each winter's cold wave. With surface ablation of 2 m. or more per annum, the bands at the lower end of his Fig. 1, 30 waves removed, must be in ice which was 60 m. under the surface at their point of origin—a depth far below any penetration of winter cold.

In 1948 on the Arolla and Trift Glaciers (and in 1950 on the Mer de Glace) I verified that the difference in whiteness of the two parts of each band is due to the white band being bubbly ice, the dark band clear ice—densities about 0·85 and 0·91 respectively, rather than to surface dirt. It seems hard to imagine any process by which rhythmic surface compressions could convert clear ice into bubbly ice at the surface; even more difficult 60 m. or more below the surface.

As Henri Bader suggested in the preceding issue of the Journal, I am strongly convinced that bubbly ice is the normal product of firnification of cold snow, with no melt water present. If melt water is present, clear ice results. For instance, the lane of white bubbly ice on the Gorner Glacier can be traced to that cold, arctic, north-facing slope, up against the Silbersattel of Monte Rosa—the one and only large area of Arctic-like accumulation at an altitude of well over 4000 m. in the Alps. That Gorner white bubbly lane is a longitudinal lane.

To introduce transverse dikes of bubbly ice into glaciers such as the Arolla or the Mer de Glace and, at that, dikes of bubbly ice that should penetrate down 100 m. beneath the surface, is one unique test which any explanation of Forbes's bands must meet (along with others).

Then, too, if nothing more is needed than pressure of a nearby steep ice fall, reacting on a flat glacier whose surface offers rhythmic seasonal fluctuations in its viscosity, as on the Mer de Glace, Arolla and Trift (in the Gothardgebiet), why are there no vestiges of ogives on the Leschaux, below the Talêfre ice fall? On the Saleinaz? On the Z'mutt, beneath the Stockje Gletscher ice fall? On the Gorner, beneath the ice fall coming down from the Jägerhorn area? On the Morteratsch beneath its own ice fall—or beneath the Pers Gletscher ice fall?

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4 *April* 1951

JOEL E. FISHER

SIR,

Mr. Fisher's very interesting observations on the Arolla Glacier, the Trift Glacier and the Mer de Glace, contending that the white bands of the "ogives" consist of ice containing air and that the dark bands consist of clear ice, are undoubtedly an important contribution to the problem of ogive formation. These views must certainly be considered when attempting a solution. Whether the pressure wave hypothesis can be reconciled with Fisher's basic observations only the future can show. Nevertheless the following reasons make it appear quite probable.

The causes of the sudden increases in speed in the summer, as may be observed at the Mt. Collon Glacier, are, in my opinion, not due to the changes in viscosity of the surface ice layers since shallow sections of the glacier are influenced by the annual temperature variations—as Fisher rightly observes. The sudden increase in speed seems much more likely to be due to the melt water which on reaching the glacier bed gives a sudden added impulse to the ice by various influences. Measurement of the speed in the tunnel of the Mt. Collon Glacier yielded very small values in winter (for instance 3 cm. a day). Calculations according to Somigliana indicated that during the winter the glacier does not slide upon its bottom layer in the lower, flat reaches of the tongue. This result has since been confirmed by observations in the lower tunnel of the Mt. Collon Glacier and by further investigations in other glaciers. The sudden increase in speed at the surface of the Mt. Collon Glacier in July, which is a multiple of the winter speed, can therefore only be explained by the additional impulse caused by gliding upon the glacier bed. This implies, however, that extensive variations in pressure must occur which will influence the entire cross section of the glacier with varying intensities in different places and at different times. This might cause the effect of the pressure waves to penetrate deeply into the glacier, even causing change in the lowest ice layers which only come to the surface at the end of the glacier.

A glacier phenomenon can never be due to one single cause, many influences are usually brought to bear. It seems to me that more research will be necessary before we can answer the question

whether the different textures of the ice established by Fisher have a primary influence upon the formation of Forbes's Bands, for instance because bubbly ice has a different viscosity from that of clear ice, or whether, on the contrary, the difference in texture *is a result* of pressure variations or even simply a secondary phenomenon of the glacier surface. Unfortunately technical difficulties due to rapid plastic distortion did not permit crystallographic investigations to be made of the upper Mt. Collon Glacier. It is remarkable that the wave formation of the glacier surface below the ice fall, similar to that of the water surface immediately below a water fall, is by far the most intensive at that point and flattens out in the direction of the advance. Ablation reached the following values according to measurements made by E.O.S. in the summer of 1950: at 2390 m. about 7·3 m., at 2270 m. about 7·8 m. and at 2220 m. about 8·2 m. These were exceptionally high amounts. On the other hand, it is equally remarkable that important variations of the Newtonian viscosity may occur in the interior of the glacier as was proved later in the Z'mutt tunnel (E.O.S.) which, with a length of 1060 m., had a maximum ice cover of 80 m.*

Finally, I must thank Mr. Fisher for his remarks which will help in the further study of the formation of Forbes's Bands. The point he has raised regarding the different conditions obtaining in different glaciers deserves particular attention.

Versuchsanstalt für
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17 *April* 1951

R. HAEFELI

SIR,

Pot-holes and Glacier Mills

I agree with Professor Hollingworth (*Journal of Glaciology*, Vol. 1, No. 9, 1951, p. 490), when he says that in the subglacial stream under a strong hydrostatic head a swirling action, *i.e.* the scouring out of a pot-hole by rolling stones, is hardly possible. Unfortunately I am unacquainted with conditions in polar glaciers, but in alpine glaciers I know them well. In the latter, the subglacial stream is nearly always in contact with the free air, since the subglacial channel is subjected to continuous alterations. The ice roof of the channel is attacked by the comparatively warm, splashing water and moves steadily downhill with the glacier. The water level in the stream fluctuates enormously, not only from summer to winter, but more particularly from day to night. If for any reason the flow is momentarily obstructed, the hydrostatic head increases rapidly and must in time lead to a breakthrough that will certainly be violent and sometimes even catastrophic. Generally, as I have said, the stream under an alpine glacier is in contact with the free air. In the case of very deep pot-holes, higher hydrostatic pressure would have to be assumed, owing to their depth, and there could therefore be no swirling action. It may, however, be possible that the water in the pot-hole finds some exit to the ground, perhaps at a fissure in the side of the pot-hole, or the water-jet may fall tangentially into the hole and issue again by passing helically up along the wall and thus return to the glacier bed.

It is often found that above a step in the glacier bed, and close to the step, the subglacial stream divides into several arms spreading over a wide area. These cut into the tread of the step, circular lumps being formed between them. This is the reason for the frequent occurrence of this glacier phenomenon above steps. Crevasses occur in the ice where the glacier passes over, but here there is also the circumstance that the glacier stream is on a steeper slope, and consequently is better able to form pot-holes.

I do not deny the possibility of pot-holes being formed by the direct fall of water into a crevasse, but I am of the opinion that the frequency of such occurrence is very much less than the formation of pot-holes by the freely swirling subglacial stream.

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26 *March* 1951

R. STREIFF-BECKER

• Details of this work will be communicated to the International Commission on Snow and Ice at Brussels in August 1951.