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The RODADERO (CUZCO, PERU),—A FAULT PLANE of UNUSUAL ASPECT.

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

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ART. XXII.—*The Rodadero (Cuzco, Peru),—A Fault Plane of Unusual Aspect;* by HERBERT E. GREGORY.*

Introduction.

OVERLOOKING the city of Cuzco, perched high on a jutting eminence, stands the famous Inca fortress of Sacsahuaman. The enormous size of the blocks used in its construction, the incredible labor expended in quarrying and transporting, and the skill exhibited in nicely fitting the stones into walls without mortar, give this structure a unique place among the works of prehistoric man. Seven hundred feet north of Sacsahuaman and at a somewhat higher elevation is the equally famous Rodadero, a grooved and polished rock mound in which have been cut the "Seats of the Incas" (fig. 1).

Topographically the Rodadero is one of four knobs or bosses of intrusive igneous rock rimmed about with massive blue limestone which forms the plateau overlooking Cuzco from the north. Three of these intrusive masses are more or less cloaked with vegetation and the products of weathering; the Rodadero, however, is bare, singularly fresh and firm, and gives the impression of a ledge of rock stripped and polished by the hand of man. The insignificant influence of weathering revealed by the exposed surface of the Rodadero is worthy of comment, in view of the fact that at nearby localities disintegration of rock of identical character has reached an advanced stage. Thus in the banks of the Tullumayo the firmer portions of the basic igneous ledges are separated into blocks with rounded edges, and other portions consist of concentrically weathered bowlders embedded in a disintegrated groundmass (fig. 2), and still other parts of the original mass are represented by a yellow-white, clay-like

* Geologist, Peruvian Expedition of 1912.

substance containing weathered crystals of feldspar and augite. Along the Huatanay large masses of the rock have been converted into epidote. It would appear, therefore, that the Roda-

Fig. 1.

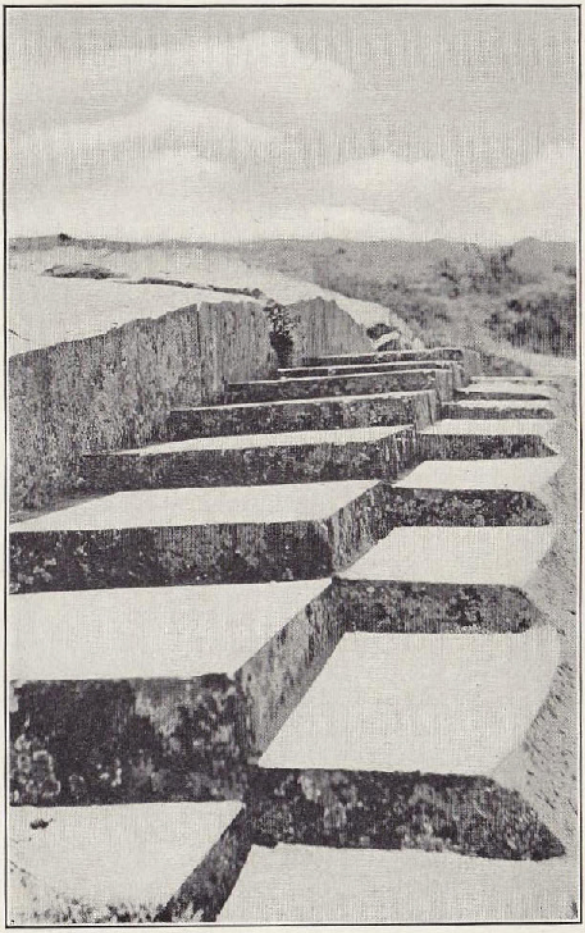

Fig. 1. "The Seats of the Incas." South slope of the Rodadero; highly polished seats accurately cut from massive diorite. According to tradition these seats were used by the royal family during the construction of Sacsahuaman.

dero has been recently exposed through natural agencies aided perhaps by artifical stripping during the process of filling and terracing which has greatly modified the original topography.

