CORRESPONDENCE

The Editor,
Journal of Glaciology

SIR,

Discharge of debris by Glaciar Hatunraju, Cordillera Blanca, Peru

I have news about work at Laguna Paron from Ing° César Portocarrero, who has replaced Dr Benjamin Morales, and from Alcides Ames, who stayed for 6 months in Grenoble with Dr Louis Reynaud. The debouchment of the tunnel into this lake was completed at the end of 1983 by large-diameter boring instead of blasting as initially planned (Lliboutry and others, 1977, p. 252).

Prior to undertaking the engineering work, six corings were made under the direction of Ing° Andrés Huamán, which now allow further interpretation and discussion of the information given by Lliboutry (1977). The floor of the valley, where it dams the lake, was found to consist of strata of fine material, gravel, and "blocks" (cobbles or boulders). There is no correlation between the sequences in the different bore holes, 50 m apart from each other. One coring, 75 m deep, was done on Glaciar Hatunraju, at 4300 m a.s.l., where I had calculated that the glacier should reach its lowest altitude. Here, under 62 m of ice, there are 4 m of fine material, beneath which are 3 m of "blocks", and 6 m of gravel. This substantiates the statement that the huge moraine creeps without any interstitial ice.

The glacier thickness at this site is less than predicted. In the published longitudinal section (Lliboutry, 1977, fig. 10, p. 265), the dashed line (corresponding to an annual negative balance b = 0.8 m/year) should be adopted and, between the calculated positions of the bottom under points (41) and (38), it should be replaced by a straight line. With b = 0.8, the discharge of Glaciar Hatunraju across its upper cross-section should be 110 000 m^3 of ice per year.

Cores showed a mixture of ice (60% by weight), quartzose sand (25%), and pebbles 1–3 cm in size (15%). By volume, these figures become 81.8, 11.4, and 6.8%, respectively. This finding contradicts the statement (Lliboutry, 1977, p. 257) that a small ice cliff showed no morainic inclusions. Nevertheless, this exposure was in the upper part of the covered glacier; the ice found at the surface there was formed in the lower part of the accumulation zone, which is probably not reached by debris falling from the surrounding rock walls.

Thus, my previous estimate of the amount of debris carried by the glacier has to be revised. At point (38), the discharge is 24 800 m^3 of ice per year, including 18.2% of debris, i.e. 4520 m^3 per year. The thickness of the ablation moraine there can be estimated at 1.2 m (corresponding to the ablation of debris-laden ice over 80 years, on the 600 m up-stream). Thus, about 560 m^3/year of ablation moraine has to be added. The discharge of debris into the valley should be about 5080 m^3/year, instead of 3000 m^3/year. The Hatunraju moraine ($92 \times 10^6\ m^3$) could have been built up in 18 000 years under the present conditions, without assuming that there is soft material beneath the glacier in its upper part, and that this is carried into the valley. If the latter assumption is made, the time necessary might be halved.

A tentative estimate of the amount of cirque erosion during the Holocene can be inferred. The rock wall with hanging patches of ice, which surrounds the accumulation zone of Glaciar Hatunraju, is about 2700 m long and 800 m high. To deliver 5080 m^3 of debris per year, it has to recede, due to frost shattering, at a mean rate of 2.4 mm/year, which is only 24 m during 10 000 years of the Holocene. Although this estimate is conservative, it shows that it took the whole of the Pleistocene to form the cirque.

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SIR,

Spatial and temporal variation of electrical conductivity, pH, and water temperature in the Gornera, Switzerland

Gurnell and Fenn (1985) have provided a valuable description of the spatial and temporal variations of electrical conductivity in the pro-glacial stream of the glacier de Tsidjiore Nouve, Switzerland. Comparison of their measurements of the spatial variation of pro-glacial stream conductivity with some I took in the same month (July 1981) at the nearby Gornergletscher shows several points which may be of value in future work.

Table I shows the longitudinal profile of Gornera water quality I measured from the glacier portal to the Grande Dixence Prise d'Eau on the afternoon of 19 July 1981 in a rather severe snowstorm (air temperature = 3.5–5.6 °C, barometric pressure = 0.790 bar at portal). The observed conductivity is neither constant, nor slowly increasing, as would be expected during down-stream solute acquisition. Instead, both the conductivity and water temperature vary in an approximately random fashion. This is caused by sampling *different* parcels of water as they travel down-stream.

A "water parcel" is used here as an operational approximation to a "water particle", which is an infinitesimally small volume of water used to describe fluid flow by particle mechanics (Halliday and Resnick, 1966, p. 440). Water parcels examined during the present work were 0.25 dm^3, removed from the flow in a plastic beaker, and completely measured within 10–20 s. In the general case, a water parcel should represent the minimum water volume necessary to measure a chemical, or physical, water property in the field at a given time, using a given method. The uniformity of properties for several water parcels varying in length, width, or depth along a stream should be confirmed by measurements, not assumed.