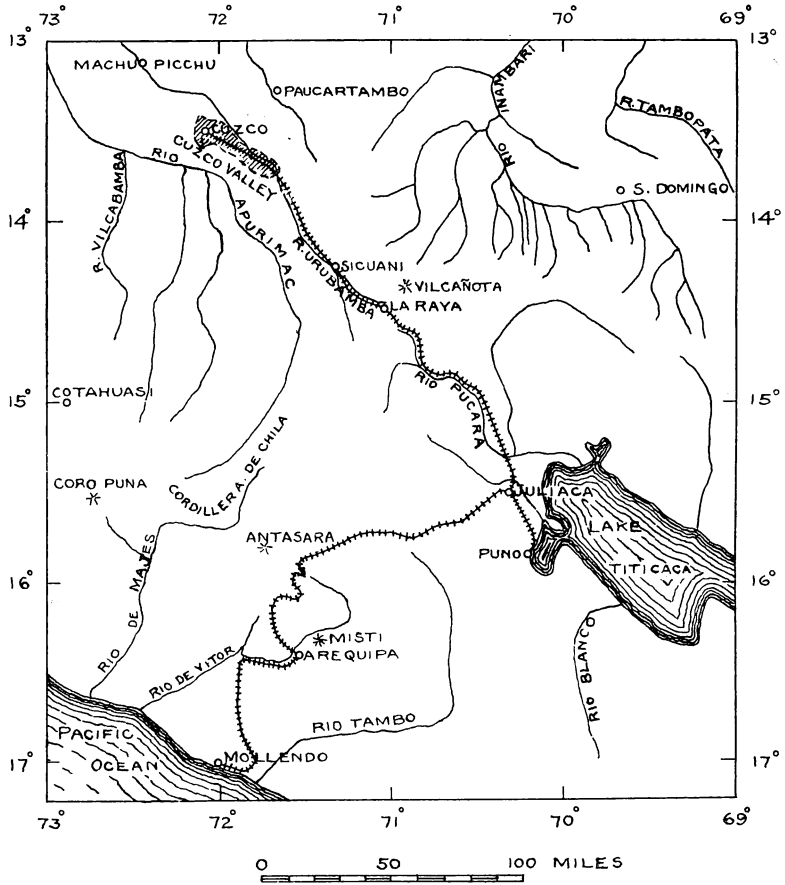


FIG. 2. Outline map of a portion of Southern Peru, showing the location of Cuzco Valley.

and Western Cordillera have little significance. The dominant topographic feature of southern Peru is a widely extended plateau, not chains of lofty mountains, as represented in standard atlases.

Relief.—The rim of the Cuzco Valley stands at an average elevation of about 13,500 feet and is surmounted by peaks

reaching upward to heights exceeding 14,500 feet. This bordering wall is breached by passes between 12,000 and 14,000 feet high, through which access is afforded to the valley floor, lying below 11,100 feet. The extremes of elevation are the summit of Cerro Pachatusa (15,915 feet) and the mouth of the Huatanay (10,100 feet).

The floor of the Cuzco Valley, 19 miles in length, is divided by the Angostura and Oropesa narrows into three oval areas of flat-lying land, displayed like links in a chain. From these valley flats thinly coated rock slopes rise with a gradient of 1,000 to 2,000 feet to the mile, in places becoming precipitous. The steeply inclined slopes continue upward from the central

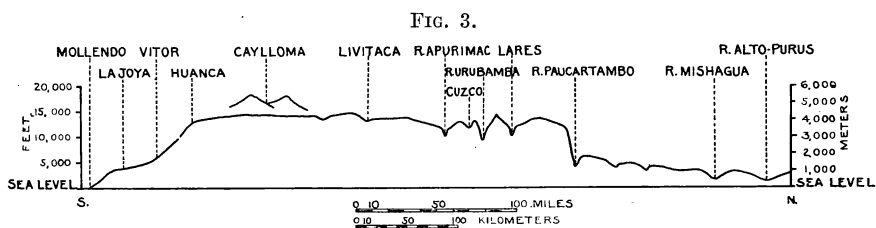


FIG. 3. Surface profile of Southern Peru, drawn across the mountainous area from the Pacific Ocean to the Amazon Plains on the 72° W. longitude.

valley until areas of slight relief (the pampas) are reached. Huaca-Cancha, Bambanusa, and Huanca-Huanca pampas spread out at elevations of 13,500 feet; Pampa de Kkallachaca and adjoining plateaus, developed on the limestone north of Cuzco, stand at about 12,000 feet—1,000 feet above the valley floor. The outer wall inclosing the Cuzco Valley is trenched in many places by streams leading away from the valley and toward the Apurimac and the Urubamba; the serrate rim of the valley therefore does not correspond to the divide between drainage basins. In general the southward facing slopes of the valley are cut by deep canyons and exhibit great local relief; the northward-facing slopes are gentler and less abrupt and in places above Angostura Narrows are traversed by flat-floored, terraced valleys.

Extrusive volcanic rocks have modified the topography of Bambanusa Pampa and have interfered with the normal development of relief at Oropesa and Rumicolca; elsewhere the surface is elaborately dissected in response to the influence of the variable composition and complicated structure of the underlying sedimentary rocks.

The three basins.—The expanded portion of the valley floor between Cuzco and the Angostura Narrows may be termed the Cuzco Basin. It is an intensively cultivated area, the seat of Inca civilization at the time of the Spanish conquest, and the present home of over 90 per cent of the inhabitants of the Cuzco Province. The basin is bordered by gravel fans and low cliffs cut in poorly consolidated sediments. As viewed from its eastern margin the floor of the basin is flat, but near at hand it is seen to consist of two portions separated by a low rock ridge thickly mantled with sand. This ridge has little topographic importance but serves to separate two areas of tillable land and to determine the location of the villages of San Sebastian and San Geronimo. The portion of the basin floor west of this agricultural divide is almost without relief (fig. 4). As seen from Ttica-Ttica the minor inequalities on the floor of the basin disappear and a graded surface, sloping gently eastward and broken only by groves of eucalyptus and the houses of the city of Cuzco, is presented to view (fig. 5). The landscape is a garden with plats of barley and potatoes, bordered by high stone walls and traversed by irrigation ditches. In the vicinity of San Geronimo the flat floor of the Cuzco Basin is confined to a strip half a mile wide bordering the Huatanay. The village itself is set on the edge of an enormous alluvial fan built outward from the mouths of rock-walled canyons which score the slopes of Picol (fig. 6).

The topographic features of the Cuzco Basin are duplicated in several respects by the Oropesa Basin (fig. 7). The Oropesa Basin has, however, less width and a flatter floor than its larger companion. The Lucre Basin shows the least relief of the three subdivisions of the Cuzco Valley.

Drainage.—The sinuous line marking the rim of the Cuzco Valley forms a rough rectangle with a length of 22 miles and an average width of 7 miles. The 154 square miles thus inclosed is drained by a single stream, the Huatanay, which occupies an axial position from its source to the village of Huacarpay. Thence it turns sharply northward, escapes through the valley wall, and joins the Urubamba at Sierra-Bella. The Huatanay rises in flat-floored glaciated swales at the base of Cerro Sencca, where numerous springs issuing from till insure perennial flow. During the rainy season the supply obtained from ground water is supplemented by torrents which traverse deep rock grooves, cut in the mountain slopes to heights of 14,000 feet. Through the city of Cuzco the

FIG. 4.

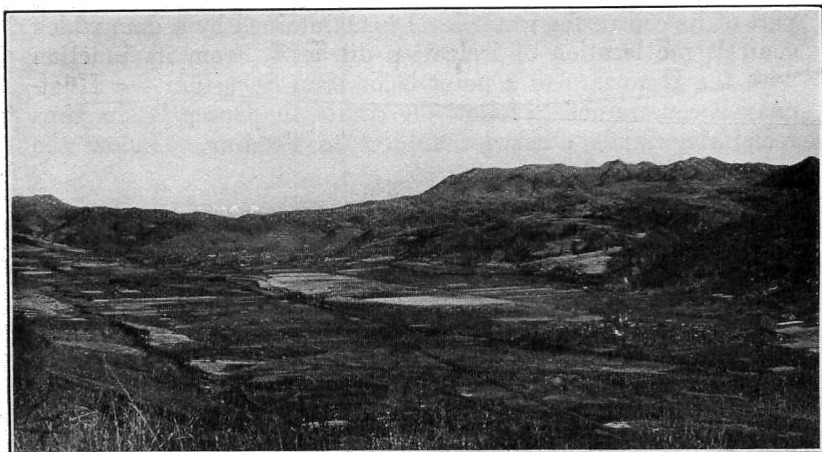


FIG. 4. View of floor of the Cuzco Basin from Quispiquilla; San Sebastian is in the right foreground; Cuzco in the middle distance.

FIG. 5.

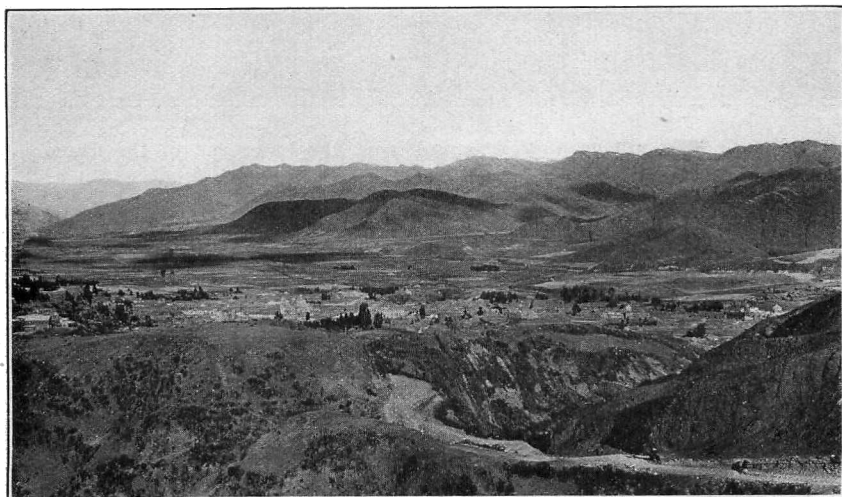


FIG. 5. View of the upper end of Cuzco Basin from a point overlooking the city of Cuzco. The canyon in the foreground is cut in a gravel fan, which encloses the Basin on the west. Angostura Narrows seen in the distance terminates the basin on the east.

Huatanay⁴ occupies a channel lined by walls of ancient design which lead the stream to the south side of the valley. In this part of its course the water level is maintained by a dam which controls the location of irrigation ditches. From its junction with the Huancaro to a point below San Sebastian the Huatanay is constrained to follow the rim of the Cuzco Basin, thus reclaiming lands otherwise subject to flooding. Below the

FIG. 6.

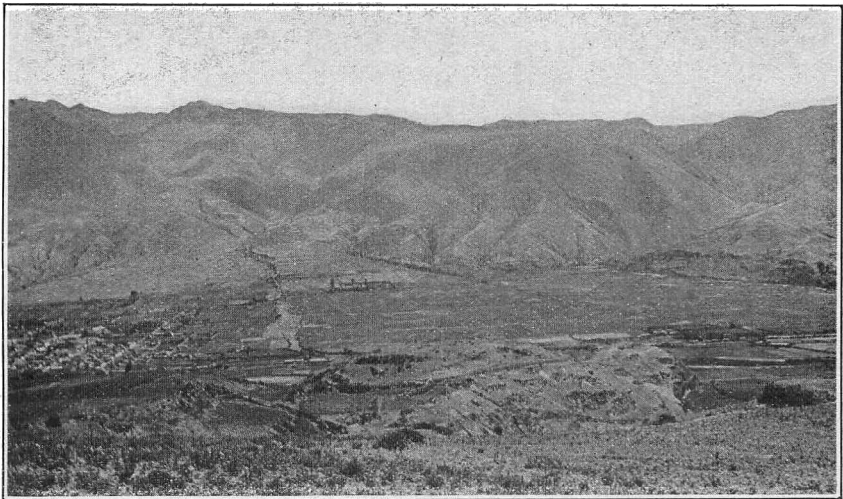


FIG. 6. The village of San Geronimo at the lower end of the Cuzco Basin showing its position on the margin of an alluvial fan.

mouth of Rio Huilcarpay the stream returns to the center of the valley, following a natural course around the low divide separating the two portions of the Cuzco Basin, and encircling the foot of San Geronimo fan until confined by the walls of the Angostura Narrows. Below Angostura the Huatanay, except where artificially controlled, is a sluggish, meandering stream. For an 8-mile stretch below Saylla, across the flat floors of the Oropesa and Lucre basins (fig. 7), the total fall of the stream is only 160 feet. The quality of the profile of the Huatanay is shown in fig. 8.

Tributaries to the Huatanay vary greatly in amount and permanency of flow. Above Cuzco the streams are moderately

⁴Locally called Rio Zappi.

supplied from springs in the limestone gorges; the western branches within this area contribute little. Within the city of Cuzco the Huatanay receives two canalized tributaries, Chunchullumayo⁵ and Tullumayo,⁶ which have played a prominent part in the history of the city. The Chunchullumayo receives its small perennial supply from a network of branches

FIG. 7.

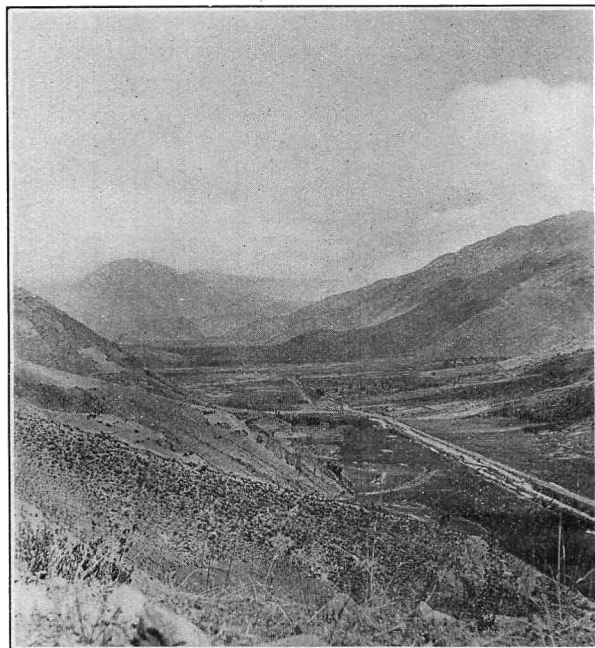


FIG. 7. Oropesa Basin. View looking east from a point on the cliffs at Angostura Narrows.

issuing from glaciated valleys floored with till and occupied by swamps. In its lower course along the border of the Cuzco gravel fan the stream is supplied directly by ground water which makes good in part for the loss from irrigation ditches. During October 18 springs and seeps, many of them accompanied by landslides, were noted along the lower mile of the Chunchullumayo, and it is probable that more than half of the

⁵The local name for the stream formed by the union of Rio Quilque, Rio Sipaspueyo and Rio Ayahuaycco.

⁶The lower portion of Rio Choquechaca.

run-off originates in this manner. The prevalence of these springs in the suburbs of Cuzco indicates an abundance of ground water—an undeveloped source for much-needed supplies for domestic use.

The Tullumayo, fed by concealed channels in limestone, has cut a trench across the igneous mass at Sacsahuaman and drops precipitously into the city, whence it is led through artificial conduits to its junction with the Huatanay. From the ancient fortress to the city streets the fall of the Tullumayo is 400 feet in a horizontal distance of 1,000 feet, or about 2,000 feet to the mile. That the water power thus available was recognized

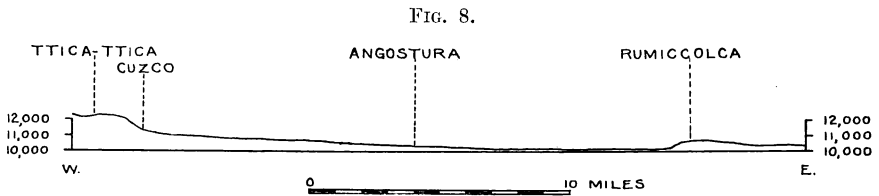


FIG. 8. Longitudinal profile of Rio Huatanay from Ttica-Ttica Pass to the Rumiccolca lava field. The portion of the stream channel from Huacarpay to Sierra-Bella is not shown.

by the Spanish conquerors is indicated by the presence of an abandoned mill flume.⁷

The largest stream entering the Cuzco Basin from the north is Rio Cachimayo,⁸ which rises on the glaciated, grass-covered slopes of the Huatanay-Urubamba divide at an elevation of 13,500 feet and, after flowing for a mile along the southern base of sandstone slopes forming the valley rim, cuts a canyon through limestone pampas and emerges at San Sebastian. Its waters are derived from marshy land at the head of the stream, from rills in the sandstone ridge, but chiefly from springs issuing from cracks in the limestone. The Cachimayo, particularly in its lower course, is heavily charged with chloride of sodium, which is recovered by evaporation at the Government salt works. Several small streams on the porous limestone of Kkallachaca and Era pampas are perennial. In their upper courses swamps and bogs are common, and definite channels are usually absent. On reaching the edge of the basin the water forms continuous rills occupying rock ditches and broken by

⁷The ruins of the old mill at Sacsahuaman have been ascribed to the Incas, but the presence of lead cement, to which my attention was called by Professor Bingham, is inconsistent with such an interpretation.

⁸The upper portion of this creek is known as Rio Lkalla-Chaca.

falls. Where traversing the basin floor these streams are confined within walls of masonry, which, however, have little function to perform except during periods of heavy rainfall.

The Huancaro is the chief southern tributary of the Huatanay within the Cuzco Basin. Though its drainage area is small, its wide, gravel-filled floor, its moderate, grass-covered slopes, its flat, longitudinal profile, and its position on a fault zone result in a run-off whose uniformity is unusual for this region. Measurements taken during September and again in November, 1912, showed that the Huancaro at its junction with the Huatanay carried more water than the master stream.

The Huanacauri, which joins the Huatanay 1 mile below San Geronimo, is a typical example of the streams entering Cuzco Basin from the south. The lowest half mile of its course is sunk in gravels, and terraces flank the streams for about a mile from its mouth. At a distance of 2 miles the gently sloping, relatively wide valley floor is broken up into a number of sharply cut rock canyons, and at its headwaters the tributary canyons are so numerous and so closely spaced that no undissected land remains. Swamps are lacking; springs are rare; many canyon stretches are dry or occupied by a broken chain of rock-rimmed pools. The surface run-off is very rapid, and stream flow is the immediate and short-lived consequence of showers. The valley form and conditions of run-off along the Huanacauri fairly represent the relations prevailing in the non-glaciated portion of the Cuzco Valley.

Streams entering the Cuzco and Oropesa basins from the lofty northern border of the Cuzco Valley possess certain distinctive features. The Chchiraura is a continuous perennial stream from its source in the Pachatucsa cirque to its mouth at Huasau. Its descent is broken by numerous falls, and at the group of herdsmen's cottages after which the stream is named, the floor drops 1,200 feet in the course of half a mile. Rio Huaccoto, rising in the Atascasa highlands, receives its water from a series of glacial deposits deeply mantling the bed-rock over an area of about 3 square miles. In place of defined drainage channels the headwaters of the Huaccoto include lakes, swamps, rills trickling underneath peaty flats, and masses of water-soaked gravels and boulders. At the village of Huaccoto three tributaries unite to form a permanent stream, which at once drops into a canyon with sloping box head and descends to its terminal fan, $1\frac{1}{2}$ miles distant, on a slope of 1,500 feet to the mile. Emerging from the mouth of its

rock-walled canyon the stream, with diminished flow, enters a gravel trench 20 to 110 feet in depth and after a further descent of 500 feet reaches the Huatanay. As regards permanency of flow and the number of tributaries the Huaccoto, draining a glaciated highland, is strongly contrasted with streams from the unglaciated southern rim of the Cuzco Valley.

During the dry winter season—March to November—many of the large streams of the Cuzco Valley are reduced to brooks, some of them become intermittent, and the minor tributaries, except in areas coated with glacial débris, cease to flow altogether. Deficient rainfall combined with the demands of irrigation deplete the water to such an extent that during my stay at Cuzco all the streams in the valley could be crossed dry-shod by taking advantage of friendly bowlders of moderate size. Even in the Huatanay at San Geronimo stepping stones 6 inches in height were well above water. During the rainy season—December to March—especially in January and February, an enormous amount of water is crowded into the narrow channels to depths of 6 to 10 feet. Where not artificially protected the streams on the valley floor and on the larger fans overflow their banks. Even during the dry season abrupt increase in discharge follows the infrequent but heavy downpours. In spite of the large annual rainfall and the presence of grass on many slopes the conditions of run-off for the Cuzco Valley approximate those characteristic of arid regions. On the flat-lying fertile lands of the Cuzco Basin disastrous flooding is always to be guarded against. That success in restraining flood waters has not been attained is indicated by stretches of gravel-strewn flats, by the abandoned lands above the Angostura Narrows, and by the zones of bare gravel extending across the San Geronimo fan in the midst of terraced fields that are in a high state of cultivation. The fertile, low-lying lands south of San Sebastian, below Saylla and in the Lucre Basin, devoted to pasturage instead of to agriculture, indicate the control exerted by flood waters.

Lakes.—Lakes in the Cuzco Valley are small and few in number. On the floor of the Lucre Basin, which is practically without relief, two permanent water bodies, Laguna de Huaton and Laguna de Lucre, occupy shallow depressions. I am informed that during the rainy season these lakes unite with their bordering swamps to form a body of water nearly 2 miles in length.

On the highland rim of the Cuzco Valley are lakes sunk in glacial débris. With a few unimportant exceptions, they

are grouped on the southwest flank of the Pachatusa and Atascasa mountains and are best developed about the head of Rio Huaccoto. In this region are ten or more lakes occupying kettle holes or perched on the inner slopes of abandoned moraines. All of them are small; the largest water body seen covers less than 2 acres and the average area is but little more than half an acre. The depth of water in the lakes examined did not exceed 6 feet, but water marks at heights of 4 to 10 feet above the surface indicate considerable fluctuation in response to rainfall. The number of water bodies which have been converted into swamps and are now occupied by *Yureta*, the chief peat-maker of southern Peru, exceeds the number of existing lakes.

Solution depressions 25 to 200 feet in diameter dot the surface of the Yucay, Kkallachaca, and adjoining pampas. A few contain water throughout the year; many remain as bogs through the dry season, and high-water marks indicate a large number of water bodies whose life is limited to the season of summer rains.

II. PHYSIOGRAPHY.

REGIONAL RELATIONS.

From a physiographic standpoint Peru is essentially a plateau included between a narrow coastal belt along the Pacific Ocean and the low-lying Amazon Plains. As shown by the regional profile (fig. 3), the surface of the plateau stands between elevations of 13,000 and 15,000 feet, and its borders are sharply marked. Along the line of the railway from Mollendo to La Paz the Peruvian plateau is broken into two segments by the great interior basin holding the waters of Lake Titicaca. The two highlands thus formed in southern Peru may be appropriately termed the eastern plateau and the western plateau, occupying respectively about $\frac{1}{3}$ and $\frac{2}{3}$ of the area included in the Andes Mountains. In northern Peru the highland area narrows and the plateaus are merged; likewise in the latitude of Cuzco the Peruvian plateau is essentially a physiographic unit. As indicated on the diagram (fig. 9) the southwest flank of the plateau is drained by numerous short streams directly tributary to the Pacific Ocean. Heading in valleys of gentle gradient, these watercourses descend rapidly to the coastal plain, where slopes of small inclination are again encountered. Although these streams have cut deep

gorges in the plateau rim and in some places have trenched the upland surface, they are within an arid zone and therefore carry little water to the ocean. The initial topographic expression of the northeast rim of the Peruvian plateau, in a region of heavy rainfall, has undergone extensive modification in consequence of vigorous headwater erosion by tributaries of the Ucayali and the Madre de Dios. In the latitude of Cuzco the surface of the plateau is deeply dissected by the Paucartambo, the Urubamba, and especially by the Apurimac, which carries water to the Atlantic from points less than 100 miles

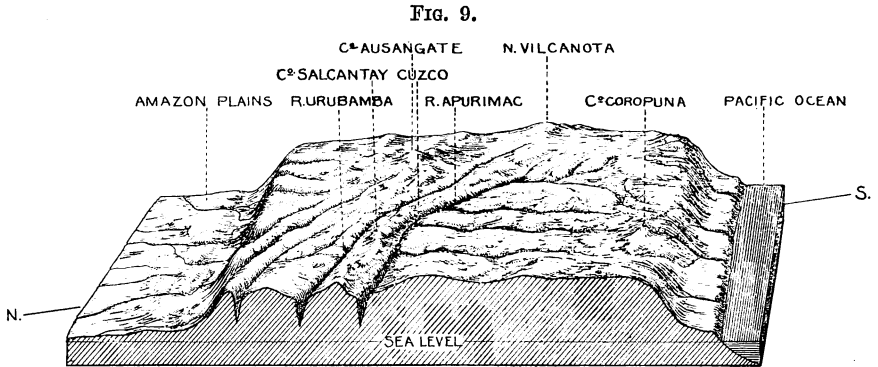


FIG. 9. Diagram of a portion of Southern Peru, including the Cuzco Valley; based on topographic data from all available sources. The block lies approximately between parallels 13 and 16 degrees south latitude. Drawn by Gladys M. Wrigley.

from the Pacific. These major streams crossing the plateau in a northwesterly direction have swift flow interrupted by rapids, but their descent is gentle compared with that of streams on the rim of the plateau. Between its source and its junction with the Urubamba, a distance of about 450 miles, the fall of the Apurimac is approximately 1,400 feet; Rio Majes, which receives its waters from the same area, descends an equal amount in about 90 miles.

