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Peru's Quelccaya Ice Cap: glaciological and glacial geological studies, 1974

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Long ice cores have been obtained in recent years from Greenland and Antarctica, and shorter cores have been retrieved from other high-latitude glaciers. It became evident that a stratigraphic record from a glacier in the tropics would be needed to test certain assumptions made in the interpretation of polar ice cores and to aid in an interhemispheric correlation of polar ice cores by providing data from an intermediate location.

Most glaciers in the tropics are on rugged mountains or steep volcanic peaks. Only two tropical ice caps are known to exist, both in the Southern Hemisphere: in Irian Jaya (formerly Dutch New Guinea), at 4°S., the North Wall Firn (elevation: 4,800 meters) covers about 4 square kilometers, and in Peru, at 14°S., the Quelccaya Ice Cap (elevation: 5,500 meters) covers about 70 square kilometers. The Quelccaya Ice Cap is larger and thicker than the

North Wall Firn; further, being in a colder environment it must be subject to much less percolation by meltwater. It thus is likely to contain the best stratigraphic record of any glacier in the tropics.

In June and July 1974 the Institute of Polar Studies, The Ohio State University, organized a four-person party to do a preliminary study of the Quelccaya Ice Cap and its environs (figure 1) to determine whether a large-scale investigation is warranted. The party included Drs. Marangunic and Mercer and Messrs. Thompson and Ricker.

The Quelccaya Ice Cap and vicinity

The Quelccaya Ice Cap (figure 2) covers a small plateau of welded tuff. Its three domes, the highest reaching 5,500 meters, suggest that the surface of the underlying plateau is uneven. The greatest ice thickness is estimated at about 200 meters. The ice spills off the plateau in spectacular ice falls that feed short ice tongues ending at about 4,800 meters in elevation. In places on the south and west sides,