Rock forming the Rodadero.

As seen in the ledge the rock forming the Rodadero is dark grey in color, with a greenish tinge when viewed in certain lights. The weathered portions are light gray or even yel-

FIG. 2.

FIG. 2. Weathered diorite forming east bank of Tullumayo; compare with figures 4 and 5.

lowish and spotted with green. Aggregates of yellow-green epidote varying in size from a pea to clusters eight to ten inches in diameter are irregularly distributed through the mass and are particularly prominent along joints. The rock as a whole appears to be massive, fine-grained, and of granitic

texture; but even in the freshest hand specimens black crystals of augite and minute clusters of epidote may be differentiated from the denser groundmass, thus giving the rock a porphyritic appearance. Petrographic analysis of the Rodadero rock, described by Squier* as "amphibolic rock" and again as "trachytic rock," by Markham† as "limestone," and by Dueñas‡ as "altered diabase," revealed the following constituents: Well-preserved crystals of augite, fresh or kaolinized plagio-

FIG. 3.

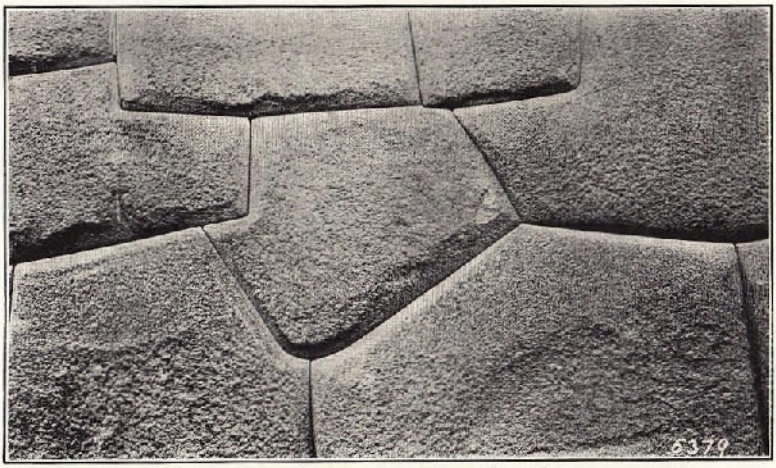

FIG. 3. Incaic wall in Calle del Triunfo, Cuzco, built of rock identical with that forming the Rodadero (A. H. Bumstead, photo.).

clase feldspars near andesine in composition, chlorite probably representing biotite and hornblende, apatite and iron grains in very small amounts; epidote occurs abundantly distributed as grains and clusters. The rock forming the Rodadero may therefore be classed as an augite diorite porphyry.

Rock of this type taken from the quarries adjoining the city was highly prized by the architects of the Inca dynasty, in spite of the labor and skill involved in working the resistant material. The best preserved walls of ancient Cuzco, for example those bounding Calle del Triunfo (fig. 3), in which the stones are fitted and polished with wonderful skill, are built of this material.

* Peru: Incidents of travel and exploration in the land of the Incas, 1877, pp. 468 and 476.

†Cuzco: A Journey to the Ancient Capital of Peru, 1856, p. 115.

‡Cuerpo de Ing. de Min. del Peru, Bol., liii, p. 179.

The ledges forming the Rodadero are traversed by incipient joints and broken by numerous faults of small displacement along which slickensides have been developed—features common to both igneous and sedimentary rock masses within the province of Cuzco.

The fluted surface.

The unusual feature of the Rodadero and the one which gives it its name (Spanish, *rodada*, a rut), is the remarkable series of polished grooves which ornament the entire surface of the irregular knob (figs. 4 and 5). An area exceeding an acre is occupied by grooves whose width varies from a few inches to four or five feet, and whose depth varies between a fraction of an inch and four feet. Smaller flutings and delicate striæ traverse the troughs and crests of the larger depressions in a longitudinal direction. Microscopic abrasion lines have smoothed and polished the channels and ridges to such a degree that one may slide down the inclines without damage to clothing—an amusement indulged in by natives and tourists alike; and, if tradition is to be accepted, by the Inca rulers themselves. The larger and smaller grooves are continuous and parallel for 100 to 300 feet, and at one locality thirty-two parallel channels with a combined width of fifty feet were traced for a distance of 180 feet. About 90 per cent of the grooves and ridges extend S. 30° W., but other trends are represented as indicated below.