As shown on the outline map (fig. 2) the heart of the plateau is attacked by tributaries to the great interior basin. These streams, however, carry no *débris* beyond the plateau borders, and their strength is sapped by a semiarid climate and a high base-level of erosion, the surface of Lake Titicaca, 12,500 feet above tide.

Above a general surface at 13,000 to 15,000 feet the Peruvian plateau is studded by snow-capped peaks attaining heights

of 18,000 to 21,000 feet, and into the plateau surface are cut a number of canyons rivaling the Grand Canyon of the Colorado in depth and ruggedness. In fact so deeply trenched are the highlands, so narrow the spacing between the stupendous gorges, and so commanding the volcanoes and erosion remnants that it is difficult for one in the midst of these features to view the region as a plateau. The sight of the forest is lost in the contemplation of the trees.

When the materials composing the plateau are examined they are found to consist of continental and marine sediments penetrated by igneous intrusions. The sediments have been subjected to widespread disturbance; flat-lying rock is rare. Folds of intricate design are everywhere encountered, and faults are characteristic features. In this expanse of highly disorganized strata the plateau surface has been developed with slight regard to structure. In other words, the Peruvian plateau is an uplifted erosion surface dating from late Mesozoic time. For the purpose of description it will be called the Inca peneplain. As in the case of Bolivia, pointed out by Professor Bowman,⁹ this conception of the Andes is widely at variance with previous interpretations of South American physiography and is quite out of accord with popular descriptions. In the view here taken the bewildering display of lofty peaks and profound canyons, which appear to be arranged in capricious fashion, find their appropriate setting as features of an organized landscape systematically developed. Coropuna, El Misti, and their companions are superposed on the western margin of the Inca peneplain; Ausangate and Salcantay are gigantic examples of erosion remnants formed of resistant rocks etched by vigorous streams on the northeastern slopes of the Peruvian plateau. This interpretation of the physiographic development of southern Peru assigns to the Cuzco Valley its proper relation as a trough of small dimensions sunk below the level of the Inca peneplain.

LAND FORMS IN CUZCO VALLEY.

Factors Conditioning Erosion.

The Cuzco Valley, located between 13° 27' and 13° 40' south latitude, is well within the Tropics. The heat incident to low latitudes is to a large degree offset, however, by the high elevation, and the influence of geographic position is reflected chiefly by alternating wet and dry seasons. Scatter-

⁹ This Journal, xxviii, pp. 197-217, 1909.

ing records of precipitation indicate that the number of rainy days in a year averages about 175. May, June, July, and

Precipitation records, Cuzco, collected from various sources. The figures for the year 1895 are considered typical.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1894								0.01	0.99	3.58	3.18	3.21	
1895	7.01	8.25	5.18	2.68	0.90	0.91	0.29	1.36	1.40	4.53	2.19	6.57	41.07
1909	8.34	2.13	1.93	9.09	1.96		0.28	0.41		1.15	3.09	1.98	30.36
1910	2.49	2.23	5.86	3.89									

August are practically without rain. Weekly rains with cloudy skies are usual for September and October, also for March, April, and to a less extent for May—the autumn months of the Southern Hemisphere. The rainy season begins in November with daily thunder showers, and during January and February precipitation is, in normal years, almost continuous. The discharge of streams during the Peruvian summer is therefore continuous and of large volume, and inasmuch as the cover of vegetation is scant and patchy, particularly on slopes of intermediate height, the run-off is only slightly retarded and vigorous erosion is favored. The sudden fluctuations of streams, due to the heavy, short-lived downpours of spring and autumn, also facilitate the removal of rock debris. As the result of a shower on October 23, 1912, the flow in the Huatanay increased from about 0.30 second-foot of clear water to approximately 8 second-feet of water containing 12 per cent of silt. On the morning of October 29 the Chunchullumayo was a trickling rill, clear except for ever-present sewage; a violent thunder shower accompanied by hail converted the stream into a torrent which undermined banks and redistributed the gravel bars. After the lapse of two hours the water, carrying 18 per cent of suspended red mud, had decreased one-half in amount; next morning the stream had assumed its normal appearance. The relation of run-off to effective erosion is thus seen to be not unlike that prevailing in arid regions.

The temperature of the Cuzco Valley, and hence the effectiveness of rock disintegration from frost, is subject to wide variations. The mean monthly temperatures range from about 41° in July to 54° in November, and the contrast between day and night temperatures is particularly marked. Extreme cold is unknown, but snow on the mountains and ice on standing

water in the lowlands are normal for June and July. At elevations of 12,000 feet the quarrying action of freezing water is probably felt for five months in the year, and above 13,000 feet frost may occur on any night the year round. Snow usually lies on Pachatusca from March to November. However, frost work, as indicated by the amount of talus, is not conspicuous compared with that of colder climates.

Ground water is an active erosional agent in the Cuzco region. Springs and seeps are common along canyon walls and within shallow quebradas. Landslides are very frequent. Within the gravel-walled quebradas adjoining the city of Cuzco eight occurred in a single season. The rock and gravel displaced by slides vary in amount from a few cubic yards to the enormous mass of material represented by the prominent scar on Cerro Picol, which is visible for a distance of 10 miles.

The relief of the Cuzco Valley is favorable for rapid erosion. With the exception of the Huatanay few streams have gradients less than 600 feet to the mile, and considerable stretches of many streams traverse slopes whose inclinations exceed 1,000 feet to the mile. (See fig. 15-20.) In such channels, aided by fluctuating run-off and patchy cover of vegetation, disintegrated materials are rapidly manufactured and easily removed. The erosional work of streams is further facilitated by the calcareous cement of certain strata, by the almost universal presence of open joints, and by the wide extent of partly consolidated glacial and lacustrine deposits.

Mountains.

With the exception of the low volcanic dome of Huaccoto none of the mountain ranges or individual peaks of the Cuzco region retain their original form. They clearly belong to a generation long postdating the great earth movements that gave to the Andes their initial elevation, but they have experienced several cycles of erosion and uplift. The present mountain summits have been carved from truncated edges of folds in which sedimentary strata, chiefly thin-bedded sandstone, have been overturned along sinuous axes. Erosion on the limbs of these complex folds has etched the higher lands into a series of *cuestas* with wide variety of trend and inclination. The crest of the ridge forming the Huatanay-Apurimac divide is in places *serate*, and the dominance of the Apurimac drainage is indicated by the contrast between the steep bare slopes cut

by narrow ravines leading southward and the grass-floored, open valleys tributary to the Huatanay. In the mountains forming the Huatanay-Urubamba divide these contrasted relations are even more noticeable. Pachatuca (15,915 feet) is a cuesta cut from the southern limb of a broad anticline in the crest of which is sunk the canyon of the Urubamba. The southern slope of Pachatuca corresponds with the dip of its component strata; its northern slope truncates the sandstone beds exposed in the precipitous canyon wall of the Urubamba

FIG. 10.

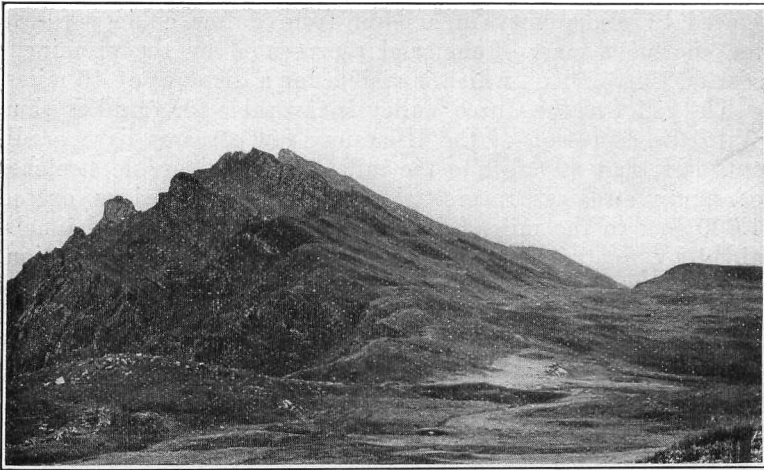


FIG. 10. The crest of Sierra Pachatuca. Elevation 15,915 feet. The precipitous slope on the left descends to the Urubamba. The plateau in the right background is formed of lava.

(fig. 10). The culminating heights of Sencca and the adjoining masses to the east are pyramids and rectangular blocks carved from steeply tilted strata; the twin summits of Cerro Picol (14,607 feet) are likewise pyramidal masses bordered by glacial cirques (see fig. 31). The jagged sky lines of Maho-Pinta and of Huanaccaurai reveal the presence of rows of teeth and sharp fins weathered from the upturned edges of strata of resistant sandstone.

The mountains coinciding in height with the level of the Inca peneplain are subdued in form, but those above that level present abrupt escarpments, sharply cut canyons, and a variety

of features indicative of mature and youthful dissection. Speaking broadly the mountainous masses of the Cuzco Valley drainage system may be said to have attained maturity. For large areas regional slopes range between 15° and 20° , and slopes of 30° are not uncommon. No mesas exist among the mountains, and undrained interstream spaces are few and small in area.

The unrestricted run-off involved in maturity of mountain form, when expressed in terms of human environment, means

FIG. 11.

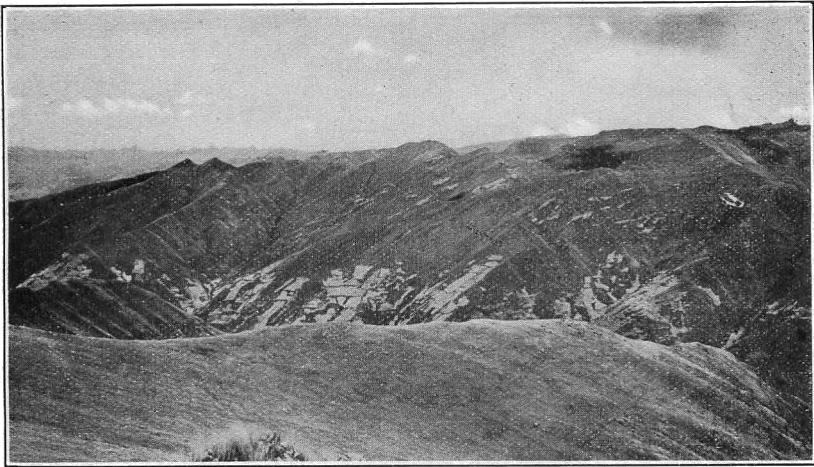


FIG. 11. Plateau surface two miles south of Oropesa looking south-east. A. H. Bumstead, photo.

unstable soil. The Incas overcame this difficulty in the more favored localities by terracing the slopes and building retaining walls at an enormous expenditure of time and labor. So skillfully were these masonry structures made that many of them stand to-day in series of ten or twenty, in places over fifty, perched on slopes with inclinations of 10° to 30° , and extending to elevations 800 to 1,000 feet above the valley floors. The present inhabitants find it impracticable to maintain the steeper slopes in tilth, and the agents of erosion have been given new life.

Plateaus.

In the Cuzco region the widespread Inca peneplain has been trenched by the Urubamba to a depth exceeding 5,000 feet and by the Huatanay to an average depth of 3,000 feet below the ancient base-leveled surface. On the southern upland border of the Cuzco Valley a remnant of the Inca peneplain is preserved at an elevation of 13,500 feet over an extent of

FIG. 12.

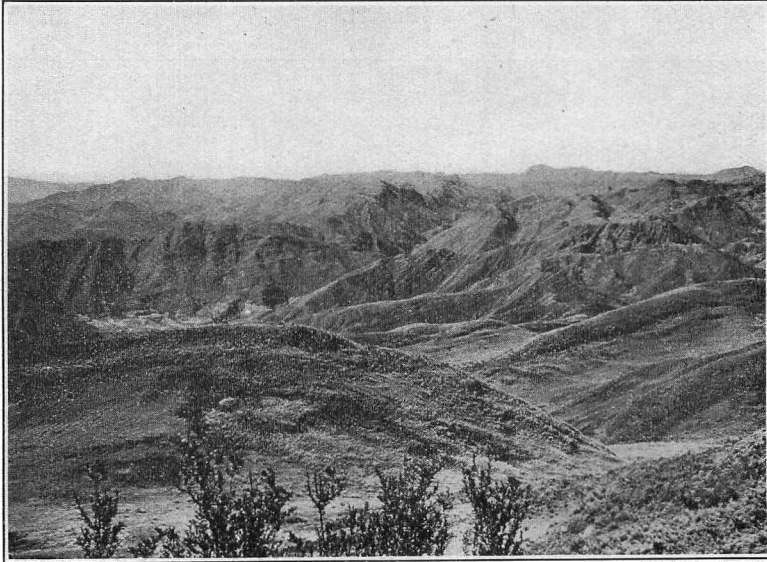


FIG. 12. Surface of Puquin Plateau, elevation 13,200-13,600 feet, showing geologic structure and character of dissection. Isaiah Bowman, photo.

about 30 square miles (fig. 11). The portion of this area known as Pampa de Huaca-cancha is a local plateau whose surface is made up of a group of low, oblong domes separated by wide, flat-floored valleys. Westward from Huaca-cancha upturned beds of alternating resistant conglomerate and weak shales have permitted intricate erosion, without, however, destroying the plateau form (fig. 12). North of the Cuzco Valley axis the Inca peneplain is represented by the Bambanusa and Huanca-Huanca pampas, whose average elevation is 13,500 feet. The surface of these pampas has been consider-

ably modified by volcanism and by the deposition of glacial débris.¹⁰ The relatively flat-lying area immediately north of the city of Cuzco, embracing the pampas of Pucro, Kkallac-haca, Era, Yucay, and Ceoraó, with a combined area of approximately 12 square miles, may be called the Limestone plateau (fig. 13). From an elevation of 13,000 feet at the base of Cerro Sencca its surface slopes east and south to the 11,500-

FIG. 13.

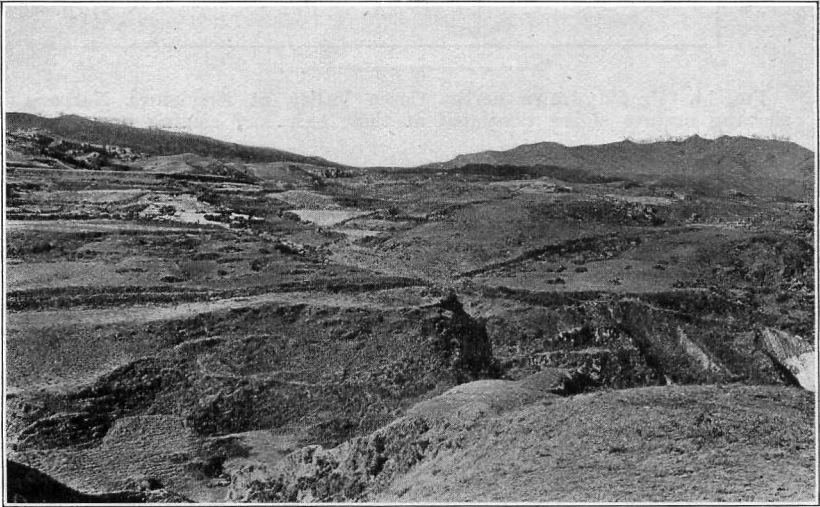


FIG. 13. General view of the Limestone Plateau, Pucro Pampa, looking north-eastward across the upper canyon of the Huatanay.

foot contour line. The bedrock on which the plateau is developed is limestone of the Yucay formation, which is believed to owe its preservation to the presence of the Huancaro and Tticapata faults, by means of which a block including the calcareous strata was brought below the general level. It is probable that at the time of regional base-leveling the limestone plateau formed part of the Inca peneplain and that its present position, 1,000 feet below the peneplain, is largely the result of erosion.

¹⁰ See p. 39.

Mature Slopes.

Slopes that have attained a mature stage of development face Huatanay River throughout its length, constituting features of large physiographic significance (figs. 5, 11, 29, 30).

FIG. 14.

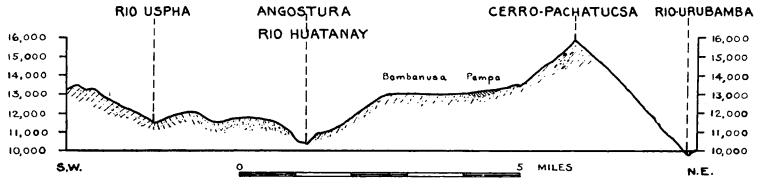


FIG. 14. Profile drawn across Cuzco Valley at Angostura Narrows showing mature slopes truncated at their base and leading upward to plateau surfaces.

As shown on the topographic map and also in the profile sections (figs. 13-18) these slopes bordering the Cuzco Valley axis occupy a zone 1 to 2 miles in horizontal width whose upper limit is the plateau surfaces of the Bambanusa, Huanca-Huanca, and Huaca-cancha pampas, at elevations of 13,500 feet. Both the lower and the upper borders of the zone of

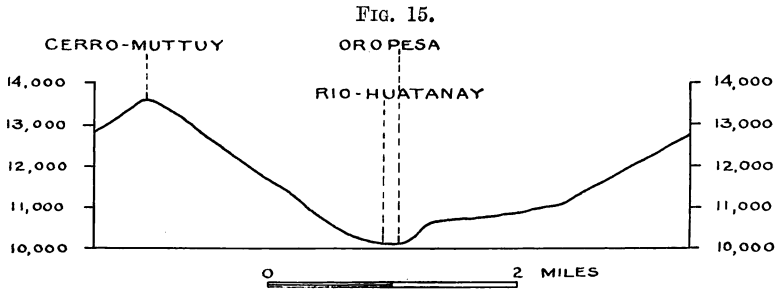


FIG. 15. Cross profile, Huatanay Valley, at Oropesa.

mature slopes are marked by topographic unconformities; at about 13,500 feet mature slopes with inclinations of 1,000 to 1,200 feet to the mile form a contact with a surface sloping about 300 feet to the mile on the Bambanusa Pampa and less than 100 feet to the mile across the Huaca-cancha Pampa. The topographic unconformity at the lower border of the zone of mature slopes is produced by the development of canyon

walls which truncate the slopes at high angles. This feature is well shown at Angostura Narrows (figs. 14 and 20) and also at Huambutio. The relations of these three slopes, developed on rock of essentially uniform composition and structure, require for their interpretation the assumption of three erosion

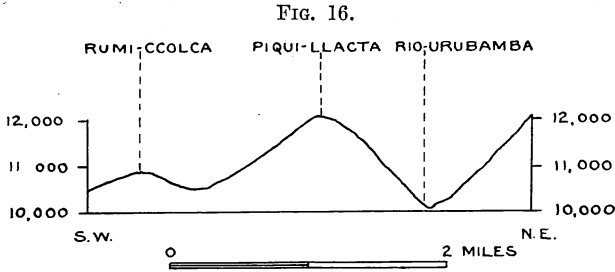


FIG. 16. Cross profile of Urubamba Valley and lower end of Cuzco Valley, drawn through Puquillacta.

cycles—the regional base-leveling of the Inca peneplain, the recent cutting of the present stream valleys, and an intermediate cycle during which the mature slopes were formed.

The lower margins of mature slopes bordering the Huatanay are in most places buried by accumulations of gravel brought

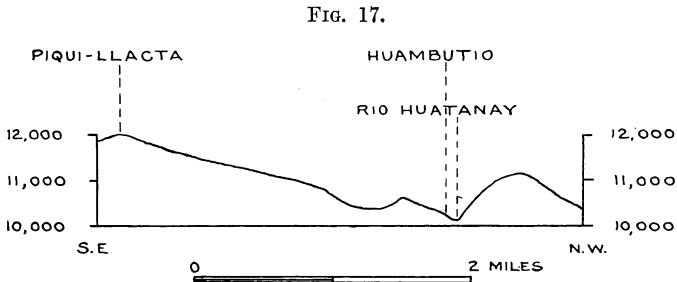


FIG. 17. Cross profile, Huatanay Valley at Huambutio.

down during Pleistocene time by swift streams from the highlands. West of Cuzco and north of San Geronimo, where bedrock is exposed by deep-cut trenches traversing alluvial fans, the mature slopes continue beneath the materials of Pleistocene age.

Valleys.

Huatanay Valley.—The history of the drainage of the Cuzco region can not be written from the facts disclosed by existing field studies. The solution of the problem involves a knowledge of crustal movements and structural relations throughout southern Peru. If the view of the regional physiography presented in this paper¹¹ is accepted, the larger drainage features are readily interpreted; the Urubamba and Apurimac

FIG. 18.

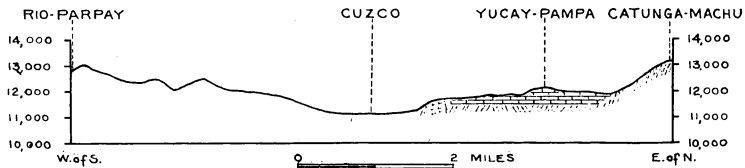


FIG. 18. Cross profile, Cuzco Valley, drawn through the city of Cuzco.

were established on the Inca peneplain and their down-trenching is the result of general uplift; the Pucara and other streams entering Lake Titicaca have found a temporary base-level on the floor of a down-faulted interior basin. If the regional slopes were followed the Huatanay should flow westward to join its master stream, and it is not improbable that during the peneplain cycle the waters from the Cuzco area found their

FIG. 19.

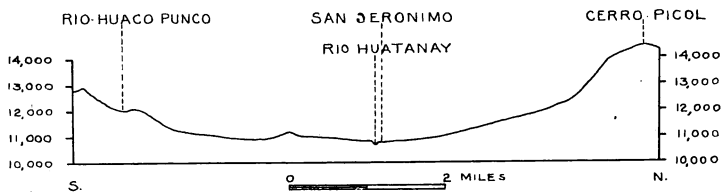


FIG. 19. Cross profile, Cuzco Valley, drawn through San Geronimo.

way to the Amazon through the Ttica-Ttica Pass, whose features as an old-age valley are well marked. The regional uplift of the Andean region was, however, accompanied by warping, by profound and widespread faulting, and doubtless also by the intrusion of igneous rock. The normal course of many

¹¹ See p. 17.

streams was thus interrupted and the initial major features of the Cuzco Valley were developed. That the drainage system of the Huatanay is not young is evidenced by the form of its valley, and by several episodes in its history (described below), each of which involves the lapse of long periods of time; that the Cuzco Valley does not antedate the formation of the Inca

FIG. 20.

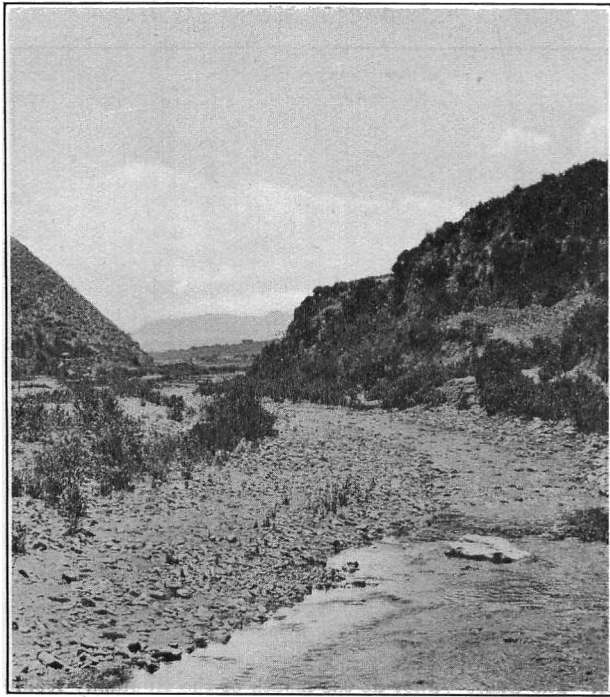


FIG. 20. Angostura Narrows showing truncation by recent stream cutting of mature slopes bordering the Huatanay.

penplain is shown by the remnants of ancient base-leveled surfaces now subject to vigorous attack. The position of the Huancaro fault with uplift on its western border points to a crustal movement that may have determined the western limit of the present Cuzco Valley; faults of the same or of later date are believed to have outlined the course of the Huatanay.

Since its drainage was directed eastward the Cuzco Valley has passed through several episodes whose sequence and significance have not been satisfactorily interpreted. Some of them, however, may be read in the light of physiography. For example, the broad floor of the Oropesa Basin has been cut and again filled by the meandering Huatanay, whose course was temporarily arrested by a lava flow. In a similar manner the ancient outlet of the Huatanay was permanently blocked

FIG. 21.

