Art. III.—*The Gravels at Cuzco, Peru;* by Herbert E. Gregory.*

Introduction.—A prominent feature of the Cuzco Valley is a fringe of unconsolidated deposits exhibited as walls or dissected slopes. With the exception of a superficial cover of recent sediments these border forms are the remnants of piedmont alluvial deposits which date from a time when waste prepared through a long period of local disintegration was stripped from the highlands and carried to the central valley below. The bulk of these deposits is assigned to the late Pleistocene on the basis of the interlocking relations which the gravels flanking the lower slopes sustain to the slightly modified glacial drift now occupying the valley heads.

The most extensive of these Pleistocene fluvial deposits and those best exposed for study are the fans which mark the mouths of nearly all valleys, even minor ravines and wet-weather channels, which enter the Cuzco basin. Two of these fans, San Gerónimo and Cuzco, the former actively aggrading, the latter in a stage of rapid disintegration, are conspicuous among the gravel accumulations of the Cuzco Valley, and are somewhat unusual, both in extent and in thickness, as border features of a valley of such limited dimensions.

The Cuzco fan, while presenting no essential features which differentiate it from other examples of its class, is deemed worthy of somewhat extended description in view of twofacts: (1) the city of Cuzco is built on the outer dissected fringe and the terminal bluffs of the fan—a city which probably marks the site of one of the earliest permanent human settlements on the South American continent. (2) Because these gravels have yielded implements, pottery, the bones of lower animals, and human bones, which on the basis of a preliminary examination were tentatively assumed to date from glacial times.†

Topography.—In superficial extent the Cuzco gravels are arranged as a wide-open V or triangle whose apex extends to the divide separating the Anta and the Cuzco basins and whose base forms a curved line reaching from the Chunchullumayo Quebrada, where it merges with a second fan, to the limestone bluffs one mile due north of the railroad station. (See map, fig. 2.) In topographic expression it consists of two parts: the lower portion on which the city is built is bounded on the north and northwest by steep-faced bluffs; on the south and west it grades imperceptibly into the main valley floor.

* Geologist of the Peruvian Expedition, 1912.

† Bingham: The Discovery of Prehistoric Human Remains near Cuzco, Peru; and Bowman: The Geologic Relations of the Cuzco Remains. This Journal, vol. xxxiii, pp. 297–325, 1912.

FIG. 1.

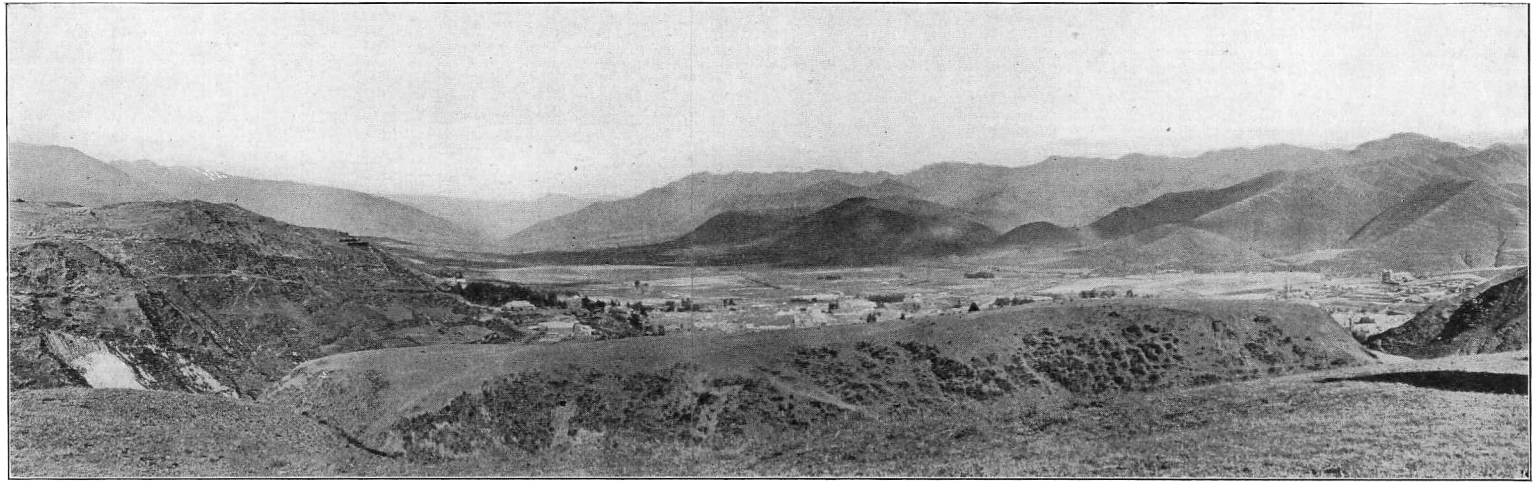


FIG. 1. View of the upper portion of the Cuzco valley showing the surface topography of a portion of the Cuzco gravels. The valley in the right foreground is the Ayahuaycco Quebrada ; the Rio Sappi occupies the steep-walled trench in the left foreground. Photograph by Hiram Bingham.