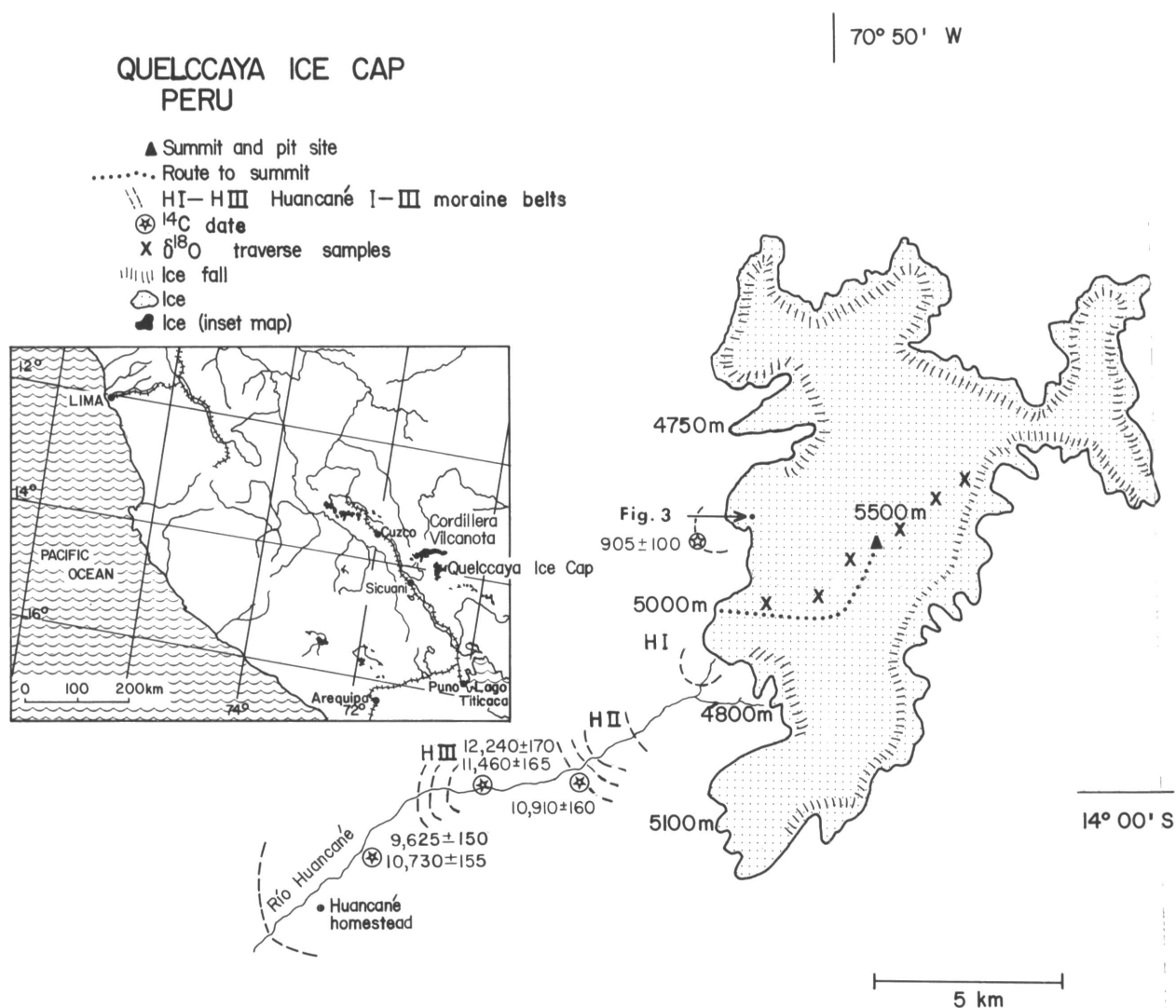


Figure 1. Sketch map of the Quelccaya Ice Cap, Peru, and inset location map. Sketch map was prepared from aerial photographs; it shows approximate sites of the snow pit and δ oxygen-18 traverse samples. Also shown are the approximate positions of end moraine belts to the southwest of the ice cap within 15 kilometers of the ice margin, and sites of carbon-14 age determinations. Elevations are by aneroid.

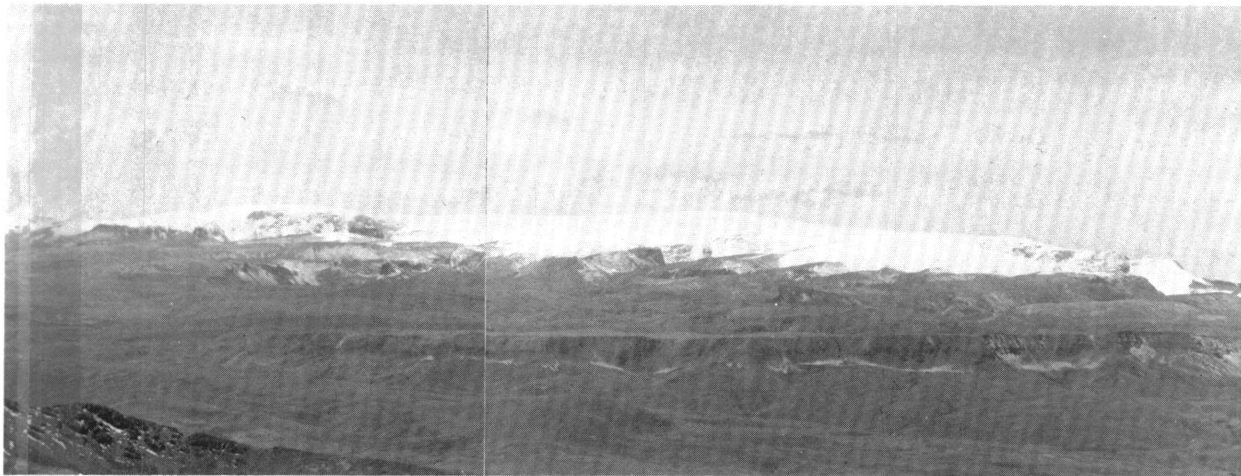


Figure 2. Quelccaya Ice Cap viewed from 30 kilometers to the southwest.

however, ice falls are absent; the ice cap ends at elevations of 5,000 to 5,100 meters in steep or precipitous cliffs. Cliffed margins are typical of cold glaciers in the polar regions; these also have been noted at about 5,800 meters in elevation on Mount Kilimanjaro at 3°S. (Gillman, 1923, page 17).