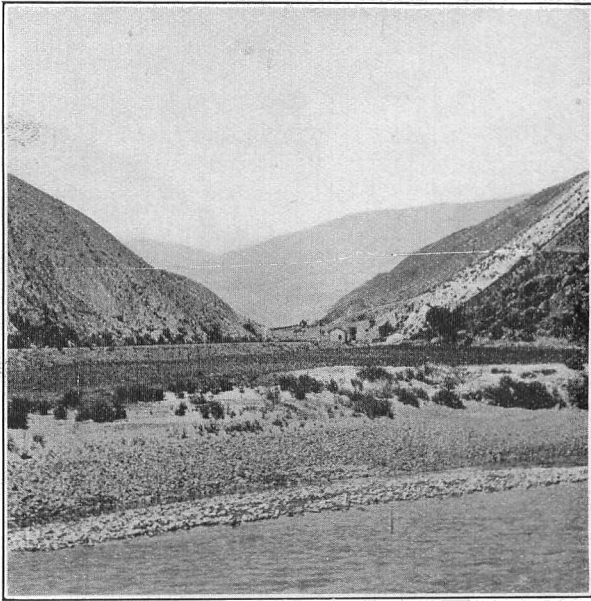


FIG. 21. The Cuzco Valley at the mouth of the Huatanay looking south across the Urubamba River. Huambutio in middle distance.

by the volcanic flows of Rumicolca, and the stream was turned abruptly northward over the low pass at Huambutio to join the Urubamba at Sierra-Bella (fig. 21). The Cuzco Basin has experienced successive stages of downwarp and at one period was entirely or at least partly separated from the lower Cuzco Valley and held the waters of an ancient lake.¹² I have been unable satisfactorily to account for the narrows at Angostura. That the region bordering the narrows has been

¹² See p. 34.

subject to intermittent uplift is indicated by a succession of unlike slopes, and that erosion by the Huatanay at this point has had a predominant vertical component is shown by its narrow valley. It is possible that at certain periods in its history the narrows marked the position of a divide, but further study is necessary before the relation of the narrows to the development of the Cuzco Valley can be interpreted.

Contrasted portions of valleys.—The features—penneplain remnants, mature slopes, and truncated spurs—indicating three cycles of erosion, are matched by three unlike portions into which most streams in the Cuzco Valley are divided. For example, the Llampuhuaycco, rising in glacial débris, flows for a mile through an old-age valley, marked by a wide, flat, grass-covered floor in which the stream is neither aggrading nor degrading to an appreciable degree and is carrying little sediment. The middle portion of the stream begins abruptly with waterfalls and rapids and descends precipitously, carrying much sediment along the bed of a narrow rock-walled canyon. Its tributaries drop rills of water from the sloping mouths of hanging valleys. This middle torrent portion is followed by a canyon intrenched in a gravel fan of Pleistocene age. These contrasted portions of the Llampuhuaycco Valley are duplicated in stream channels throughout the Cuzco region.

Relation of valleys to structure.—Most of the streams entering the Cuzco Valley are consequents and owe their position to the topographic slopes. In general they cross the strata nearly at right angles, and their spacing and length are results of initial topographic conditions which determined the shape and extent of their drainage basins. Of the larger consequent streams the Huaccoto is typical. It rises on the Urubamba divide by gathering waters from numerous springs in glacial débris; follows the dip slope to the Huaccoto volcano, which it avoids by a circuitous route; traverses a canyon cut across the strata to Huayllabamba Finca; and reaches the Huatanay by following a depression at the side of the San Geronimo fan. It is everywhere conformable to pre-existing topography and presents no evidence of structural control.

Subsequent streams are represented by many tributaries to northward-flowing consequents on the south side of the Cuzco Basin. The Chhocco branch of the Huancaro has selected for its course the more calcareous beds of a syncline (fig. 22); the upper Huilcarpay and the east branch of Rio Pillau exhibit the same relations. The Uspha is walled for a distance of 2

miles on the north by a single stratum of coarse sandstone of high dip, from which the stream has stripped the less resistant rocks to form a deep gorge less than 100 feet in width. The selection of weaker rock for channels is strikingly shown at the headwaters of this stream, where vertical strata of conglomeratic sandstone stand like teeth in a comb; between the

FIG. 22.

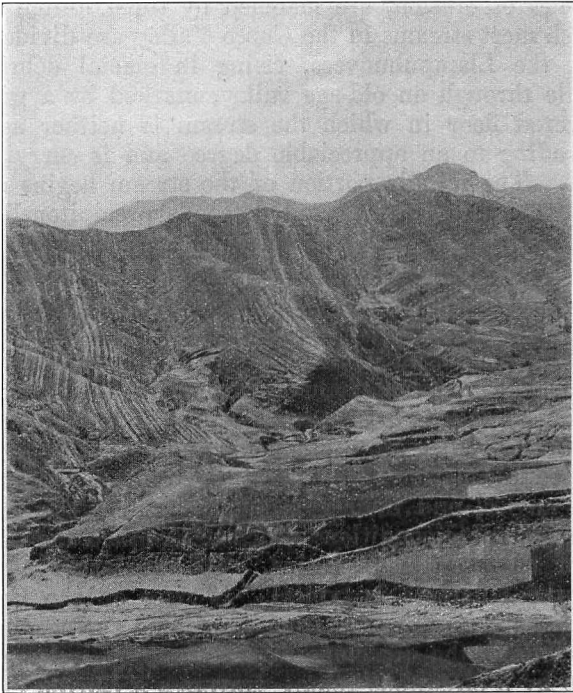


FIG. 22. Valley of Rio Chhocco at its junction with the Huancaro.

teeth are valleys, 4, 6, and 20 feet wide and 10 to 40 feet deep, worn from the less durable beds of shaly calcareous sandstone. The east branch of Rio Kkaira, 2 miles long, draining the back slopes of Sencco-Oreco and Maho-Pinto, also occupies a subsequent valley and when viewed from a favorable point presents an unusually fine example of a valley developed by stripping the back slopes of a hogback (fig. 23). The Lkalla-Chaca has found a favorable location at the contact between

the sandstone of Catunga-Machu and the limestone of the Yuca Pampa. Consequent streams draining into the Oropesa and Lucre basins also have small subsequent tributaries. Numerous small obsequents carry water during the rainy season from the slopes of minor cuestas.

Streams in the Cuzco Valley have taken advantage of the

FIG. 23.

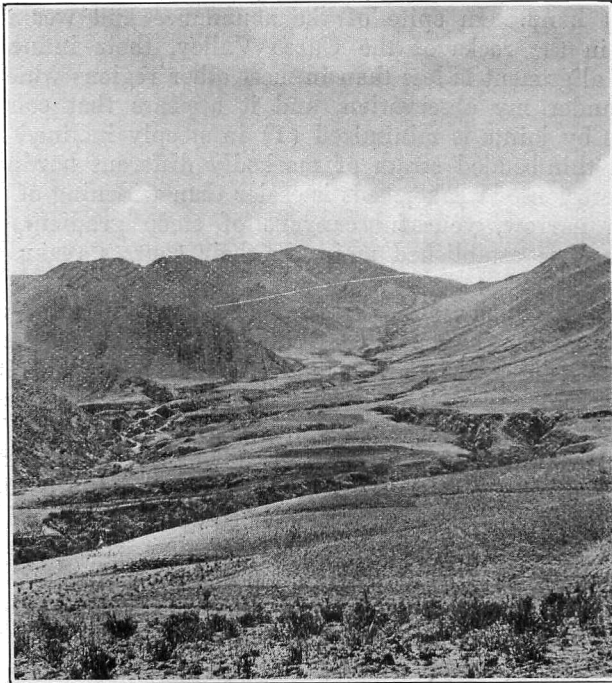


FIG. 23. Valley of the east branch of Rio Kkaira.

major zones of faulting. For at least 3 miles of its course the Huancaro follows a fault line, a fact that partly explains its wide valley floor and its stage of development, which is somewhat more mature than that of other transverse valleys tributary to the Cuzco Basin. The Zappi portion of the Huatanay likewise is located along a zone of faulting. Jointing, commonly associated with minor faults, is well developed in all the rocks about Cuzco. Many joints are open or filled

with weak cement, but their influence in guiding streams has in large part been offset by the steep inclination and complicated folding of the strata, and no dominant control of jointing in valley development is obvious. In a minor way, however, the influence of joints is evident. In three rock canyons where joint direction and spacing were studied the streams were observed to zigzag along the narrow floor, following the larger joints, particularly at waterfalls. In several places, however, a stream has gnawed a groove across a ledge, disregarding the joints near at hand. In spite of the abundance and weakness of joints in the rocks of the Cuzco Valley, their influence on stream alignment is less than in most other regions which have come under my observation, and it appears that control of streams by joints is minimized (1) in steeply inclined strata; (2) in thin-bedded strata of markedly different hardness, in which erosion of weaker beds is easier than widening of joints; (3) in narrow, youthful canyons of steep gradient, where streams once established maintain their courses regardless of structure.

Valleys in unconsolidated deposits.—One of the prominent features of the Cuzco Valley is the large number of canyons and quebradas, cut in gravel and stratified sands. Tributary to the Huatanay at Cuzco are four canyons each exceeding 150 feet in depth, more than a quarter of a mile in length, and not over 1,000 feet in width. They are cut entirely in gravel and have almost vertical walls (fig. 24). On the edge of the limestone plateau at San Sebastian and traversing the fans bordering the valley are many similar examples. That these valleys should have retained their extremely youthful form since Pleistocene time indicates rather exceptional ground-water conditions and also alluvial deposits of unusual compactness. (See pp. 46-51.)

LAKE MORKILL.

The lacustrine strata constituting the San Sebastian formation^{12a} marks the position of a lake which formerly occupied the Cuzco Basin—an ancient water-body whose surface lay well above the present site of San Sebastian and San Geronimo. This vanished sheet of water, for which the name Lake Morkill¹³ is proposed, is believed to have reached its maximum

^{12a} See p. 78.

¹³ Named in honor of W. L. Morkill, a loyal friend of scientific research in Peru. As the representative of the Peruvian Corporation Mr. Morkill has substantially assisted the work of our several expeditions.

expansion in early Pleistocene time. During this period an observer standing at the site of Sacsahuaman would have seen before him an unbroken expanse of water stretching southward

FIG. 24.

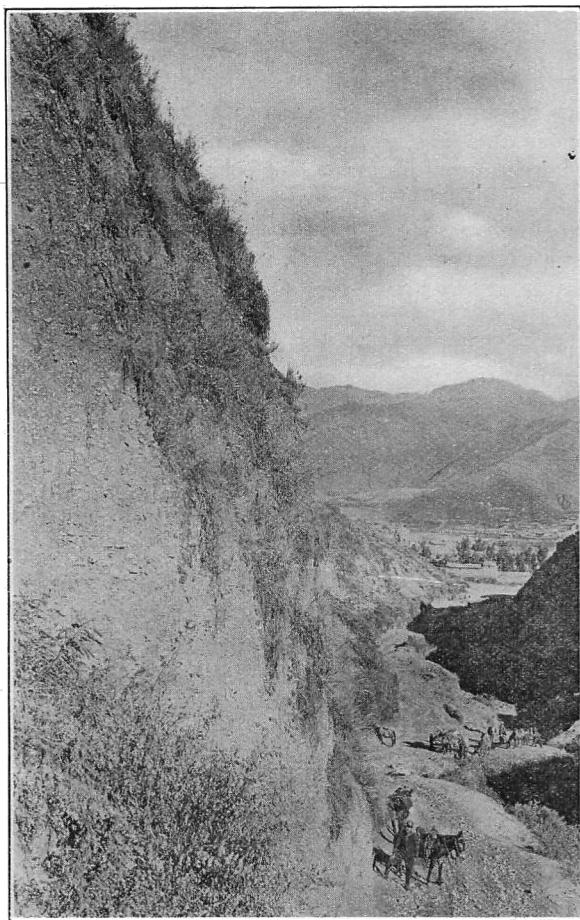


FIG. 24. Canyon cut in gravel. Northeast wall of Ayahuaycco quebrada. Hiram Bingham, photo.

to the Angostura Narrows and overlapping the slopes of the northern and southern walls of the Cuzco Basin. On the left the bays of Huancaro, Ttancarpata, Pillau, and Huanacauri

would have been seen to indent the shore line deeply; on the right the Bay of Tticapata would have been concealed from view by the blunt-headed cape of the Era Pampa. Here and there the regularity of the shore line would have been further modified by low wave-cut cliffs separating deltas of sand and gravel brought to the lake from the bordering highlands. On traversing the strand patches of swamp land and areas of vegetation growing within the shallow marginal waters would have been encountered, and the shells of fresh-water animals could have been gathered from the beach. Mastodon and deer grazing near the lake would not have been an unusual sight.

If the hypothetical observer had been equipped with a sounding line he would have discovered that the west end of the lake was shallow with gently sloping floor extending under water for a distance exceeding a mile. At the east end of the lake a depth of over 200 feet would have been found half a mile from the base of Sencoco-Orcco. Along its southern margin a narrow, shallow under-water shelf would have been succeeded by a cliff-like slope leading to deeper water and at nearly all points along the northern shore the sounding line would have indicated 50 to 100 feet of water near land. The site of San Geronimo would have lain about 200 feet below the surface of Lake Morkill and San Sebastian would have been submerged to a depth exceeding the height of the present cathedral.

The order and significance of the various episodes in the eventful life history of Lake Morkill await further study; only an outline sketch can be presented on the basis of existing knowledge.

The basin in which the waters of the lake were originally collected owes its initial form and dimensions to an irregularly shaped, uneven-floored depression developed by faulting during one or more periods. The geologic date of the crustal movements that produced the down-sunken block has not been determined; in fact, it is probable that displacements accompanying regional uplift have occurred at intervals throughout the Tertiary and later periods. The Cuzco Basin postdates the development of the Inca peneplain and may be tentatively assigned to late Tertiary, probably Pliocene time. The down-sunken floor of this early lake basin was partly filled with débris furnished by a number of swiftly flowing streams; at the same time the outlet channel below San Geronimo was deepened. To what extent the lake confined within the original

down-sunken rock basin was drained away and how much its water was shallowed by accumulations on its floor are not indicated clearly by existing geologic features. The narrow gorge at Angostura, still partly filled with Pleistocene gravels, was cut to nearly its present depth during preglacial time; the elevation of its floor, 10,400 feet, is sufficiently low to have permitted the drainage of all ponded water within the Cuzco Basin, provided the present relative altitudes of basin and border prevailed. It is probable that the close of the Pliocene epoch found the Cuzco Basin with a few shallow ponds and swamps united into a sluggish drainage system and surrounded by expanses of sands and silts of a former lake floor. It is possible, indeed, that the Cuzco Basin had reached a stage of completely integrated drainage by the close of the Pliocene and that no bodies of water were to be found in it.

The advent of the Pleistocene was a matter of fundamental importance to Lake Morkill, for during the glacial epoch climatic conditions in the Andes were favorable for aggradation. Waste coating the upper slopes was carried into the valleys in such quantities that the streams were unable to dispose of it, and terraces and deltas and fans of gravel were built on the borders of the depression. At Angostura the rock-walled canyon of the ancient Huatanay appears to have been completely filled with debris to the 11,100-foot contour line, forming a dam that held the waters flowing into the Cuzco Basin and converted the eroded valley floor into a sheet of water whose maximum extension is represented by the boundary of the San Sebastian formation (see map, Pl. II). Lake Morkill was thus given new life. Into this water body were carried the muds and finest sands screened from the masses of waste accumulated along its borders. In large part the material was siliceous, furnished by disintegrated sandstone. Calcareous ooze weathered from the Yucay limestone was also supplied. That Lake Morkill fluctuated in volume in response to changing climatic environment is indicated by alternating beds of limestone, silt, peat, and adobe exposed in nearly all sections of the lake beds. From time to time wide zones of shore were exposed for periods long enough to enable plants to send their roots into the fine materials, for the sun to bake and crack the muds, and for streams to spread gravels over portions of the recovered lake bottoms. Lake Morkill probably existed during all or nearly all of the glacial epoch. Older glacial gravels appear to be interbedded with lake sediments; the

later glacial gravels rest in places on the highest lacustrine strata.

The drainage of the lake was accomplished by cutting down the dam at Angostura—a process that was not continuous, as is indicated by terraces cut in the gravels. Periods of vigorous cutting alternated with periods when sinking of the outlet trench was greatly retarded or even ceased.

Although the history of Lake Morkill thus outlined is believed to include the major events, two factors remain to be evaluated—the extent to which the lake was obliterated by filling and the effect of crustal movements expressed in the distortion of the lake beds. The filling must have been considerable, for the lake basin is less than 2 miles in width, the bordering slopes are steep and thoroughly drained, and the amount of débris as indicated by existing deposits is enormous. The original position of the lake beds—horizontal along the valley axis, gently sloping lakeward along the ancient shores—has been modified along the northern shore by later movements. North of San Sebastian the dip of the lacustrine strata reaches a maximum exceeding 15° ; the beds are traversed by numerous faults with displacements measured by a few inches, bringing the northern portion of the beds above the southern. The uppermost strata as well as those below have suffered modification, indicating that the movements, in part at least, were later than the time of maximum expansion of the water body and could therefore have had little effect in producing the basin itself.

Estimates of the duration of the life of Lake Morkill measured in years are of little value, because the rate of accumulation of limestone, of peat, of sands, and of adobe is subject to wide variations, and until the beds on the north shore of the lake have been correlated with those on the south shore no reliable data regarding periods of retreat and advance of the waters can be obtained. That the sheet of water existed while glaciers still scored the slopes of Seneca and Patchatusca is indicated by the fact that early glacial gravels at least are interleaved with lacustrine deposits; gravels of a second glacial epoch are piled about the ancient coast and their local accumulation resulted in raising the lake levels or perhaps even in forming the lake itself. Beginning in Pliocene time, the lake is believed to have existed with many and large changes in volume to the close of the last stage of ice advance. With the decrease in the supply of waste following the retreat of the

ice final down-cutting of the outlet and removal of the accumulated lake sediments began, a process continuing to the present time.

Lake Morkill is one of a number of ancient fresh-water bodies occupying depressions in the Inca peneplain of southern Peru which await investigation. The only one heretofore studied presents features closely similar to those found in the Cuzco Basin.¹⁴

GLACIATION.

Introduction.

The position of the present snow line in southern Peru has been determined for only a few places. Even less is known regarding the position of existing glaciers and of the moraines formed in Pleistocene time. Extreme views are held by Hauthal,¹⁵ who expressed the opinion that no general Pleistocene glaciation occurred in Peru, and by Dueñas,¹⁶ who considered the Cuzco Valley at elevations of 11,000 feet and below to have been occupied by ice. Adams¹⁷ placed the lower limit of glaciers in the Poto region of southern Peru at 2,500 feet above the ice fields of the glacial periods.

No glaciers exist within the drainage basin of the Cuzco Valley, and no perennial accumulations of snow are to be found even at an elevation of 15,915 feet, the culminating point on the valley rim, but snow rests on the highest summits well into summer. After showers Picol and Pachatusca and Sencca may be mantled with snow during the warmest months, and on rare occasions the lower slopes and even the floor of the valley are coated with white late in the spring and early in autumn. During the glacial period all the higher peaks and ridges were snow-capped and tongues of ice occupied the heads of many valleys tributary to the Huatanay. The lowest undoubted deposits resulting directly from ice action stand at approximately 12,500 feet. Several well-developed moraines were mapped at 13,000 feet, and the valley profiles at this elevation indicate the presence of ice. Above 13,500 feet the landscape at all points has been molded by ancient glaciers and

¹⁴ Gregory, H. E., *Geologic reconnaissance of the Ayusbamba (Peru) fossil beds*; this *Journal*, xxxvii, 125-140, 1914.

¹⁵ *Quatare Vergletscherung der Anden in Bolivien und Peru*, *Zeitschr. für Gletscherkunde*, i, p. 203, 1906.

¹⁶ Dueñas, *op. cit.*, 1907.

¹⁷ An outline review of the geology of Peru, *Smithsonian Inst. Report for 1908*, p. 409.

cirques at valley heads, and lake-dotted morainal accumulations are characteristic features. For the Cuzco region as a whole the lower limit of Pleistocene ice may be placed at an elevation between 12,500 and 13,000 feet, its position between these levels depending on the topography. These figures for the

FIG. 25.

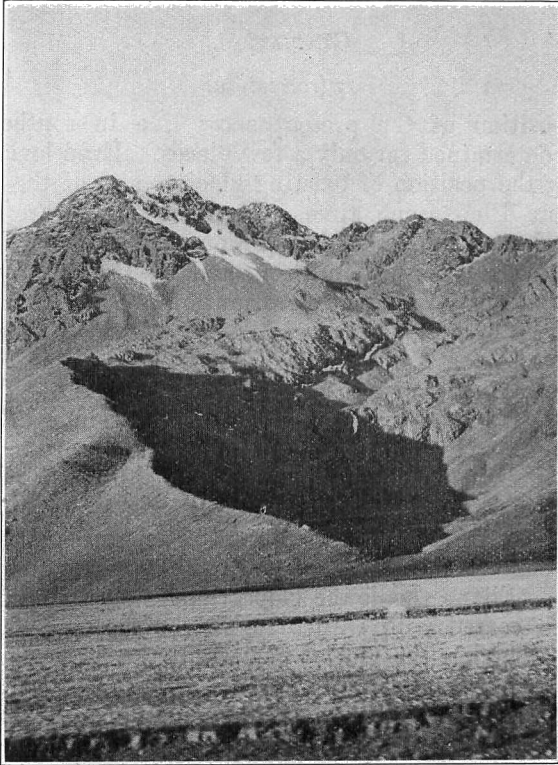


FIG. 25. Moraines at La Raya Pass.

limit of glacial action in the Cuzco Valley do not apply generally to southern Peru. Diverse conditions prevail on opposite sides of mountain crests, and even within a single valley the terminal moraines are at widely different elevations. Along the Urubamba the prominent moraines at La Raya, 110 miles (178 kilometers) southeast of Cuzco (fig. 23), lie high above the railroad, which at this point has an elevation of

14,235 feet; but between Ollantaytambo and Torontoy, 40 miles northwest of Cuzco, "well-developed terminal moraines at least 400 feet high stand but 8,500 feet (aneroid) above sea level."¹⁸

Unpublished topographic maps of the Peruvian Expeditions of 1911 to 1914 give trustworthy figures for the position of the present glaciers and of Pleistocene moraines at Salcantay, in latitude 13° 20' south. On the north side of this mountain group the ends of the glaciers rest at 14,500 feet and the lowest moraine lies at 11,100 feet; for the east side the corresponding figures are 14,300 and 11,200 feet, and for the south side 14,300 and 12,200 feet.

Glacial Features North of the Cuzco Valley Axis.

The east-west trend of the Cuzco Valley gives to its opposite sides unequal exposure to the rays of the sun. It is, therefore, to be expected that northward-facing slopes in this latitude should present less evidence of glaciation than slopes facing southward. When the highlands forming the valley rim are examined, this assumption is found to be in accord with the facts.

Along the north rim of the Cuzco Valley the evidence of ice action is unmistakable and glacial features retain their original expression with only slight modification. Streams flowing from Sencca, Fortaleza, and Catunga-Machu head in cirques and flow between stretches of lateral moraines 1,000 to 2,000 feet long and 10 to 50 feet high. On the southwest slope of Sencca cirques between 13,500 and 14,000 feet are plainly visible from the valley below. In the upper reaches of the Rio Muyo-Oryco, where the direction of ice movement is at right angles to the strike of jointed sandstone, a flight of four steps was noted with risers 5 feet to 60 feet in height. The largest tread has an area of about 1 acre; the smallest, of 300 square feet. Two of the treads are overdeepened and retain ponds on their striated floors. A series of terminal moraines, the lowest at about 13,500 feet, are trenched by the northern tributaries of the upper Huatanay, and ground moraines with uneven surface occupy interstream spaces. The projecting ledges of sandstone as well as of limestone are poorly adapted to retain striae, and the effect of glacial scour on dividing ridges is scarcely perceptible. A remarkable

¹⁸ Bowman: The Geological Relations of the Cuzco Remains, this Journal, xxxiii, p. 317, 1912.

imitation of glacial striation is seen on the Rodadero, at an elevation of 11,750 feet (fig. 26). The grooves and striae and polished surfaces on this intrusive mass of augite diorite are in fact so closely similar to features produced by ice that it occasions no surprise to find them generally used as proof of glaciation. When, however, the Rodadero is studied in detail, the "glacial markings" are found to have been developed by faulting.¹⁹

FIG. 26.

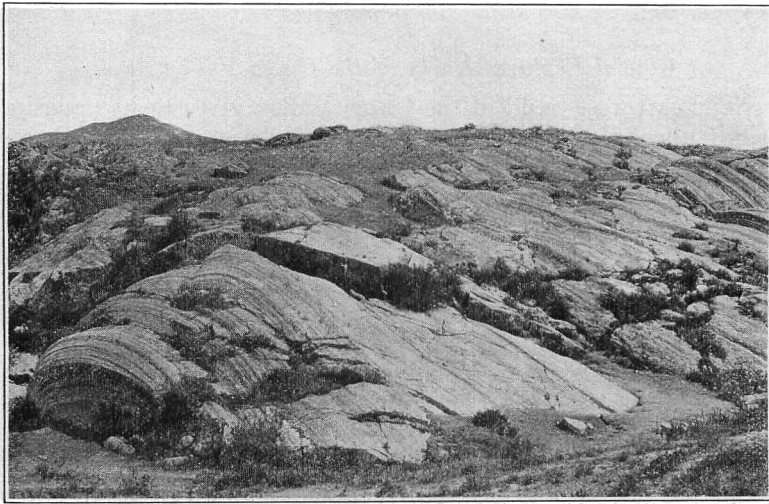


FIG. 26. El Rodadero, near Cuzco. Hiram Bingham, photo.