FIG. 2.

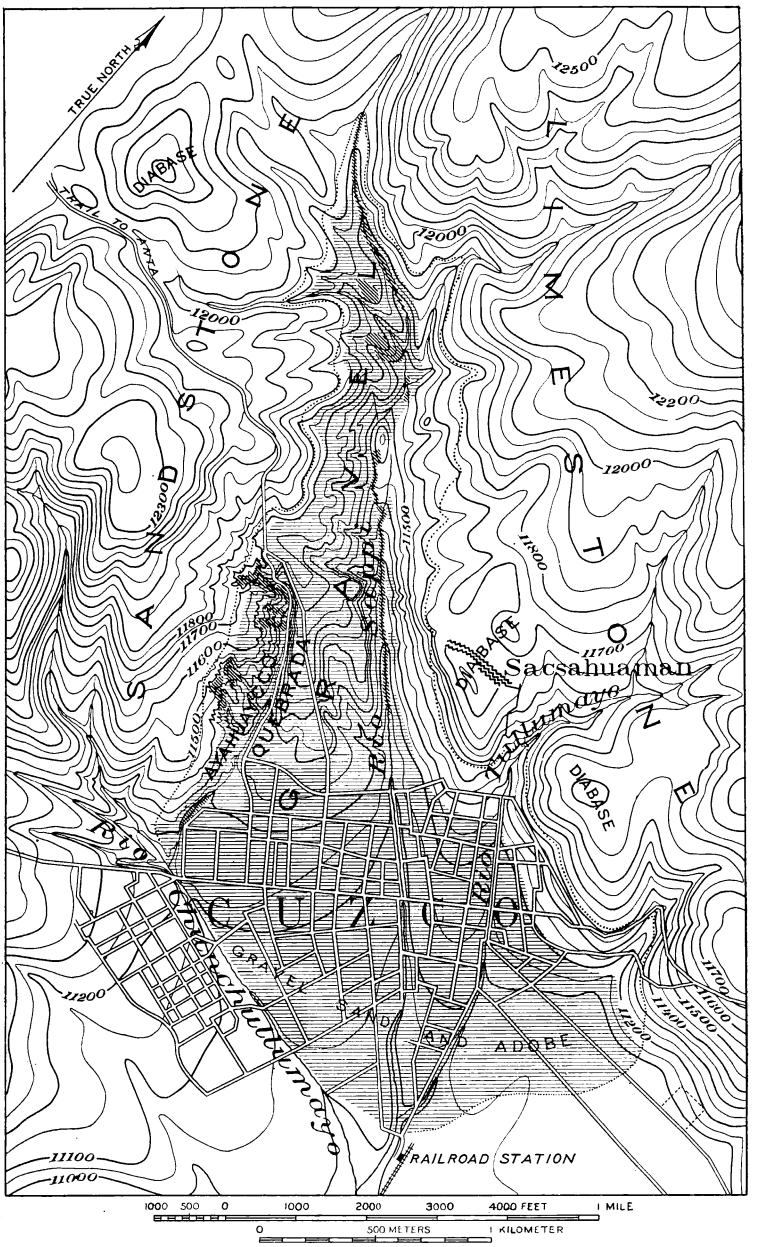


FIG. 2. Map of the Cuzco gravels, showing present distribution (light shading) and supposed former extent (dotted line), also areas of bed rock (heavy shading). Topography by the Peruvian Expeditions of 1911 and 1912.

Its slope is 200′ per mile and its surface is diversified by flattened hills much reduced by grading, valley filling, and canalization of streams, processes which have been going on since Inca days. The upper portion of the fan (fig. 1) is a nearly level plateau, deeply trenched by the Ayahuaycco Quebrada,* and by gravel-walled canyons tributary to the Huatanay.† The Ayahuaycco ravine reaches a depth exceeding 140′. Its northeast wall, cut entirely in gravels and sands, presents slopes of 20° to 60° which increase to 60° to 80° at the base (see fig. 1, p. 6; fig. 6, p. 13); its southwest wall is of gentler slope, and consists in part of bed rock. The five western tributaries of the Huatanay are sharply cut gravel canyons ending in box heads, —the southernmost one, leading to a flat 240′ above the river, is confined between banks with an average slope of 70°, and at one point presents a vertical wall 110′ high. In fact at certain points in these canyons the walls are undercut ten to fifteen feet without, however, interfering with the stability of the compact gravel mass. Such canyon faces, built entirely of coarse unconsolidated sediments, are made possible by the distribution of calcareous cement among the finer constituents, and by exceptional conditions controlling ground water circuation. To reach the upper gravel flats from the city requires an ascent of 400′.