The large area exposed, the freshness and perfection of carving, the continuity and parallelism of the striæ which give this exposure a unique character, have naturally attracted the attention of students of nature. Squier* described the Rodadero ("La Piedra Lisa") as a rock "squeezed up in plastic state between irregular and unyielding walls, and then hardened into shape with a smooth and glassy surface." The statement of Rivero and Von Tschudi† illustrates the extreme philologic method of scientific research, and the liability of being led astray by a name: "A short distance from the fortress is a large piece of amphibolic rock known by the name of 'the smooth rolling stone' which served and still serves for diversion to the inhabitants by rolling like a garden roller having a sort of hollow formed in the middle through friction."

Dueñas, whose "Aspecto Minero del Department del Cuzco"‡ is worthy of high commendation," describes the Rodadero as a glaciated surface, a view also held by Posnansky.§ Sivi-

* Peru, 1877, p. 476.

† Peruvian Antiquities, 1853, p. 249. M. E. Rivero and J. J. von Tschudi. Translated into English by F. L. Hawks.

‡ Cuerpo de Ing. de Min. del Peru, Bol., liii. pp. 25–26, 1907.

§ Bol. Oficina Nac. Estadist, No. 64–66, La Paz, 1911.

Fig. 4.

Fig. 4. East slope of Rodadero, looking south. Note three sets of minor faults.

Fig. 5.

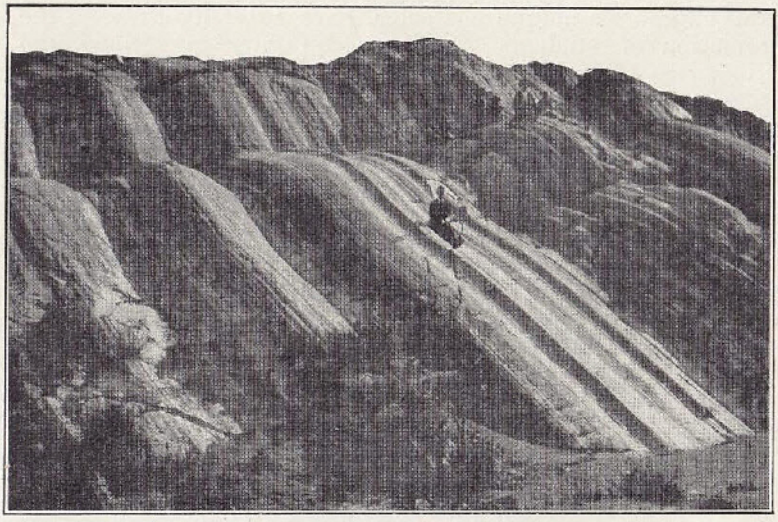

Fig. 5. The "Toboggan Slide," Rodadero. Note the variation in the depth of the grooves.

richi* considers the Rodadero an igneous intrusion molded by glaciers before the molten rock had cooled. The popular explanation of the smoothed, hummocky surface of the Rodadero is in line with the views expressed above, and it must be admitted that we are dealing with a remarkably exact imitation of a "rôches moutonnés" surface. The resemblance between the Rodadero and glacially eroded surfaces, made familiar by field experience, is in fact so close that my first impression was in accord with the views of Dueñas and Posnansky in spite of the warning of my observant colleague, Professor Bowman.† The theory that an ice sheet played a part in molding the Rodadero

FIG. 6.