The twin peaks of Cerro Picol are bordered by cirques whose characteristic features are well expressed. Below the pyramidal summits grass-cloaked or bare, striated rock platforms bordered by precipitous inner walls testify to vigorous glacial plucking. On the lip of a cirque facing Ccorao an unbroken moraine rises to a height of 400 feet, inclosing a basin of about 30 acres. The time elapsing since the retreat of the ice from Picol has not been sufficient for the development of surface drainage within the cirque, and water collected on its swampy floor escapes by seepage to find its way to the Urubamba. As viewed from Cuzco, 7 miles distant, this walled

¹⁹ Gregory: *The Rodadero; A Fault Plane of Unusual Aspect*, this *Journal*, xxxvii, pp. 289-298, 1914.

cirque has the appearance of a crater and has doubtless given rise to the erroneous belief that Cerro Picol is volcanic.

Bedrock about the headwaters of Rio Huaccoto and extending north to Cerro Atasccasa is almost completely cloaked with glacial débris. Eight moraines, 500 to 3,000 feet in length, were noted along the borders of flat-floored, smooth, grass-covered valleys leading southward to the edge of rock-walled canyons. Striated boulders attaining diameters of 4 feet and more, plucked from ledges of igneous and sedimentary rocks, strew the surface. Within an area of about 6 square miles the till is very unevenly spread; depressions between interlocking moraines are common, small lakes and swamps occur, and no definite lines of drainage have yet been established.²⁰

Glacial features of large variety and unusual freshness are displayed in the region drained by the Chchiraura. North of the tiny group of herdsmen's cottages known as Ccasa-Cancha the stream consists of two branches which surround the igneous mass of Ichchu-Orcco. The western branch rises in a swamp whose basin has been overdeepened by ice. It has the typical features of a glaciated valley and is bordered in part by banks of morainal material and in part by rock walls. Exposed ledges of andesite are scoured and striated on both horizontal and vertical surfaces. Erratics are abundant on divides at 13,500 feet and are found to a small extent at 13,000 feet and below. The terminal moraine has been almost completely removed. The south branch of the Chchiraura rises in a rock-walled cirque nearly square in ground plan, perched high on the flank of Pachatucsa, 14,500 to 15,500 feet above sea level. The floor of the cirque dips to the south at an angle of 20° and descends by giant steps with scoured treads from the inner edges of which huge blocks have been removed and carried to lower levels. Patches of ground moraine and irregular masses of marginal moraines are distributed over the bare rock floor at the mouth of the cirque, and the base of the slope at 13,500 feet is plastered with a mass of till, the remnants of the youngest of a series of terminal moraines.

Below the lip of the cirque the valley extends as a wide, smooth-floored, flat trough bordered by walls which rise steeply to heights exceeding 400 feet (fig. 27). The gradient of the floor is scarcely sufficient to carry the stream, which, beginning as a swamp, meanders through boggy flats, passes two recessional moraines, and finally emerges from the lowest moraine as

²⁰ See p. 15.

rapids confined by closely spaced gravel walls. The two recessional moraines looped on the valley floor are 20 feet and 6 feet high; the moraine marking the farthest advance of the ice during the last period of glaciation is a V-shaped wall of débris 150 feet in height which stands at an elevation of about 13,100 feet (fig. 28).

Patches of ground moraine in this area are found below the terminal moraines, and valleys modified by ice extend to the 12,500-foot contour line and at that level hang above

FIG. 27.

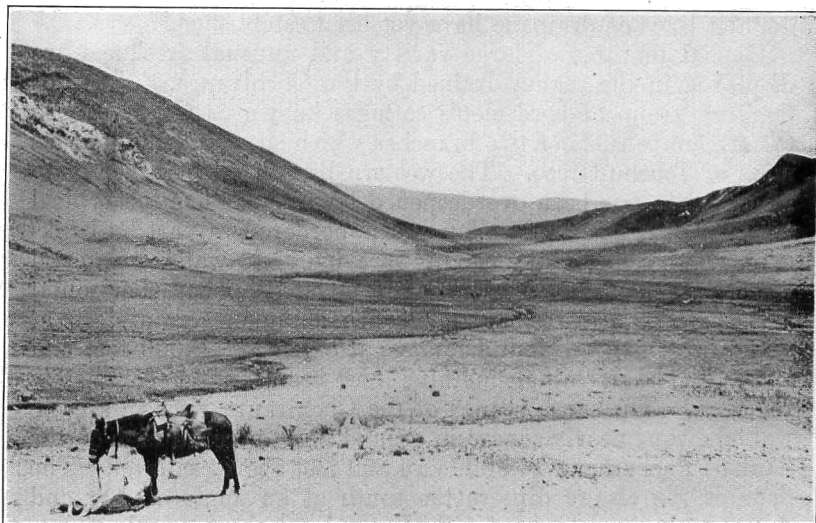


FIG. 27. Glaciated Valley near headwaters of Rio Chehiraaura.

deep-cut canyons trenching the mature slopes descending southward to the Huatanay. Though somewhat difficult of access, this locality is well worth a visit by those interested in Pleistocene geology.

Glacial Features South of the Cuzco Valley Axis.

The glacial features on the southern margin of the Cuzco Valley are less prominent and less well preserved than those on the northern rim above described; the southern ice cap was thinner and shorter-lived. No lateral or terminal moraines

were observed in valleys heading at Saekkaira and Puna-Cancha, no well-defined cirques were found at valley heads, striae and ice-worn boulders are exceedingly rare, and evidence

FIG. 28.

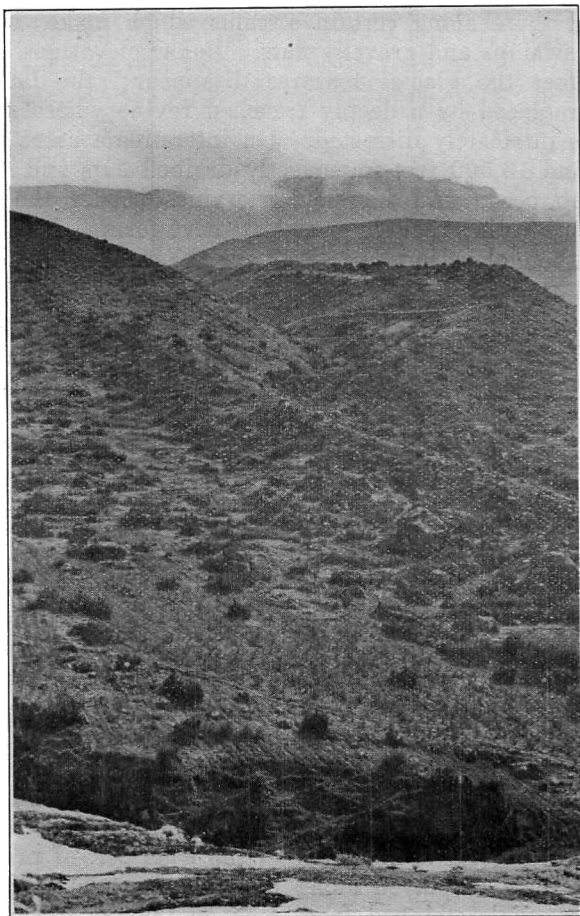


FIG. 28. The lowest of a series of three moraines in the Chchiraura Valley.

of glaciation consists mainly of valley form. The headwaters of the Qquilque, the Occopata, the Huilcarpay, the Uspha, and streams which have their sources in the Huaca-Cancha

Pampa occupy smooth-floored, steep-sided depressions with the flat longitudinal profiles characteristic of glaciated valleys. Many of the notches in the southern highland rim are cols on which ice tongues leading toward the Cuzco Basin united with those directed toward the Apurimac. Ground moraine, largely covered with débris washed from the valley sides, is exposed here and there along certain streams which make their way through swamps and gravelly flats. Below elevations of about 13,000 feet the glacial features disappear; the flat valley floor is replaced by a deeply trenched ravine whose marginal walls are intricately dissected. On interstream areas between 13,000 and 13,500 feet imperfectly drained flats and stretches of swamp occur and incipient moraines border the highest knobs—suggesting that ice or at least névé formed a continuous sheet at these elevations.

Glacial Gravels.

Distribution and character.—The swing of the climatic pendulum which introduced the ice age appears also to have initiated a period of increased rainfall. Streams were thereby increased in volume and their erosive power was greatly augmented. The significance of this change of stream habit is readily appreciated when we watch the action of streams following heavy showers and realize the havoc that would be wrought even to-day by maintaining at flood stage the streams on the steeply inclined slopes of the Cuzco Valley. The opportunity for collecting waste from the highlands is much less favorable now than formerly, because large areas of the valley sides consist of firm or slightly disintegrated rock. At the close of the Pliocene epoch the slopes were probably deeply coated with waste which had been accumulating for ages, and the enlarged streams of early Pleistocene time found vast quantities of material ready for transportation. The thoroughness with which these streams performed their task of removing superficial material is indicated by the wide belt of practically bare rock now displayed along both sides of the valley axis.

The materials stripped from rock on the upper slopes was transferred by streams of glacial time to the floor of the Cuzco Valley and to its bordering lower slopes. The amount carried into the Cuzco Basin and added to the bottom deposits of Lake Morkill is unknown, for later erosion has removed much of the valley fill and cut deeply into the lacustrine sediments. The deposits on the lower slopes, however, are exposed for

study. The Cuzco Basin is bordered by an almost continuous terrace of gravel overlying and interbedded with adobe, sand, and limestone—the cut edges of fans and quiet-water deposits, now elaborately dissected (fig. 29). The Oropesa and Lucre basins contain accumulations of gravel, and beyond the limits of the Cuzco Valley dissected fans and gravel terraces are prominent along the Urubamba and Apurimac drainage systems.

Two compound fans of unusual dimensions—Cuzco and San Geronimo—are shown on the topographic map. The Cuzco

FIG. 29.

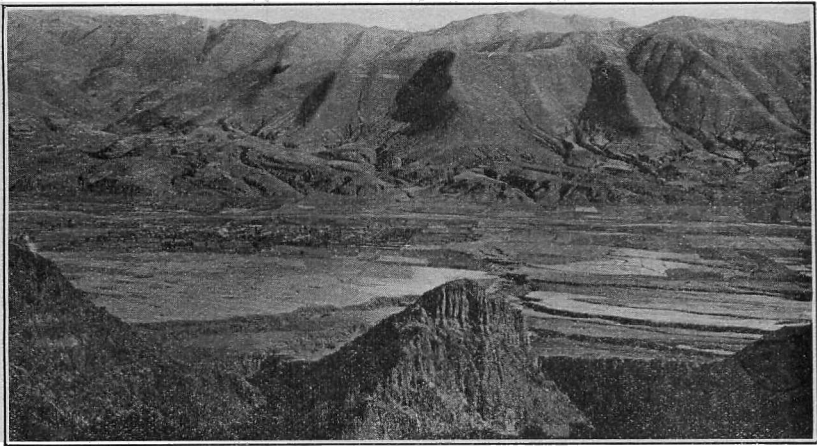


FIG. 29. Dissected terraces south side of Cuzco Basin, looking across the village of San Geronimo from the base of Cerro Pícol. A. H. Bumstead, photo.

fan, on whose lower slopes the ancient Inca city was built, has a length of $2\frac{1}{2}$ miles and a maximum width exceeding 1 mile. The surface of the upper portion is nearly flat; the lower portion has a slope of 200 feet to the mile. Canyons exceeding 150 feet in depth are sunk into the gravel without reaching the base of the deposits. The accumulation of gravel at this locality is favored by the topography, for a narrow preglacial valley at elevations of 11,000 to 11,500 feet is bordered by walls which attain heights exceeding 14,000 feet in a distance of less than 3 miles. The structure, composition,

and physiographic history of this fan have been fully described in a previous paper.²¹

The San Geronimo fan is formed of enormous quantities of land waste washed from the slopes of Cerro Picol and deposited on the floor of the Cuzco Basin. The alluvial sediments thus supplied extend nearly across the Cuzco Valley and are responsible for the existence of the agricultural community centered

FIG. 30.

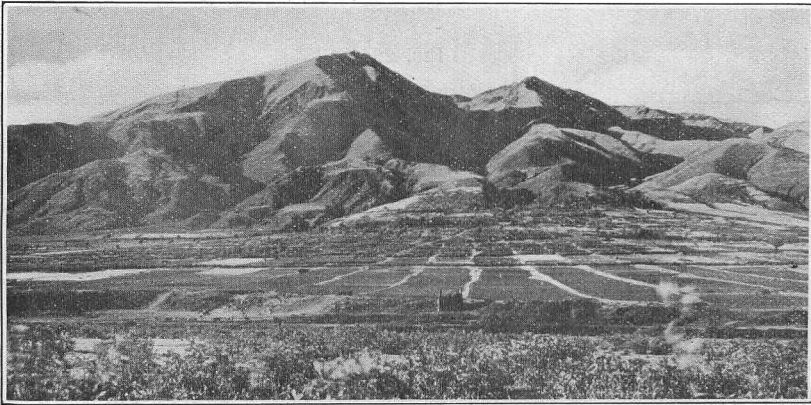


FIG. 30. The San Geronimo fan extending south from the base of Cerro Picol. A. H. Bumstead, photo.

at San Geronimo. Measured along Huatanay River the foot of the San Geronimo fan is 4 miles long; its width from the base of the rock slopes southward to its periphery is a little less than $1\frac{1}{2}$ miles. Its surface slopes about 450 feet in a mile. As seen in the photograph (fig. 30), the fan has received its gravels from the streams traversing the steep middle slopes of Cerro Picol—streams which head in cirques and glaciated valleys leading from pyramidal summits. From the crest of the mountain (14,607 feet) to the head of the fan (11,500 feet) these streams descend at the rate of about 1,600 feet to the mile. At the present time the mountain slopes are almost bare, and little material is carried by the swiftly flowing brooks. In fact, the streams traversing the fan are now intrenching themselves near the mountain base, and their work

²¹Gregory, The gravels at Cuzco, Peru, this Journal, xxxvi, pp. 15-29, 1912.

is confined largely to transporting gravel from the head of the fan to its lower margin, where deposition is progressing to such an extent that many ancient fields have been buried.

At Angostura Narrows the Ayahuaycco and Llampusuaycco, rising in the Bambanusa Pampa, aided by streams from Sencco-Orcco, deposited gravels in the preglacial gorge, completely blocking the channel. On the north side of the valley much of this gravel remains as a dissected terrace whose front is over 200 feet in height and whose top forms a table at an elevation of 11,100 feet.

The assignment of the piedmont gravels of the Cuzco Valley to late Pleistocene time rests on the following observations:

(1) The deposits were obviously not laid down under present conditions, for they are now undergoing dissection. Their interpretation demands the assumption of climatic and soil conditions favorable for vigorous erosion of waste-cloaked upper slopes and rapid aggradation of lower slopes and valley floors. The inference that Pleistocene time provided these conditions for most localities is supported by world-wide observations.

(2) When traced up valleys in which the deposits have not been obliterated by erosion, the gravels are found to interlock with materials whose glacial origin is unquestioned.

(3) As regards degree of freshness of material and amount of dissection the Cuzco gravels differ in no essential from piedmont deposits of Switzerland, the Sierra Nevada, and the Rocky Mountains, whose Pleistocene age has been demonstrated.

(4) The close association of the piedmont gravels with well-defined glacial remains, the shallow weathering of the deposits, and the insignificant amount of more recent waste overlying the fans and terraces support the belief that the gravels are contemporaneous with the moraines and cirques of the highlands and belong to the latest period of glaciation represented in the Andes, an ice age which may tentatively be correlated with the late Wisconsin epoch of North America. Patches of an older till-like material beneath the moraines of the Bambanusa Pampa and beds of poorly sorted gravel interstratified with the lacustrine deposits in the Cuzco Basin suggest that sediments laid down during an earlier cycle of glaciation are preserved in the Cuzco region. The evidence for this assumption is, however, inconclusive.

Postglacial erosion of gravels.—With the retreat of the ice from the Cuzco Valley the removal of glacial deposits began. Streams which formerly united to build a fringe of gravel fans

about the Cuzco Basin now undertook to destroy their previous work. Degradation, heretofore active on the upper slopes, was extended to the lower slopes, and aggradation was halted even on the valley floor. The time elapsing since this change

FIG. 31.

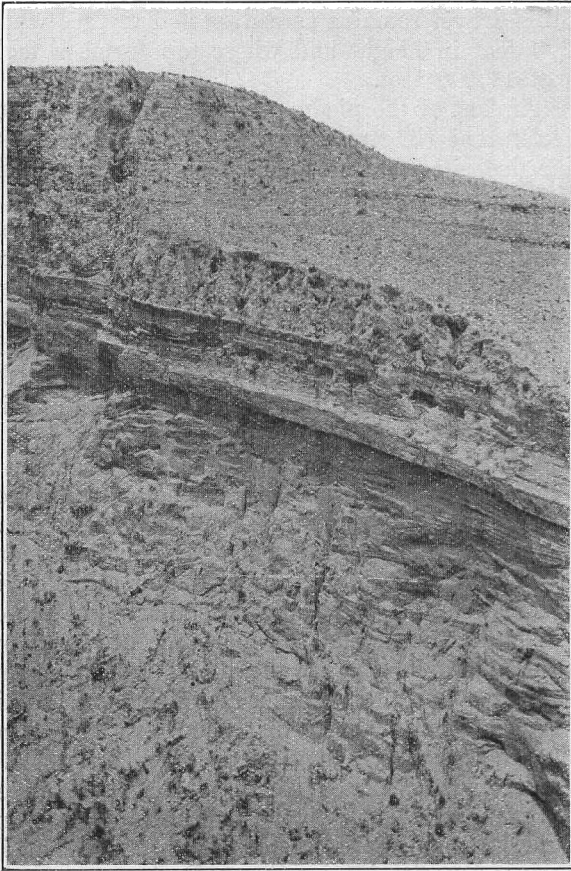


FIG. 31. Wall of canyon, 100 feet deep in lacustrine deposits, one mile north of San Sebastian.

in stream habit has not been sufficient to remove all waste from the lower slopes and to redistribute the piedmont materials, but the work already accomplished is large in amount. All tributaries to the Huatanay have partly re-excavated their

channels; on a few of them the work is complete. The fans are trenched with canyons which compare in depth with adjoining rock-walled gorges. Above Cuzco the Huatanay (Zappi) has again reached bedrock and the entire Cuzco fan is dissected by straight-sided, gravel-walled trenches 100 to 200 feet in depth (figs. 5, 13, 24). A section of the San Geronimo

FIG. 32.

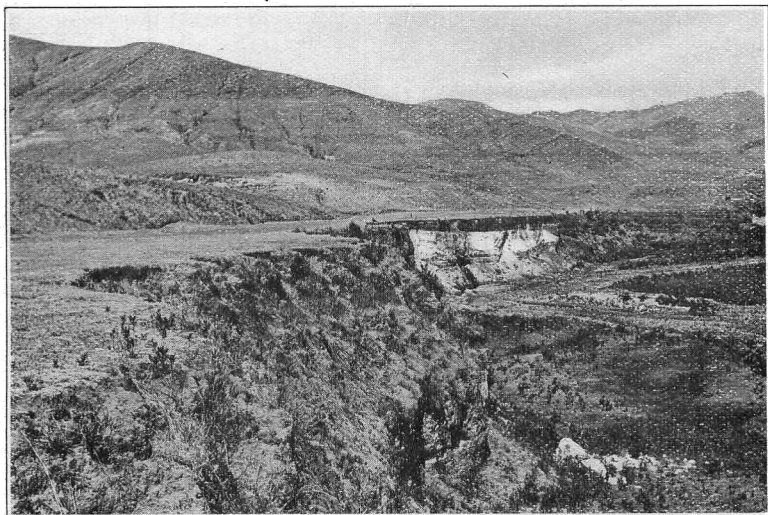


FIG. 32. Terraces along the Huatanay, at Condor-Roma, cut in ancient lacustrine deposits.

fan reveals the presence of a series of narrow, flat-bottomed, vertical-walled gravel canyons intrenched to a depth of 100 feet, without, however, reaching strata of preglacial age. Likewise the tilted lake beds adjoining the village of San Sebastian are deeply trenched (fig. 31). At Angostura Narrows bedrock has been exposed by the removal of about 600 feet of gravel (fig. 20), and along the south side of the Cuzco Basin dissection of piedmont gravels and lake sediments is unusually conspicuous (fig. 29).

Terraces.—That postglacial erosion has not continued at a uniform rate but has been subject to marked fluctuation and interrupted by periods of aggradation is indicated by a widespread development of terraces. Along the upper Huatanay

a flight of three terraces was seen. The lowest step, 8 feet above the stream, is cut in rock; the other two are developed on gravel at elevations of 12 to 20 feet and 50 to 60 feet respectively above the valley floor. At the mouth of the

FIG. 33.

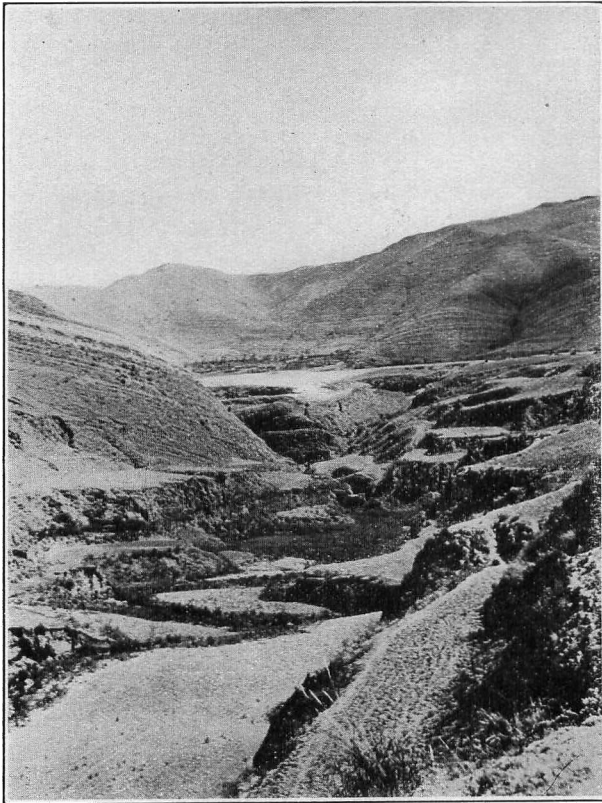


FIG. 33. Group of terraces at Ttancarpatá.

Huatanay the terrace 12 feet above the stream again appears. The terraced bank of the Huatanay below the mouth of the Huancaro is shown in fig. 32. At this locality the flat floor of the lowest terrace is practically undissected; the second terrace is trenched by quebradas. The material of both terraces is lacustrine in origin, and the foot of the upper terrace is

believed not only to represent a former level of the Huatanay but also to mark the shore line at a stage in the life of Lake Morkill. A flight of dissected terraces, three in number, the highest at 11,100 feet, flanks the Huanacauri for a distance of 2 miles above its mouth. The largest number of well-developed terraces preserved in the valleys about Cuzco is five; the smallest, two. A typical group of terraces for the smaller tributaries to the Huatanay is illustrated in fig. 33.

In the Ayahuaycco Quebrada and certain other steep-walled canyons no terraces were seen, but these exceptions to the common pattern are not significant, because conditions in narrow trenches with very steep bordering slopes are unfavorable for the preservation of terraces. Moreover, many terrace flats have been modified as the result of irrigation and the construction of *andenes* during the centuries of human occupation.

Additional proof of climatic fluctuation which resulted in the alternate deposition and removal of alluvium involved in the construction of terraces is afforded by the presence of series of recessional moraines, three to five in number, which cross the floors of glaciated valleys.²² It is probable that detailed study would result in the correlation of the terraces and moraines and furnish the necessary data for writing the climatic history of the Cuzco Valley from the close of the glacial age to the present. The result of canalization of streams to prevent flooding and the realignment of channels designed to reclaim valley flats must, however, be taken into account. Much to my regret the demands of other work prevented a study of recent physiographic history and its relation to the Inca population.

III. THE SEDIMENTARY ROCKS.

INTRODUCTION.

The sedimentary rocks of the Cuzco Valley and adjoining areas between Urubamba and Apurimac rivers consist essentially of Mesozoic strata intricately folded and traversed by innumerable faults of large and small displacement. The complicated structure of these rocks, which are widely variable in composition and texture, requires detailed study of a high degree of refinement before a satisfactory analysis of the stratigraphic column can be presented. On the basis of the recon-

²² See p. 41.

naissance examination eight groups of strata have been tentatively outlined. For purposes of description these are classified as follows:

- Recent—Gravels, sands, travertine.
- Pleistocene—Glacial gravels; moraines; lacustrine deposits.
- Pleistocene-Pliocene—San Sebastian formation: Lacustrine sands, clays, limestones.
- Tertiary (?)—Volcanic rocks: Andesite and basalt. Bambanusa formation: White and pink friable quartz sandstones.
- Upper (?) Cretaceous—Yucay formation: Blue-gray brecciated limestone.
- Jura-Trias (?)—Huayllabamba formation: Red and brown thin-bedded sandstone and arenaceous shales. Molle-Orcco conglomerate member: Coarse sandstone and conglomerate. Pachatusa formation: Brown volcanic conglomerates and sandstones.
- Permian (?)—Qquilque formation: Brown and gray sandstones, limestone conglomerate, and gypsum.