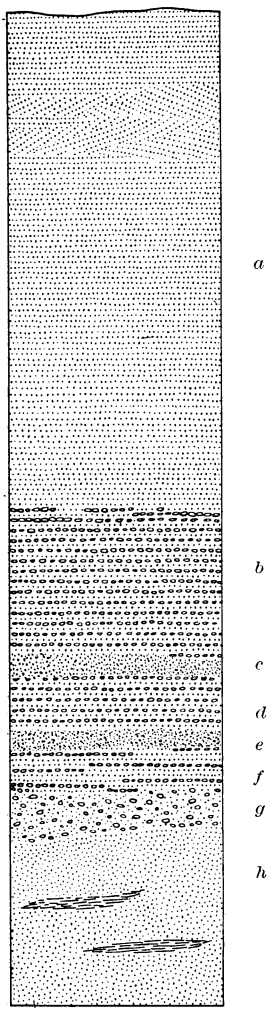
Throughout the entire area covered by the fan gravels, rock is exposed only in the bed of the Huatanay and at a few places in the Ayahuaycco and its tributaries. (See map, fig. 2.)

Structure.—Speaking broadly, the Cuzco fan is built of thick, widespread deposits of gravel within which are included lenses of fine sand. Most of the gravels are very coarse, approximately one-half of their bulk consisting of pebbles exceeding an inch in diameter. Stratification in the gravels is nowhere well developed, but may be detected in large exposures by the relatively high per cent of flattened pebbles which tend to assume horizontal positions. However, many portions of the quebrada walls 1000–2000 square feet in area appear equally well stratified vertically and horizontally and a photograph of such banks reveals essentially the same structure regardless of the position from which it is viewed. (See p. 1, fig. 6.) In fact the difference between the unmodified fan deposits composed exclusively of gravel and the slides, artificial gravel heaps, or the bowldery floor of the present torrential streams is to be detected only by the closest scrutiny. In brief a large part of the materials of the fan constitute a heap of unassorted

* Quebrada is a Spanish-American term applied to narrow steep-walled water courses regardless of dimensions. As used locally the term includes both arroyos and canyon. Ayahuaycco signifies, "Valley of the Dead."

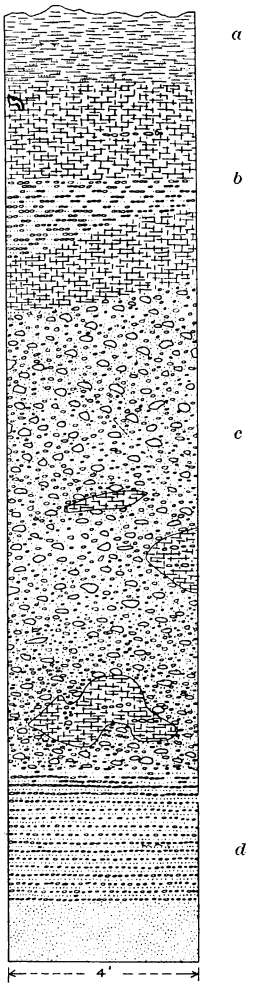
† The Huatanay consists of the Rio Sappi and its affluents.

FIG. 3.



a, 14 ft., horizontally bedded sand with slight cross-bedding.
b, 4 ft., gravel and sand interbedded.
c, ½ ft., fine sand cemented.
d, 1½ ft., gravel and sand interbedded.
e, fine sand cemented.
f, sand with stringers of gravel.
g, coarse gravel.
h, 5 ft., sand with two clay lenses.

FIG. 4.



a, soil and debris.
b, 4 ft., adobe with lenses and stringers of gravel.
c, 10 ft., coarse gravel with masses of adobe.
d, 4 ft., sand with thin-gravel beds in upper part.

FIG. 3. Section II, west bank of Ayahuaycco Quebrada at mouth of canyon portion of valley. Dip S. W. ∠ 2°.