The longer ice tongues reach the foot of the escarpment at the heads of steep-sided valleys. Beyond the present glacier termini, belts of end moraines lie on the valley floors, separated by alluvial deposits extensively covered by peat bogs.

After studying aerial photographs we chose an approach route along a ridge that reached the ice cap at an elevation of about 5,000 meters (above the level of the ice falls). The ice margin here is a gently sloping ramp between two stretches of ice cliffs; from this point the route to the summit is straightforward without crevasses or other obstacles.

Preliminary results: glaciology

On the summit of the main dome, at 5,500 meters, we dug a pit 3.8 meters deep and cored another 3 meters, thus reaching a total depth of 6.8 meters. Firn temperatures were measured, density measurements were made, and snow samples were collected for later laboratory analysis.

The pit stratigraphy suggests a net snow accumulation of about 3 meters during the budget year 1973-1974. No sign of reworking of the deposited snow by wind was noted on the snow surface or in the

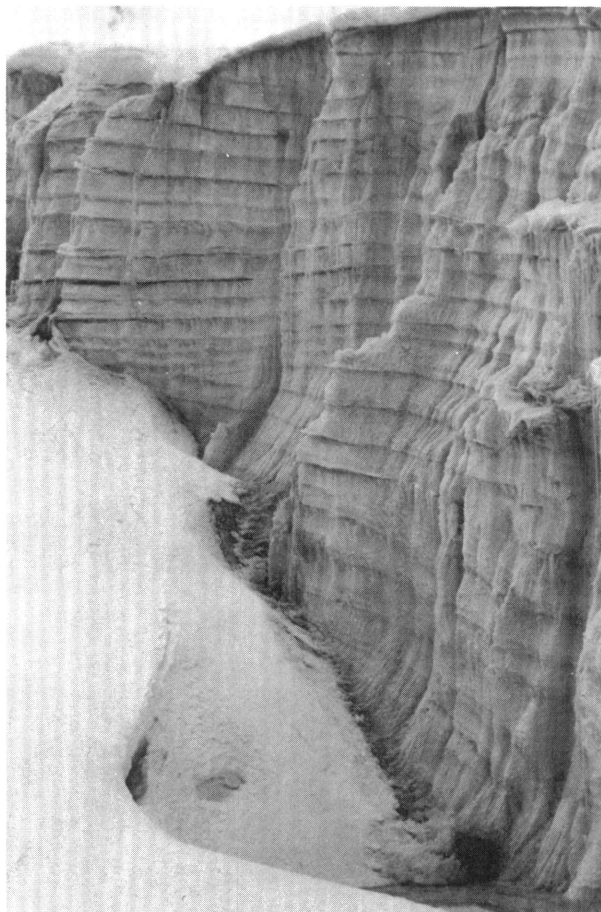


Figure 3. Particle layering of an ice cliff near the margin of the Quelccaya Ice Cap (see figure 1 for location).

