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CORRESPONDENCE

The Editor,

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SIR, *A peculiar melt pattern in fresh-water ice*

We recently observed a peculiar but fascinating melt pattern on fresh-water ice which we thought might be of interest to others. Basically, we had frozen a sheet of ice at −25°C in a 6 m by 3 m by 1 m pool inside one of our large cold chambers, and then had left the chamber controls set to idle at −2°C over a weekend. However, a malfunction in the refrigeration unit caused a loss of refrigeration, although the large evaporator fans continued to blow air across the ice surface. When we checked on the Monday, the chamber ambient temperature was +15°C and there was 2–3 cm of water on top of the ice. The top ice surface, however, was not planar but had large "craters" approximately 4 cm average diameter and 1–1.5 cm deep, quite equally spaced over the whole ice surface (Fig. 1). This figure shows the upper surface of the ice as viewed from an oblique direction. In general, each of the craters was surrounded by six others in a reasonably regular hexagonal pattern (Fig. 2). This figure is a plan view made with side lighting which clearly shows this hexagonal arrangement. To see whether this phenomenon was simply related to the crystalline grains in the ice, a thin section was made by simply melting a piece of the ice between crossed polaroids. This section indicated that the ice was columnar grained (type S2) with an average grain diameter of *c.* 0.5 cm (i.e. an order of magnitude smaller than the observed craters). The fine hair-like structure evident in Figure 2 is a result of the photographic technique, since it was not readily observable by the naked eye. These hair-like lines appear to be the result of a type of thermal etching (personal communication from N. K. Sinha) and, in some cases, the crystalline boundaries are clearly evident (as shown by the arrows in Figure 2). Finally, there was a series of thin (*c.* 0.2 cm diameter) channels which ran from many of the summits between these craters to the bottom of the sheet of ice. These can be partially seen in Figure 1 and are fully seen in Figure 3. This figure shows an

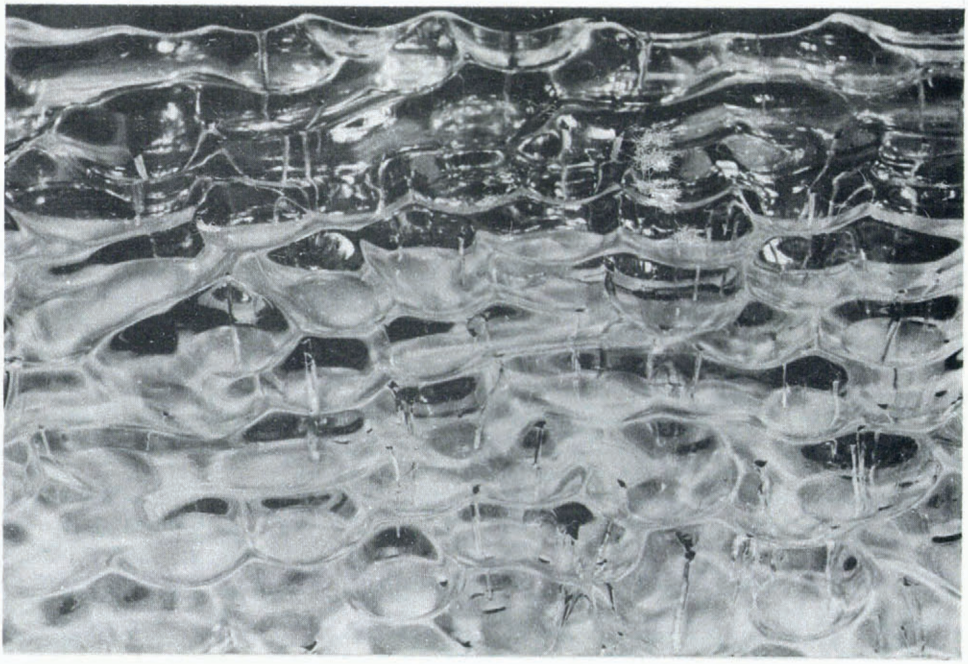

Fig. 1. Photograph of the upper surface of melting fresh-water ice showing the numerous cavities and worm-like channels through the ice. The cavities were c. *4 cm in diameter and 1–1.5 cm deep.*