The age of only one of these stratigraphic groups, the Yucay formation, is directly proved by paleontologic evidence. The presence of characteristic glacial deposits is the basis for the assignment of the great accumulations of undisturbed gravels to the Pleistocene. The date of deposition assigned to the lacustrine sediments constituting the San Sebastian formation rests on physiographic relations, supplemented to a slight degree by evidence from fossils. The position in the time scale of the Bambanusa, Huayllabamba, Pachatusa, and Qquilque formations has not been satisfactorily determined. The basis of subdivision is lithologic dissimilarity, little known structural relations, and a meager knowledge of the regional geology of southern Peru. The shales in the basal beds resemble in certain respects the Carboniferous (Pennsylvania) strata of Lake Titicaca,²³ but coal, massive limestones, and heavily bedded gray sandstones are absent, and marine fossils, so abundant at Titicaca Island and Copacobana, were not found at Cuzco. It is not improbable that the formations provisionally classed as Permian (?) and Jura-Trias (?) may have originated in one geologic period, and the system to which they are ultimately assigned may be any part of the stratigraphic column from Carboniferous to Lower Cretaceous.

²³ Gregory, H. E., Geological sketch of Titicaca Island and adjoining areas, this Journal, xxxvi, pp. 187-213, 1913.

QUILQUE FORMATION.

As displayed in the field the strata included in the Quilque formation are bounded on the east and north by the Huancaro fault; in other directions the formation extends beyond the limits of the area mapped. Although showing numerous small folds with variously oriented axes the beds in general form an anticline trending approximately north. The dips on the east limb of the major fold reach angles exceeding 80° ; high dips prevail also on the west limb but decrease in amount with increase of distance from the central axis. Alternating beds of brown sandstone and chocolate-colored shale are exposed on the two limbs; the truncated crest includes beds of limestone conglomerate and of gypsum. Unequal resistance of the various strata has determined the lines of major drainage; the broad upper valley of the Quilque in particular appears to owe its position and form to the weathering of soluble beds. The character and arrangement of strata in the upper portion of the Quilque formation is shown in the following section of the east limb of the anticline.

I. Section of upper beds of the Quilque formation in an area of intricately folded strata along the Ferrobamba trail, beginning three-quarters of a mile from the mouth of Quilque Quebrada.

Average strike approximately north; dip 30° E- 90° .

Top.	Feet.
1. Sandstone, brown, fine to medium grained; quartz grains with calcareous and argillaceous cement; beds 4 to 5 feet thick, subdivided by fine lines or stripes of darker material; lenses and pellets of clay common; much secondary lime along joints	80
2. Shale and argillaceous sandstone; red to chocolate; calcareous in places; highly variable in texture, composition, and structure	8
3. Sandstone, brown, calcareous, lenticular and nodular	1
4. Shale and argillaceous sandstone, like No. 2; in places recemented bits of fine sandstone	4
5. Sandstone, brown, calcareous, fine grained; minutely striped and cross-bedded; beds displaced 3 feet by a fault trending, about east	1
6. Shales, light red to chocolate; calcareous; irregularly bedded; resemble compact weathered sandy clay, rearranged by pressure	10
7. Sandstone, brown, like No. 1	4

	Feet.
8. Shale, chocolate, like No. 6	9
9. Sandstone, brown, like No. 7, but crumbly, nodular, highly argillaceous, and minutely cross-bedded	7
10. Shale, chocolate, like No. 6	6
11. Sandstone, brown, like No. 1; much cross-bedded ...	9
12. Shale, chocolate, like No. 6	12
13. Sandstone, brown	4
14. Shale, chocolate	1
15. Sandstone, brown	1
16. Shale, chocolate	2
17. Sandstone, brown, much cross-bedded	13
18. Sandstone, light gray; weathers yellow-gray; uniform medium grain; very thin-bedded, cross-bedded; a patch or lense on bottom of bed No. 17	1
19. Shale, chocolate, highly arenaceous	8
20. Sandstone, gray, cross-bedded, thin-bedded, uniform medium grain; calcareous cement; apparently dif- fers from No. 7 only in color	4
21. Shale, chocolate	12
22. Sandstone, brown, like No. 1	9
23. Shale, chocolate, with 4-inch band of brown sandstone	5
24. Sandstone, gray, friable, calcareous, with arenaceous and calcareous concretions; weathers bright yellow on upper surface	5
25. Shale, red to chocolate	4
26. Sandstone, brown, with bands of paper-thin shale near top	3
27. Shale, chocolate, with 1-inch bands of brown sandstone and half-inch lens of blue limestone	4
28. Sandstone, brown, with 1-inch cap of gray sandstone	4
29. Shale, chocolate	4
30. Sandstone, brown	3
31. Shale, chocolate	2
32. Sandstone, brown, capped with thin layer of gray sand- stone	2
33. Shale, chocolate	1
34. Sandstone, brown	1
35. Shale, chocolate	5
36. Sandstone, brown	1
37. Shale, chocolate, and brown sandstone, in alternating beds, 2 to 3 inches thick	6
38. Sandstone, brown	3
39. Shale, chocolate	7
40. Sandstone, brown, extremely thin-bedded and cross- bedded	15
41. Shale, chocolate	6

	Feet.
42. Sandstone, brown, very fine, minutely cross-bedded; calcareous cement; vertical tubes like worm holes; carbonaceous patches; surface sun-baked and with imperfect mud cracks; mud lumps and tiny lime concretions on surface	0.5
43. Shale, chocolate; sun-dried surfaces; flakes of muscovite	5
44. Sandstone, brown	1
45. Shale, chocolate	3
46. Sandstone, brown	7
47. Shale, chocolate	2
48. Sandstone, brown	1
49. Shale, chocolate	1.5
50. Sandstone, brown	1
51. Shale, chocolate	2
52. Sandstone, brown and gray bands	3
53. Shale, chocolate	6
54. Sandstone, brown, with 1-foot layer of gray sandstone at top	9
55. Shale, chocolate	1
56. Sandstone, brown	1
57. Shale, chocolate	12
58. Sandstone, brown	4
59. Shale, chocolate	10
60. Sandstone, brown	4
61. Shale, chocolate, with thin bands of sandstone	14
62. Sandstone, brown; sun-baked surfaces and ripple marks	1
63. Sandstone, gray	1
64. Sandstone, brown, interbedded with chocolate shale ..	50
65. Interval (estimated)	100
66. Limestone conglomerate, gray to blue-gray; chiefly concretionary pebbles and irregular fragments of limestone, the size of small shot to half an inch in diameter; a few chert pebbles; bed lenticular; top not exposed	4
67. Sandstone, gray to yellow-green; medium-grained quartz; thin-bedded, cross-bedded; includes thin sheets of finely laminated shale	15

Most of the beds in Section I do not retain their individuality for more than a few hundred feet; overlapping lenses rather than widely extended layers of uniform thickness constitute the bedrock, and the strata themselves, in many places, are made up of thin imbricated sheets of small areal extent. Many

beds contain gypsum in small amounts, and thin lenses and seams of gypsum were observed at several localities. Stratigraphically below the strata included in Section I elongated lenses of limestone conglomerate and of limestone 3 inches to 4 feet in thickness become more abundant; and at the head of the tributaries to Rio Qquilque bands of limestone, limestone conglomerate, and gypsum are widely displayed. In places these rocks are represented by masses of white paste.

In the valley of the Rio Ayahuaycco the more calcareous portion of the Qquilque formation is represented in a section which contains the following strata:

II. Section of calcareous portion of Qquilque formation in a branch of Ayahuaycco Quebrada, about half a mile above its junction with Rio Qquilque.

Top.	Feet.
1. Shale, dark red, calcareous; with gypsum in seams and beds	30
2. Limestone conglomerate, composed of concretionary pellets, size of bird-shot	0.3
3. Limestone, calcareous or massive shale, brown, mottled with patches and bands of yellow; concretionary ..	6
4. Sandstone, yellow, highly calcareous, with shale partings	2
5. Limestone conglomerate, pellets from size of bird-shot to size of buckshot	2
6. Sandstone, banded green, yellow, and brown; thin-bedded	4
7. Shale, banded, and copper-green limestone; shale gypsiferous	12
8. Limestone, arenaceous, red-brown, in general massive, but full of gray limestone concretions; bands of gypsum and lenses of limestone conglomerate. This bed may not be in place	30
	86.3

The strata in this section have been disarranged by a number of small faults.

The nature of the rocks and the order of deposition indicated by Sections I and II are fairly typical for the entire Qquilque formation. In places, however, as at the head of the Huatanay, lenses of limestone conglomerate, separated only by thin layers of brown or gray sandstone, highly calcareous shale, or gray-blue massive limestone, are particularly abundant. In the bed of the Huatanay south of Sacsahuaman is a bed of con-

glomerate 20 feet thick consisting of limestone and gypsum balls, intersected by seams of gypsum. In places the sandstone of the Qquilque formation is coarse grained or conglomeratic, and at a point three-fourths of a mile northeast of Ttica-Ttica Pass the upturned beds of sandstone contain pellets of shale, subangular pebbles of quartz exceeding half an inch in diameter, and angular fragments of scoriaceous basalt of much larger dimensions.

The age of the Qquilque strata is unknown; their assignment to the Permian rests on imperfectly determined field relations. That these beds are continental rather than marine in origin is suggested by various features described above.

PACHATUCSA FORMATION.

The volcanic conglomerates and sandstones forming the heights of Pachatusca and Atasecasa, on the northern rim of the Cuzco Valley, are grouped in the Pachatusca formation. The strata constitute part of the south limb of a giant anticline whose crest has been trenched by Urubamba River to a depth of nearly 6,000 feet. Sierra Pachatusca has thus been carved into a cuesta whose bluntly serrated crest, attaining a height of 15,915 feet, constitutes the commanding topographic feature of the bordering walls of the Cuzco Valley. From the summit of the cuesta the descent to the Urubamba is precipitous; toward the south a dip slope at an angle of 20° to 30°, gouged by ancient glaciers, extends for more than a mile (fig. 10).

In a broad sense the strata included in the Pachatusca formation may be classed as volcanic conglomerate. They exhibit, however, wide variations in amount, character, and distribution of the igneous constituents. In the Pachatusca hogback, where the tilted beds of dark-red conglomerate are 5 to 40 feet thick, the lowest strata examined are composed largely of quartz pebbles; the upper beds include angular and subangular fragments of quartz, sandstone, quartzite, basalt, and several varieties of dense basic rock embedded in a matrix of similar material. Six pebbles were collected in the field as representatives of different types of igneous rock. In color the specimens are brown, red, greenish, white, drab, and mottled; their textures range from scoriaceous through porphyritic to microcrystalline. When the pebbles were subjected to microscopic analyses, however, they were all found to belong to the andesite family. They consist of andesine as pheno-

crysts and as a constituent of the groundmass; brown hornblende, in many places resorbed; iron ore, chiefly magnetite, distributed as grains and also replacing biotite and hornblende; titanite and apatite in small quantity. Calcite, serpentine, chlorite, chalcedony, and quartz constitute the list of secondary minerals. One of the specimens collected proved to be an andesitic tuff, or tuffaceous sandstone. It consists of well-rounded grains of clear quartz, partly decomposed fragments of microcline and oligoclase, and lapilli of andesite, all firmly cemented by silica. In comparison with other fragments the chunks of andesite are large and angular and suggest contemporaneous igneous activity at no great distance.

In texture the individual strata of the Pachatusa formation vary widely and abruptly, both along the strike and in the direction of dip. No beds of fine ash were noted. Large blocks of lava are common and at one locality a mass of amygdaloidal andesite 80 feet long and 30 feet thick was observed. The size of these masses, their conformable relation to underlying beds, and the fact that vesicles on their surfaces as well as larger cavities and joints are occupied by sandstone suggest contemporaneous extrusions. It is not improbable that further study will reveal the presence of lava flows as persistent members of the stratigraphic series.

In the Atascasa region the presence of igneous knobs and the wide variation in thickness and extent of the lenslike beds have produced a topography of hills and flats entirely unlike the Pachatusa cuesta. In this area the strata of the Pachatusa formation are cut by intrusions and their volcanic constituents are apparently nearer their source. Volcanic ash in beds and lenses 2 to 90 feet thick is interstratified with volcanic conglomerate and sandstone. Near the intrusive masses the arenaceous sediments have been converted into quartzite, and beds of volcanic breccia near one of the dikes are believed to indicate the site of an ancient vent which supplied at least part of the igneous fragments present. In addition to igneous fragments the conglomerate and ash beds at Atascasa contain innumerable rounded and subangular quartz fragments as much as half an inch in diameter, also feldspars and blocks of sandstone, shale, and quartzite.

The Pachatusa beds are believed to be of continental origin, but their age is undetermined. The strata seem to underlie conformably the red sandstones and shales of the Huayllabamba formation at the edge of the overlying Ichchu-Oreco lava and

are assigned to the same system (p. 71). Several thousand feet of strata underlying the Pachatucsa beds, displayed in the wall of the Urubamba canyon, have not been studied.

HUAYLLABAMBA FORMATION.

Brown sandstone and chocolate-colored arenaceous shale are by far the most common rocks in the Cuzco Valley. They underlie the highlands south of the Huatanay and form the north side of the valley of that stream from Tticapata eastward to the Urubamba. The part of these widely extended arenaceous beds west of the Huancaro fault is included in the Qquilque formation;²⁴ for the remaining much larger part the term Huayllabamba formation is proposed.

In addition to the typical strata of brown sandstone and chocolate-colored shale which constitute about 90 per cent of the Huayllabamba formation, it contains gray sandstone and a few thin layers of black shale, gray shale and limestone. Along the highlands forming the divide between the Huatanay and the Apurimac drainage basins, gray and brown conglomerates are so abundant as to justify separate grouping: the Molle-Orcco conglomerate member. Throughout their extent the strata of the Huayllabamba formation are disturbed; a bewildering variety of normal and asymmetric folds are represented by truncated remnants and faults of small displacement may be numbered by hundreds. The trends of the axes of synclines and anticlines fall in general within the northwest quadrant, with an average for the more prominent folds of about N. 50°-60° W.; many fault planes strike in the same direction. There are, however, numerous exceptions to the general trend and a complete analysis of the stratigraphy involves traverses separated by distances of a mile or less.

In the time at my disposal I found it impossible to determine the limits of the Huayllabamba formation, but typical sections showing the character and arrangement of its strata were measured at a number of places both north and south of the Cuzco Valley axis.

Huayllabamba Formation north of Rio Huatanay.

III. Section of the Huayllabamba formation: north side of Angostura Narrows, beginning at the 13,000-foot contour line and extending S. 50° W. down the slope.

²⁴ See p. 55.

Strike N 70°± W; dip S 30°-40°. Measured with the assistance of K. C. Heald.

	Feet.
1. Sandstone, brown, massive, microscopically fine grained; gray quartz with ferric and calcareous cement	3
2. Shale, chocolate, arenaceous, irregularly bedded, calcareous, imbricated, nodular	6
3. Shale, chocolate, and calcareous sandstone, in alternating beds, 3 to 6 inches thick; contains thin lenses of gray quartz sandstone	25
4. Sandstone, brown	4
5. Concealed by débris	50
6. Sandstone, white quartz, medium grained; in three beds separated by layers of brown sandstone	6
7. Shale, chocolate	3
8. Sandstone, brown	6
9. Shale, chocolate, and sandstone, in about equal amounts; beds 2 to 6 feet thick; much broken	40
10. Sandstone, brown, with small lenses of chocolate shale	6
11. Shale, chocolate, and sandstone, unevenly bedded, lenticular, imbricated	12
12. Sandstone, brown	5
13. Shale, chocolate, with bands of brown sandstone; sandstone cross-bedded; shale surfaces sun-baked, and traversed by mud cracks	14
14. Sandstone, brown	2
15. Shale, chocolate	4
16. Sandstone, brown	7
17. Shale, chocolate	2
18. Sandstone, brown	4
19. Shale, chocolate, with layers of brown sandstone	6
20. Sandstone, gray, highly calcareous, with overlapping lenses of brown sandstone and chocolate shale; also pebbles of shale 1 inch in diameter	4
21. Shale, chocolate	3
22. Sandstone, gray, like No. 20	5
23. Shale, chocolate	1
24. Sandstone, brown to chocolate; very thin-bedded, tangentially cross-bedded, ripple marked; worm tubes; sun-baked surfaces specked with flakes of muscovite	12
25. Shale, chocolate, nodular, imbricated	5
26. Sandstone, banded, alternating paper-thin layers; surfaces coated with brown and black hematite	10
27. Shale, chocolate, calcareous	2
28. Sandstone, brown; on its uneven surface are plastered lumps of clay shale	4
29. Shale, chocolate, sandy and calcareous, unevenly bedded	3
30. Sandstone, brown, thin-bedded and banded like No. 26	9

	Feet.
31. Shale, chocolate	2
32. Sandstone, brown, thin-bedded, cross-bedded, ripple marked	11
33. Shale, chocolate, with lens of sandstone; footprints(?) on sun-dried surfaces	3
34. Sandstones, alternating gray and brown; with lenses, stringers and nodules of calcareous chocolate shale	14
35. Shale, chocolate	3
36. Sandstone, brown, with lenses of shale at top	10
37. Shale, chocolate	6
38. Sandstone, brown, extremely thin-bedded	3
39. Shales, chocolate	3
40. Sandstone, gray, with bands and lenses of chocolate shale	12
41. Shale, chocolate	2
42. Sandstone, gray, fine grained; contains chunks of shale and a few well-worn quartz pebbles	28
43. Shale, chocolate; upper surface highly uneven, chan- neled	2
44. Sandstone, brown, with 4 to 6 inch bands of chocolate shale	40
45. Sandstone, brown, and chocolate shale, in alternating beds 1 to 8 feet thick, with features essentially like Nos. 30-45 inclusive	300

703

Two hundred feet of rocks, exposed in scattered outcrops and stratigraphically above the beds included in Section III, differ from the measured strata only in having a somewhat more regular lamination and a slightly greater calcareous content. Two thin layers or lenses of black argillaceous limestone were noted. All the beds are thin, individual layers rarely exceeding 5 feet. The transition from shale upward into sandstone is in most places accomplished by means of a sandy zone made conglomeratic by the presence of fragments of the underlying shale. The shales themselves usually consist of alternating arenaceous and argillaceous layers one-sixteenth to 1 inch thick. Many of the arenaceous shale laminae present smooth, glistening, sun-baked surfaces specked with mica, dotted with mud lumps, crossed by polygonal cracks. Features interpreted as worm trails and borings and impressions of plant fibers were noted at a few places. The beds are traversed by closely spaced joints which furnish the talus slopes with rhombohedral blocks a few inches in long diameter.

IV. Section of Huayllabamba formation on south branch of Rio Huaccoto.

Strike N 70° W; dip 40° S.

	Feet.
1. Shale, chocolate to dark red; friable	10
2. Sandstone, brown, with included fragments of chocolate shale	0.2
3. Shale, chocolate	0.2
4. Sandstone, brown	6
5. Shale, chocolate, with lenses of sandstone	7
6. Sandstone, brown	4
7. Shale, chocolate, with thin beds of sandstone	12
8. Sandstone, brown	3
9. Shale, chocolate	2.6
10. Sandstone, brown, with two 3-inch bands of chocolate shale	13
11. Shale, chocolate	4.5
12. Sandstone, brown	3
13. Shale, chocolate	1.5
14. Sandstone, brown; with 5-inch lens of chocolate shale	12
15. Shale, chocolate	2
	81

The Huaccoto section is about 1,000 feet, stratigraphically, below the strata included in Section III. The distinction between sandstone and shale in this section is not well marked. All the shale beds are arenaceous, and the sandstone strata are laminated, rarely cross-bedded. Intermittent exposure to the sun is attested by mud cracks and films of glistening, compact mud which mark the division planes between laminæ.

In a series of strata at Cerro Pícol, whose position in the stratigraphic column is below the beds of Section IV, thin beds of dark-red arenaceous limestone were noted, and the chocolate-colored shales were found to be more calcareous than at the localities represented by Sections III and IV. Also, thin beds of gray sandstone, banded, minutely cross-bedded, and containing pebbles of gray shale, chocolate-colored shale, and red limestone, constitute about 15 per cent of the 700 feet of the strata examined.

At Ccorao Pass, at an elevation of 12,500 feet, thin bands of brown argillaceous limestone are interbedded with the familiar brown sandstones, chocolate-colored shales, and gray sandstones.

V. Section of Huayllabamba formation, Ccorao Pass between Sequeray and Catunga-Huayna.

Strike N 80° W; dip 40° ± S.

	Feet.
1. Sandstone, brown to gray, fine grained, even grained, massive; composed of quartz with small amounts of feldspar and mica and specks of iron ore. Many shale pellets near upper surface. Forms cliff	20
2. Shale, dark red to chocolate; calcareous; sun-baked, includes beds and lenses of dark-red sandstone	30
3. Sandstone, brown, in part gray, with thin beds of shale; mostly fine grained, but includes beds with quartz grains the size of bird shot and pellets of chocolate-brown clay, foliation surfaces mud cracked	65
4. Sandstone, gray, fine grained, feldspathic	1
5. Limestone, dark red, or highly calcareous sandstone, in beds about 2 inches thick, including shale layers . . .	5
6. Sandstone, brown, medium grain, even grained, slightly calcareous	6
	127

The strata in Section V are disturbed by numerous faults of small displacement. Green copper stain is common on slickenside surfaces. The chocolate-colored shales, abundant in Sections II and IV, are here relatively rare.

The lofty mass of Sencca, overlooking the Cuzco Basin from the northwest, consist essentially of strata of brown and gray sandstone interspersed with beds of chocolate-colored shale. Much of the sandstone is feldspathic and approaches arkose in composition and texture; many beds include irregular layers of conglomerate consisting of angular chunks of shale. The strata, particularly at the base of Sencca, are intricately fractured and where most disturbed are impregnated with malachite accompanied with lesser amounts of azurite.

In the bed of the Huatanay and along the Chunchullumayo, thin strata of black limestone and of black shale were found, and a measured section of the west bank of Rio Cachimayo, 2 miles above San Sebastian, includes 15 feet of black, slightly carbonaceous shale, in the midst of which are two layers, each half an inch thick, of nodular limestone. In other respects the rock in Cachimayo Valley is typical for the Huayllabamba formation.

Huayllabamba Formation south of Rio Huatanay.

On the south side of the Cuzco Valley, beds assigned to the Huayllabamba formation were studied at several localities. The rocks forming the deeply carved slopes bordering the Huatanay east of Rio Huancaro are brown sandstone and chocolate-colored shales which differ in no essential particular from the strata of the Huayllabamba formation previously described. On the highlands south of Saylla few of the alternating beds of arenaceous shale and fine-grained brown sandstone exceed 1 foot in thickness on the lower north slopes. Above 11,500 feet the strata thicken, and the ragged serrate crest of Maho-Pinta, at about 13,500 feet, consists of beds of sandstone in nearly vertical position, 4 to 20 feet in thickness. Between the sinuous rows of 'teeth are trenchlike passages resulting from the erosion of the less resistant shale. One mile farther south the tiny streams forming the headwaters of Rio Kkaira follow the strike of shale beds and are inclosed between unevenly spaced walls of brown and gray sandstone 20 to 80 feet in height. Approximately 80 per cent of the sandstone between the Huatanay and Rio Uspha is brown in tone and fine to medium in texture. Gray sandstone is irregularly distributed and in common with the more abundant brown rock contains lenses of conglomerate consisting of fragments of chocolate, red, rarely green clay shales. At a point on the middle course of Rio Huanacauri several beds of gray and pink limestone, of small extent but sufficiently thick for quarrying, were noted among the prevailing arenaceous strata. At a number of localities the surfaces of shale and of thin sandstone beds are sun-baked and cracked and exhibit other features indicative of intermittent exposure to the atmosphere.

Molle-Orcco conglomerate member.—On the highlands forming the divide between the Huatanay and the Apurimac drainage basins the typical sandstones and shales of the Huayllabamba formation grade upward into a series of beds including many strata of a coarse conglomerate. This phase of the formation is well displayed at Molle-Orcco. The conglomerate beds, involved in a series of intricate folds, form many high ridges and have determined the courses of the smaller streams. Where in vertical position they rise above the surface as a series of parallel dikes, producing an extremely rough topography (fig. 34).

The proportion of conglomerate to sandstone in the Molle-Orcco member is variable. At Ceochacolla a succession of

conglomerate beds is interrupted by insignificant amounts of finer-grained material; at certain other localities the conglomerate strata are widely spaced. In places beds a few feet thick consisting chiefly of pebbles exceeding 1 inch in diameter may be traced continuously for more than a mile; elsewhere the conglomerate is displayed as lenses 3 to 10 feet thick and a few

FIG. 34.

