SIR, *Subglacial cavitation phenomena: reply to comments by G. D. McKenzie and D. N. Peterson*

The observations made by McKenzie and Peterson are particularly interesting and underline, if that were necessary, the complexity of glacier dynamics.

The description these authors give draws our attention to three points: first the small scale of the forms described (15 to 20 cm), then there is the very heavy debris content of the contorted ice (64% of till), finally the basal-sliding velocity, much smaller at Casement Glacier than at the Glacier d'Argentière (factor of 1 : 25).

At Argentière, at the level of the resumption of contact between the ice vault and the bedrock or of the pad of ice which accompanies this resumption of contact (at the location where we reported the uphill movement of ice wedges), we have sometimes been able to observe distorted ice very similar to that reported beneath Casement Glacier; the similarity is indeed amazing. Melting by hot water of these natural formations has shown that—at Argentière—they constitute a minor phenomenon, local and temporary. This ice, equally heavily laden with sand, takes up in turn distorted, folded or simply expanded forms belonging more to the phenomena of restriction or contrariwise of compression at the level of the subglacial cavities than to a type of non-laminar flow.

In our opinion this localized phenomenon is explained: (a) by the nature of the ice which, heavily laden with solid debris, has less internal cohesion than pure ice; but especially (b) by the effects of compression on this ice at the level of resumption of contact of ice masses endowed with differing movements due to differing local topographic conditions; and (c) by the very jerky regime of glacier sliding velocities which favours the development of these forms.

At Argentière the distorted ice had not held our attention much, as the large glacier velocity (averaging 3 cm h^{-1} with extreme values exceeding 10 cm h^{-1}) did not leave it time to develop. The plastic deformation of the ice was thus less apparent, often ephemeral, and was on the whole insignificant in comparison with the sliding displacement over the rock bed which is, under this glacier and in this location, the dominant process.

Institut de Géographie Alpine,
Rue Maurice Gignoux,
38031 Grenoble Cédex, France
29 May 1974

ROBERT VIVIAN
GERARD BOCQUET

SIR, *Froude criterion for ice-block stability*

It was interesting to note the comments by Ashton (1974) concerning the Froude number concept for the stability of ice packs as originally developed by Kivisild (1959). The paper by Ashton refers to the case of the stability of a unique ice-floe in front of an ice cover. It should be noted that this is not necessarily the same as the criterion to define the moment at which the whole ice pack stops growing up-stream by accumulating ice-floes at the upper end under which further ice-floes could be washed. It is this criterion for the progression limit of an ice cover which was studied by Kivisild. It results in a different concept of Froude number and it is derived from the behaviour of the whole ice cover. The instability of a single ice-floe does not prevent the up-stream progression of the ice cover. Individual floes may become unstable and move under the cover. Rafting increases the thickness and the cover is again stable as a whole.

In that case there is still an up-stream progression of the ice cover and the whole mass becomes unstable only when the Froude number based on the water depth reaches a critical value. This will be achieved by a change of water depth up-stream of the cover that may be caused by an accumulation of rafted floes under cover.

In nature, the total ice thickness of the cover does not stay constant, it depends on the quantity of rafted ice in the cover. We have recently carried out further investigations on this problem on rivers in Yukon, confirming that the Froude criterion rather than temperature or ice thickness is the most important parameter in defining the development and break-up of dynamic ice covers, hanging ice dams, and jams.

Foundation of Canada Engineering Corporation Limited,
Suite 210, 9731, 51st Avenue,
Edmonton, Alberta T6E 4W8, Canada
10 October 1974

J. PENEL

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SIR, *Hail-debris flow in north-central Nevada, U.S.A.*

I should like to bring to the attention of other glaciologists some observations of an unusual phenomenon. On 17 July 1974, a group of geologists from Stanford University observed the remnants of a hail-debris flow in arid, north-central Nevada. The observation took place at the intersection of Highway 82 and the stream bed of Faulkner Creek in Antelope Valley, east of Antelope Peak in the Monitor Range. The flow was partially melted, and it most likely was the product of a regional thunderstorm that had occurred the day before.

The flow consisted of a 15 cm thick, 10–20 m wide, mass of cubic closest packed, rounded to sub-rounded hail. The grains consisted of both clear and white, bubbly ice ranging from 2.5 to 10.0 mm in diameter. The surface and edges of the flow were covered with fine-grained sediment and pieces of brush. This covering seemed to have served as insulation, preserving the flow in daytime temperatures of up to 32–35° C.

The observation took place at an altitude of 1 936 m above sea-level. The flow traveled about 8 km, originating from the canyon east of Antelope Peak at an altitude of approximately 2 317 m above sea-level. Therefore, the flow traveled down a slope of 0.047 6.

Both water and air were considered as possible materials lubricating the flow. However, field evidence revealed only water-marked chutes and ripple laminations under, and around, the flow, indicating an alluvial origin.

RICHARD C. METCALF

Department of Geology,
School of Earth Sciences,
Stanford University,
Stanford, California 94305, U.S.A.
13 August 1974