FIG. 4. Section III, Ayahuaycco Quebrada, 200 feet from mouth. Note absence of gradation between strata. Bowlders six to eight inches in diameter rest directly upon the smoothed surface of adobe. Gravels traverse adobe masses vertically and horizontally.

bowlders of various sizes between which finer materials have been irregularly deposited. The sand beds consist of fine well-washed quartz grains which in places are bound together by films of calcareous mud. Through the body of the fan the sand is displayed as lenses rarely exceeding 2′ in thickness, and usually dying out laterally within a distance of 100′. The largest bed observed is six feet in thickness and extends for about 225′. Near the upper surface of the fan the sand lenses are more abundant and have a somewhat wider extent; at one point constituting nearly 1/5 of the material exposed.

At the outer edge of the fan where its deposits interleave with silts and calcareous muds of an ancient water body, sands and adobe assume the leading rôle, the gravels playing a minor part. There is here also a much more frequent alternation of beds and a much greater change in short horizontal distances.

FIG. 5.

Fig. 5. Section IV, Detail of gravel shown in section III; size and orientation of pebbles drawn to scale.

The stratified phases of the Cuzco gravels slope in general southward at various degrees of inclination. At the mouth of the canyon portion of the Ayahuaycco the well-stratified beds of sand included within the gravel mass dip south at an angle of 3°–5°. At the edge of the bluffs facing the city and on the slope northwest of Santa Ana church dips of 8°–10° south were measured, while the strata which cap the deposits along the Anta road are practically horizontal. Cross-bedding though present is not a conspicuous feature, doubtless being obscured by the prevailing unstratified condition of the gravels, but cut and fill channels trending in various directions are revealed in nearly every section.

The accompanying sections (sec. I and figs. 3–9) illustrate the structure and arrangement of beds in selected portions of the delta.

Section I. Mouth of Ayahuaycco Quebrada.

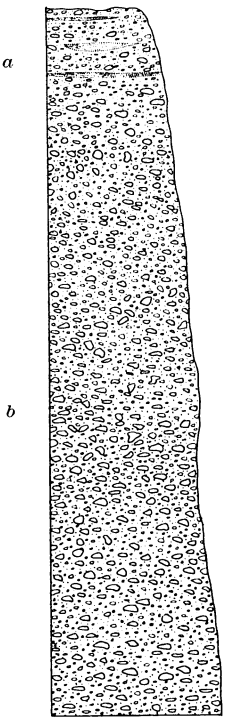
Dip 4° south.

		Feet
1.	Soil, red-brown, sandy, with bands of brown adobe, streaked with calcareous bands and penetrated by root tubes	10
2.	Gravel, composed of subangular pebbles 1 to 6 inches in diameter, of brown and grey sandstone, rarely limestone; partially cemented by calcareous films. Bottom rests unconformably on the channeled surface of No. 3	4

		Feet
3.	Sand, coarse, mingled with clay-adobe, firmly cemented with lime; dull yellow on weathered surfaces, brown and white beneath	3
4.	Gravel, composed of flattened subangular pebbles of grey and brown sandstone, 1 to 6 inches in length. Many pebbles partially decomposed. Contains irregular lenses of coarse sand	5

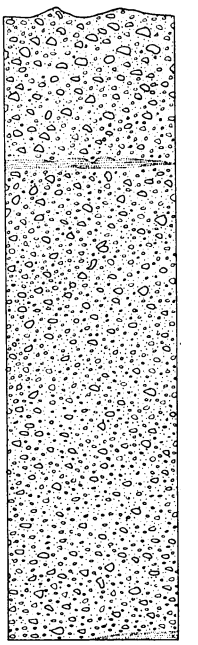
For Sections II–VIII see accompanying figures.

FIG. 6.



a, 30 ft., coarse gravel, with lenses of sand.
b, 120 ft., coarse gravel, massive.

FIG. 7.



a, 15 ft., very coarse gravel.
b, 1 ft., fine sand, stratified.
c, 50 ft., very coarse gravel, massive.

FIG. 6. Section V, North bank of Rio Sappi at mouth of tributary descending from the Cuzco-Anta divide.

FIG. 7. Section VI, Bank of tributary to Rio Sappi, descending from the Cuzco-Anta divide.

Composition. Source of Material.