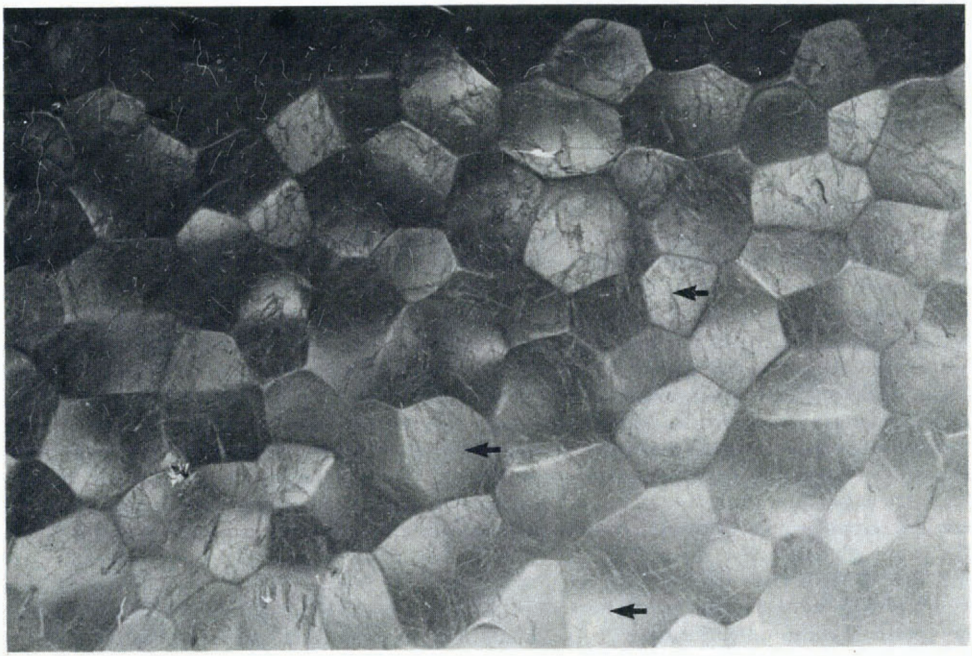

Fig. 2. Photograph of the upper surface of the ice using side lighting showing the regular hexagonal pattern of the cavities. The fine hair-like structures show internal defects in the ice and thermally etched grain boundaries on the surface (arrows).