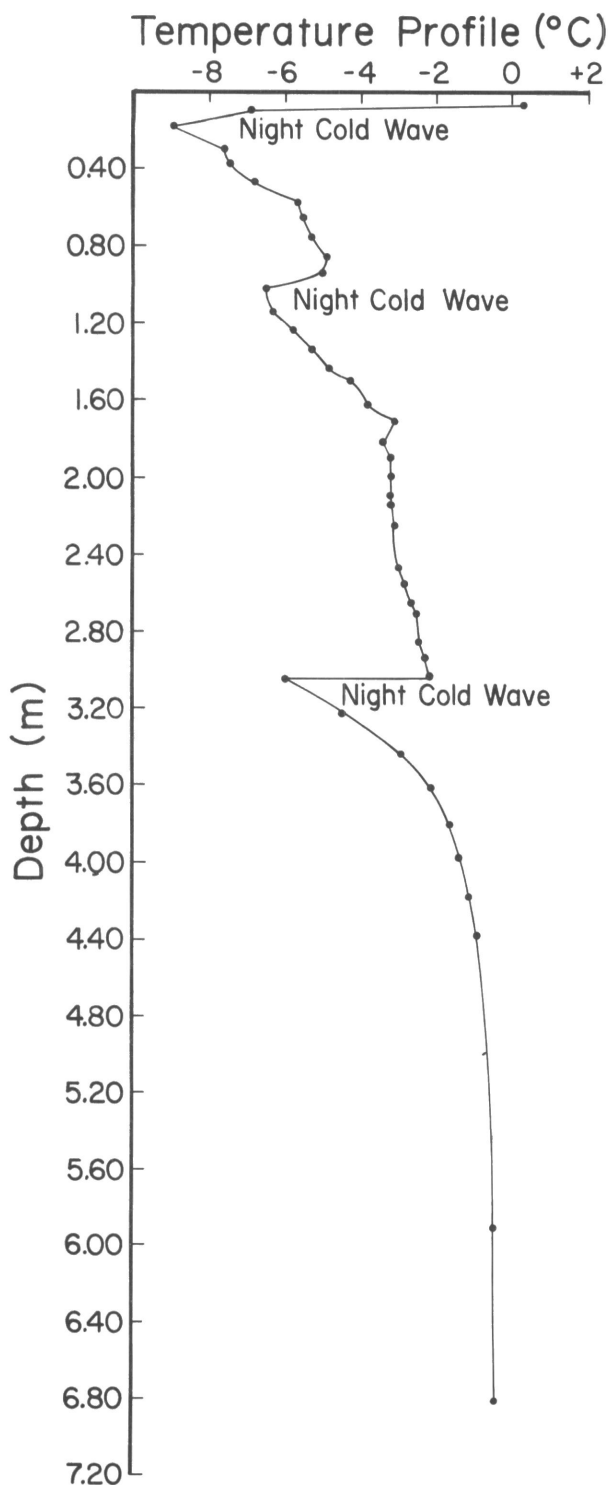


Figure 4. Temperature profile from a snow pit dug at the end of June 1974 on the ~5,500 meters high summit of Quelccaya Ice Cap's main dome. Note that the sharp decreases in temperature profile at surface, 1-meter, and 3-meter depths, are night cold waves that appear as a result of deepening the pit on 3 consecutive days (June 29 through July 1, 1974).

snow pit. Particle layering is very distinct in a cliff near the margin of the ice cap, having layer intervals ranging from .5 to 1 meter (figure 3); this suggests that these variations in particle content could be used to date temperate ice in the same way as they are being used to date polar ice (Thompson, 1973). The 3-meter accumulation is in agreement with the annual accumulation suggested in microparticle and oxygen isotope ratio measurements discussed by Thompson and Dansgaard (1975).

The temperature profile (figure 4) from the snow pit indicates that the ice cap probably is temperate. The temperature at the end of June 1974 ranged from -9°C . near the surface (representing radiative cooling at night) to -0.5°C . at 6.8 meters in depth. Sharp drops with increasing depth in the temperature profile occurring at 1 meter and again at 3 meters are due to nightly cooling, the pit having been dug on 3 consecutive days.

The density profile for the upper 3 meters of the snow pit (figure 5) shows a range of 330 kilograms per cubic meter near the surface to 500 kilograms per cubic meter at a depth of 2.85 meters. The density increase with depth is what would be expected in a wet snow facies.