The highlands which contributed material to the Cuzco fan consist, on the northeast, of grey-blue limestone through which protrude small knobs of greenish igneous rock (altered diabase)

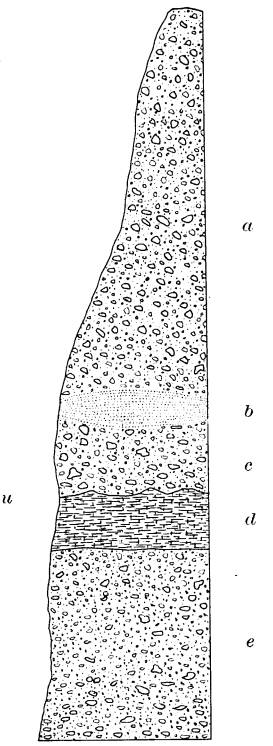
along the Huatanay and on the Anta divide. The contributary area on the west and northwest is underlaid by brown and grey sandstone, chiefly the former. Sandstone furnished the bulk of the material, and in the Ayahuaycco Quebrada fully 95 per cent of the pebbles have this origin, igneous pebbles being nearly absent. Along the Huatanay tributaries the sandstone is still dominant, but limestone makes up about 10 per cent and diabase 3 per cent to 5 per cent. Bowlders of limestone exceeding 5 feet in diameter are found in this area. The relative scarcity of large bowlders of sandstone appears to be due to the fact that closely spaced intersecting joint-planes break up this rock into cubes of a few inches on a side. That brown sandstone should rank first as the source of material is due (1) to the more precipitous slopes on the west border of the fan; (2) to the more abundant fragmental waste resulting from the weathering of sandstone as compared with limestone; (3) to the fact that those portions of the fan where limestone and diabase bowlders were formerly most abundant (e. g., along the Huatanay river) have been most completely removed by stream erosion. It was noticed that limestone fragments are more abundant in the topmost beds of the fan—a natural consequence of the fact that the limestone occupied southern slopes and was more or less protected by a cover of snow and ice during the early part of the period of excessive aggradation. So far as observed, coarse, sandstone gravel forms the layer immediately in contact with bed rock.

Three types of material are represented in the fan: gravel, coarse to very coarse; sand, fine, compact; and adobe. The structure and composition of the gravel and sand have been discussed. Brown adobe occupies about an acre on the west bank of the Ayahuaycco Quebrada, where it attains a thickness of thirty feet and includes three bands of white lime silt. The material lies in horizontal beds, is impalpably fine but firm and compact. The adobe and associated beds are alike highly calcareous and are traversed by vertical root tubes encrusted with lime. This deposit, as well as the less extensive accumulations near Santa Ana church and at the mouth of the Ayahuaycco, differ in no essential from the beds of adobe and unconsolidated limestone abundantly displayed in the Cuzco Valley beyond the border of the fan. They are believed to represent the shores of ephemeral lakes which existed contemporaneously with the gravel-bearing streams.

Age of Deposits.

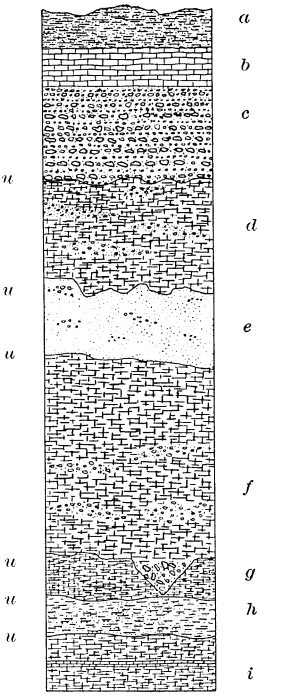
As previously stated, the Cuzco gravels are believed to have reached their greatest extent and thickness in late Pleistocene times. More recent deposits have, however, been superposed.

FIG. 8.



a, 40 ft., gravel, massive.
b, 4 ft., fine sand.
c, 7 ft., gravel, massive.
d, 6 feet, compact clay adobe.
e, 20 ft., coarse gravel, massive.
u, unconformity.

FIG. 9.



a, 2 ft., soil and adobe.
b, 2 ft., fine shell limestone.
c, 5 ft., gravel, coarse and fine, horizontal.
d, 6 ft., massive adobe, with lenses of gravel.
e, 4 ft., fine sand with gravel patches.
f, 10 ft., adobe with thin lenses of gravel.
g, 2 ft., compact adobe.
h, 2 ft., fine sand and clay.
i, 3 ft., adobe with thin band of shell limestone.
u, unconformity.

FIG. 8.—Sec. VII, Bank of unnamed tributary to Rio Sappi opposite the Rodadero.

FIG. 9.—Section VIII, Bank of the Chunchullumayo, near junction with Rio Huatanay.

Surface wash from the bordering slopes, controlled in amount and character by climatic changes, has probably been accumulating continuously since glacial times, and has greatly increased since human occupation began. Soil wash resting unconformably on the surface of the fan may be observed at favorable localities. On the lower sandstone slopes bordering the Cuzco

fan, where the fields may have been cultivated for five or six centuries, soil wash and associated deposits have accumulated to depths of ten to twenty feet at the base of the slopes. A section exposed on the bank of the Ayahuaycco Quebrada presents the following order of stratification:

Recent deposits northwest bank of Ayahuaycco Quebrada.