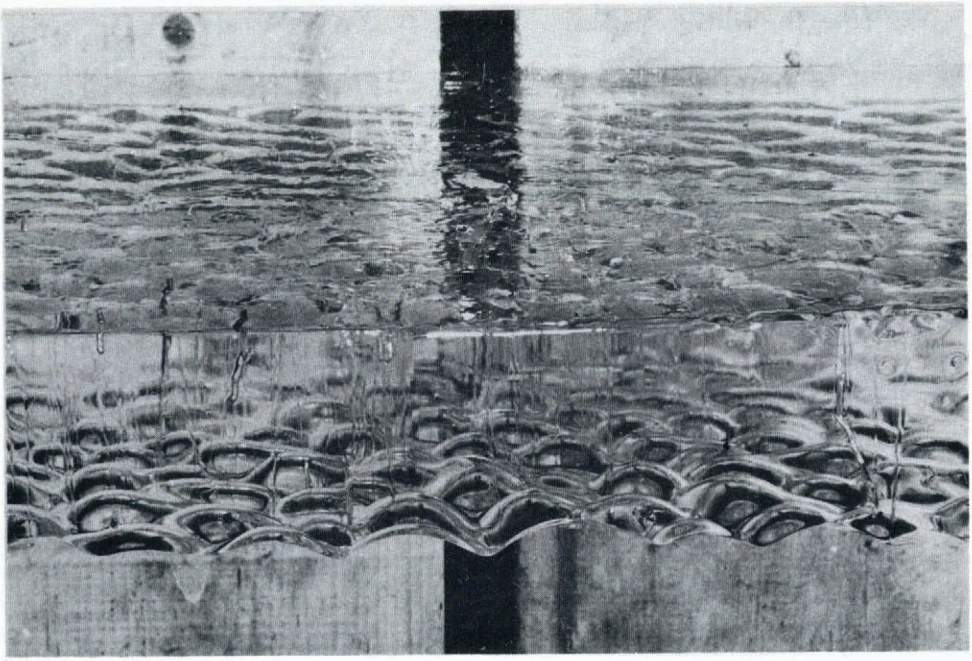

Fig. 3. Photograph of an oblique view of the bottom and side of an ice block cut from the ice and placed on two wooden panels. The underside of the upper surface of the ice and the thin worm-like channels through the ice are clearly visible. The thickness of the ice block was c. 10 cm.

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oblique view of the bottom and side of an ice block which was cut from the sheet of ice and placed on wooden panels. Since the ice was transparent, both the underside of the top surface and the worm-like channels can be clearly seen in the photograph. The thickness of the ice block was *c.* 10 cm.

In discussions with some of our colleagues on this matter, several interesting theories have been put forward to explain this curious melt pattern, although none has adequately explained the general regularity of the pattern nor the numerous thin channels through the ice. Can anyone, as a matter of general interest, propose a mechanism by which such a melt pattern may occur?

We should like to thank Patricia Grichen for taking the excellent photographs shown here.

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Sir,

Glacier energy balance and air temperature: comments on a paper by Dr M. Kuhn

In the study of the relationship between glacier ablation and atmospheric processes there seem to be two distinct approaches. In the first, the energy balance at the glacier surface is described explicitly in physical detail and the individual components are evaluated by careful and difficult measurement to assess their relative importance in the ablation process. A good example is by Ambach (1963). In the second approach, highly simplified relationships are postulated to relate the ablation, or more often the mass balance or run-off, to one or more selected meteorological elements or indices. Example of this approach using statistical methods are by Lang (1973) and Østrem (1973) whilst Hoinkes and Steinacker (1975[a], [b]) take a more intuitive approach. There need be no real conflict between the two approaches but supporters of the first often claim that the empirical coefficients derived from the second method are not governed by any "physical" law, for example LaChapelle (1965). On the other hand, supporters of the more empirical approach could accuse the others of being hopelessly Utopian as the energy balance method is too sophisticated for application to practical problems like the estimation of discharge from large glacierized areas.

The recent paper by Kuhn (1979) represents an admirable step towards the reconciliation of these two approaches, something also attempted less elegantly by Braithwaite (unpublished). Kuhn outlines the theoretical basis of the energy-balance approach in some detail and then derives a simple bulk-transfer relationship between air temperature and sensible heat flux. The relationship involves two variables T_a and T_0, which can be reduced to one by assuming that the surface temperature T_0 is 0°C, and all the other variables like the density of air, the friction velocity, the roughness length, and a function of stability are lumped together with the true constants (specific heat of air at constant pressure and Von Kármán's constant) into a new quantity α which is actually a parameter. The validity of this process rests upon the fact that some "variables" are less variable than others and can be treated as if they were constants as a first approximation. The purpose of my letter is first to point out a misconception in one of Kuhn's definitions and secondly to suggest an extrapolation of his conclusions, perhaps further than he would like.

Kuhn defines the T_a which appears in his equation (7) as the air temperature "that prevails at the level of the glacier but outside its thermal influence". However, from the integration of his flux-gradient relation (equation (6)), it seems that T_a is actually the air temperature that one would measure in a standard meteorological screen placed 1 to 2 m above the glacier surface. The air temperature at this level is already influenced by the glacier, as shown by several studies done on Axel Heiberg Island among others. For example, Müller and Roskin-Sharlin (1967) compared monthly mean air temperatures at the Base Camp on Axel Heiberg Island with those at approximately the same altitude on White Glacier at a distance of several kilometres and found a cooling effect. Ohmura (1972) discusses the finite-difference solution of a simplified thermodynamic equation which describes the advection of air from the Arctic Ocean over a stretch of tundra and then over a melting glacier. From a graph presented in Müller and others (1973) it can be seen that the solution involves progressive cooling of the air as it flows down-wind of the tundra–glacier edge where there is a sharp discontinuity in the sensible heat flux.