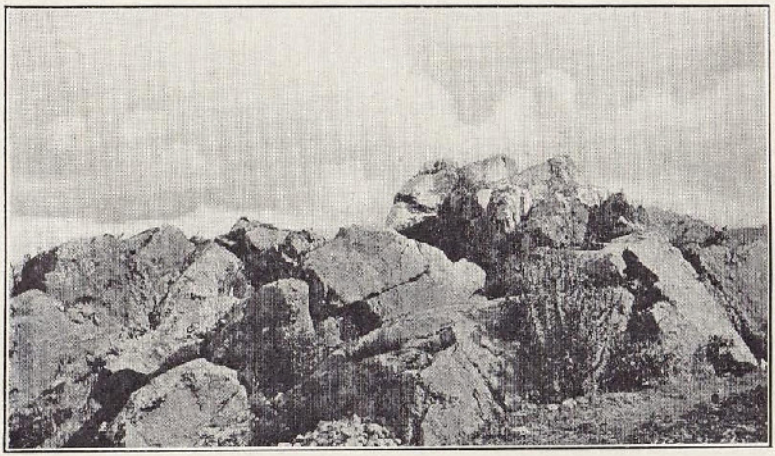

FIG. 6. Ledge of limestone adjoining the striated Rodadero. Compare with figures 4, 5, 7, and 8.

was, however, abandoned in view of the following observations:

(1) There is no evidence of glacial erosion in the Cuzco region at so low an elevation. The Rodadero stands at 11,700 feet, while the lowest moraines on the Seneca, three miles distant, are intersected by the 12,500-foot contour. (2) The striations on the Rodadero are duplicated on another igneous knob one-half mile to the eastward, but the projecting ledges of resistant limestone immediately surrounding the igneous masses show no signs of glacial action either on the surface or in recent excavations. (Fig. 6.) The freshness and perfection of

*Tesis Universidad del Cuzco, p. 18; Topografia Infantil Cuzco, 1911.
†This Journal, xxxiii, p. 317, 1912.

detail suggest late Pleistocene glaciation, and it is difficult to conceive that limestone and sandstone ledges could have failed to record the effects of long-continued action of an ice mass of the proportions required for the work at the Rodadero. (3) No graving tools in the shape of polished or striated bowlders and

Fig. 7.

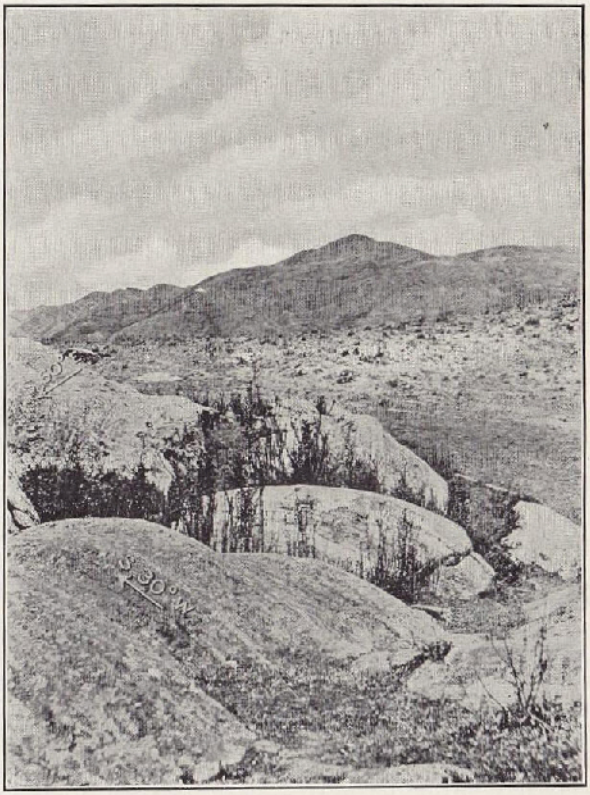

Fig. 7. A portion of the Rodadero, showing striæ trending in two directions. View looking west.

no erratics were found on the surface nor in the gravels adjoining. (4) While the general trend of the grooves is S. 30° W., other directions were noted, and at one locality deep grooves running S. 30° W. are succeeded, after a break of a few feet, by equally well-marked striations running S. 60° E. (fig. 7). (5) The lee side and stoss sides of the entire mass and of individual

knobs are alike affected. There is no plucking. (6) In places a paste of broken igneous fragments overlies the smoothed and fluted surface. The removal of the brecciated material reveals the familiar grooves beneath. (7) Two slabs pried from the

FIG. 8.