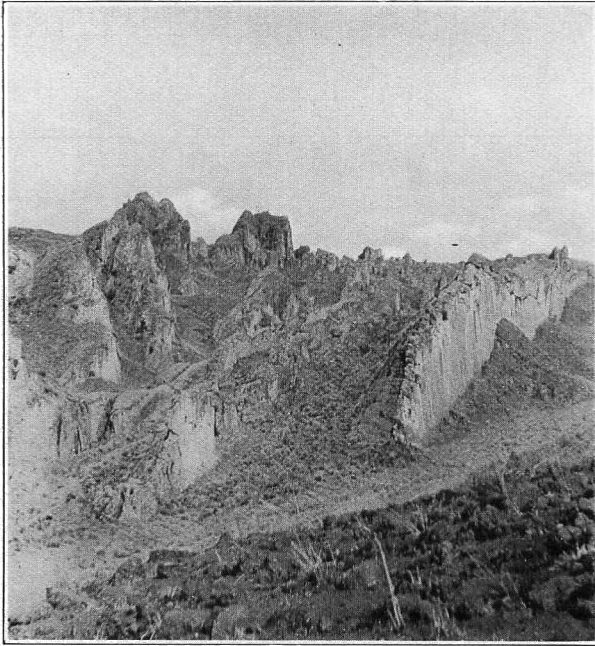


FIG. 34. Molle-Orcco conglomerate in vertical position at Molle-Orcco.

hundreds of feet long. At some localities the conglomerate forms merely a patch 3 to 6 inches thick overlying gray or brown sandstone. Individual pebbles 2 to 3 inches in diameter occupying isolated positions in several cubic feet of sandstone, as well as strings of pebbles entirely detached from their neighbors, are not uncommon.

The Huayllabamba formation, including the Molle-Orcco conglomerate, is well displayed for study on the Cuzco-Ayus-bamba trail leading up the Huancaro Valley (fig. 35).

VI. Section of Huayllabamba formation, including the Molle-Orcco conglomerate member, on west bank of Rio Huancaro below the mouth of Rio Chehocco.

Northeast limb of syncline. Strike $N 80^{\circ} \pm W$; dip $90^{\circ}-10^{\circ} S$.

Feet.

1. Sandstone, gray on surface, gray-brown below, and conglomerate, cross-bedded, in places banded with black sand. Conglomerate constitutes about 30 per cent of bed and is arranged in lenses 10 to 100 feet long, 1 inch to 4 feet wide, in irregular masses 3 to 6 feet in diameter, and as isolated strings of pebbles;

FIG. 35.

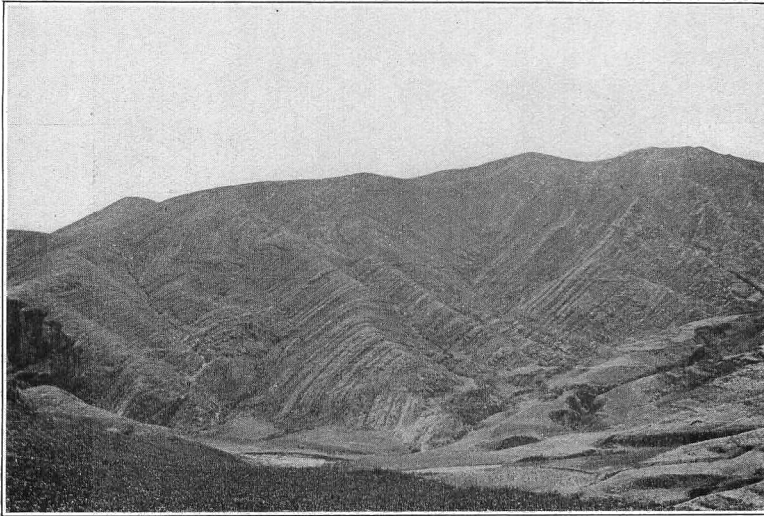


FIG. 35. General view of strata comprising the Huayllabamba formation, including beds of the Molle-Orcco conglomerate member. Ayusbamba trail.

- pebbles reach a maximum size of 8 inches and average about 1 inch; types noted include quartz of various colors, feldspar, biotite granite, porphyritic trachyte, diabase, green, yellow, and brown quartzite; hornstone, slate, brown sandstone, brown shale, and limestone. The pebbles are fairly well worn and rounded and are embedded in sand held together by ferric, argillaceous, and calcareous cement 30
2. Sandstone, dark red, friable, calcareous 3
 3. Sandstone and conglomerate like No. 1, except for abundant flat pebbles of dark-red sandstone and shale 8

	Feet.
4. Sandstone and conglomerate like No. 1, thin-bedded	3
5. Sandstone, brown, with pebbles of clay shale	2
6. Shale, chocolate colored, arenaceous, and thin-bedded calcareous sandstone	5
7. Sandstone, brown, with lenses of red calcareous shaly sandstone	9
8. Conglomerate, gray	2
9. Sandstone, red, calcareous, friable, shaly	5
10. Alternate layers of sandstone like Nos. 9 and 7, and lenses of pink-gray limestone a fraction of an inch in thickness.	15
11. Sandstone, gray-brown, with few lenses of conglomerate	4
12. Sandstone, dark red, shaly, highly calcareous	4
13. Sandstone, gray-brown	4
14. Sandstone, dark red, shaly	5
15. Alternating bands of sandstone like Nos. 12 and 13	13
16. Sandstone, gray to brown, conglomeratic in places and containing lenses and narrow, more or less continuous bands of sandstone like Nos. 12 and 13	110
17. Sandstone, red, calcareous, friable	5
18. Sandstone, brown and gray, and chocolate-colored shale, in beds and lenses 6 inches to 4 feet in thickness. Sandstone has calcareous cement; red shaly beds vary in composition from calcareous sandstone through argillaceous calcareous shale to pure limestone. Foliation surfaces sun-baked, rare ripple marks	305
19. Sandstone, dark red, highly calcareous, fine grained; quarried for building stone	6
20. Sandstone, gray, conglomeratic; abundant brown, flat pebbles of shale	27
21. Sandstone, brown, calcareous, with limestone lenses	9
22. Conglomerate, gray, with pebbles of brown sandstone and shale	10
23. Sandstone, brown, calcareous	5
24. Sandstone, gray and brown; with beds and lenses of conglomerate like No. 1 and many fragments of brown clay shale	55
25. Concealed by débris; probably brown shaly sandstone	100
26. Sandstone, brown and gray, with layers of abundant brown shale pebbles; strike N. 80° E.; dip 40° SW.	60
27. Beds 3 inches to 6 feet thick, of gray sandstone, with rare conglomerate pebbles; brown sandstone, with many brown shale pebbles; red to chocolate calcareous shale and shaly sandstone; beds of limestone one half inch and less in thickness. Shaly parts of sandstone beds sun-baked and mud cracked	90

	Feet.
28. Sandstone, gray, coarse, with very thin bands of red calcareous shaly sandstone. Few pebbles except of brown shale	14
29. Limestone layer in chocolate shale; upper surface sun-baked and marked by mud cracks, worm tracks and footprints (?)	0.5
30. Sandstone, brown, thin-bedded, cross-bedded	5
31. Limestone, thin-bedded, shaly, arenaceous; surface of separate layers strewn with fine micaceous sand; sun-dried, sun-cracked; shows footprints (?)	1
32. Sandstone, gray, with thin beds of shale and shaly limestone	14
33. Shale, chocolate, sandy, with mud cracks, baked surfaces, tracks, etc. Strike N. 70°-80° E.; dip 30° S. Open joints, producing waterfall, trend N. 20° W. and E.; both sets nearly vertical	6
34. Sandstone, gray, with interbedded brown and chocolate calcareous shaly sandstone and thin limestone	30
35. Concealed by gravel	180
36. Sandstone, brown, and chocolate shale in alternating beds; dip nearly horizontal	45
	1208.5

On the divide between the headwaters of the Chchocco and Llavliccasa, branches of the Huancaro, where the Molle-Orcco conglomerate is involved in a knot of twisted folds, the following section, typical for the area southwest of the Huancaro, was measured:

VII. Section of Molle-Orcco conglomerate member of the Huayllabamba formation near the head of Rio Chchocco.

Strike N 20° W; dip 80° SW.

	Feet.
1. Sandstone, gray and brown, and conglomerate; pebbles irregularly distributed	20
2. Shale, chocolate-brown, with layers of sandstone	3
3. Sandstone, brown, calcareous cement, cross-bedded; lenses of clay pebbles and of conglomerate	20
4. Shale and shaly sandstone, chocolate, calcareous	4
5. Conglomerate and coarse sandstone, brown; subangular and rounded pebbles as much as 1 foot in diameter of red and gray quartz, feldspar, sandstone, shale, limestone, granite and diorite, and slate	16
6. Shale, chocolate, arenaceous	6
	69

Origin and Age of the Huayllabamba Formation.

The source of the materials composing the strata of the Huayllabamba formation is unknown. The terranes whose disintegration gave rise to the sediments were doubtless pre-vaillingly siliceous and must have included metamorphic rocks and a variety of igneous intrusives. Many features of the sediments indicate deposition by streams of fluctuating flow. The prevailing red color of the beds and the presence of slightly altered feldspars suggest an arid climate. On the evidence derived from field observation a large part at least of the Huayllabamba formation is believed to be of continental rather than marine origin. It is interesting to note that in general appearance as well as in several detailed features of composition and structure the Huayllabamba strata are not unlike the Newark sediments of Connecticut and New Jersey. No fossils other than impressions of plant fibers and doubtful footprints of a small animal of the dinosaur type were found in the Huayllabamba beds. The age of the strata is therefore unknown. They underlie the Yucay limestone (Upper (?) Cretaceous) and are unlike the richly fossiliferous Carboniferous (Pennsylvanian) strata of the Titicaca region.²⁵ The formation may be Permian, Triassic, or Jurassic, or it may include strata from more than one Mesozoic system. In the present report the Huayllabamba formation, including the Molle-Orcco conglomerate, is assigned tentatively to the Jura-Trias.

YUCAY FORMATION.

The plateau surface north of the city of Cuzco and including the Yucay, Pucro, Kkallachaca, and Era pampas is developed on limestone. The plateau is sharply bounded on the south by steep cliffs facing Rio Huatanay; on the northwest, north, and northeast the sandstone rim of Sencca continued through Fortaleza and Seqqueray forms the bordering wall. The topography of the pampa surface is subdued; rounded knobs separated by basin-like valleys are typical features (fig. 13). Sink-holes are common, and at one point part of the roof of an underground channel remains as a natural bridge. The rock forming the plateau is typically developed on the Yucay Pampa, and Yucay appears therefore to be a suitable name for the calcareous beds of this area.

²⁵ Gregory: Geologic sketch of Titicaca Island and adjoining areas. This Journal, xxxvi, pp. 187-213, 1913.

The Yucay formation consists of limestone of two types—(1) a black to gray massive variety, firm and compact, breaking with conchoidal fracture; (2) a drab-gray, thin-bedded, slightly arenaceous rock. The massive variety constitutes the bulk of the formation; the laminated type occurs in masses of small dimensions. Both types of rock develop light-gray tones on weathering and both are sparingly fossiliferous. The strata are traversed by joints and much broken by normal and thrust faults of a few inches to a few feet displacement;

FIG. 36.

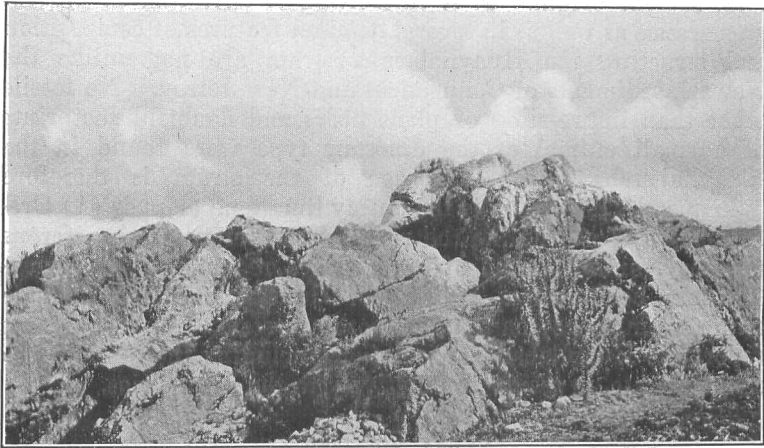


FIG. 36. Typical exposure of Yucay limestone, Kkallachaca Pampa.

slickensided surfaces are common. An exposed ledge reveals brecciation carried to an extreme; even a hand specimen may consist of 10 to 15 angular fragments firmly re-cemented. The entire Yucay formation may be described as consisting of finely brecciated limestone broken into joint and fault blocks which in turn form knobs and ridges tilted at various angles and in nearly every direction. The rock outcrops are not unlike the broken surface of a lava flow (fig. 36).

Under such conditions measurements of strikes and dips have only local value and the determination of the attitude of the formation as a whole was found impossible in the time at my disposal. Moreover the intricate faulting of the sandstone beds inclosing the limestone has obscured the relations between the Yucay formation and the Huayllabamba forma-

tion. West of Fortaleza laminated limestone appears to overlie conformably the brown Huayllabamba sandstones; at two other points a hiatus is indicated by diverse dips and irregular contacts; and at two localities areas of Huayllabamba strata in normal attitude protrude through the limestone beds.

Fossils of marine habitat collected at three localities were studied by Dr. T. W. Stanton, of the United States Geological Survey, who submits the following report:

"I have examined your small collection of fossils from the limestones near Cuzco, Peru. The collection is in five lots with distinctive labels but the preliminary examination made it evident that the lots include only one fauna and probably came from a single horizon, as you had determined from the field relations. At least two of the species—a *Pecten* and a *Cucullaea*—occur in all five lots, the same naticoid shell in four of them and a *Cardita* in three.

It has not been possible to make specific determinations, partly because the fossils are not very well preserved and partly, and more especially, because the collections which have been described from South America are so meager in both number and size, and the localities from which they came are so widely scattered over the continent, that it would be accidental if any of the described forms should be found in a collection from a new locality like this one from Cuzco. The fossils include only echinoids, pelecypods, and gastropods. The entire absence of cephalopods in a collection believed to be of Cretaceous age is noteworthy. The basis of the opinion concerning age may be best indicated by the following briefly annotated list of the forms best recognized. In addition to those listed there are several specimens too imperfectly preserved for even generic identification.

Diplopodia? *sp.* A single imperfectly preserved specimen of a regular echinoid doubtfully referred to *Diplopodia*. It may be a *Cyphosoma*.

Hemiaster? *sp.* This irregular echinoid is also represented by a single specimen which shows the form fairly well but does not possess all the essential details of the sculpture and the apical disk.

Ostrea? *sp.* A small simple oval form represented by only two or three specimens.

Pecten *sp.* The collection contains at least two species of *Pecten* belonging to the group often called *Vola* or *Neithea* which Fischer, Dall and others consider the typical section of *Pecten*. Several species of this group have been described from the Lias of South America but none of them is identical with any of the present forms from Cuzco, which are more like Cretaceous types of the genus so far as may be judged from such imperfect specimens.

Avicula sp. A small simple form resembling *A. linguiformis*.

Cucullaea sp. A small, rather short form without distinctive sculpture.

Cardita sp. A strongly sculptured form not exceeding an inch in height or length.

Pleuromya sp. A single small specimen apparently belonging to this genus.

Natica? sp. Several casts of small stout naticoid shells which may include more than one species and possible more than one genus.

Turritella? sp. Two very small casts which do not retain the sculpture.

Fasciolaria? sp. A single specimen doubtfully referred to this genus on account of form and sculpture.

Cinulia? sp. An imperfect cast and an imprint of part of the surface.

There can be little doubt that these fossils are Mesozoic and probably not older than Cretaceous. In the absence of Ammonites and other characteristic types for closer age determinations it would be imprudent to assign them to a definite horizon, though I think it most likely that they belong to the Upper Cretaceous."

Limestones of identical character and containing fossils of the same age remain as patches on the Fortaleza, Catunga, and Machu highlands and are exposed in thick beds near Ayusbamba, on Apurimac River 15 miles south of Cuzco, as well as at points farther west. The preservation of remnants of once widespread Upper (?) Cretaceous limestone is believed to have resulted from the development of downsunken fault blocks.

The Yucaj limestone is extensively used in construction for walls, foundations, pavements, and also in chiseled blocks for buildings. The famous Inca fortress of Sacsahuaman is built of enormous blocks of Yucaj limestone brought from a quarry about 1 mile distant.

BAMBANUSA FORMATION.

The sandstones exposed along the eastern edge of the Bambanusa Pampa north of Ccasa-Cancha constitute the Bambanusa formation. Typical outcrops south of the Ichchu-Oreco lava field are white or light gray in tone; the unweathered rock is, however, in many places pink in color. Pure quartz sandstone with sugary texture is the predominant rock type, and its constituent grains are so feebly held together by cement that the rock crumbles under a blow of the hammer and piles of clean quartz sand are found at the base of cliffs. Erosion favored

by this easy disintegration has produced pinnacles and columns and bizarre forms which have no counterpart in the erosion remnants of other formations in the Cuzco region (fig. 37). At all places visited the rock is traversed by joints along many of which movement has taken place, as is indicated

FIG. 37.



FIG. 37. Erosion column formed of Bambanusa sandstone.

by slickensides and by numerous faults of a few inches displacement. The rock does not, however, show the crushing and shattering so common to the older sandstone of this district. The material filling the joints, even where calcareous, is more resistant to erosion than the rock itself, and the position of joints and faults is indicated by ridges rather than by depressions.

VIII-A. Section of the Bambanusa formation 1 mile north of Ccasa-Cancha.

Strike N 30° W; dip 8° NE.

	Feet.
1. Sandstone, massive pink to white, even grained, consisting of uniform fine grains of clear quartz loosely cemented by calcite. Elaborately cross-bedded by inconspicuous lines. Forms towers and hoodoos ...	20
2. Sandstone, thin-bedded; banded pink, light red, and gray; in places merely overlapping flakes; quartz grains, calcareous cement. Includes layers of arenaceous limestone	60
	80

VIII-B. Section of Bambanusa formation half a mile west of Section VIII-A.

Strike N 25° ± W; dip 6° E.

	Feet.
1. Sandstone, pink to gray in tone, massive, fine grained, cross-bedded; white and pink quartz; calcareous cement	15
2. Shale, argillaceous and arenaceous; in beds the thickness of paper	1
3. Sandstone, pink; well-rounded grains of quartz, microscopic size; calcareous cement; cross-bedded and highly lenticular	6
4. Sandstone, dark red; quartz grains very fine; calcareous cement. Arranged as irregular lumps and lenses; one lens consists of white quartz and chert pebbles ranging in size from that of a pea to that of a small hickory nut	4
	26

The Bambanusa beds dip at a low angle and in a direction opposite to those of the bordering Pachatucsa formation as well as of the underlying Huayllabamba sandstones. This unconformable relation is well shown at the head of the Chchiraura Canyon, where the eroded edges of brown sandstone strata, tilted south at an angle of 40°, are covered by pink-white beds with a northward inclination of about 35°.

The strata on the Urubamba divide between Pachatucsa and Atasccasa are for the present grouped with the Bambanusa formation. The series consists of coarse sandstones and conglomerates in massive beds, 4 to 40 feet thick. On weathered

surfaces the rock is white to gray in color; pink tones resulting from the presence of pink quartz fragments and a small amount of ferric cement characterize the fresh rock. Portions of the ledges studied are fine-grained, but the typical sandstone members are coarse and gritty and consist of subangular, clear quartzes and fragments of decomposing feldspar. The conglomeratic phases are displayed as thin lenses or narrow stringers and consist of partly rounded, usually elongated pebbles of quartz, quartzite, and sandstone, rare igneous fragments, pellets and slabs of shale, and crystals of feldspar which retain their original form. The pebbles range from a fraction of an inch to over 2 inches in diameter and are arranged without evident sorting. The rock as a whole is firmly cemented with silica and iron, some parts in fact being developed as a glistening pink quartzite. The strata are highly cross-bedded, a structural feature exhibited both by curved bands and straight lines in the sandstone members and even more markedly by lenses and beds of conglomerate and coarse sandstone 6 to 10 feet in thickness. Unlike the Bambanusa sandstones south of Ichchu-Orcco, the beds on the divide, doubtfully assigned to this formation, dip southwest, in harmony with the strata of the Pachatucsa formation. A continental origin for the Bambanusa formation is suggested by the structural features already described, but the geologic period during which the depositing streams were active is not known. Superficially the formation appears to be geologically young, perhaps early or middle Tertiary, and the field relations suggest that its component strata were laid down as sands and gravels in a basin developed by warping or faulting of the underlying older strata. On the other hand the absence of the Yucay limestone (Upper (?) Cretaceous) from the area south and east of Cerro Picol may indicate that parts of the Bambanusa formation are contemporaneous with the Pachatucsa and Huayllabamba formations, assigned to the Jura-Trias (?).

SEDIMENTARY ROCKS NEAR THE MOUTH OF THE HUATANAY.

The sedimentary rocks of the lower Cuzco Valley were not mapped; they may belong with the Huayllabamba formation. The following notes were made during a rapid traverse from Sierra-Bella to Huacarpay.

The banks of the Huatanay at its junction with the Urubamba are formed of beds of resistant brown sandstone, 4 inches to 1 foot in thickness, interstratified with chocolate-red

shale. The beds, broken by faults and intruded by basic rock, strike west to N. 70° W. and dip to the south at angles of 30° to 40°. The bedding planes of both shale and sandstone present firm, glistening surfaces traversed by mud cracks, ripple marks, and worm trails (?) and are dotted with irregularly shaped fragments of mud shale. For a distance of about a mile south of Huambutio station, partly decomposed strata of limestone and gypsum in approximately horizontal attitude replace sandstone and shale. The limestone is blue-gray or banded with brown, and both massive and laminated beds are present. The gypsum, which is dark blue and white in color, is displayed as lenses and furnishes elaborately carved oblong and cubical blocks of the talus. A large part at least of the gypsum is secondary in origin and occupies joints in the limestone.

The canyon of the Urubamba along the railroad between Sierra-Bella and Cay-cay is cut in brown sandstone interbedded with shale and lenses of conglomerate composed of imperfectly rounded pebbles of quartz, sandstone, and bright-red shale.

SAN SEBASTIAN FORMATION.

The Cuzco Basin northward from Angostura Narrows is inclosed by a low interrupted wall of poorly consolidated sediments. These beds are well displayed both north and south of the village of San Sebastian, from which the name of the formation is derived. On the south side of the valley eastward from the mouth of the Huancaro the strata of the San Sebastian formation are practically horizontal and form conspicuous white banded cliffs along Rio Huatanay (fig. 32); along the northern rim, in the vicinity of San Sebastian, the strata dip gently to the south and merge with the alluvium of the main valley floor. The sediments include sand, limestone, peat, and adobe, with small amounts of gravel, and were deposited within and on the immediate shores of ancient Lake Morkill.²⁶ The nature of these lacustrine deposits is shown in the following typical sections:

IX. Section of San Sebastian formation on Rio Huancaro near its junction with the Huatanay.

²⁶ See p. 34.

Strata horizontal.

	Feet.
1. Adobe and fine sand forming present surface	3
2. Sand, white, calcareous	1
3. Adobe, yellowish	2
4. Limestone, white, compact, massive in places, elsewhere very thinly laminated; abundant shells of Physa, Sphærium, and Planorbis; roots represented by rusty tubes; quarried for lime	6
5. Adobe with lenses of white lime; several overlapping lenses of gravel, pebbles as much as one half inch in diameter of quartz, sandstone, and aggregates of black sand	9
6. Sand and adobe like No. 12	2
7. Limestone, white, fossiliferous	0.5
8. Adobe and sand like No. 12	10
9. Limestone, white, with carbonized material in 1-inch bands, lens-shaped; capped by yellow weathered zone	1
10. Adobe, light red, in very thin beds; exceedingly irreg- ular and wavy in deposition and containing lenses 3 to 5 feet thick of fine sand and fine gravel with pebbles of quartz and lime concretions as large as buckshot, all very well worn; contains also minute streaks of white lime and of carbonized materials ..	5
11. Shale-like materials, black, in bands 2± inches thick, consisting of (1) white weathered adobe at base; (2) gray shale with abundant impressions of grass, stems, roots, etc., and rare shells; and (3) thin beds of black peat. These beds are continuous, but portions of 1, 2, and 3 interleave at distances of 20 to 100 feet	3
12. Adobe consisting of fine sand with clay; highly cal- careous; lime in minute specks and streaks; rare coarser-grained material of same composition in lenses	18
	61.5

This section is shown in fig. 38.

X. Section of San Sebastian formation on bank of Rio Huatanay, half a mile south of San Sebastian.

Beds horizontal.

	Feet.
1. Adobe, massive, brown, firmly cemented; traversed by vertical root tubes; contains scattering grains of sand the size of buckshot in lower part. Toward top color gradually changes to yellow-gray	5

	Feet.
2. Limestone, white, massive; abundant shells; a calcareous, consolidated mud silt	5
3. Shales or mud, white, yellow, black and brown; thin-banded; calcareous, unconsolidated; becoming more arenaceous and more carbonaceous in middle	4
4. Limestone, like No. 2	6
5. Adobe like No. 1, separated from No. 4 by an erosional unconformity	10

FIG. 38.