		Feet
1.	Wash from hill slope and cultivated field, red-brown in tone, composed of sand and clay with inclosed rock pebbles and earth clods	1/4
2.	Ash, cross-bedded in layers 1/4 to 1 inch, composed of alternating bands of black charcoal, burnt grass, etc., and grey wood ashes. Fragments of bones, teeth, also of ancient pottery, are abundant. Near the base pebbles of sandstone and thin bands of sand are found	10
3.	Gravel, rudely stratified, composed of pebbles one to four inches in diameter; also scattered bones and sherds	8
4.	Sandstone ledge, on top of which lie two large limestone bowlders not of local origin	4

The thickness of cover over deposits of ashes varies from one to eight feet within a distance of 300 feet along the Ayahuaycco Quebrada. The thickness and position of deposits of human origin is likewise variable. The recent date of the wood ash and overlying strata is plainly shown by the presence of sherds and of bones of modern types and by a comparision of the ash shown in section along the quebrada with that exposed in a bank 300 feet further east. In structure and composition the two are essentially alike, although one is the present city dump and the other is definitely interbedded with gravels and soil wash. An even more striking illustration of aggradation is the presence along the lower Ayahuaycco of a wall of Incaic or pre-Incaic design which had been buried by four to eight feet of gravel, partly stream-laid, partly washed from the slopes. This buried wall was exposed (about 1870) in cutting an artificial channel for the wet-weather stream which drains the quebrada. The original wall, resting on what is believed to be an eroded portion of the fan, is composed of hewn limestone blocks of excellent workmanship and has been continued upward by a poorly constructed retaining wall of stone and adobe which serves as a border for the fields below.* Similar buried walls were noted at other localities,

* For further details regarding this wall see Bowman: "A Buried Wall at Cuzco and its Relation to the Question of a pre-Inca Race," this Journal, vol. xxxiv, pp. 497–509, 1912. Bowman concludes that the burial of this wall may date from 2000 B. C. to 4000 B. C. Although such antiquity is possible, yet the geological conditions are satisfied on the basis of a much shorter period of time.

and at a point south of San Sebastian such a wall buried beneath the soil of a cultivated field is exposed in the valley of the Huatanay, where it stands plastered against the bank of

FIG. 10.

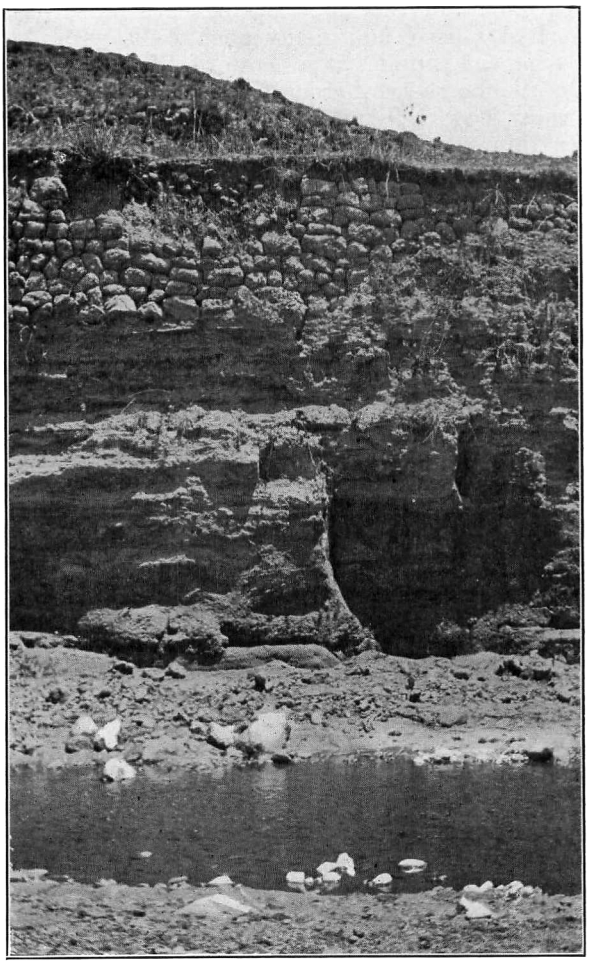


FIG. 10. Buried wall exposed in the bank of the Rio Huatanay.

the stream, twenty feet above the bed, like an ornamental border on wall paper (fig. 10). This wall, probably built to protect the fields from the summer overflow of the Huatanay,

has remained in place, while the canalized stream has entrenched itself in the sands and gravel bordering the Cuzco basin.