Preliminary results: glacial geology

The glacial geological investigations were directed toward obtaining a radiocarbon-dated chronology of ice-marginal variations. The deeper part of the ice cap's stratigraphic record may overlap temporally with datable ice-marginal variations, and dating of older glacial events is valuable for comparison with sequences from other parts of the world. In this sparsely-vegetated environment, little organic matter associated with glacial features was expected, particularly since virtually no radiocarbon dating has been possible in the course of glacial geological studies elsewhere in Peru (*e.g.*, Clapperton, 1972). Abundant peat was found, however, incorporated into end moraines and interbedded with alluvium, some and perhaps most of which is outwash.

Studies were concentrated in the valley of the Río Huancané (figure 1). In full-glacial time the ice flowing from the ice cap down this valley joined ice flowing south from the Cordillera Vilcanota, producing a complex belt of massive end-moraine ridges between Huancané homestead and the outer glaciation limit about 12 kilometers away. During a brief, cursory study, no organic matter was found in these moraines, which may date from more than one glaciation.

Between the ice cap and Huancané homestead the glacial features are easier to interpret because they

reord successive ice-marginal positions of the proto-Quelccaya Ice Cap only. Three end-moraine belts are present, with their outermost ridges being about 1, 3, and 9 kilometers beyond the present ice margin; these belts are provisionally referred to as the Huancané I, II, and III moraines, in order of increasing distance from the present ice margin.

The Huancané I moraine belt extends about 1 kilometer in front of the present glacier fronts. At least six ridges generally are present, most of them less than 5 meters high and 10 meters wide, apparently formed during two episodes of advance and retreat. In places, where the glacier bulldozed into bogs, the moraine ridges contain abundant peat. Material from a cushion of vegetation that formed the surface of the bulldozed bog has been dated at 905 ± 10 years before present (I-8441).

The Huancané II moraine belt is about 700 meters wide and comprises about eight ridges lying 4 to 5 kilometers from the present ice margin. A single, 80-meters-wide ridge 3 kilometers from the ice margin is believed to be the youngest recessional moraine of the Huancané II belt; but it may represent a separate, younger event. A clast consisting of 60 centimeters of peat in contact with clay is incorporated into the basal part of the outermost Huancané II moraine ridge. The peat is uniform in texture throughout, and none has the characteristics of peat from near the surface of a bog. It thus is uncertain whether the peat stratigraphically covers the clay or vice versa. The radiocarbon age of the peat farthest from the peat-clay interface is $10,910 \pm 160$ years (I-8209).

The Huancané III moraine belt is about 500 meters wide and comprises about six ridges, the outermost lying 9 kilometers from the present ice margin. An exposure 1 kilometer upstream from the innermost ridge consists of the following: thin turf, 270 centimeters of coarse sand, 60 centimeters of peat, 90 centimeters of clay, 0 to 7 centimeters of peat, >90 centimeters of coarse sand with base obscured. The radiocarbon age of the uppermost peat is $11,460 \pm 165$ years (I-8210). The basal 1 centimeter of the underlying thin peat has been dated at $12,240 \pm 170$ years before present (I-8443). Two kilometers in front of the outermost Huancané III ridge, 1 meter of peat is covered by 2 meters of gravelly sand and covers more than 1 meter of sandy gravel with base obscured. The basal peat is $10,730 \pm 155$ carbon-14 years old (I-8212), and the uppermost peat is $9,625 \pm 150$ years old (I-8211).

Full interpretation of these results must await age determinations of some of the 21 undated samples already collected, as well as further field work to collect other samples for dating and to distinguish between glaciofluvial and fluvial deposits. If the age determinations are accepted, the only firm conclusions that can be drawn are (1) that the Huancané II

moraines are less than 10,910 years old, and (2) that the Huancané III moraines are more than 11,460 years old. The age of sample I-8443 shows that the Huancané III moraines are more than 12,240 years old. A further reasonable conclusion is that the Huancané III moraines are at least several centuries older than 11,460 years, because considerable sedimentation and peat growth occurred after their formation and before that date.