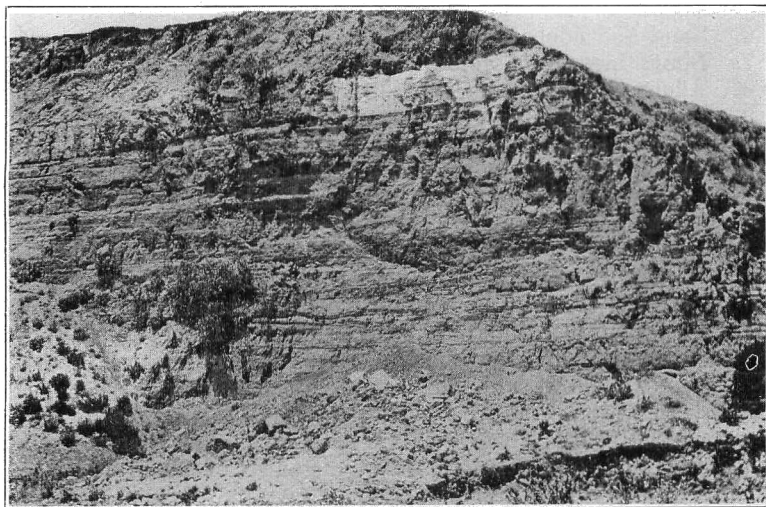


FIG. 38. Section of San Sebastian formation near the mouth of Rio Huancaro.

6. Sand, gray to black, coarse, cross-bedded, thinly stratified, with bands of fine brown sand	2
7. Sand and clay in alternating dark-red and gray regular beds, 1 inch to 1 foot in thickness; sand fine with few coarse beds; clay and adobe increase in amount toward top; forms vertical banks of river	55

87

At the mouth of Rio Huilcarpay, 800 feet east of the locality including the strata of Section X, the laminae of adobe unconformably overlie and are interleaved with lenses of fine and coarse cross-bedded black sands and gravels. Thin beds of decomposed peat are also present.

XI. Section of San Sebastian formation half a mile south of San Geronimo railroad station.

Dip 0 to 2° North.

	Feet.
1. Sand, fine, and scattered cross-bedded lenses of gravel overlain by gravel and boulders forming the surface of a fan	40
2. Limestone, white, very thin-bedded, containing abundant shells; also impressions of plants in one adobe-like band; bed persistent and cut by a number of quebradas in this vicinity	2
3. Gravel lens; pebbles of sandstone, subangular, as much as 2 inches in diameter; partly cemented	1
4. Sand, fine, and adobe in alternating very thin beds	55
5. Clay, drab, highly calcareous, containing plant roots, and shells	0.3
6. Sand, fine, compact, quartz; beds a fraction of an inch thick, with rare lenses of coarse sand and beds of hard calcareous adobe 4 inches to 1 foot in thickness. Beds of adobe project as shelves on quebrada walls	70
	168.3

The area of sands, limestone, and adobe about half a square mile in extent, forming the flats south of San Geronimo at elevations between 10,650 and 11,000 feet, may be considered part of a slope included in the coast and under-water shore of ancient Lake Morkill, now much dissected. The slope of the rock-surface valley side on which the materials were deposited is about 20°.

Near the west end of ancient Lake Morkill, where the gentle shore slopes were alternately flooded and exposed in response to fluctuating volume of lake water, a number of sections were measured. A characteristic exposure is shown in fig. 39, and the following section is considered typical for this locality:

XII. Section of San Sebastian formation in Chunchullumayo quebrada, near junction with Rio Huatanay.

Dip about ¼° East.

	Feet.
1. Soil of adobe, dark red	2
2. Limestone, white, thin-bedded; shells abundant	2
3. Gravel, coarse and fine, well stratified; pebbles 2 to 3 inches in diameter, rarely larger	5
Unconformity.	

	Feet.
4. Adobe, dark red, massive, highly calcareous, with lenses of fine and of coarse gravel; abundant vertical root tubes and rare shells	6
Unconformity.	

FIG. 39.

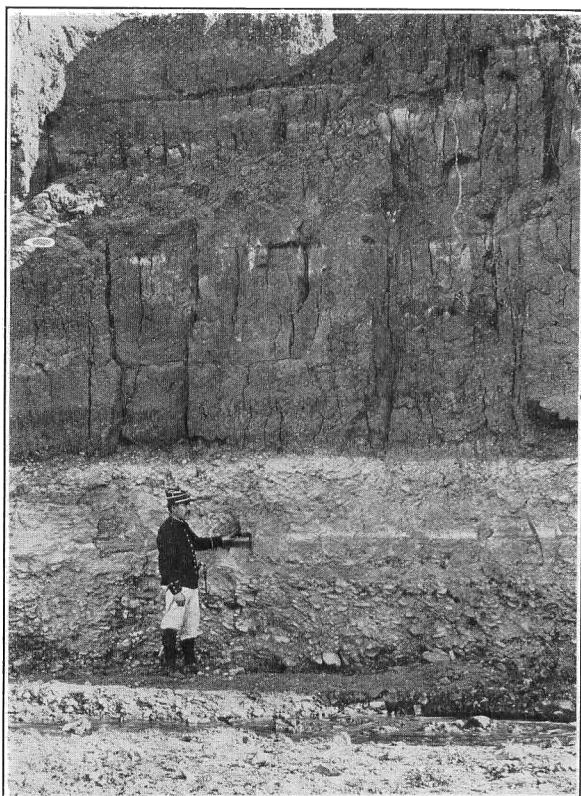


FIG. 39. Section of San Sebastian formation near the Cuzco railway station. Contains adobe sand, fossiliferous limestone and gravel. Hiram Bingham, photo.

5. Sand, fine, yellow at top; with gravel of flat fragments; upper surface channeled; vertical root tubes; rare shells	4
6. Adobe, dark red, massive, firm, calcareous; with small lenses and masses of fine gravel	10
Unconformity.	

	Feet.
7. Silt, earthy, calcareous, compact, banded with white layers representing old soils; few shells	7
Unconformity.	
8. Sand and coarse gravel composed of angular fragments of sandstone	4
	44

In quebradas immediately north of the village of San Sebastian over 200 feet of sediments assigned to the San Sebastian formation are exposed. At their contact with the Yucay limestone the beds are nearly horizontal; farther southwest they slope toward the Huatanay with a dip gradually increasing to 15° (fig. 31). In this locality the lacustrine beds are chiefly sand (fig. 40); limestone and adobe being comparatively small in amount, as shown in the following partial section:

XIII. Section of San Sebastian formation in wall of unnamed quebrada 1 mile north of San Sebastian Cathedral.

Strike N; dip 6° W.

	Feet.
1. Limestone forming surface slope; thin-bedded, soft, porous, chalky; contains shells	12
2. Sand, hard-packed; alternating fine and coarse; lenticular, cross-bedded	30
3. Limestone, thin-bedded, impure	5
4. Adobe with abundant plant impressions	2
5. Sand	16
6. Adobe	3
7. Sand like No. 2	60
8. Sand, fine, and adobe with 3-inch band of white limestone	16
9. Gravel, with pebbles as much as 2 inches in diameter	1
10. Gravel, fine, and coarse sand, dark gray, with thin beds of fine light-red sand; cross-bedded and intricately faulted along planes showing displacement of individual blocks of one half inch to 8 inches	25
11. Sand, even grained, fine, cross-bedded; faulted	20
12. Limestone, white	3
13. Sand	2
	95

In the sediments at San Sebastian the calcareous beds are highly variable in thickness and extent; in certain places examined only one thin bed of limestone was found in 100 feet

of strata; elsewhere three or four strata are included in 25 feet of sands. On a hill 1 mile east of the village, where 150 feet of bedded sands were exposed, no limestone was seen. Car-

FIG. 40.



FIG. 40. Faulted and cross-bedded strata of fine sand, San Sebastian formation, about $1\frac{1}{2}$ miles north of San Sebastian cathedral.

bonaceous material is rare in the sharply cut quebradas north of San Sebastian, but at one point along the highway lignitic peat occurs in abundance and has led to unsuccessful mining.

Origin and Age of the San Sebastian Formation.

Strata of sand and of "tripolite" at various localities in the Department of Cuzco, probably including San Sebastian, were noted by Dueñas,²⁷ who offers two hypotheses to account for their presence—(1) that the ocean of Tertiary time covered the Andes Mountains; (2) that Lake Titicaca formerly extended northwestward into the Apurimac and Urubamba valleys—an assumption which appeared to Dueñas as the more probable. The San Sebastian beds are, however, local deposits, and their composition and stratigraphic arrangement indicate lacustrine origin. Quiet, fresh water is required for the deposition of pure-white limestone containing abundant shells of *Physa*, *Sphaerium*, and *Planorbis*. Some of the clay beds also demand quiet water for their accumulation, and the long root tubes in the compact silt and adobe, as well as impressions of reeds and layers of earthy lignite, suggest shores or delta flats. Lenses of gravel, channeled beds, and ancient soils indicate that the lake was playa-like in character, or at least suffered fluctuations in volume sufficient to expose and cover the shore slopes alternately. Fossils occur in abundance, and it is keenly disappointing to learn from Dr. Dall and Professor Schuchert, who kindly examined my collections, that the shells belong to species which range from the Jura to the present. The plant fragments, also, are unfortunately not diagnostic. In the absence of paleontologic evidence the age must be determined by the less direct methods of physiography. The problem is to interpret the relations existing between the lacustrine deposits and the glacial gravels of the Cuzco region. On the basis of such study the San Sebastian formation is assigned to late Pliocene or early Pleistocene time. This conclusion is fairly satisfactory from the physiographer's standpoint and conflicts in no way with the paleontologic evidence.

It may be noted that the age of the San Sebastian beds is the same as that assigned to the deposits at Ayusbamba, where vertebrate fossils were obtained.²⁸

PLEISTOCENE AND RECENT FORMATIONS.

Deposits of glacial origin, including moraines, gravel fans, and lacustrine sediments, are widely distributed within and on the borders of the Cuzco Valley. These are discussed under

²⁷ *Op. cit.*, p. 24.

²⁸ Eaton, G. F., Vertebrate fossils from Ayusbamba, Peru, this Journal, xxxvii, pp. 141-154, 1914.

a separate heading.^{28a} Post-Pleistocene or Recent formations include gravel and sand plains resulting from the erosion of glacial gravels and the late readjustment of stream channels as the result of natural and artificial processes. Travertine is found along nearly all drainage channels crossing the Yucay limestone. At many waterfalls and rapids the lime of the highly charged water is deposited on reeds and various grasses, preserving their forms in great detail. On the west branch of Rio Sebolla-Huaycco, about half a mile above its mouth, the stream is bordered by a cliff 40 feet in height composed entirely of lime-incrusted plants of species identical with those which constitute the harsh, stunted vegetation of the present day. At other places casts of plants ground up and dissolved by running water are redeposited as beds of banded gray travertine containing minute fragments of leaves, branches, and fibers.

IV. THE IGNEOUS ROCKS.

INTRODUCTION.

The igneous origin of two rock masses in the Cuzco Valley, El Rodadero and Rumicolca, has long been recognized, but the indiscriminate use of the terms "amphibolic rock," "basaltic rock," "trachyte," "granite," "sienite," and "porphyry" renders most of the published descriptions of little use for geologic purposes. Microscopic analyses by Dueñas²⁹ of specimens from El Rodadero and from Huaccoto mark the beginning of systematic petrographic studies in this part of Peru. During the course of the field season of 1912 most of the exposures of igneous rock within the Cuzco Valley were visited, and it is believed that the geologic map combined with the petrographic notes gives a fairly complete description of their distribution and character.

Extrusive masses are typically represented by the volcanoes at Huaccoto and Rumicolca; intrusives by El Rodadero and the outcrops at Chchiraura; and clastic volcanic materials may be studied on the slopes of Cerro Pachatusca.

Volcanic activity in the Cuzco Valley has been local and relatively feeble. The exposures of igneous rock, both intrusive and extrusive, are small, the largest (Rumicolca) covering an area of less than 2 square miles. Except at Atascasa the original masses have suffered little from erosion.

^{28a} See p. 39.

²⁹ *Op. cit.*, pp. 178, 192, 1907.

The rocks are prevailing basic in composition. Specimens assigned to the syenite family were collected at two localities; varieties of andesite, basalt, or diabase constitute the other outcrops. The generalization of Dueñas applied to the entire Department of Cuzco is thus confirmed: "El tipo más general es el de andesitas con hornblendita ó bien con aujita ó todavía con mica negra, presentándose á menudo el caso de tenerse andesitas que además de un piroxeno ó anfíbol, encierran también biotita."³⁰

The lavas at all localities present substantially the same appearance and are believed to represent simultaneous outflows. The rock is but slightly weathered, and the flows retain to a large degree their original topographic expression. They antedate the last period of glaciation, however; the edges of the igneous mass at Ichchu-Orcco have been scored by ice, and till is banked about the base of the Huaccoto volcano. On the basis of these observations the most recent expression of volcanism is tentatively assigned to late Tertiary time. The age of the intrusive rocks is likewise unknown. The igneous mass underlying the fortress of Sacsahuaman penetrates Upper (?) Cretaceous sediments; most of the other dikes and bosses are surrounded by strata of earlier age. It is possible that some of the intrusive rocks are contemporaneous with the beds in which they are now found, a view supported by the presence of ash and tuff in the Pachatucsa and Huayllabamba formations. Detailed field work is necessary before the age relations of the intrusive igneous rocks can be discussed with confidence.

All the igneous masses are in a belt with northwest trend on the north side of the Cuzco Valley, lying between Huatanay and Urubamba rivers, no igneous rocks being found south of the valley axis. When the zone containing the volcanic rocks is extended southeastward it embraces the isolated volcano of Tinta, the hot springs of Agua Caliente, and the great faults bounding the sunken block at Lake Titicaca. Innumerable small faults are also included. It may be that these features indicate a zone of crustal weakness associated with the Tertiary uplift of the Andes.

DESCRIPTION OF AREAS.

The outcrops of igneous rock shown on the geologic map were examined in the field and a suite of specimens was collected. In the microscopic study of the rocks valuable

³⁰ Op. cit., p. 31.

assistance has been given by James S. Stewart, graduate student in the geological department of Yale University, working under the supervision of Professor L. V. Pirsson.

Ttica-Ttica Pass.

Overlooking the ancient highway leading through the pass between Cuzco and Anta is an elongated knob of igneous rock, part of the encircling wall of the Cuzco Basin. The ledge is largely concealed by a superficial cover of weathered material, 4 to 10 feet deep, in which are included large boulders and fragments of blue limestone so thoroughly recemented in places as to present the appearance of a stratum of conglomerate. The igneous rock composing the mass is greenish gray in tone; its texture is microcrystalline except for the presence of minerals of secondary origin, which are abundant, especially in weathered specimens. Epidote occurs in irregular lumps as much as a quarter of an inch in diameter; and the joints in the rock are lined with films of epidote and with sheets, specks, and stellate masses of glistening black hematite, which give to the rock a unique appearance.

When viewed in thin section the rock from Ttica-Ttica Pass is seen to consist of orthoclase, plagioclase, apatite, titanite, and iron ore associated with minerals of secondary origin—epidote, muscovite, chlorite, calcite, and hematite. The plagioclase, which greatly exceeds the orthoclase in amount, is in large part albite with less abundant oligoclase; it occurs as small tabular phenocrysts and as irregular prisms in the groundmass. The crystals of apatite are unusually large for rocks of this class. The few grains of titanite and the very abundant chlorite present no uncommon features. As the rock consists essentially of alkali feldspars it may be termed a syenite.

A quarry on the south slope of the igneous knob has furnished stone for constructing the aqueduct which supplies water to Cuzco and appears well adapted for this purpose.

Sacsahuaman and El Rodadero.

The famous Inca fortress of Sacsahuaman, built of enormous limestone blocks, overlooks the city of Cuzco from a height of 600 feet above the Plaza. The base on which it rests is part of a cliff of igneous rock which for a distance of nearly a mile borders the city on the north. The pavements of steeply inclined streets and ancient terraced gardens conceal the face

of the cliff within the city; along Rio Huatanay (Zappi) its full height is in view and the precipitous ravine of Tullumayu trenches the rock slope from top to bottom. The rock composing the igneous mass is best exposed for study at the top of the cliff, where four knobs or bosses of igneous rock, including El Rodadero, rise above the general surface. All parts of the igneous mass are essentially alike in composition, but the rock presents very different aspects as the result of weathering and the development of secondary minerals. At El Rodadero it appears fresh and firm and the ledge retains the slickensides of an ancient fault plane; in the banks of the Tullumayo groups of concentrically weathered boulders embedded in a disintegrated matrix represent the rock; in the banks of the Huatanay complete decomposition has taken place and only a yellow-white paste containing weathered crystals of feldspar and augite remains. Large masses have been converted into epidote. Hand specimens of the less-altered rock are dark gray in color, with a greenish tinge when viewed in certain lights; weathered fragments are light green or even yellowish and marked with bright-green spots. On the whole the rock is massive, dense, fine grained, and of granitic texture; but even in the freshest hand specimens dark-colored crystals of augite and minute clusters of epidote may be distinguished, thus producing a porphyritic appearance. In certain localities aggregates of yellow-green epidote varying in size from bodies as large as a pea to clusters 8 or 10 inches in diameter are irregularly distributed through the mass and are particularly prominent along joint planes. At a few points the rock contains inclusions 1 to 6 inches in diameter of white and pink marble and of red, brown, gray, and pink quartzite.

When examined under the microscope the rock from Sacahuaman and El Rodadero is found to consist of plagioclase, orthoclase, augite, titanite, apatite, ilmenite, leucoxene, epidote, calcite, chlorite, zoisite, and antigorite. The plagioclase occurs in broad tabular forms of two generations and exhibits albite twinning. Though kaolinized and corroded, probably by hydrothermal action, the plagioclase is subject to analysis by optical methods and found to range in six different sections from albite to andesine with an average composition of about Ab_2An_1 ,—that is, to be slightly more basic than oligoclase. The orthoclase is small in amount, has irregular outlines, and in most sections is replaced by secondary minerals. The augite is green to colorless and occurs in tabular forms and stout

prisms; only in the freshest rock are its original characters preserved; in many specimens it is represented by chlorite, rarely by uralitic hornblende. Hornblende with green color, characteristic cleavage, and crystal outline was observed in only one section. Apatite is sparingly distributed as small prisms and as inclusions in titanite. Black, opaque ilmenite with rhombohedral twinning is displayed as small laths and squares. Titanite, which appears to be both primary and secondary in origin, occurs in irregularly shaped fragments with sharp angles and with characteristic optical properties. Of the secondary minerals chlorite developed after augite and probably also representing hornblende and biotite attains typical development. Colorless to dirty-brown leucoxene is found about the borders and along cleavage planes of the ilmenite crystals. The common calcite and rare zoisite and antigorite present their usual features. Epidote is extremely abundant as grains scattered through the rock, as isolated clusters, and as a coating for cleavage planes; one thin section examined contains practically nothing but epidote. The rock is holocrystalline with granitic to porphyritic texture and may be classed as an augite diorite porphyry.

Two inconspicuous knobs about 2 miles north of El Rodadero are composed of diorite porphyry in less-altered condition than similar rock at Sacsahuaman. The texture is coarse, and partly decomposed phenocrysts of augite assume larger sizes than the minerals of the groundmass. Under the microscope oligoclase feldspar with inclusions of apatite is seen to be the most abundant mineral; orthoclase is rare. Hornblende is well-defined six-sided crystals of dark-yellow tone and shreds of pleochroic biotite are present; the augite is much decomposed and relatively rare. Scapolite, iron ore, muscovite developed after orthoclase, and chlorite occur.

Detached outcrops in the bed of the Huatanay west of Sacsahuaman were not studied, but they appear superficially to resemble closely in composition the rock of El Rodadero.

Stone from the Sacsahuaman mass taken from quarries near the city was highly prized by builders of the Inca dynasty. The best-preserved walls of ancient Cuzco, in which the stones are fitted and polished with incredible skill, are formed of this material (fig. 41).

Huaccoto.

The village of Huaccoto lies at the base of a small volcano. Even at a distance this irregularly shaped ragged mound of bare black rock 400 feet in height presents a striking contrast to the softly molded grass-coated hills and swamp lands which surround it. Near at hand the igneous mass is seen to consist of five knobs separated by basin-like depressions within which drainage is poorly developed. No crater is visible; the lava appears to have emerged intermittently from several vents,

FIG. 41.

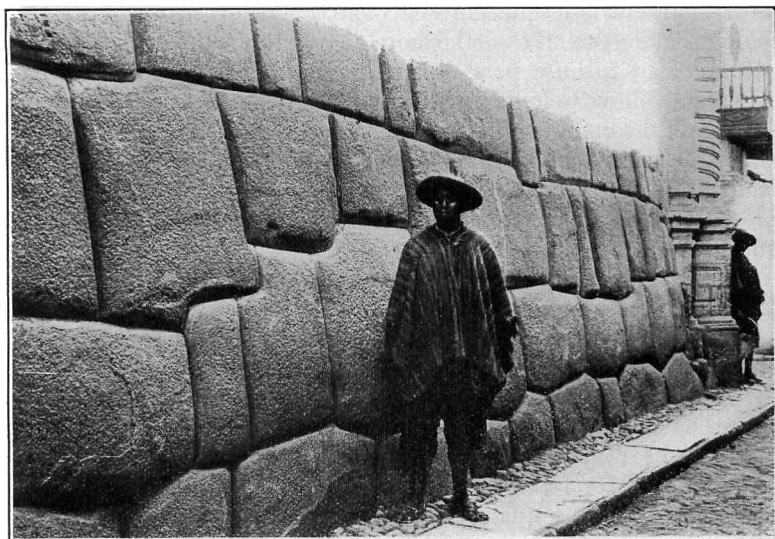


FIG. 41. Inca wall, Cuzco, built of augite diorite porphyry.

making its way to the branched valley of the Huaccoto. The longest continuous flow extends for about half a mile in a southerly direction and terminates in a broken wall 10 to 15 feet in height. The original rough surface of the scoriaceous lava has been greatly modified by the action of frost. Details of vents, ropy structures, and caves are in large part replaced by a superficial cover of broken blocks tilted at various angles.

The unweathered lava is light gray in tone, but weathering produces a uniform color of rich red-brown. The rock varies widely in texture. In some places flow structures are well

developed and amygdaloidal cavities filled with calcite and barite are seen; in other places the rock has a dense groundmass in which phenocrysts of biotite, commonly in well-formed crystals, are prominent. Parts of the flows are massive and microcrystalline. Inclusions of quartzite and of slate and segregations of biotite and of magnetite were noted.

The Huaccoto lava may be classed as hypersthene andesite; its constituent minerals, as revealed by the microscope, are plagioclase, biotite, pyroxene, iron ore, and apatite. The plagioclase, which ranges from andesine to labradorite, occurs as laths and as square prisms with both albite and Carlsbad twinning. The biotite occurs in relatively large brown shreds with characteristic pleochroic colors. The pyroxene crystals, which belong to the orthorhombic variety hypersthene, are displayed as minute prisms ranging in pleochroic colors from greenish yellow to reddish yellow. Iron ore in tiny grains is scattered throughout the section, and prisms of apatite were noted as inclusions in the feldspar. The texture of the rock is hyalopilitic; crystals of feldspar, hypersthene, and biotite are embedded in a groundmass of cryptocrystalline fragments and glass.³¹

The rock from Huaccoto is well adapted for construction. Flow structure aided by jointing favors separation into slabs suitable for paving, curb stones, and door facings; softness and uniformity of texture of selected blocks render it suitable for carved stone work for exterior and interior decoration, and the red color of weathered portions is attractive. These qualities have made the Huaccoto volcano the seat of a quarrying industry for hundreds of years. Rudely paved roads connect the numerous quarries, and the ruins of workmen's huts are surrounded by piles of chips and partly finished blocks. During the Spanish building epoch in particular the Huaccoto lava was extensively used. The façades of the churches at San Geronimo and San Sebastian and of the Jesuit monastery now used by the University of Cuzco were probably built of stone from this locality. Even at the present time a few small quarries are in operation, the stone being carried by llama, burro, or cargador down the difficult trail to villages 3,000 feet below. As compared to the diorite extensively used by the Incas, the basalt from Huaccoto weathers rapidly in the Cuzco climate and where found in ancient buildings it is

³¹ The Huaccoto lava has been previously described by Dueñas (op. cit., pp. 192-193).

chipped, broken, and pitted, and fragments may be pried from columns and lintels with a pen knife. Disfiguration from weathering is however partly compensated by increased attractiveness of color.

Ichchu-Orcco.

The igneous mass of Ichchu-Orcco is topographically a cuesta; its inner face, fronting Cerro Pachatucsa, is a cliff 340 feet high, and its top slopes southward at the rate of about 200 feet to the mile. Neither craters nor lava streams are found, the surface of the rock is worn into knolls and ridges thinly coated with erratics. The absence of features associated with volcanic outflows is not, however, indicative of intrusive origin or of great age, for the entire mass has been glaciated, the evidences of ice work being particularly clear along the west side of the cuesta. The geologic relations of Ichchu-Orcco were not determined. Its history is probably similar to that of Huacoto, a local volcanic outflow of late Tertiary times.