Ground Water.—A large proportion of the water which falls on the surface of the Cuzco fan is rapidly absorbed, and percolating downward through the porous gravels to a depth of 100 to 400 feet, emerges as springs along water courses and on the periphery of the fan. Springs are numerous in the lower part of Cuzco, and many open wells within the city reveal permanent supplies at a depth of fifteen to twenty-five feet. On the northeast border of the fan the direction of ground-water flow is southwest, following the rock slope beneath a thin superficial cover; on the west border, where similar relations exist, the flow is east. The high content of lime in well and spring waters is due to the presence of tiny fragments of limestone widely disseminated through the gravels in quantities sufficient to furnish calcareous cement for the partial consolidation of portions of the mass. One result of ground-water action, which has also an archæological bearing, is the presence of numerous small caves and pockets and shelves in the steeply inclined gravel walls,—cavities which mark the position of ephemeral seeps and areas of less consolidated material. The floor of these caves is covered with stratified sands and they appear to have been used extensively as sepulchres.

Landslides and creeps resulting from the action of ground water may be observed at numerous places along the ravines which trench the Cuzco gravels, where the conditions for their formation are exceptionally favorable. The alluvium rests on steep rock surfaces, coarse gravels overlie lenses of fine sand and adobe, the water courses follow deep, narrow canyons, cut in unconsolidated deposits, the amount of ground water is relatively large, and markedly fluctuating in response to periodic showers. Following an ordinary storm accompanied by a heavy downpour, the writer observed six small slides and numerous seeps along the Chunchullomayo in positions where vertical, dry gravel walls had been noted on previous days. In the heavier gravel masses trenched by gravel-walled canyons the effect of slides is chiefly to give the valleys an unsymmetrical shape with the steeper wall on the side toward which ground water flows. In valleys where one bank is gravel and the other gravel underlaid by rock, the lack of symmetry is very pronounced,—a perpendicular wall of gravel facing a moderate slope of gravel, decomposed rock and miscellaneous slide debris. Slides, mostly of small or of moderate dimensions, are conspicuous along the Sappi and the Ayahuaycco where they extend to the stream bed or remain as plasters attached to the walls. The southwest bank of the canyon portion of the latter stream is almost continuously faced with

slides like an artificial revetment. The northeast wall is marked by two slides, one immediately above and one immediately below the locality from which bones were excavated by the expedition of 1911. Moreover this wall is capped by a sloping terrace with an escarpment at its inner face, indicating that a mass of gravel $30 \times 300 \times 150$ feet has slid downward ten feet toward the valley axis. An examination of old slides as well as of those which have occurred within the last few years shows that except where decomposed rock forms the slipping plane there is no clean break between the gravel in place and the transported portion or between different portions of the slide material itself. Where sand or adobe lenses have been involved it is easy to determine both the fact and the amount of displacement, but in the massive gravel where evidence of stratification is absent, it is impossible to determine with assurance which is slide and which is original bank, especially after the low top escarpment has been obliterated by further sliding and soil creep. Two artificial trenches were cut into gravels across a plane, which on independent evidence is known to mark the contact of slide gravel with the original valley wall. In these cases neither the orientation of pebbles, nor a ragged contact, nor open spaces, nor effects of ground water gave evidences of displacement. A tunnel eleven feet long and with a cross section $4\frac{1}{2} \times 3$ feet was sunk into the steep gravel wall of the Ayahuaycco Quebrada at the exact point from which human bones were taken by the members of the Peruvian Expedition of 1911. The section exposed is entirely gravel, consisting of pebbles of brown sandstone (90 per cent), gray sandstone (9 per cent), limestone and igneous fragments (1 per cent), ranging in size from one-half inch to four, rarely six inches, and so firmly packed that no timbering of the tunnel was required. The material is uniform in texture, contains no bands or lenses of sand, no division planes, or other unmistakable evidences of stratification. Even the pebbles are variously oriented and about a third of them, including many thin, flat slabs, slope at angles between 60° and 90° to a horizontal surface. The relation of landslides to the gravels in which human bones were found by the Expedition of 1911 is discussed by Doctor Eaton (see p. 5) and need not be further considered here. In certain of the slides the gravel pebbles appear to have moved differentially among themselves, to have assumed an angle of repose by internal readjustment, somewhat analogous to the movement of particles involved in glacier motion. It would therefore appear impracticable to determine the position and dimensions of landslides and slumps in the unassorted portions of the Cuzco gravels. Evidence of displacement indicates the presence of landslides, but unfortu nately the absence of such evidence does not prove the absence of landslides or "creep" at any given point.