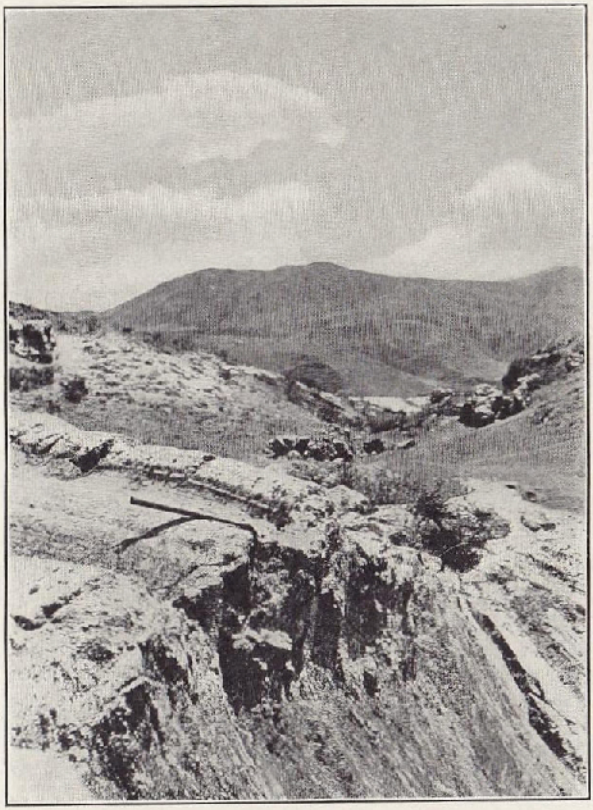

FIG. 8. Normal fault, post-dating the major thrust fault which produced the slickensides.

ledges were found to be striated on both their lower and upper surfaces. (8) Microscopic examination of the rock shows that the surface zone has been modified in texture—the sort of metamorphism resulting from pressure of rock on rock, not of ice on rock.

The Rodadero a fault plane.

Field relations and rock texture indicate that the diorite mass whose striated surface forms the Rodadero is intrusive into sediments of Mesozoic age. However, the smoothed, unweathered exposures immediately adjoining the limestone outcrops exhibit no modification of texture incident to cooling and no interfingering of igneous and sedimentary rock. In fact the theory advanced by certain observers that the Rodadero represents an ancient cooling surface is quite out of harmony with the field evidence as well as with the theories of the mechanics of igneous intrusion. The presence of limestone in immediate contact with diorite—a relation which furnishes opportunity for solution along the contact—has doubtless facilitated the stripping of the igneous boss.

The Rodadero is believed to be a portion of a thrust fault plane marked by an unusual expression of slickensides. Unlike normal slickensides the striated grooves of the Rodadero occur indiscriminately on flat, convex, concave and undulating surfaces; and although generally straight and parallel they may also be seen curving gently around minor knobs. The criteria usually employed to distinguish slickensides from striæ of glacial origin are not applicable.* The groups of striæ of various orientation merge imperceptibly into one another and are apparently contemporaneous, thus indicating the presence of stresses opposed to the dominant direction of movement. Readjustment of pressures following the major faulting has resulted in the production of minor, normal faults which interrupt the continuity of the grooves. These faults, trending roughly 90° and 45° to the prevailing direction of striæ, are themselves marked by slickensides and fault breccia and exhibit prominent "drags" (fig. 8).

* Geikie: Structural and Field Geology, p. 309.