The igneous material composing Ichchu-Orcco includes two varieties. One is a dense, glistening black rock devoid of cleavage or flow structure, slightly porphyritic with biotite phenocrysts, and very resistant to weathering. In the cliff it presents a rude columnar structure and breaks out into blocks 2 to 4 feet in diameter, controlled by a system of nearly horizontal joints. The other variety is a gray, highly micaceous rock found at and near the surface. This type generally contains minute open cavities even in fresh specimens, and the more weathered portions are commonly amygdaloidal. Bowlders found in the stream bed below the igneous cliffs and presumably from this mass, although possibly from the ash of Pachatucsa, exhibit the scoriaceous texture characteristic of surface flows.

Microscopically the two types of rocks are identical in composition, except for difference in weathering and in amount of glass present. The component crystals are plagioclase, biotite, pyroxene, apatite, and iron ore set in a groundmass of minute crystals and glass. The plagioclase occurs as laths, square prisms, and six-sided crystal sections; its composition is intermediate between andesine and labradorite, with about equal quantities of albite and anorthite molecules as determined by the Michel-Lévy method. Brown biotite is present as shreds, crystals, and crossed twins. Pyroxene of two varieties is found—extremely scarce monoclinic diopside of pale-

greenish tone and the orthorhombic variety hypersthene in irregular grains and prisms of green to brown color. The larger crystalline fragments of hypersthene are closely associated with the mica and in some places appear as poikilitic inclusions within spongy biotite crystals. Apatite occurs in prismatic and basal crystal sections; grains of iron ore are widely scattered. The rock may therefore be called hypersthene andesite.

Atascasa.

The geology of the Atascasa area is too complex to admit of a satisfactory interpretation by a reconnaissance survey. Contacts are concealed for the most part by glacial drift, the rocks are faulted and brecciated, and the sediments intruded by igneous masses are themselves in large part composed of igneous material. This area has, therefore, been mapped in a more or less arbitrary fashion, and only the more prominent igneous outcrops are indicated. Ancient intrusive masses which contributed materials for the Pachatuca formation are probably represented, together with dikes of later age. Extrusive rocks contemporaneous with or later in age than the Pachatuca beds are doubtless also present. Exclusive of fragments, many of them tons in weight, incorporated in sandstone and tuff, the igneous rocks examined from this area belong to the trachyte and the andesite families.

The westernmost outcrop shown on the map is a low ridge with cliffs on its southern face and broken by prominent joints trending N. 60° W. The rock is imperfectly gneissoid in structure and pink in tone. Under the microscope it is seen to consist essentially of much-altered pink orthoclase in prismatic and tabular forms. Albite is also present, and apatite occurs with characteristic features. Chlorite, probably derived from the cryptocrystalline matrix, is scattered throughout the section, and glass is present in small amounts. The texture appears to be hyalopilitic. The rock may be classed with trachytes or syenites.

As seen in the ledge the three other areas of igneous rock outlined on the geologic map include massive, bedded, brecciated, and conglomeratic facies. At one point an agglomerate of igneous fragments incorporated with masses of quartzite and sandstone suggests the site of a volcanic pipe. Thin sections cut from specimens collected from the larger igneous masses within the three areas under discussion contain plagi-

clase, the chief mineral, associated with biotite and iron ore. Quartz, calcite, and chlorite occur as secondary minerals. Examination of the least-altered crystals proved the plagioclase to be andesite—in one of the thin sections andesine and labradorite. In one of the specimens studied the iron ore is seen to have resulted from resorption of hornblende in a rock whose original components were probably hornblende phenocrysts set in a plagioclase groundmass. Igneous fragments embedded in the volcanic tuff and breccia have essentially the same composition as the dikes, and the igneous portion of the whole complex may be assigned therefore to the andesite family. The sedimentary rocks associated with the igneous masses at Atascasa are further described on p. 59.

Chchiraura.

Along the east bank of Rio Chchiraura, below the village from which the stream receives its name, igneous rock may be seen penetrating the Huayllabamba sandstones. In the lower portion of the valley the rock is dense and massive; farther up it becomes a tuff. The rock, where fresh, is black to purple in tone, with a dense groundmass in which feldspars are distributed as phenocrysts. Weathered surfaces bring out the porphyritic texture, showing white laths and dark cubes embedded in a gray groundmass.

As revealed by the microscope the dense variety consists of plagioclase feldspar, iron ore, apatite, chlorite, and calcite. The plagioclase, which occurs as phenocrysts and also as minute laths, was determined as labradorite. Apatite in tiny prisms is included in the feldspar. The chlorite and perhaps also the iron ore have probably been derived from a ferromagnesian glassy matrix. The texture is hyalopilitic, but the glass of the groundmass has been greatly modified. The original rock was doubtless a basic andesite; it is so completely altered that closer classification is impossible. Sections prepared from rock near the upper surface of the Chchiraura mass consist essentially of lapilli and ash derived from andesite. The feldspars are albite and oligoclase with lesser amounts of orthoclase and andesine. These crystals of feldspar rest in a groundmass of minute feldspar crystals and abundant grains of iron ore. The iron is secondary in origin, being probably derived from a ferromagnesian glass in the matrix. Calcite, muscovite, chlorite, and a little quartz complete the

list of secondary minerals. This andesitic tuff is believed to be genetically related to the basic andesite over which it lies.

Oropesa.

Between Oropesa and Huacarpay the Rio Huatanay follows the cliff front of an igneous mass nearly 2 miles in length. No crater and no well-defined flows were seen during my brief examination. The surface of the mass, however, is covered with irregular blocks of lava standing at various angles, and along the railroad near Huacarpay ropy amygdaloidal lava clearly indicates the extrusive character of at least a part of the mass. As viewed in the hand specimen the fresh rock is dark gray and dense except for innumerable specks of biotite and rounded bits of calcite occupying amygdaloidal cavities. Weathered specimens are light gray with micas of bronze color. The rock has the surface appearance of a scoriaceous minette.

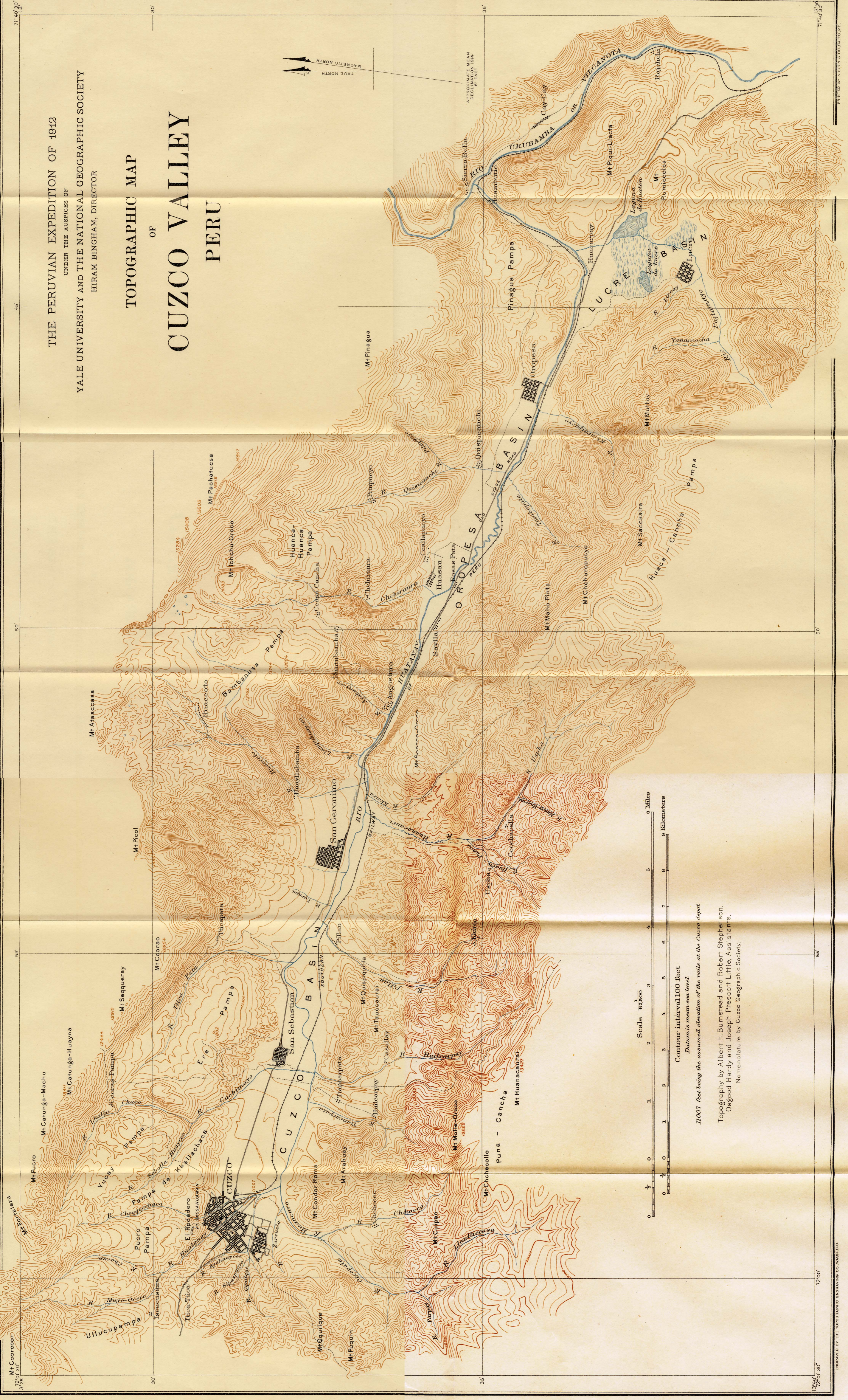
The constituent minerals of the Oropesa lava as revealed by the microscope are biotite, hornblende, augite, plagioclase, iron ore, and calcite. The biotite occurs in long brown, strongly pleochroic plates, as phenocrysts and as smaller shreds in the groundmass. The hornblende is also brown and pleochroic, closely resembling the biotite, from which it differs in crystal outline. Augite occurs in colorless prismatic and elongate sections, rarely twinned. The plagioclase, which presents both laths and tabular forms, was found to be predominately labradorite. Grains of iron ore are few in number and widely scattered. The essential constituents are labradorite, biotite, and augite; hornblende and iron ore are accessory. The texture is hyalopilitic—small laths of feldspar embedded in a matrix of glass. Included in the lava are fragments of gray granite, garnetiferous gneiss, amphibolite, quartzite, and garnetiferous mica schist. In accordance with the classification in general use the Oropesa lava may be termed a basalt or mica basalt.

Sierra-Bella.

At Sierra-Bella, within the canyon of the Urubamba, the remnant of a lava flow forms a terrace rising 150 feet above the river (fig. 42). The terrace front is a wall formed of well-developed columns. On the opposite side of the river, dikes of intrusive rock, essentially like the columnar lava in composition, cut the country rock. It is possible that

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

TOPOGRAPHIC MAP OF CUZCO VALLEY PERU



Scale 62,500
 0 1 2 3 4 5 6 7 8 9 Miles
 0 1 2 3 4 5 6 7 8 9 Kilometers

Contour interval 100 feet
 Datum is mean sea level

11007 feet being the assumed elevation of the rails at the Cuzco depot

Topography by Albert H. Bumstead and Robert Stephenson.
 Osgood Hardy and Joseph Prescott Little, Assistants.
 Nomenclature by Cuzco Geographic Society.

THE PERUVIAN EXPEDITION OF 1912
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RECONNAISSANCE GEOLOGIC MAP OF CUZCO VALLEY PERU

LEGEND

SEDIMENTARY ROCKS

- Glacial moraines
- Glacial gravels

QUATERNARY

- Qps San Sebastian Formation (Laminated sands, clayey shales, and shales)

PLEISTOCENE

- Tb Basabasca Formation (White friable sandstone)

TERTIARY

- Ky Yucay formation (Marine brecciated limestones)

CRETACEOUS

- Jh Hualayabamba formation (Brown sandstone and arenaceous shales)

LOWER JURATRIAS?

- Jpo Molle-Oreco conglomerate member (Shales, sandstones, and coarse sandstones)

PERMIAN

- Jp Pachabamba formation (Foliated conglomerates and sandstones)

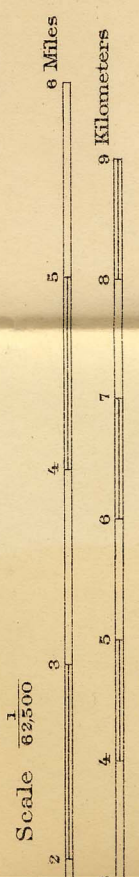
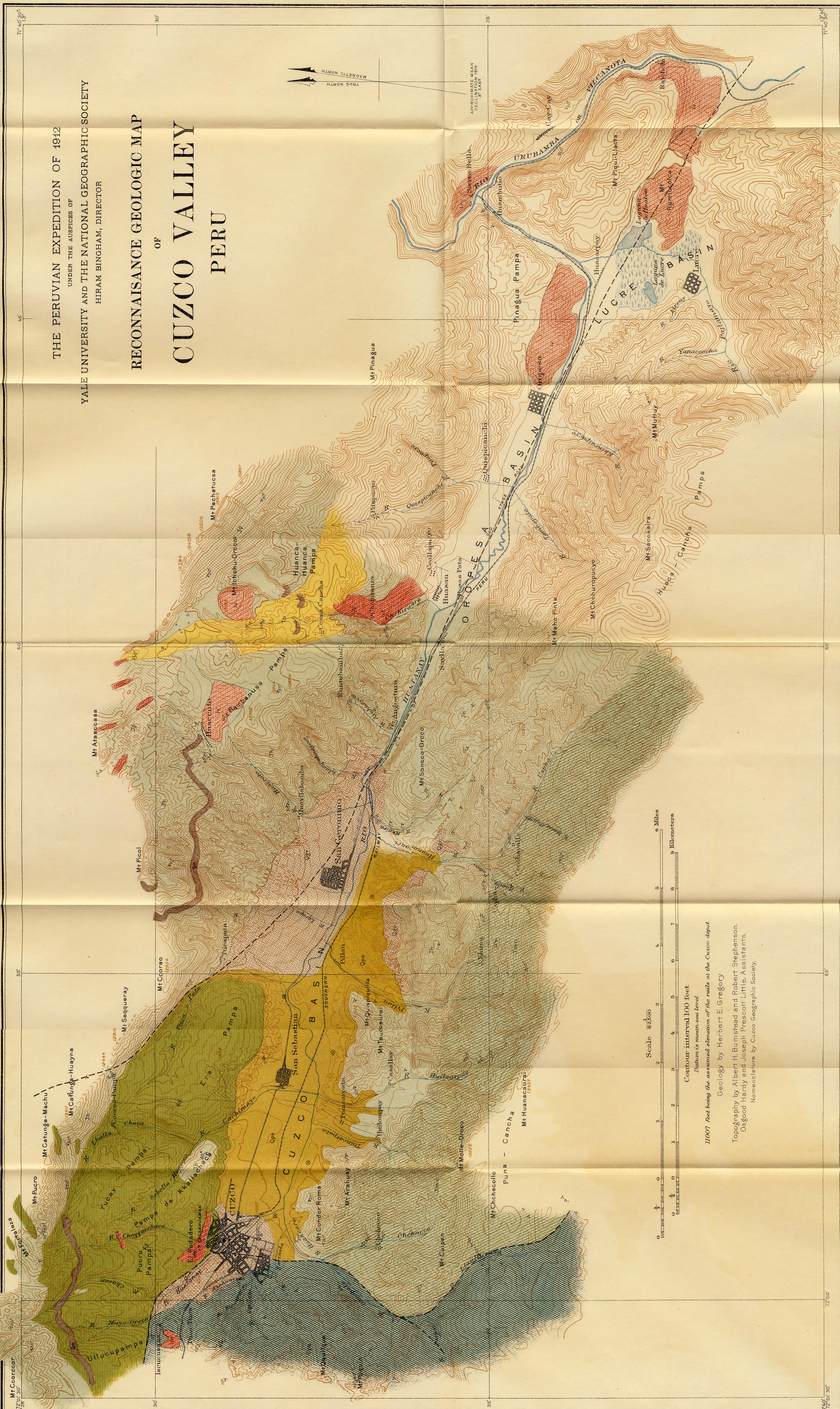
TRIASSIC

- Qm Quimique formation (Brown shales and shaly sandstones)

IGNEOUS ROCKS

- Lavae Andesites and Basalts
- Intrusives Diorite and Syenite

- Faults
- ↗ Strike and Dip
- ⊗ Strata Horizontal



11000 Feet being the assumed elevation of the rails at the Cuzco depot

Geology by Herbert E. Gregory

Topography by Albert H. Bumstead and Robert Stephenson,
Osgood Hardy and Joseph Prescott Little, Assistants.

Nomenclature by Cuzco Geographic Society.

these dikes, or similar ones in the immediate neighborhood mark the source of the extrusive masses.

In the hand specimen flow structures and zones consisting chiefly of lithophysæ are conspicuous features of the rock from Sierra-Bella. Under the microscope the extrusive variety is

FIG. 42.

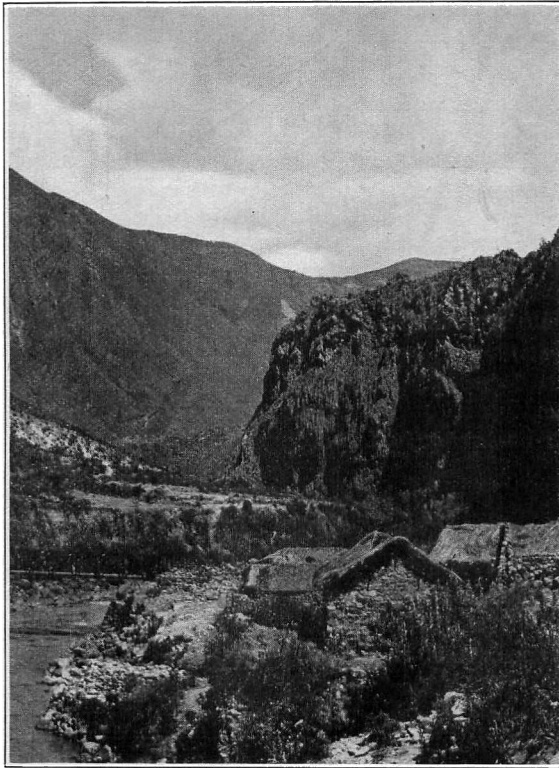


FIG. 42. View looking down the Urubamba River at Sierra-Bella. Lava flow on the right.

seen to consist of labradorite in lath-shaped crystal fragments, biotite in narrow elongated shreds of dark-brown color, and widely scattered grains of iron ore. Calcite and tridymite occur as amygdules. In texture the rock is hyalopilitic—a mesh composed essentially of minute laths of feldspar in a groundmass of glass. In a microscopic slide prepared from a

specimen taken from a dike at the south end of the Sierra-Bella bridge the plagioclase was found to be andesine near oligoclase, with the formula Ab_3An_1 . Considered as a whole the igneous rocks at Sierra-Bella may be classed as andesites.

Rumiccolca.

The lava field at Rumiccolca possesses features of unusual interest. It is the largest exposure of igneous rock within the

FIG. 43.

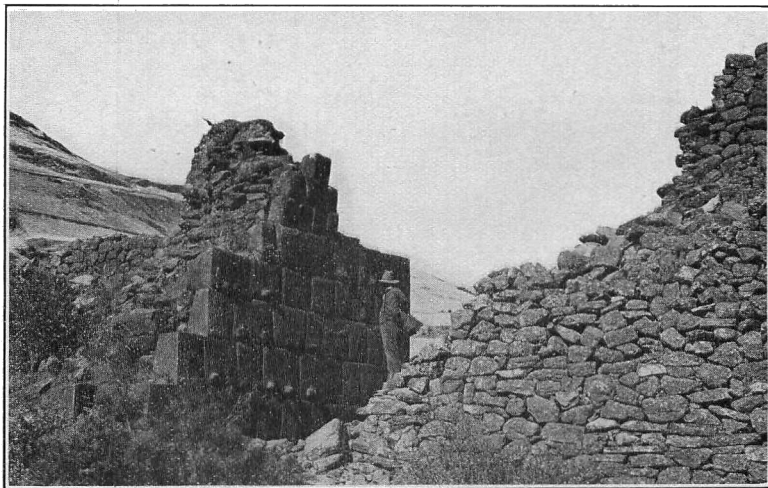


FIG. 43. Inca wall of hypersthene andesite, Rumiccolca quarry. Hiram Bingham, photo.

Cuzco region; its presence is responsible for the position of the lower Huatanay River; stone from Rumiccolca was extensively used by Inca and Spanish builders and the present quarries³² are the principal source of rock used in modern construction (fig. 43). Lava flows from at least three centers within this area retain their original forms. Their surfaces are marked by mounds and hollows, and small flows extend like fingers from the sides of the larger masses. Caves and steam cavities are present, and in certain places broken blocks of scoria from the original ropy surface may be seen. Along

³²For a picturesque description of the ancient quarries at Rumiccolca see Squier, Peru, pp. 418-419.

the railroad paralleling the Urubamba (here called the Vilcanota) the lavas and associated intrusive rocks form a palisade wall of large columns decorated by radiating sheaves and fans composed of columns of small diameter (fig. 44). It is

FIG. 44.

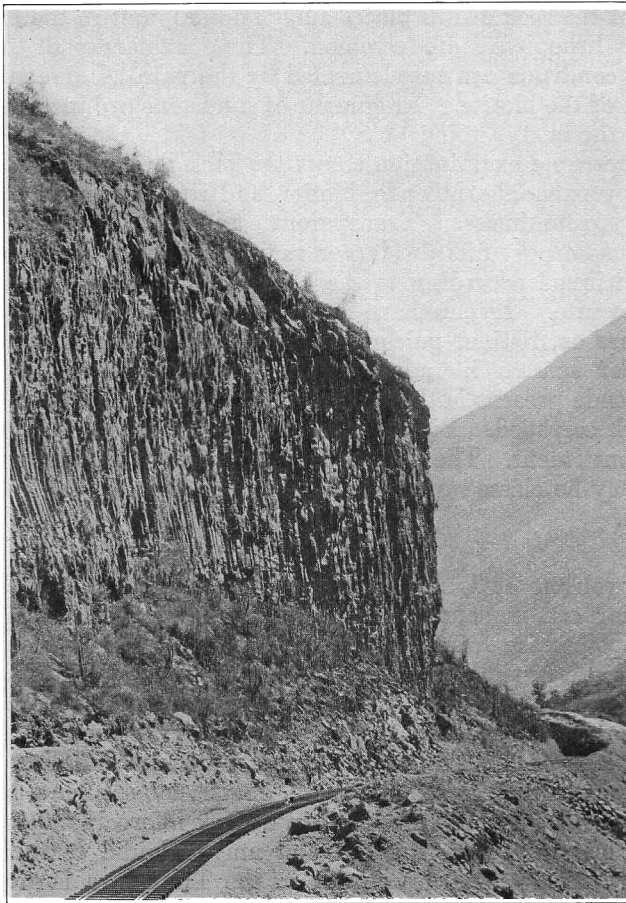


FIG. 44. Wall of columnar lava lining the canyon of the Urubamba between Cay-Cay and Rajehchi. Leon Campbell, photo.

probable that the lava at this point formerly extended across the Urubamba, thus effecting an important modification in the drainage.

As viewed in the ledge the rock from Rumicolca is of two types, which, however, grade into each other—(1) a massive rock of light-gray tone, microcrystalline except for the presence of flakes of biotite which dot the surface; (2) a banded rock with alternate belts of white, light gray or pink, and dark gray or black. The bands occur as individuals or in series and vary in width from threads to ribbons 2 to 3 inches wide. Both types of the rock are in places amygdaloidal, and in the banded variety lithophysæ are common. These evidences of former fluidal condition are supplemented by the parallel arrangement of part of the biotite. Fragments of sandstone are incorporated within the lava.

Microscopic examination shows the rock to consist of plagioclase, pyroxene, hornblende, biotite, and iron ore set in a dense glassy groundmass. Transparent tridymite traversed by numerous cracks fills the larger cavities. The laths of plagioclase twinned according to the Carlsbad law were determined as bytownite. Hypersthene is the variety of pyroxene present; it occurs as distinct pale-green pleochroic prisms and also as irregular masses included within the hornblende. All the hornblende present is the brown variety common in basalts and is much corroded. Biotite of characteristic aspect is a prominent constituent. The texture is hyalopilitic to fluidal and the rock may be classed with the hypersthene basalts.³³

Tinta.

The volcano of Tinta, 75 kilometers southeast of the Rumicolca, is a conspicuous landmark on the Juliaca-Cuzco Railroad. The topographic forms of the cone and the sprawling outflows of lava are but slightly modified by erosion. Weathering of the black scoriaceous lava is insignificant, and the cavities within the rock are almost free of secondary filling.

The lava of the Tinta volcano is a pyroxene andesite. The constituent minerals are oligoclase, augite, hypersthene, biotite, apatite, and iron ore embedded in a dark microcrystalline and glassy matrix. Both fluidal and amygdaloidal textures are present. A detailed description of the Tinta lava is given by Dueñas.³⁴

³³ Under the name "labradorita á biotita" Dueñas (op. cit., p. 192) describes a rock "que afloran-en la sección comprendida entre Urcos y Sierra Bella" which may have been collected from the Rumicolca quarry.

³⁴ Op. cit., pp. 190-191.