Thus, by 11,000 carbon-14 years ago, when the Laurentide Ice Sheet in North America still extended to the northern part of the Great Lakes, the Quelccaya

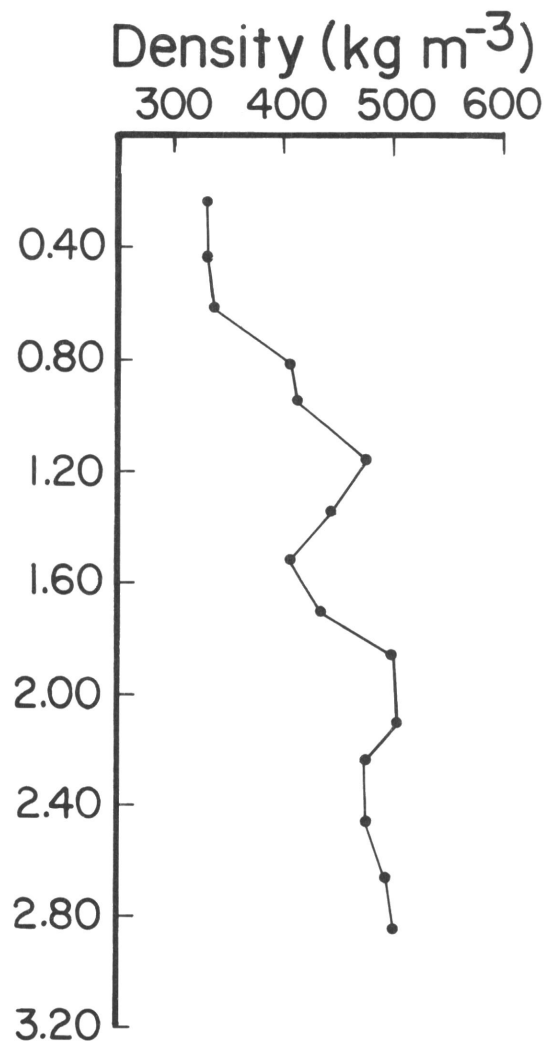


Figure 5. Density profile from the snow pit at ~5,500 meters on the summit of Quelccaya Ice Cap's main dome.

Ice Cap cannot have been much larger than it is now; dating of samples already collected should show whether it was indeed any larger. At that time glacial conditions in Peru at 14°S. resembled those in southern Chile and Argentina at 48° to 50°S. (Mercer, 1970, page 20), probably Venezuela at 9°N. (Giegengack and Grauch, 1973), and Alaska at 62°N. (Denton, 1974, page 890).

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Oxygen isotope and microparticle studies of snow samples from Quelccaya Ice Cap, Peru

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During a preliminary investigation of the Quelccaya Ice Cap (14°S. 70°50'W.), in June and July 1974, a snow pit 3.8 meters deep was dug on the summit of the main dome (elevation: 5,500 meters). Firn temperatures were measured and snow samples were collected for later laboratory analysis.

The stratigraphy revealed in the walls of the pit suggests a net snow accumulation of about 3 meters during the budget year 1973-1974. No signs of reworking of the deposited snow by wind were noted on the snow surface or in the pit's walls. Particle

layering in intervals from 0.5 to 1 meter is very distinct in a cliff near the margin of the ice cap; this suggests that variations in particle content could be used to date cores from this ice cap in the same way as they recently have been used to distinguish annual layers in polar cores (Hamilton and Langway, 1967; Thompson, 1973; Thompson *et al.*, in press).

Results of the microparticle and the stable oxygen isotope ratio studies of these samples are noteworthy. The microparticle concentration profile (figure 1)