The lower Ayahuaycco Quebrada furnishes evidence of the manner in which slides modify valley form and aid in the burial of extraneous matter. The stream has occupied this portion of its valley since about 1870, when an artificial readjustment of drainage was effected. During these forty years the stream has cut a ravine twenty to thirty feet deep and about twenty feet wide. Three slides are visible within one hundred feet. The one nearest the stream's mouth covers about twenty square feet and is pasted against the vertical wall as a patch two feet thick. In this case stratification is well marked, but the break is so completely healed that, without the discordance in bedding, the displacement could not be detected. The second slide blocked the stream, which, rising to the crest of the dam, cut downward and formed a new floor. Later trenching developed a terrace 12×20 feet, the edges of which reveal material identical with the gravel in the original bank. The material of the slide, the material deposited by the stream, the material fallen on the terrace, and the material of the standing wall are indistinguishable in structure, texture and composition. The fact of the slide is demonstrated by a broken lense of sand revealed by an artificial trench. From the gravels of the slide midway between top and bottom were excavated two pieces of imported pottery, relics carried by the stream or fallen from the top of the bank. A deeper cutting of the channel, accompanied by smoothing of the slope, would have left those fragments of household furniture firmly embedded in a wall of gravel beneath twenty feet of sediment, all so like the gravel of the original fan as not to be differentiated with certainty. It seems reasonable to suppose that much greater thicknesses of sediment forming much higher banks of gravel may have passed through similar stages.

Erosional History.—The present position and structure of the Cuzco gravels and the general physiographic relations of the area suggest the outline of the original deposits as indicated on the map (fig. 2). The dissection of the fan probably began with the establishment of permanent drainage in the Sappi, whose relatively large watershed and its fall of about 400 feet per mile gave it considerable erosive power over the gravels marking its path. Coincident with the cutting of the Sappi canyon, but at a slower pace, its tributaries were cut and the front of the fan was developed into cliffs by headward erosion of short, steep, wet-weather streams assisted by groundwater activities. The Ayahuaycco probably originated as a line of drainage at the western edge of the fan and worked progressively north and east, following the rock slope downward and maintaining, approximately, the present relation of one bank on or near rock and the other bank cut in gravel.

That the dissection of the Pleistocene and recent gravels has

not been progressively continuous, is shown by the terraces along the upper Huatanay (Sappi) and still more plainly by the well-developed terraces, two to five in number, flanking the streams entering the Cuzco valley beyond the limits of the fan. No well-marked terraces persist in the upper Ayahuaycco Quebrada, a location unfavorable for their preservation. The canyon is narrow, the banks are of gravel or of gravel on rock, and the stream is fed by wet-weather torrential tributaries with gradients of over 1500 feet per mile. Here, as along other streams entering the Cuzco valley, terraces may have been buried and re-excavated many times in response to minor climatic fluctuations during historic as well as prehistoric times, the evidence for which is conclusive. It is unprofitable, from a geological standpoint, to work out the details of erosional history in and about Cuzco, because of the extensive modification of slopes and terraces resulting from cultivation and flood-water irrigation. However, the evidence indicating periodic destruction and building of terraces, even within the past one hundred years, removes the necessity of ascribing great antiquity to animal bones, parts of human skeletons, and fragments of pottery found along stream banks and which may have been deposited on terraces or on banks, or in the numerous small cave-like openings in the gravels, to be transported, buried, or reëxposed during alternating processes of deposition and degradation. It is interesting to note that in the canyoned tributaries of the Sappi and of streams leading from the limestone plateau and from the sandstone highlands bordering the Cuzco basin on the south,—valleys from which terraces and slides have been removed and whose banks offered no temptation to occupation, valleys whose present precipitous gravel walls are clearly of glacial age,—no traces of human occupation were revealed by careful search. From these same gravels, however, mastodon bones have been collected, on the Huancaro and in the lower Cuzco valley. The fact that these bones from the Ayahuaycco gravels are of modern types (see article by Eaton, p. 5) obviously corroborates this view of depositional history, and also indicates important climatic changes since the Spanish conquest.

It will be noted that the explanations given in this paper are chiefly of negative value so far as archæological research is concerned. That man existed in South America in glacial or preglacial times, and that the human bones discovered in the Ayahuaycco Quebrada "appear to be from 20,000 to 40,000 years old" as tentatively held by Bowman,* is not definitely disproven by the field studies of the present writer. On the other hand, the geologic data do not require more than a few hundreds of years as the age of the human remains found in the Cuzco gravels.

* This Journal, vol. xxxiii, p. 321, 1912.